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TECHNICAL UNIVERSITY IN ZVOLEN
FACULTY OF WOOD SCIENCES AND TECHNOLOGY
DEPARTMENT OF FIRE PROTECTION
DREVARSKY KONGRES

International Scientific Conference

# FIRE PROTECTION, SAFETY AND SECURITY 2017

May 3rd – 5th, 2017, Zvolen, Slovak Republic

## CONFERENCE PROCEEDINGS

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TECHNICKÁ UNIVERZITA VO ZVOLENE

# Editor`s note

The Book is published in an electronic form. It consists of original scientific and professional papers written in English and formatted according to the editor`s requirements. All presented papers passed detailed review carried out by two reviewers at least.



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# Foreword

The establishment of the Technical University in Zvolen is directly connected with the beginnings of the university technical education world-wide, and with the foundation of the Mining Academy in Banská Štiavnica.

In 2017, the Technical University in Zvolen celebrates the 255$^{th}$ anniversary of university technical studies in Slovakia, 210$^{th}$ anniversary of forestry studies in Slovakia and the 65$^{th}$ anniversary of the University of Forestry and Wood Technology in Zvolen establishment, the Technical University in Zvolen since 1992.

The Department of Fire Protection as an important workplace of the University and the Faculty of Wood Sciences and Technology is celebrating 20 years of its existence, too.

The Department of Fire Protection is a guarantee workplace for the study field “Rescue Services”, which take place in teaching in study programme “Fire Protection and Safety” at the 1$^{st}$, 2$^{nd}$ and 3$^{rd}$ level of university study, in full-time and part-time form. The Department employees provide and teach the profile subjects related to burning of materials, materials reaction to fire, fire safety of buildings, safety of technological processes, crisis management, tactics, technical resources, organization and management of fire and rescue services.

In research, the Department is profiled in the areas of materials research, internal security, hazardous substances, accident prevention, fire investigation, forest fire risk management and minimizing the negative impacts on the environment.

On occasion of the 20$^{th}$ anniversary the Department of Fire Protection organised an International Scientific Conference titled Fire Protection, Safety and Security 2017, which was held in Zvolen on May 3$^{rd}$ – 5$^{th}$, 2017. As a result of the Conference the Conference Proceedings, a common publication presenting the state-of-the-art knowledge in the fields of Fire Protection and Safety, Fire-Fighting Eqipment and Fire Tactics as well as Crisis Management and Crises Situations Coping, was published.

The aim of this Proceedings is to present the knowledge and results that the Department employees, its graduates and the colleagues from partner institutions achieved in above mentioned research fields in the last years.

## Editorial Board

## The reviewing process

Manuscripts submitted for the inclusion in the **Fire Protection, Safety and Security 2017 International Scientific Conference Proceedings** are subjected to the following review procedures:

- It is reviewed by editor for general suitability for this publication.
- If it is judged suitable two reviewers are selected and a double blind review process takes place.
- Based on the recommendations of the reviewers, the editor then decide whether the particular contribution should be accepted as it is, revised or rejected.

## Reviewing Committee

The Reviewing Committee is composed of the Editorial Board members, the Conference Scientific Committee members in particular, excluding the editors of the Conference Proceeedings.

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## Section A: Fire Protection, Safety and Security

## Section B: Fire-Fighting Equipment and Fire Tactics



## Section C: Crisis Management and Crisis Situations Coping

# Section A: FIRE PROTECTION AND SAFETY

# Fire resistance of wooden materials and its improvement by means of protective agents

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**Abstract**

The aim of this work was to experimentally verify the resistance of wooden materials with and without the use of protective agents. Research verified the ability of wooden material to resist point heat source for the period of 70 minutes with the use of protective agents and without them. To verify the assumption that the protective agents improve the fire resistance of given material, the temperature on the surface and inside the sample, weight loss over time, accompanying phenomena (formation of smoke, ignition) and external macroscopic manifestations (carbonization, formation of cracks) were recorded. The results support the argument that protective agents increase fire resistance. In the discussion, the data and observed phenomena are compared with the results of other surveys. In conclusion, the pros and cons of increasing the fire resistance of materials by individual preparations are evaluated.

*Keywords*: weight loss; protective agent; retarder; heat flow; heat; temperature;

## 1. Introduction

Flame resistance is the ability of materials, structures to withstand thermal stress. Testing is used to particularize the information about progress during the thermal degradation of the element and its external or internal changes (discoloration, cracking, cell structure change etc.). The aim is to create a material or structure which is primarily capable of withstanding the required fire load or with additional adjustments to increase the pre-existing fire resistance. Flame resistance is determined by the required criteria and the time in minutes. We are able to improve flame resistance through chemical processing of materials (constructions) with injections, fire protection coatings or linings (walling, cladding) (Mitterová 2010, Reinprecht 1996). The adjustments can be differentiated according to the application:

- on the material, on the structure,
- prior to fire or immediately before the rescue work in the development or operation.

Firesorb is a fire-suppressing additive for fire category A. Liquid solution of hydrophilic polymer absorbs multiple amounts of water compared to its own weight and creates a an adhesive heat resistant gel (Firesorb, 2009). Bochemit ANTIFLASH is a water soluble concentrate designed to reduce the reaction of wood to fire with preventive fungicide and insecticide effect. The product is classified into class C reaction to fire. It consists of 20% boric acid (Bochemit ANTIFLASH, 2011).

For practical purposes nowadays it is sufficient to use the standardized assessment of reaction of material to fire and fire resistance of the structure. Reaction to flame of the material is regulated by the Decree of the Ministry of Interior no. 94/2004 Coll. in § 9, which refers to The National Council of Slovak Republic Act no. 133/2013 Coll. The Decree of the Ministry of Interior no. 94/2004 Coll. according to § 8 allows to determine the fire resistance of fire construction by the initial test according to The National Council of Slovak Republic Act no. 133/2013 Coll. or by calculation according to the technical standards - eurocodes. Fire resistance of structures may be determined in accordance with normative values for

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different types of materials and the structure design (see Eurocodes STN EN 1990-1999). Before each standard value a specific calculated or measured value by the assay in an accredited laboratory, which can more exactly determine its properties necessary for fire protection, should take precedence..

## 2. Experimental Procedure

### *2.1. Sample*

Wood is a heterogeneous material with anisotropic mechanical properties. Its macroscopic structure depends primarily on the type of wood - timber. The sections, areas, lines of the wood in strain determine the macroscopic features, and are characteristic of each type of timber (Požgaj et al., 1997, Buck, 1998 Klinda, 2010).

The anatomical structure of wood, e. g. the aperture sizes of micro- and macro-capillaries, affects the physical properties, transport of agents and heat. The physical properties by their course of reaction to thermal load form a changing characteristics of the wood as complex changing over time, which results in a change of properties and parameters during measurement (Požgaj et al., 1997).

The sample was drawn from solid spruce (Picea Abies). It was designed in a such way that the total active surface of the flame affected the sample, and also to prevent the heat transfer to the side of the prism, which did not interact with the flame. In each group, the samples with a different density, from different parts of the tree were represented. After drying, the sample had an average dimensions 154x116x198 mm (width x height x length) corresponding to the free shrinkage in individual anatomical directions (originally 160x120x200). (Klement, Detvaj, 2007).

After drying, holes were drilled into the samples to provide space for the thermocouple probe at the intersection of the middle of the longitudinal axis (x - 99 mm) and the transverse axis (y) at a distance of 46 mm (B), 77 mm (A) and 108 mm (C). The tip of the probe was at a distance of 30 mm (B), 15 mm (A) and 45 mm (C) from the opposite side of the sample, which was affected by the flame (see Fig. 1 p. 3).The moisture of the probe was determined in each dimension with the use of non-destructive humidity meter NMC 100. The moisture of the probe was in the range of 9.7% ± 1%.

The density of the sample was in the range of 360-446 kg / m3 (at zero moisture). The weight loss was determined as the differences in weight in time at 30 second intervals. When loading the sample, the weight loss was not recorded, i.e. the first indication of weight was recorded following 30 seconds after inserting the probe onto the stand.

The heat flow of the flame was quantified as an open thermodynamic system. Based on the engineering practice, we counted with the ratio of 1: 1 of gas mixture and air in the total volume. Initial conditions were the temperature t = 15 ° C, relative humidity φ = 0, the average heating value of the gas according to the Slovak gas company - SPP (2010) equal to 9.56 3-KW.h.m and the duration of action (measurement) t = 70 min. (4200 p. ± 1.166 h.) The diameter of the burner was 0,008 m. The flow rate was set as w1 = 34.5 cm s -1 and w2 = 37.5 cm s-1. To calculate the theoretical heat flow we multiplied the volume of the burned gas by heating value, giving us the value of Q1 = 1.384 KW and Q2 = 1.505 KW.

### *2.2. Laboratory measuring*

Measurement consisted of point heat source (flame) affecting the sample. Two different sizes of flame – small and large - and a singular distance between the point heat source and the sample was used (see Fig. 1, p. 3 for layout). The application of the heat lasted for 70 minutes. A total of 6 series was examined. One series consisted of three samples, in which the weight loss (with the use of digital scales - Kern KB 10000-1N), the temperature (with the use of thermocouples - the devices ALMEMO 2590-4S and ALMEMO ZA 9020-FS) and visible signs of thermal degradation of components of the individual samples was monitored. Overall 18 samples were examined.

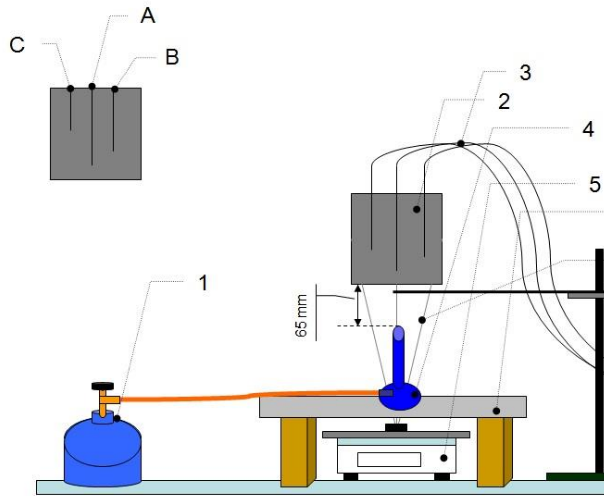


Figure 1 Scheme of laboratory measurement
1 - propane-butane (gas) cylinder; 2 - test sample; 3 - thermocouples T2, T3, T4; 4 - burner; 5 - scales; 6 - safety structure, 7 - stand with thermocouple T1; 8 - stand with the test sample; 9 – temperature measuring device; A, B, C - position of thermocouples T2, T3, T4 in the sampleExperimental part – principles of the test and measurement

## 3. Results

For the calculation of statistical interference the mathematical statistics program Statistica 10 was used.

### *3.1. Thermal degradation – Temperature curve*

Thermal degradation was evaluated according to the effect of the protective agent – samples without any treatment, samples treated with Firesorb and samples treated with Bochemit; and the size of the flame emitted by the point heat source – small and large, on the course of the temperature measured with the thermocouples T1, T2, T3, T4. By analyzing the average temperatures with the use of basic statistics, by the means of Kolmogorov-Smirnov test a violation of the normality of all the dependent variables was found. For more detailed specification nonparametric tests were used.

There was a statistical significance of the difference of the effect of the protection agent on the temperature (Table 1). The greatest impact on the temperatures measured by T1, T2, T3 and T4 had the sample without any treatment, followed by the sample treated with Bochemit and the least impact had the sample treated with Firesorb. The sample without any treatment reached the highest median temperatures (see Fig. 2, Fig. 3, Fig. 4, Fig. 5). The sample treated with Bochemit reached lower temperatures and the lowest temperatures were reached by the sample treated with Firesorb (see also Fig. 2, Fig. 3, Fig. 4, Fig. 5).

Table 1 The results of Kruskal-Wallis ANOVA of the relation of the temperatures measured by T1, T2, T3 and T4 to individual treatments of the sample

| | Kruskal-Wallis ANOVA by Ranks; T1; Independent (grouping) variable: PA; Kruskal-Wallis test: H ( 2, N= 2556) =151.6795; p =0.000; Chi-Square = 76.59155 | | | | | Kruskal-Wallis ANOVA by Ranks; T2; Independent (grouping) variable: PA; Kruskal-Wallis test: H ( 2, N= 2556) =446.2843; p =0.000; Chi-Square = 367.4366 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Depend.: T1 | Code | Valid N | Sum of Ranks | Mean. Ranks | Depend.: T2 | Code | Valid N | Sum of Ranks | Mean. Ranks |
| WT | 101 | 852 | 1253768 | 1471.559 | WT | 101 | 852 | 1307919 | 1535.116 |
| FI | 102 | 852 | 884972 | 1038.699 | FI | 102 | 852 | 719783 | 844.816 |
| BO | 103 | 852 | 1129107 | 1325.242 | BO | 103 | 852 | 1240145 | 1455.569 |
| | Kruskal-Wallis ANOVA based on the order; T3; Independent (grouping) variable: PA; Kruskal-Wallis test: H ( 2, N= 2556) =119.3390; p =0.000; Chi-Square = 65.59953 | | | | | Kruskal-Wallis ANOVA based on the order; T4; Independent (grouping) variable: PA; Kruskal-Wallis test: H ( 2, N= 2556) =132.3862; p =0.000; Chi-Square = 83.89374 | | | |
| Depend.: T3 | Code | Valid N | Sum of Ranks | Mean. Ranks | Depend.: T4 | Code | Valid N | Sum of Ranks | Mean. Ranks |
| WT | 101 | 852 | 1271589 | 1492.475 | WT | 101 | 852 | 1288065 | 1511.813 |
| FI | 102 | 852 | 945577 | 1109.832 | FI | 102 | 852 | 957045 | 1123.292 |
| BO | 103 | 852 | 1050680 | 1233.192 | BO | 103 | 852 | 1022736 | 1200.394 |

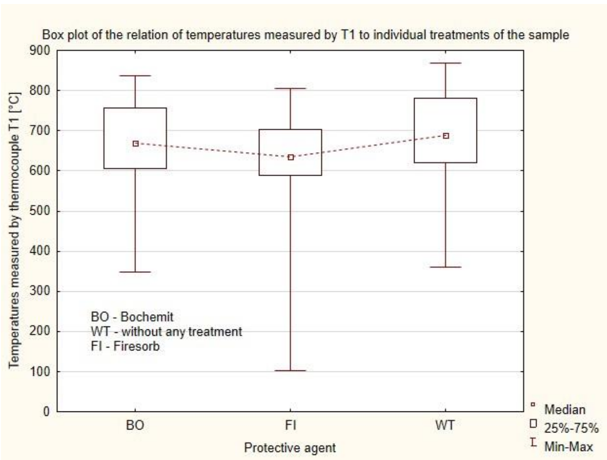


Figure 2 Box plot of the relation of temperatures measured by T1 to individual treatments of the sample

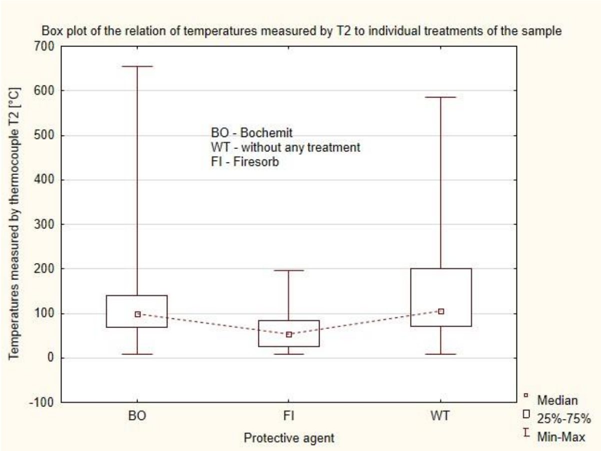


Figure 3 Box plot of the relation of temperatures measured by T2 to individual treatments of the sample

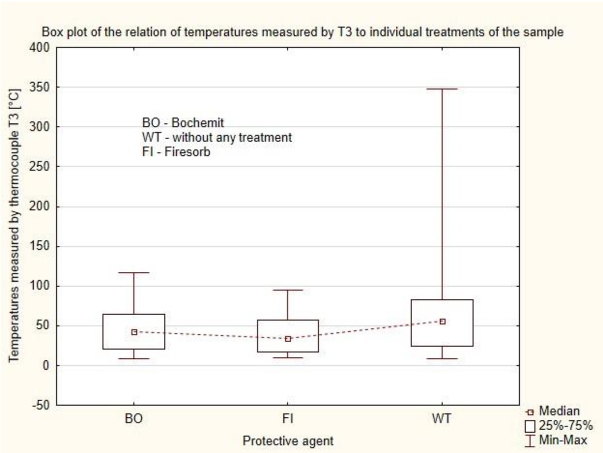


Figure 4 Box plot of the relation of temperatures measured by T3 to individual treatments of the sample

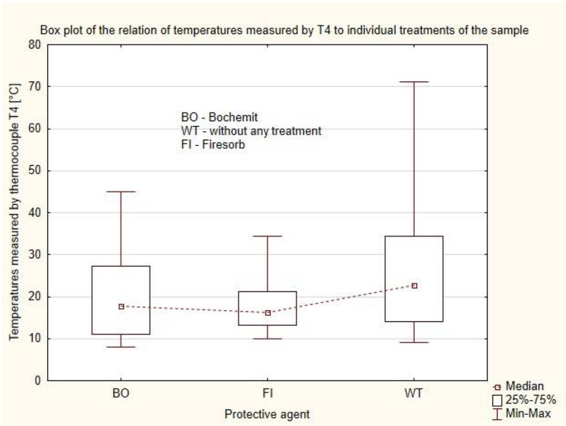


Figure 5 Box plot of the relation of temperatures measured by T4 to individual treatments

There was a statistical significance in the difference of action of the two different sizes of the point heat sources on the measured temperatures, with the exception of the temperatures measured by T4 (Table 2). Greater impact on the temperatures measured by T1, T2, T3 had the large point heat source in comparison to the small point heat source. The samples exposed to the larger heat point source reach higher median values of temperatures compared to the samples exposed to smaller heat point source (see Fig. 6, Fig. 7, Fig. 8 and Fig. 9).

Table 2 The results of Kruskal-Wallis ANOVA of the relation of the temperatures measured by T1, T2, T3 and T4 to the sizes of point heat sources

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Depend.: T1 | Kruskal-Wallis ANOVA by Ranks; T1; Independent (grouping) variable: PHS; Kruskal-Wallis test: H ( 1, N= 2556) =1353.762; p =0.000; Chi-Square = 1376.908 | | | | Depend.: T2 | Kruskal-Wallis ANOVA by Ranks; T2 Independent (grouping) variable: PHS; Kruskal-Wallis test: H ( 1, N= 2556) =208.8164; p =0.000; Chi-Square = 150.3912 | | | |
| | Code | Valid N | Sum of Ranks | Mean. Ranks | | Code | Valid N | Sum of Ranks | Mean. Ranks |
| SS | 101 | 1278 | 947524 | 741.412 | SS | 101 | 1278 | 1364343 | 1067.561 |
| SL | 102 | 1278 | 2320322 | 1815.588 | SL | 102 | 1278 | 1903503 | 1489.439 |
| Depend.: T3 | Kruskal-Wallis ANOVA by Ranks; T3; Independent (grouping) variable: PHS; Kruskal-Wallis test: H ( 1, N= 2556) =27.13230; p =0.000; Chi-Square = 20.33808 | | | | Depend.: T4 | Kruskal-Wallis ANOVA by Ranks; T4; Independent (grouping) variable: PHS; Kruskal-Wallis test: H ( 1, N= 2556) =0.0120403; p =0.9126; Chi-Square = 3.912516 | | | |
| | Code | Valid N | Sum of Ranks | Mean. Ranks | | Code | Valid N | Sum of Ranks | Mean. Ranks |
| SS | 101 | 1278 | 1536750 | 1202.464 | SS | 101 | 1278 | 1631876 | 1276.898 |
| SL | 102 | 1278 | 1731097 | 1354.536 | SL | 102 | 1278 | 1635970 | 1280.102 |

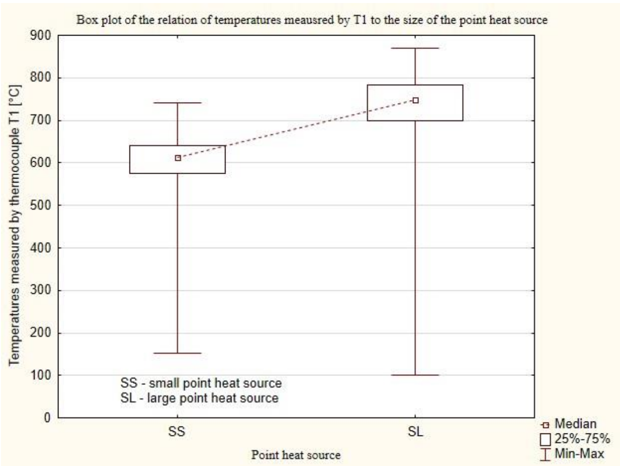


Figure 6 Box plot of the relation of temperatures measured by T1 to the size of the point heat source

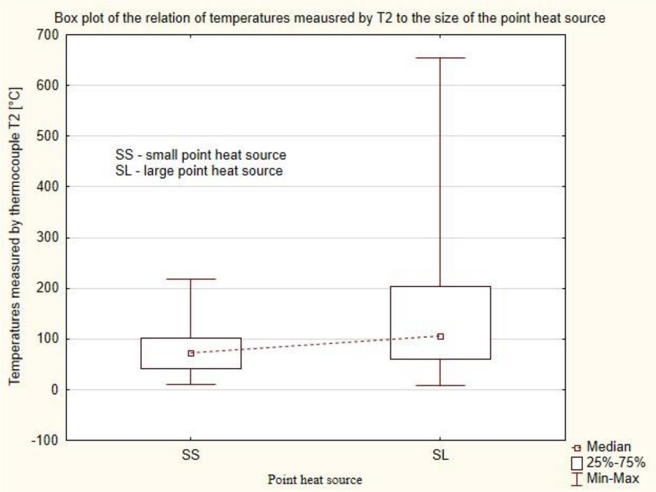


Figure 7 Box plot of the relation of temperatures measured by T2 to the size of the point heat source

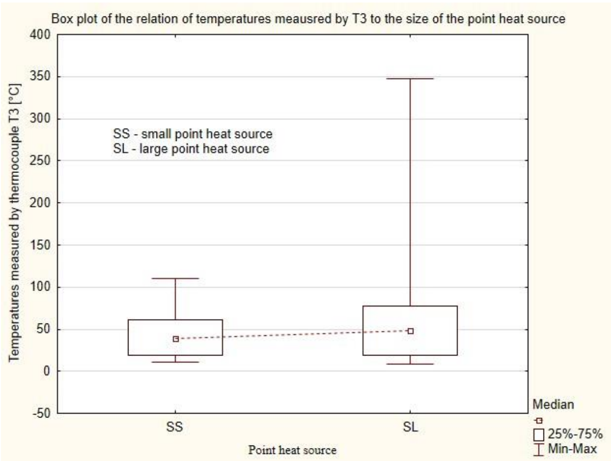


Figure 8 Box plot of the relation of temperatures measured by T3 to the size of the point heat source

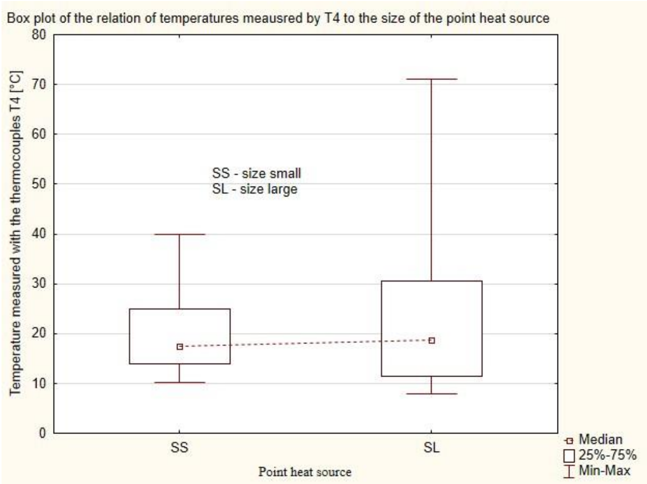


Figure 9 Box plot of the relation of temperatures measured by T4 to the size of the point heat source

The data show that there is a mutual statistical significance of the temperatures measured by T1, T2, T3, T4, reaching the level of p <0.001. Cohen's d values obtained from the Spearman correlation coefficient showed that the effect size of the examined relationships is medium in the case of the relation of T2 to T3 (d=0.724115) and T2 to T4 (d=0.567332) and large in the case of the relation of T3 to T4 (d=0.882782) (see Table 2). The relations of temperatures measured by T1 to all others showed small effect size. That was caused by fire-through or by creation of a crack in the sample reaching all the way to the thermocouple T2.

Table 3 The Spearman correlation of the relations between the temperatures measured by T1, T2, T3 and T4. Effect sizes of the correlations between the temperatures measured by T1, T2, T3 and T4

| Variables | Correlation matrix (Spearman); MD pairwise deleted; Marked correlations are significant at p <0.0500 | | | | Variables | Effect sizes of the correlations (Cohen`s d) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | | T1 | T2 | T3 | T4 |
| T1 | 1.000000 | 0.351314 | 0.182319 | 0.100201 | T1 | 1 | 0.123421 | 0.03324 | 0.01004 |
| T2 | 0.351314 | 1.000000 | 0.850949 | 0.753214 | T2 | 0.123421 | 1 | 0.724115 | 0.567332 |
| T3 | 0.182319 | 0.850949 | 1.000000 | 0.939565 | T3 | 0.03324 | 0.724115 | 1 | 0.882782 |
| T4 | 0.100201 | 0.753214 | 0.939565 | 1.000000 | T4 | 0.01004 | 0.567332 | 0.882782 | 1 |

### *3.2. Thermal degradation - Weight loss*

Thermal degradation was assessed according to the effect of the protective agent and the size of the point heat source on the course of weight loss. Analysis of the weight loss using basic statistics by means of the Kolmogorov-Smirnov test showed violation of normality. For more detailed specification nonparametric tests were used.

The data show that there is a statistically significant difference in the effect of the protecting agent on the weight loss (Table 4). The greatest impact on weight loss had the treatment of the sample with Firesorb. Smaller impact on the weight loss had the lack of treatment of the sample and the smallest impact had the treatment of the sample with Bochemit. The samples treated with Firesorb showed the highest median of percentage of weight loss (Fig. 10). Lower percentages of weight loss reach the samples without any treatment, while the lowest percentages of weight loss reach the samples treated by Bochemit. The samples affected by large point heat source reached the highest median values of percentage of weight loss whereas the samples affected by the small point heat source reached lower median values of percentage of weight loss (Fig. 11). The range of percentage of weight loss is wider in the samples affected by the large point heat source in comparison to the samples affected by the small point heat source.

Table 4 The results of Kruskal-Wallis ANOVA of the relation of the protective agent used and the size of the point heat source

| Depend.: WL | Kruskal-Wallis ANOVA by Ranks; HU; Independent (grouping) variable: PA; Kruskal-Wallis test: H ( 2, N= 2520) =1045.893; p =0.000; Chi-Square = 1174.216 | | | |
|---|---|---|---|---|
| | Code | Valid N | Sum of Ranks | Mean. Ranks |
| WT | 101 | 840 | 934585 | 1112.601 |
| BO | 102 | 840 | 650905 | 774.887 |
| FI | 103 | 840 | 1590970 | 1894.012 |

| Depend.: WL | Kruskal-Wallis ANOVA by Ranks; HU; Independent (grouping) variable: S; Kruskal-Wallis test: H ( 1, N= 2520) =459.0138; p =0.000; Chi-Square = 167.6597 | | | |
|---|---|---|---|---|
| | Code | Valid N | Sum of Ranks | Mean. Ranks |
| SS | 101 | 1260 | 1197000 | 950.000 |
| SL | 102 | 1260 | 1979460 | 1571.000 |

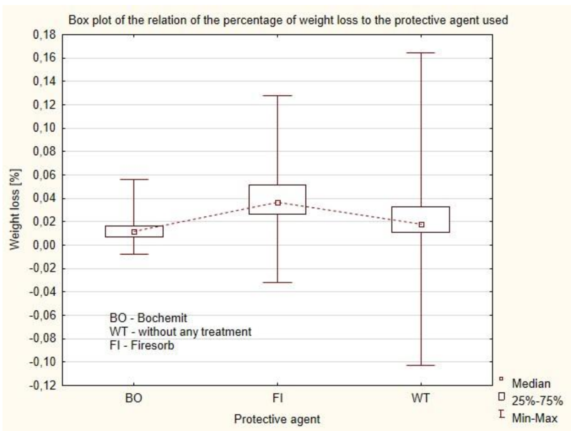


Figure 10 Box plot of the relation of the percentage of weight loss to the protective agent used

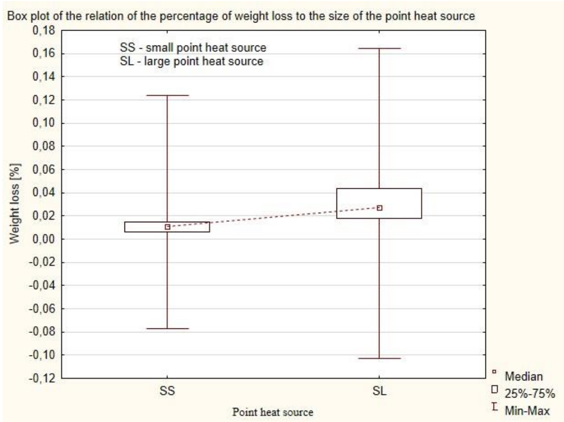


Figure 11 Box plot of the relation of the percentage of weight loss to the size of the point heat source

The average time of the observation of flame burning when the small heat source was used was in the samples without any treatment within 30 seconds. In the samples treated with Bochemit it was within 40 seconds. In the samples treated with Firesorb it was within 300 second. When using the large heat source, the time of the observation of flame burning in the samples without treatment was 15 second, with the use of Bochemit it was 40 seconds and with the use of Firesorb it was 450 seconds.

The average weight loss from the total weight of the sample when applying the small heat source in the sample without any treatment was 1.7%, with the use of Bochemit 1.6%, with the use of Firesorb 4%. When applying larger heat source, the average weight loss of the sample without adjustment was 4.4%, with the use of Bochemit 2.0% and with the use of Firesorb it was 7.3%.

## 4. Discussion

The sample treated with Bochemit showed a better resistance to thermal stress than the sample without any treatment. Firesorb showed the best values in the observation of flame burning, but the worst results in weight loss, which was caused by thermal degradation of the protective layer of gel applied on the sample. The limits to the application of Bochemit concern questions about its health safety (Kaszonyi, 2011). Also it can be used only indoors and in covered outdoor spaces. The usage of Firesorb is affected by its rather short lifespan as a gel formation compared to Bochemit, and its usage mainly outdoors.

The heat exposure changed the colour of the samples from light to medium brown. This is also supported in the study by Mehrotra et al. (2010). According to Johanson et al. (2006), the change of colour does not adequately assess the strength of the material. For all of our measurements, the colour change took place in the same sequence, but the rate of the change depended on the heat flow applied to the sample. The greater the heat flow, the faster the change of colour occurred. In samples without any treatment, the process of thermal degradation of wood and its components took place by the change in colour from light to brown. It also took place via the creation of vapors and combustion gases, from pure white to dark, which was caused by the degradation of the wood components.

Temperatures above 100 ° C after prolonged time cause the thermal degradation of the accompanying components e.g. the change of the colours and surface properties (Kačíková, Netopilová, Osvald, 2006; Solari, 2001). When Bochemit was applied, the sample changed colour to pale yellow and under the influence of heat flow gradually began to darken until finally it became brown. The Firesor and water gel did not change colour, it lost its moisture, until the protective layer formed by the gel was so thin that the sample began to change colour from light to brown.

The time of occurrence of the flame burning depended on the size of the applied point heat source. The flame burning was observed in all of the samples. The formation of flame burning was affected by the shape and the cracks on the surface of the sample. The thermal degradation of the main components of wood by temperaturse above 100 ° C is manifested by weight loss as well as changes in the physical and mechanical properties of wood. After that begins the burning without a flame and flame burning (Mountain et al., 1984; in: Kačíková, Netopilová, Osvald, 2006, Reinprecht 1996). In the samples without any treatment and in the samples with the use of Bochemit the flame burning was observed just right after the occurrence of the locally charred areas.

The spread of the flame on the surface of the samples ended, when the formation of inflammable gases and their concentrations decreased to a level at which the flame could burn no longer. In samples without any treatment the flame spread was quicker than in the other samples. After the creation of a char layer on the sample the flame spread slower. Flame spread in the sample treated by Bochemit took place only within the radius of the point heat source. In samples with Firesorb the flame spread occurred as well only within the radius of the exposure of the point heat source. We believe that during the measurements the phenomenon of natural flame-resistance of wood was observed, resulting in a slowing of the weight loss of the samples and slowing of the fire spread along the surface of the sample. Increased production of coal reduces formation of inflammable gases and helps to protect the wood from another thermal degradation (Rowel et al., 1984 in: Kačíková, Netopilová, Osvald, 2006). After the char layer was created, the flame burning did not occur, except in the cases when cracks (collapses), which disrupted the integrity of the char layer. Subsequently, the burning changed its location outside the radius of impact of the flame. Our measurements support the claim that reducing the values of the measured temperatures from T2 to T4 is caused by heat transfer through the material (Hottel, Sarofim, 1979; Sazima et al., 1989). According to Bučko, Osvald (1998) the thermal degradation is mainly influenced by the properties of the material and the environment. Their research and also the research by Kačíková, Netopilová and Oswald (2006) support the assertion that cracks, moisture of the material, thermal conductivity and surface treatment of wood by anti-pyrogenic agents affects the combustion. Results of the research by Chaouch et al. (2010) point to the complexity of the relationship between the thermal properties and the thermal degradation rate, density and composition of wood. Their research also shows a positive correlation between the basic composition of wood and its weight loss.

The shedding of the ashes was observed in the sample without any treatment and in the sample with the use of Firesorb. In samples treated with Bochemit the shedding proceeded more slowly. This finding is also supported by the research team of authors Dobele et al. (2007), where the charred layer of the sample treated with fire retardant was more stable.

We observed increase in the weight of the sample, which could have been caused by the relative humidity of the environment and subsequent water absorption of the sample. The humidity of the environment ranged between 80% to 100% and the moisture of the wood ranged from 9.4 to 11.4%. According to the authors Borrego and Kärenlampi (2008) the humidity of air and the sample play an important role, whereas the greatest differences can be observed between the saturation point of wood fibers and the relative moderate humidity. Bochemit is based on salts, which may result in an increased ability to bind air humidity and this with chemical treatment of the wood may affect the heat flow. This assumption is supported by the research of Muller-Hagerdorn et al. (2003).

We assume that all the variations of temperatures T2, T3, T4 in samples without any treatment and in samples treated with Bochemit were due to the formation of cracks in the samples. The downward fluctuations in the temperature on T1 in samples treated with Firesorb were caused by the protective properties of the gel created by Firesorb. We assume that the decreases of the medians of the temperatures measured by T1 to T4 were caused by the properties of the material to resist heat transfer through the material. Overall, on average the samples without any treatment reached the highest temperatures. The samples treated with Bochemit reached lower temperatures and the samples treated with Firesorb reached the lowest temperatures. We assume that the fluctuations of temperatures measured by T1, T2, T3, T4 in the samples exposed to large heat source were caused by greater heat flow through the material. Decrease in the range of temperatures measured by T1 to T4 was caused by heat transfer through the material. In total samples exposed to small heat source reached lower temperatures, whereas higher values of temperatures were reached in the samples exposed to large heat source.

The samples treated with Firesorb showed better resistance to the heat flow in comparison to the samples without any treatment, which is supported by the research carried out by Chromek et al. (2010), because the observed time of occurrence of the flame burning in the samples treated with Firesorb was longer compared to samples without any treatment. The weight loss rates in samples treated with Firesorb were higher than in the samples without any treatment. Research by Salgado (2009) supports our assertion that Firesorb has a high resistance to heat flow, and can be used in forest ecosystems, but the potential impact on the environment must also be dealt with.

The samples treated with Bochemit showed a better resistance to heat flow in comparison with the sample without any treatment. This result is supported by the research by Pedieu (2011), who regards the boric acid as a good fire retardant in the manufacture of particleboard materials. The time of the observation of flame burning was longer compared to the samples without any treatment. Study by Gao et al. (2006) support our measurements and the assumption that the preparations containing boron exhibit a good resistance to flame.

Firesorb and Bochemit have different features. The solution of water with Firesorb forms a gel. Water combined with Bochemit creates a liquid solution. The application of the two preparations limits their use. Firesorb is used rather to combat the already established fire and to protect the buildings exposed to the effects of the fire. Bochemit is used for preventive protection of wooden elements and constructions.

Desired environmental friendliness and harmlessness to health are also the limiting parameters of these products, because fire retardants have an impact on the human body and are not recommended for use in large quantities in areas with the presence of people. Also, gels and preparations have their adverse impact on the ecology. Every element that is not found naturally in the environment represents an environmental burden. Therefore the advisability of application and the form of protection of given structural element and construction and as well as the preventive measures to reduce the possibility of adverse events should be take into account. In the study by Basanta (2002) no record of significant microbiological changes was found after the application of Firesorb into some selected types of soil. But field studies to confirm and evaluate the environmental impact were recommended. The study by Díaz-Raviñ (2006) supports the argument that the environmental impact of Firesorb is negligible compared to the effects of fire.

## 5. Conclusion

The samples resist heat stress better with the use of protective agents. Concerning the time of occurrence of the flame burning, the samples with the use of protective agents showed better results compared to the samples without any treatment. External morphological features such as roughness, cracks that caused the spread of flame outside it's radius, and the emergence of the smoldering areas near the cracks affect the visual signs of thermal degradation of the samples. The creation of charred layer and the subsequent reduction in weight loss were observed in all samples. In practice this phenomenon is called natural flame-resistance. In some samples the weight was increasing with time, which, as we believe, is the effect of the relative humidity of the environment and water absorption of the wood.

If we take the ability of the material to resist the effects of the heat flow as the criterion for assessing the effectiveness, then Firesorb increases the resistance but gives way itself (thermally degrades) and protects the sample for a longer period of time in comparison to Bochemit.

Bochemit produces a layer which is more stable than the gel layer created by water and Firesorb.

Bochemit reduces the rate of the disintegration of the charred layer, thus enhancing the endurance and the ability to resist the heat flow of the sample compared to the sample without any treatment. Therefore it is difficult to assess which of the products, Firesorb or Bochemit, resist the heat flow better. Considering the weight loss, Bochemit is more resistant. If we take the time of the sighting of the flame burning into account, then Firesorb is more resistant.

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# Selected cellulosic materials and their flammability from view of normalized method by oxygen index

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**Abstract**

Fire safety solutions are applied practically in each building structure (e.g. in technological and industrial structures, and other ones, too). It is caused by legislation in force with the goal to ensure sufficient protection level against fires, and protection of health and lives of people, property protection and the last, but not the least, environmental protection. Increasing level of fire safety level can be reached by application of selected fire-protecting elements, systems, and devices and by these means to minimize danger and probability of fire origin, fire extent and consequences. In a technology of cellulose products based on tissue paper, lots of flammable substances and materials are presented. In a technological production process of tissue products – hygienic toilet paper, hygienic napkins and handkerchiefs, the strong bleaching and oxidizing substance - hydrogen peroxide that in a contact with certain organic substances supports the burming process, is substituted by more suitable and in terms of fire safety more safe substance – the enzyme. Experimental investigation is oriented on verification and comparation of bleaching substances (hydrogen peroxide and an enzyme) effect on flammability of cellulose based materials. Subject of test are samples of input materials of tissue paper production - separated waste paper, pulp and intermediary products. The article is focused on determinatrion and comparation of oxygen index of cellulose materials using the standardized method STN EN ISO 4589-1:2001. Part 1. Plastics. Determination of burning behaviour by oxygen index. Experimental flammability determination of cellulose-based products contributes to new knowledge that can be utilized in practice for increasing fire safety in technologies of processing and production thereof as well as in other building structures (e.g. storage halls and others). Knowledge of fire and technical characteristics of input raw materials, intermediary products, auxiliary substances as well as output products enables, together with designs and carrying out effective preventive and fire safe measures, to minimize danger and risk of fires origin.

*Keywords*: building structure, structural fire safety, fire, flammability of materials, cellulose, waste paper, tissue paper, hydrogen peroxide, enzyme, oxygen index;

## 1. Introduction

Nowadays, a large amount of crisis situation arises all around the world; one of them is fires not only in wildland but also in inhabited areas, which may cause disruption of critical infrastructure protection [1], [2]. Fire protection level in structures depends on many factors, not least on the amount and type of flammable products, masterials and substances present in the structure. Among flammable materials that are relatively often present both in building structures and in technologies belong polymeric plastics on the cellulose basis [3], [4], [5], [6] (e.g. wood, pulp, cellulose, waste paper, tissue paper and. others). Tissue products, for example tissue paper, kirchen towels and hygienic handkerchiefs are technically processed; both natural as well as polymer cellulose materials are flammable in the Fire Class A. In this case, it is a fire of solid rigid substances with organic origin and while they burn usually, a glowing or burning residuum is created [7]. Presence of cellulose materials and tissue products significantly affects processes of burning and fire; thus, it

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is important to be acquainted with their fire and technical characteristics. One of them is the Oxygen Index (OI). Values of OI of cellulose materials can be determined by standardized method STN EN ISO 4589-1:2001 Plastics. Part 1. Determination of burning behaviour by oxygen index [8], [9]. However, there are not known values of fire and technical characteristics of tissue products in a specialized literature, it is important to determine them experimentally, to compare them and make results, which are possible to apply in an expert theory and practice. Measured values enable to compare and evaluate the possibility of fire origin in the tissue products technology with focus on a bleaching process by two different methods – by a peroxide one and an enzymatic one. At the same time, Effect of used bleaching agents (hydrogen peroxide and enzyme) on flammability of finished tissue products were studied. can be compared that in a final consequence affects fire safety topic in bulding structures, namely in a technology process of tissue products production.

## 2. Oxygen Index Method

Flammability determination of plastics – polymer substances by the Oxygen Index method has a broad application at monitoring of relative flammability of both pure materials as well as materials treated by flame retardants [8], [9]. The Oxygen Index is defined as a minimal oxygen concentration in an oxygen/ nitrogen mixture expressed as a volume part of oxygen in 100 volume parts of the N2 and O2 mixture that wil support the examined sample to burn in flame under prescribed test conditions. The lower the oxygen index, then a material is more flammable. This parameter characterize material ability to burn even in a decresed oxygen concentration, especially in the development phase of a fire in the buildings where the air supply to the space is very limited [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22].

Table 1 Oxygen index values of selected ligno-cellulosic materials [23]

| **Material** | **Oxygen Index (OI) [vol. %]** |
|---|---|
| Cellulose | 18.5 |
| Paper | 20.8 |
| Pine wood | 22.2 |
| Beeach wood | 25.0 |

The formula for the oxygen index calculation is as follows (Eq. (1)) [8], [9]:

$$OI = \frac{V_0}{V_0 + V_N} \cdot 100 \qquad \text{[vol. \%]} \qquad (1)$$

where,

OI – oxygen concentration in a volume percentage [vol. %];
$V_0$ – volume of oxygen in a volume percentage [vol. %];
$V_N$ – volume of nitrogen in a volume percentage [vol. %].

Oxygen Index method is the standardized test STN EN ISO 4589-1:2001 Plastics. Part 1. Determination of burning behaviour by oxygen index [8], [9]. It is used oft in ther most of industrially developed states because it with  have relative high accuracy and quantitatively expresses relative flammability of materials. Final values of oxygen index depend on a sample shape, its position – orientation (angle as regards gas flow direction), way of ignition and on conditions under which the test is carried out. The results are orientative only; they can differ from material behaviour under real fire conditions therefore it is required to take into account also other fire and technical characteristics when evaluating fire hazard [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22]. The Table 1 refers to Oxygen Index values of selected ligno-cellulosic materials [23].

## 3. Experimental part – principles of the test and measurement

Burning process at Oxygen Index determination is evaluated by visual observation of flame and flame spread in a controlled oxidation atmosphere. For measurement purposes the equipment Stanton Redcroft – FTA module (Fig. 1) was used.

The tested sample was ignited at the upper end of the sample holder; i.e. vertical positioning was used and flame burning that spreads upstream of the oxidizing agent flow was monitored. The flame burning lasts at least 180 seconds or for time required for reaching 50 mm length for samples I up to IV and VI; or 80 mm length for the sample V, respectively. The gas flowing rate (oxygen/nitrogen mixture) was (40 ± 2) mm.s-1.

The device was connected to the oxygen and nitrogen pressure vessel. The precise amount of oxygen and nitrogen was adjusted by a needle valve. The main flowmeter indicated flowing amount – the oxygen concentration in the oxygen/nitrogen mixture that flows through the combustion tube.

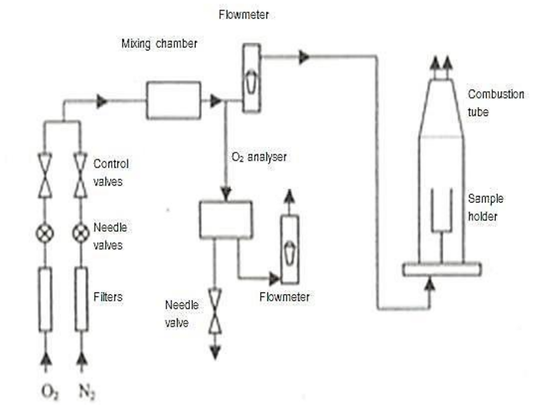


Fig. 1 Scheme of equipment for plastics flammability determination by the means of Oxygen Index Method [8], [9], [15]

The sample was positioned in the sample holder inside the fire resistant combustion tube. After opening gases input, the sample was ignited by a gas burner and time in which the sample burns through – the burning time in seconds, was measured. The device for determination of oxygen index allows simultaneously to measure linear flame spread rate on surface of polymer materials – the length of burned part in mm as well as to create model of flame-free propagation process [8], [9], [15].

### *3.1. Subjects of test – samples of selected cellulose materials*

The subjects of test are samples of following cellulose materials:

- **Sample A** – waste paper, raw material of the C group quality – better quality types, i.e white newspaper pieces, journals and newspapers with minimal text and cut white coloured strips with minimum printed text [15], [24], [25].
- **Sample B** - waste paper, raw material of the B group quality – medium quality types, prevailingly journals and newspapers sheet pieces and cut white up too yellow coloured strips with printed text [15], [24], [25].
- **Sample C** – tissue product, toilet paper made from pulp – cellulose raw material that was not treated by any bleaching agent (neither hydrogen peroxide nor enzyme was used) [15], [25].

The Table 2 refers to selected characteristics of one-layer intermediary product – the tissue paper made by an enzymatic bleaching method and that is suitable for production of multilayer toilet paper.

Table 2 Parameters of tissue product - toilet paper made with enzyme application [15]

| | |
|---|---|
| Surface area [g.m$^{-2}$] | 49.5 |
| Whiteness pursuant to ISO [%] | 78 - 84 |
| Longitudinal tensile stress/ strength [N.50 mm$^{-1}$] | min. 16.2 |
| Transverse tensile stress/ strength [N.50 mm$^{-1}$] | min. 6.0 |

The Table 3 refers to selected characteristics of one-layer intermediary product – the tissue paper made by a hydrogen peroxide bleaching method and that is suitable for production of multilayer toilet paper.

Table 3 Parameters of tissue product - toilet paper made with hydrogen peroxide application [15]

| | |
|---|---|
| Surface area [g.m$^{-2}$] | 48.5 |
| Whiteness pursuant to ISO [%] | 78 - 84 |
| Longitudinal tensile stress/ strength [N.50 mm$^{-1}$] | min. 15.9 |
| Transverse tensile stress/ strength [N.50 mm$^{-1}$] | min. 5.8 |

- **Sample D –** tissue product, toilet paper product made from waste paper mixture(C group quality - 30 % + B group quality – 70 %) bleached by enzymatic method (Tab. 2) [15], [25].
- **Sample E** - tissue product, toilet paper product made from waste paper mixture(C group quality - 30 % + B group quality – 70 %) bleached by hydrogen peroxide method (Tab. 3) [15], [25].

*3.2. Preparation of tested samples, test conditions and carrying out test and measurements*

Tested samples A and B were treated according to the standards [8], [9] on rectangle shape of the type III having dimensions 100 x 10 mm. The sample treating of the samples A and B into the type III shape was chosen depending on a shape and quality of the waste paper material and on its thickness not exceeding 10.5 mm. Tested samples C and E were treated according to the standards [8], [9] on roll shape type VI having dimensions in unrolled plane shape 200 x 20 mm. The sample treating of the samples C and E into the type VI shape – dimension of tested subject, was chosen depending on a shape and quality of the material – toilet paper made without any bleaching process and toilet paper made by hydrogen peroxide application that was so thin to be able be rolled-up on the rod; the thickness varied in the interval from 0.02 mm up to 0.10 mm [15]. Tested sample D was treated on the rectangle shape type V having dimensions 140 x 52 mm. The sample treating of the sample D into the type V shape – dimension of tested subject, was chosen depending on a shape and quality of the material and its thickness not exceeding 10.5 mm. It was flexible thin film that can be treated into the rectangular shape [15]. Tested samples A, B, C, D, and E were conditioned 100 hours at the temperature 23 ± 2 [$^o$ C], air humidity 50 ± 5 [%], and ambient temperature of testing laboratory 22,23 ± 1 [$^o$ C] and relative air humidity 44,48 [%] [15]. A gas burner was an ignition source (according to the Clause 5.5 of the standards [8], [9]) using propane without admixed air. The way of ignition of samples A (type III), C, and E (type VI) is the A method; while that of samples B (type III), and D (type V) is the B method.

By the A method, the whole upper area of the upper end of samples is ignited but the flame shall not touch perpendicular side edges of the sample. By the B method, the whole upper area of the upper end of samples as well as perpendicular side edges of the sample up to depth 6 mm are ignited. The A ignition method can be used for types III and VI. The samples of the type III were marked in the distance 50 mm from the ignited end – the upper area while those of the type VI – rolls on the rod were not marked. The B ignition method can be used for types III and V. The type III shall be marked in the distances 10 mm and 60 mm, respectively, from the ignited end whikle the the type V shall be marked in the distances 20 mm and 100 mm, respectively, from the ignited end.

**Number of samples for experiments**: 20 pieces from each sample.

**Test procedure**: The sample was ignited at the upper end and flame-burning spreading upstream the oxidizing agent flow was monitored. The test lasts minimally 180 seconds. Oxygen concentration in the oxygen/nitrogen mixture was determined by flowmeters [8], [9], [15].

## 4. Evaluation of experimental measurements and discussion

Measured values obtained by prescribed standardized test are referred ~~to~~ in the Table 4 and drawn at the Fig. 2. The method "Oxygen Index - OI" is nowadays one of the most important basic tests of the relative flammability laboratory determination of polymer materials. Oxygen concentration under normal conditions does not exceed 21 [vol. %] and it is supposed that substances having OI higher than 21 [vol. %] will not burn.

Table 4 Measured values of tested samples of selected cellulose materials [15]

| **Material** | **Oxygen Index (OI) [vol. %]** |
|---|---|
| Sample A – waste paper | 19.7 ± 0.3 |
| Sample B – waste paper | 18.8 ± 0.5 |
| Sample C – toilet paper without any bleaching process | 18.3 ± 0.3 |
| Sample D – toilet paper with enzymatic bleaching process | 18.1 ± 0.3 |
| Sample E – toilet paper with hydrogen peroxide bleaching process | 17.7 ± 0.3 |

From resulting measured Oxygen Index (OI) values that were processed in the Table 4 and Figure 2, we can state that the highest Oxygen Index value reached the sample A: 19.7 [vol. %] – i.e. waste paper with quality group C; while the lowest Oxygen Index value reached the sample E: 17.7 [vol. %] – i.e. toilet paper made by peroxide bleaching [15]. All Oxygen Index values of all samples are lower than

21 [vol. %]; based on this fact we conclude that all samples are flammable [15].

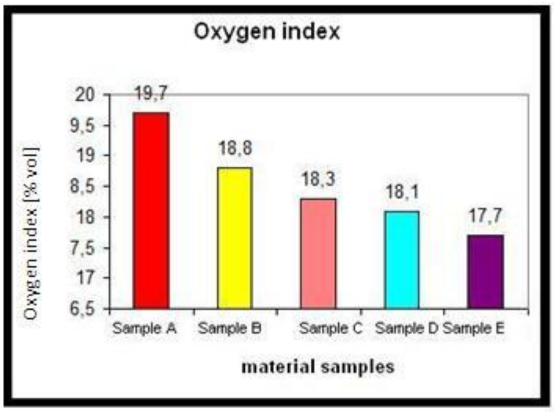


Fig. 2 Chart of final Oxygen Index values of the samples A, B, C, D, and E [15]

Samples A and B, namely the sample A: 19.7 [vol. %] - waste paper with quality group C and the sample B: 18.8 [vol. %] - waste paper with quality group C, reached higher Oxygen Index values; probably presence of printing dyers significantly affected these values [15]. The sample C: 18.3 [vol. %] – toilet paper made without any bleaching process reached Oxygen Index value higher than samples D and E; namely the sample D: 18.1 [obj.%] – a toilet paper made by enzymatic bleaching process and the sample E: 17.7 [vol. %] – a toilet paper made by peroxide bleaching process. More intensive bleaching processes probably decrease Oxygen Index values and increase flammability of final tissue products [15]. The sample D: 18.1 [vol. %] - a toilet paper made by enzymatic bleaching process reached higher Oxygen Index value than the sample E: 17.7 [vol. %] – a toilet paper made by peroxide bleaching process. Based on this fact we can assume that use of enzyme as a bleaching agent compared with hydrogen peroxide in the production process of tissue products decreases flammability of final tissue products – namely of toilet paper [15].

## 5. Conclusion

issue products, especially toilet paper, hygienic handkerchiefs, kitchen towels and other products are widely used in our households. Currently, we cannot imagine our daily life without using them.

Fire hazard of technological processes represents elimination of possibility of fire origin under normal performance conditions. In case of extraordinary performance conditions or accident situation, it is important to eliminate or restrict possibilities for fire origin on minimal reachable level. Decreasing flammability of final tissue products resulting from change of bleaching agents contributes to overall increasing protection against fire in technological process of production wood-processing products. Examination of fire and technical characteristics of treated products based on polymer cellulose materials can contribute to increase fire safety in technological processes concerning production and storage thereof in various building structures [26].

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# Characterization of thermally loaded woods species in the view of physical-chemical and fire technical properties

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**Abstract**

This paper describes chemical changes of five fast-growing species, willow (Salix viminalis L.), acacia (Robinia pseudo-acacia), poplar (hybrid) (Populus nigra x P. maximowiczii), alder (Alnus glutinosa L.) and birch (Betula pendula Roth.) with dimensions of 20 × 20 × 10 mm after thermal loading (ignition and flammable temperature). For each of them content of cellulose, hemicelluloses, holocellulose, lignin, extractives were rated. From the point of physical property, we followed fibre's characteristics (fibre length, fibre width and shape factor). After the thermal loading of the samples, we observed an increase in the amount of cellulose, probably due to changes in its structure, and lignin because of the effect of greater thermal stability as well as due to its condensation. Conversely, content of holocellulose decreased (approx. 20 %) at all of used wood samples. Because of thermal degradation of wood, increasing of fibres in shorter fractions is visible. In terms of fire technical properties, one can say that acacia with the highest density of wood is the most resistant wood specie against thermal exposition.

*Keywords*: ignition and ignitable temperature, thermal degradation of wood, chemical composition, fibres length, fast-growing species;

## 1. Introduction

Wood is a material that has always been used for different purposes. Due to its wide application (construction industry, paper industry, furniture production, ornaments, etc.) and because of its frequent use, it is necessary to know the behaviour and the changes that occur due to various forces, especially the heat. Therefore in order to understand the process of thermal degradation of wood, it is necessary to know the overall structure and the subsequent reaction of wood during its decomposition. Important information on the wood reactions to the fire and heat can be used for the prevention of fire origin, for limiting its spread and minimize the loss of life, injury and property damage (Zachar 2009, Chovanec, Osvald 1992). Just the loss of the mechanical properties together with chemical processes that occur during thermal degradation of wood, give rise to the threat to life, health and property. It should be noted, that such changes are irreversible (Gronli 1996, Kačík, Marková 2000 Hill 2006). The rate of thermal degradation is generally higher in deciduous than in coniferous wood. For example, a spruce has a higher thermal stability than a beech (Schneider, Rusche 1973). But even small amounts of corrosive additives, for example sulphuric, hydrochloric, nitric, phosphoric or boric acids and their salts have very obvious acceleration effect on the rate of thermal degradation of wood (Le Van 1984, Reinprecht 1992, 1996).

The decrease of hemicelluloses proportion is the most obvious in purposely thermally modified wood (Shafizadeh, Chin 1977). At the same time, a relative increase amount of lignin occurs (SUDO et al. 1985); or sometimes can be seen in the increase of extractive substances (Fengel, Przyklenk 1970, Kačík et al.,

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2001), respectively. Clear degradation of the hemicelluloses takes place particularly at temperatures above 170 °C, the degradation depends also on several other factors, such as time, pressure, the presence of oxygen, the presence of water, the presence of aggressive chemicals (Reinprecht, Vidholdová 2011).

Density of the wood, surface of the material or its quality, anatomical structure of wood significantly affect physical-chemical and mechanical properties of wood during thermal exposure. Under the same loading conditions, a rough surface is easier ignitable because of quality smooth surface reflects energy of a radiant or flame sources and thus ignition is more difficult. Also, the geometric shape and dimensions such as thickness, length, diameter, number of edges, curvature angles and others determine the actual resistance of the wood material against ignition; these factors affect the combustion process, its speed and intensity. An important parameter with regard to geometrical shape, is the ratio of volume to surface of the material. Wooden items such as chips, chips and dust are easily ignitable with decreasing value of this ratio (Reinprecht 1997).

The mass loss is a result of the effect of elevated temperature and also of changes that have occurred in the chemical composition of hemicellulose, cellulose and lignin. It depends on various factors such as the duration of temperature effect, initial moisture content of the material, porosity, concentration of reaction products in the environment and the oxygen concentration (Kačík et al., 2001).

Thermal stress of wood results in permanent or temporary consequences. Permanent effects occur as mass loss, degradation of carbohydrates, water loss, and softening of the lignin accompanied by decrease of mechanical properties. The extent of this permanent change of strength depends on the type of thermal load, temperature, moisture, exposure time, type and size of the sample (Oltean et al. 2007, Figueroa, Moraes 2009). But the heat treatment results also in the improvement or stabilization of dimensional properties of wood as well as in the extension of lifetime in terms of disintegration, respectively. Other consequences of such technological process can include reducing the ability to absorb moisture, increasing microbial resistance, increased flexibility, darkening material, etc. All these changes are dependent on several factors, such as time, temperature, atmospheric conditions, wood species, used technique or technology, sample size, etc.

The aim of this paper was to characterize dimensional characteristic of fibres (length, width and shape factor) and chemical changes of extractives, lignin, polysaccharides of selected fast-growing wood species, namely willow (Salix viminalis L.), acacia (Robinia pseudoacacia L.), poplar (hybrid) (Populus nigra x P. maximowiczii), alder (Alnus glutinosa L.) and birch (Betula pendula Roth.) after thermal loading (ignition and ignitable temperature).

## 2. Experimental part

### *2.1. Material*

Samples of wood species, willow - VR (Salix viminalis L.), acacia - AG (Robinia pseudoacacia L.), poplar (hybrid) - TO (Populus nigra, P. maximowiczii x), alder – JL (Alnus glutinosa L.) and birch - BB (Betula pendula Roth.) with dimensions 20 x 20 x 10 mm (standard STN ISO 871: 2010), prepared from the tree trunk, were pre-test conditioned at 23 ± 2 °C and relative humidity 50 ± 5 % for at least 40 hours in accordance with the standard STN EN ISO 291 (2008). Sample surfaces were not treated by another way.

To determine flash point and ignition temperature was used standard STN ISO 871 (2010). The principle of the test is to heat tested material in a heating chamber at different temperatures. By positioning a small pilot flame impinging on the opening cover of the hot-air furnace, released gases ignite and the flash point can be determined. Ignition temperature is determined by the same way as the flash point, but without igniting flame. The course of the temperature in the furnace is measured with thermocouples (type K) with a diameter of 0.5 mm; the data logger ALMEMO® 710 is used for temperature recording.

Prior to the determination of the flash point and ignition temperature, five subsample pieces for determining the moisture content and density were collected from the individual plants (Table 1).

Table 1 Moisture and density of samples before thermal degradation

| Wood species | Moisture (%) | Density (kg/m$^3$) |
|---|---|---|
| VR | 6.33 | 511.13 |
| AG | 6.55 | 725.86 |
| TO | 5.85 | 495.49 |
| JL | 6.75 | 538.50 |
| BB | 6.55 | 621.51 |

*2.2. Chemical content*

For chemical analysis, we chose samples from the thermally degraded part of the wood and these were disintegrated and by grain size analysis arranged to fractions. A fractional piece of wood of 0.5 up to 1.0 mm was used for the chemical analysis. Extractive agents were determined in a Soxhlet apparatus by the mixture of ethanol and toluene (2:1) according to the standard ASTM D 1107-96. Lignin was determined according to the Standard ASTM D 1106-96, and cellulose according to Seifert (1956) and holocellulose according Wise et al (1946).

*2.3. Fibers characteristics*

For determination of dimensional characteristic of fibers we used L & W Fiber Tester equipment that is used in practice for advanced analysis of fiber dimensions. Measurement by the device is based on the principle of two-dimensional imaging technology. Measurement technology is automated, allowing frequent and rapid analysis of pulp quality. The instrument measures the fiber properties such as length and width of the fibers, shape factor (aspect ratio of displayed line length between the ends of the fibers to the actual length of the fiber - length along the outline of the fiber), fine portion (fibers up to 0.1 resp. 0.2 mm), coarseness (fiber mass in μg per unit of fiber length) (Lorentzen - Wettre 2012).

## 3. Results and discussion

*3.1. Fire technical characteristics*

Based on determination of flash point and ignition temperature of individual samples during the time interval until flame was initiated, we can derive samples' strength and behaviour at the time of the fire origin and during its subsequent development. It is also possible to use data for modelling purposes of fires in laboratory scale or for investigating the causes of fires, for confirmation or denial initiation of the material from sources present at fire site, respectively.

During measuring, a gradual degradation of the timber components take place and the achievement of a sufficient concentration of combustible gases and vapours leads to ignition of the sample, resulting in a burning in flames (Rantuch et al. 2015).

The initial burning in flames (flare temperature) and thus the lowest flash point (321.16 °C) was recorded at birch samples, then followed by alder samples (326.44 °C), then almost the same value for the willow samples (338.57 °C) and poplar ones (338.66 °C) and the highest flare temperature was measured for acacia wood samples (353.54 °C). At the actual determination of the flash point, the important function plays the time period of flare – flare time, which ranged from 464.8 seconds for alder samples up to 534.4 seconds for poplar samples (Table 2). Time to flare also significantly informs on material resistance against thermal stress, because the higher the time the greater resistance against thermal loads.

At determination of ignition temperature, we recorded minor differences between the measured values for each species. The lowest ignition temperature was found at the acacia samples (405.84 °C), followed by alder samples (407.87 °C) and birch ones (409.30 °C), higher values were obtained at poplar samples (418.11 °C) and the highest temperature reached willow samples(422.41 °C). The lowest times to flare but very comparable reached poplar samples (305.8 s) and willow ones (318.9 s); longer times but also comparable times achieved alder samples (357.2 s) and birch ones (360.2 s). The highest time was measured for acacia samples (482.0 s) (Table 2). Based on this fact, we can say that this tree species (acacia) has the highest resistance against thermal stresses from all monitored plants. Martinka et al. (2015) in their work dealt with the issues of thermal resistance of spruce wood; where they referred to the initiation temperature of the combustion process (ignition) at 450 °C under the same experimental conditions.

Table 2 Flare and ignition temperatures and times of the samples

| Wood species | Flare tempe-rature [°C] | Time to reach flame tempe-ra-ture [s] | Ignition tempe-ra-ture [°C] | Time to ignition tempe-ra-ture [s] |
|---|---|---|---|---|
| VR | 338.57 | 482.4 | 422.41 | 318.9 |
| AG | 353.54 | 518.8 | 405.84 | 482.0 |
| TO | 338.66 | 534.4 | 418.11 | 305.8 |
| JL | 326.44 | 464.8 | 407.87 | 357.2 |
| BB | 321.16 | 509.6 | 409.30 | 360.2 |

### *3.2. Chemical analysis of wood*

From the results of chemical analysis (Table 3), we observed an increase of the lignin and cellulose content with increasing amount of thermal loading. The increase of cellulose content is due to changes in its structure, because of carbonization and crosslinking (Tjeerdsma et al. 1998, Esteves et al. 2008, Kučerová et al., 2009, and Čabalová et al. 2013, 2016). The increase of lignin content is because of the effect of greater thermal stability Compared to saccharides as well as due to its condensation. When thermal degradation of wood took place up to temperatures VZP and VZN, there was a degradation of polysaccharides (holocelullosis) by more than 20% at all studied species. Wood polysaccharides are created by cellulose and hemicelloses. The thermal treatment of the sample timber tends to increase the proportion of the cellulose and the total thermal degradation of the more labile hemicelluloses (Čabalová et al. 2014).

The yield of extractive substances significant increased using the lower temperature of the thermal load (VZP) at willow, acacia, and birch plant samples. It was increased mainly by products of thermal decomposition of lignin macromolecules (Fengel, Przyklenk 1970). Charring the wood (at VZN) caused a decrease of extractive substances because of their lesser solubility in organic solvents, which is caused by condensation reactions. At the poplar and alder samples, decreasing of the extractives proportion occurred, depending on the used temperature height. Decreasing of extractives in the char layer was also found for other modes of thermal load (Kačík et al. 2006, Tumen et al. 2010).

Table 3 Amounts of extractives, cellulose, holocellulose and lignin in analysed samples (results are expressed in % odw of wood)

| Wood species | Sample | Extractives | Cellulose | Holocellulose | Lignin |
|---|---|---|---|---|---|
| VR | origin | 4.19 | 46.93 | 79.44 | 18.86 |
| | VZP | 7.62 | 62.96 | 60.33 | 30.90 |
| | VZN | 6.40 | 74.43 | 60.12 | 41.11 |
| AG | origin | 6.48 | 41.24 | 81.99 | 19.25 |
| | VZP | 9.10 | 71.21 | 60.96 | 37.15 |
| | VZN | 5.90 | 85.97 | 64.69 | 72.30 |
| TO | origin | 7.36 | 43.37 | 79.03 | 19.96 |
| | VZP | 6.62 | 74.22 | 61.25 | 51.79 |
| | VZN | 6.45 | 81.66 | 61.30 | 69.19 |
| JL | origin | 10.32 | 34.68 | 76.67 | 21.01 |
| | VZP | 6.84 | 67.63 | 59.10 | 43.22 |
| | VZN | 5.21 | 84.22 | 63.64 | 69.47 |
| BB | origin | 5.89 | 33.87 | 85.13 | 17.15 |
| | VZP | 8.60 | 56.08 | 58.35 | 31.44 |
| | VZN | 6.03 | 77.31 | 62.23 | 58.33 |

*3.3. Fibers length*

From the results of the analysis of fibers of willow samples (Figure 1), it is clear that the thermal load affects their length by increasing the proportion of fibers in the shorter fractions. At the original sample, the largest proportion of the fibers (51.18 %) was found within the length class from 0.51 mm up to 1.00 mm, and . Due to thermal load up to the point VZP, only 26.00 % (a decrease of 49.2 %) of the fibers was found in this class; and among samples point VZN only 18.77 % (a fall of 63.33 %) was observed. We recorded, however, increase of the proportion of fibers in the fraction from 0.05 mm to 0.50 mm (original sample: 39.38 % proportion; up to VZP point: 71.14 % proportion; and up to VZN point 78.76 % proportion, respectively).

Geffertová, Geffert (2012) refer the short fibers proportion at the 33-year old willow timber of 15.2 % within the range of 0.20 mm up to 0.50 mm; and 71.4 % proportion within the range 0.51 up to 1.00 mm. Further, they said that from the clones of willow, the clone RAPP had the greatest average fiber length (0.501 mm); while the clone ORM - the shortest one (0.480 mm).

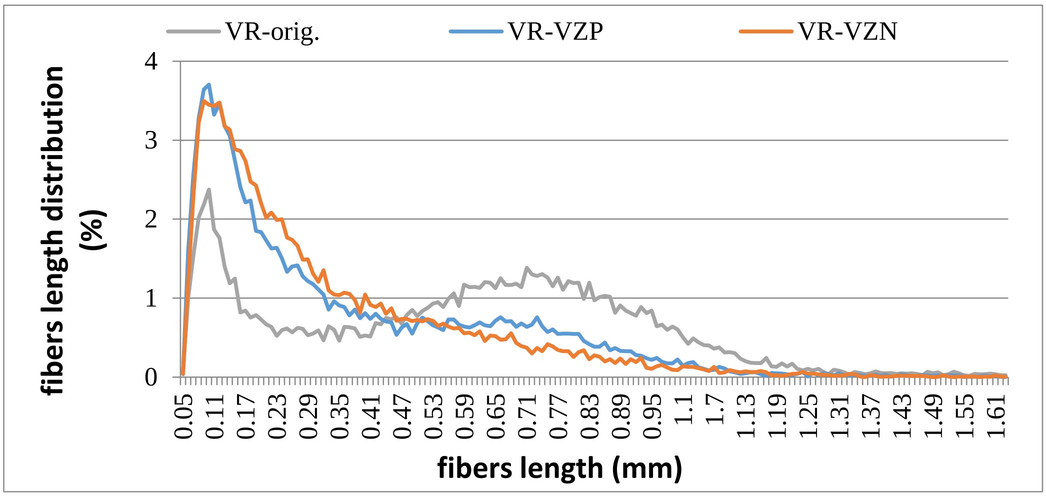


Figure 1 Fibers length of willow wood

The acacia properties were evaluated only at the original sample and sample up to the VZP point, because the sample up to the VZN point was completely charred (due to the longest exposure sample to radiant rays), and therefore the analysis of fibers by the Fiber Tester could not take place. As regards the observed fiber length (Figure 2), similarly as at willow samples, the decrease of the fibers proportion in the fraction from 0.51 mm up to 1.00 mm was observed, while in the original sample in this fraction was located 31.85 % of fibers, and at samples up to the VZP point only 27.46 % of fibers (decrease of 13.78%). One can also observe an increase in the fiber fraction from 0.05 mm up to 0.50 mm; while at the original sample in this fraction was located 52.32 % of fibers; and at samples up to the VZP point reached value 62.61%.

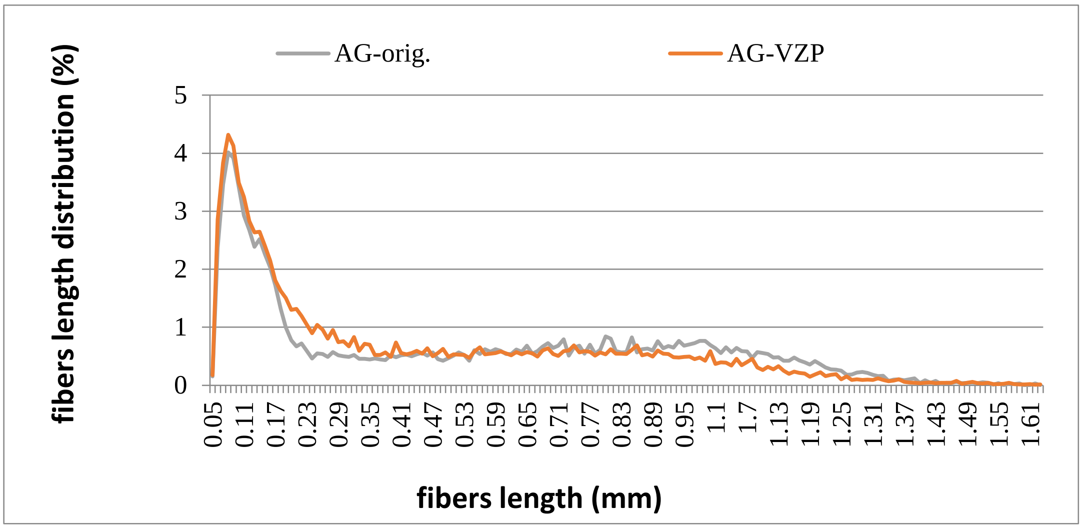


Figure 2 Fibers length of acacia wood

At the poplar samples (Figure 3), proportion of the 31.55 % of the original sample, while that of 10.7 % (a decrease of 68.08 %) was found at samples up to the VZP point and 6.31 % (down by 80 %) at samples up to the VZN point, in the length class from 0.51 mm up to 1.00 mm was located. Conversely in the length class from 0.05 mm up to 0.50 mm, the increase of fiber proportion after thermal degradation took place; at the original sample this proportion was 46.55 % of fibers while at samples up to the VZP point this value increased to 90.55 % and at samples up to the VZN point – to 93.42 %.

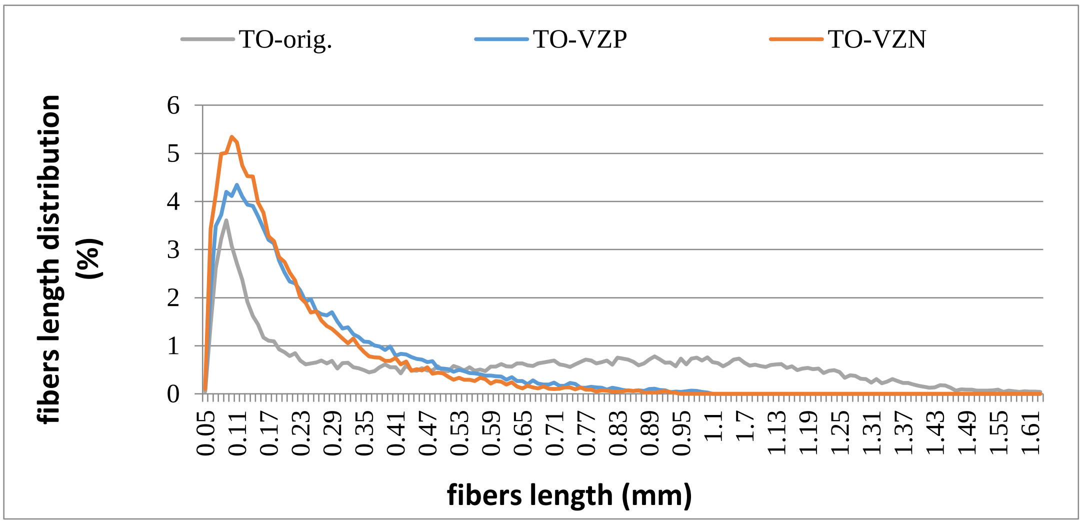


Figure 3 Fibers length of poplar wood

At the alder samples (Figure 4), only modest changes at samples up to the VZP point occurred in terms of fiber length; while in the fraction from 0.51 mm up to 1.00 mm at the original sample was located 46.07 % of fibers, at samples up to the VZP point 42.46 % (a decrease only by 7.84 %) and at the samples up to the VZN point contained in this fraction only

12.2 % of fibers (a decrease by 73.91 %). In the fraction from 0.05 mm up to 0.50 mm, in the original sample was located 49.87 % of fibers, at samples up to the VZP point the decrease took place to the value 52.85 % of fibers and in samples up to the VZN point - 87.98% of fibers.

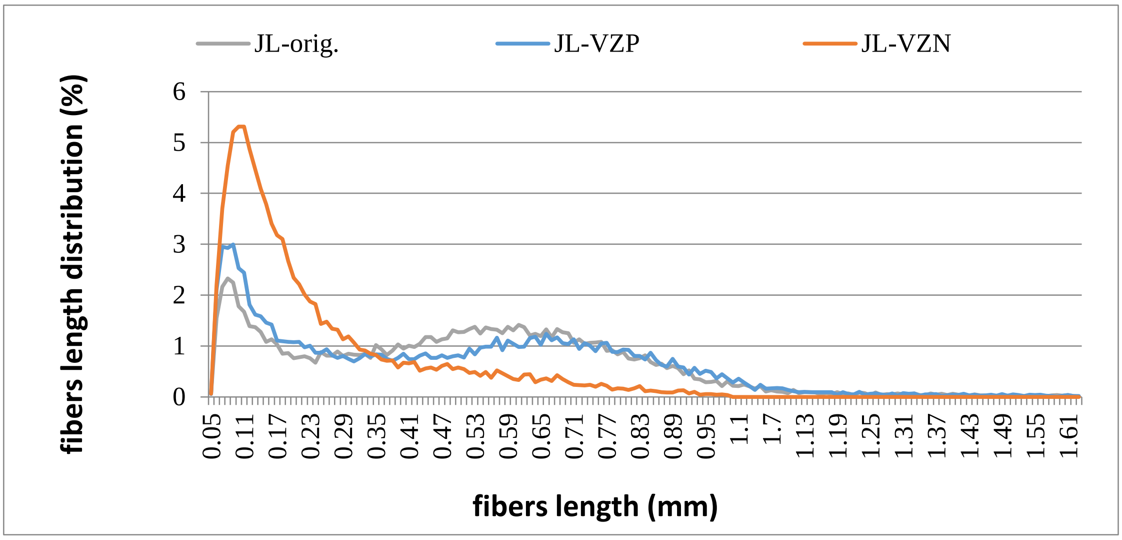


Figure 4 Fibers length of alder wood

At the birch samples (Figure 5); in the length class from 0.51 mm up to 1.00 mm 54.49 % of fibres was found at the original sample; at samples up to the VZP point a decrease to 41.49 % (a fall of 23.86 %) took place and at samples up to the VZN point it was 22.60 % (a fall of 58.52%) of fibres. Conversely in length class from 0.05 mm up to 0.50 mm, the increase of fibre proportion arose in this fraction due to the thermal load; at the original sample there were 38.23 % of fibres located; at samples up to the VZP point - 53.78 % and at samples up to the VZN point - 75.49 %.

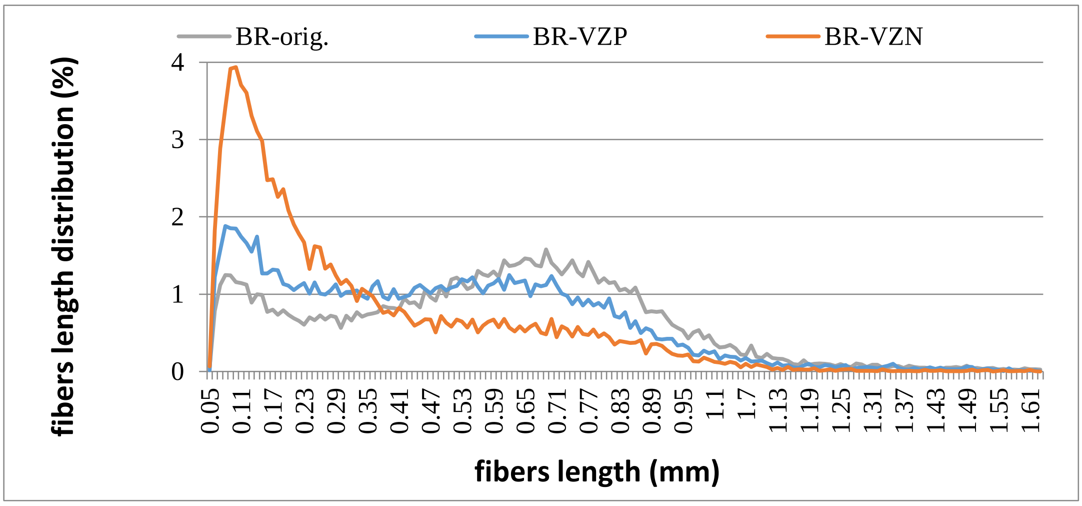


Figure 5 Fibers length of birch wood

*3.4. Fibres width*

From dimensional characteristics, we further investigated the width of the fibres of thermally loaded timber and compared it with the original, unloaded timber. The results, set out in the graphs (Figures 6 up to10)as well as in the Table 4, show that thermal action as well as high temperatures lead to decrease of the average width of the fibres. It is also obvious a decrease in the percentage of fibres in the width class from 20.1 - 30.0 microns and an increase in class up to 20.0 microns. Požgaj et al. (1997) indicate an average values of the willow fibre length of wood 0.95 mm and width 35.7 microns; Sisko and Pfäffli (1995) refer to an average length of 1.1 mm and a width 22 microns.

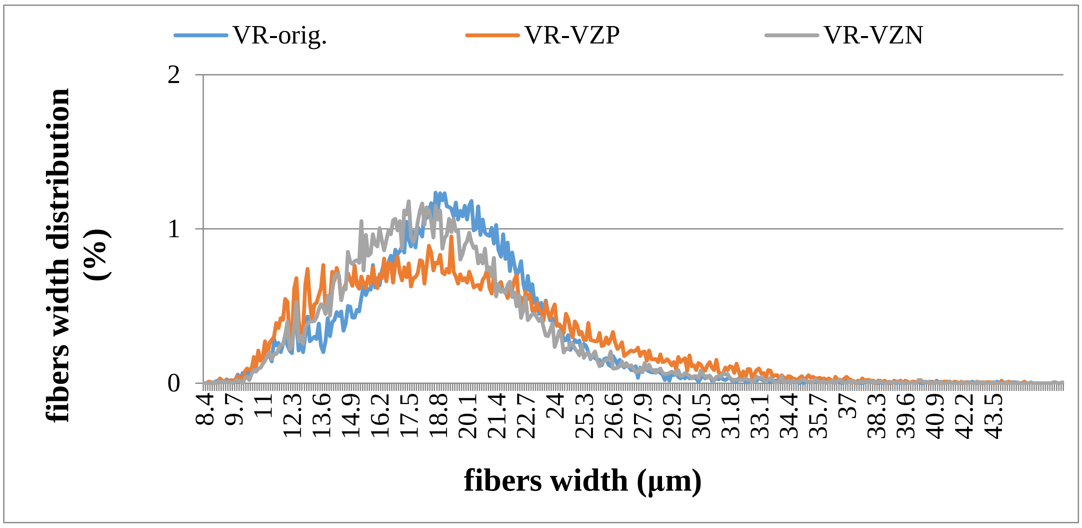


Figure 6 Fibers width of willow wood

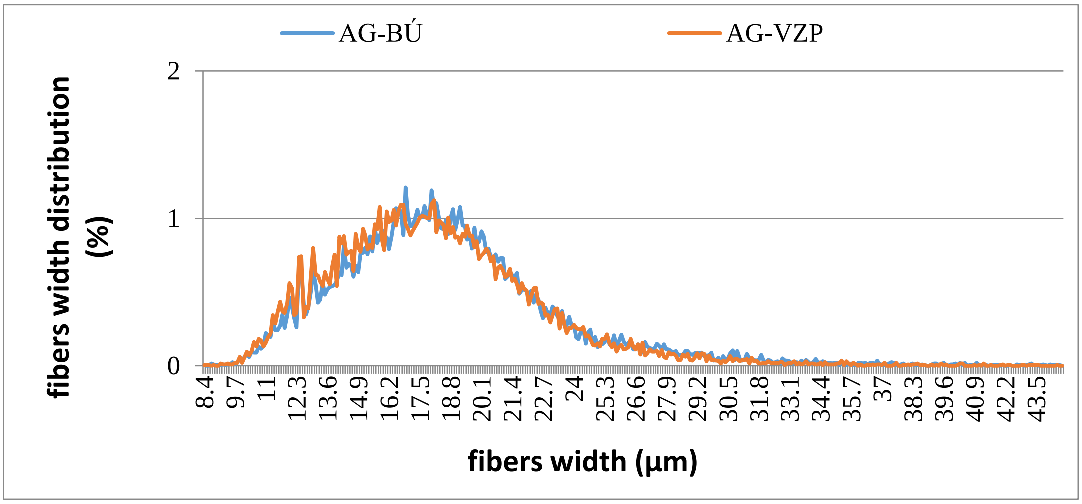


Figure 7 Fibers width of acacia wood

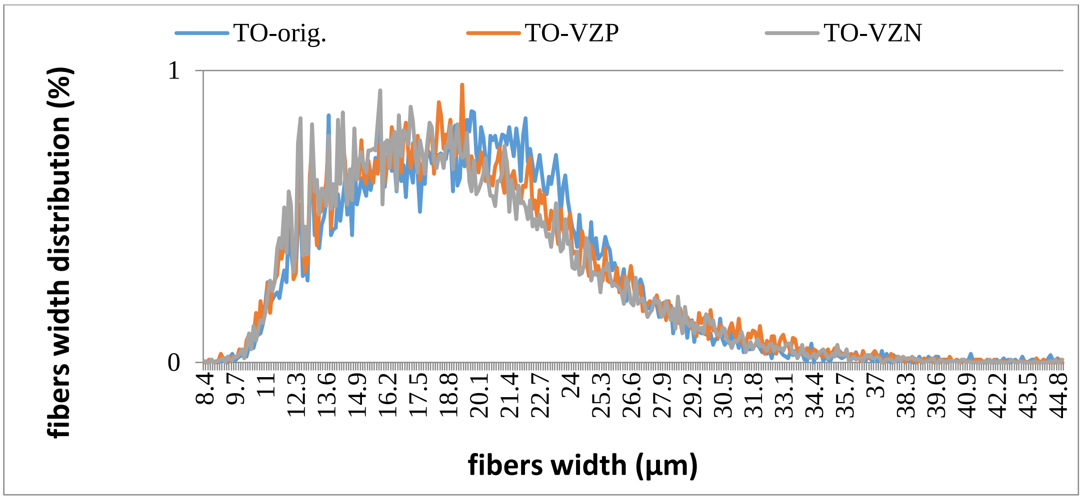


Figure 8 Fibers width of poplar wood

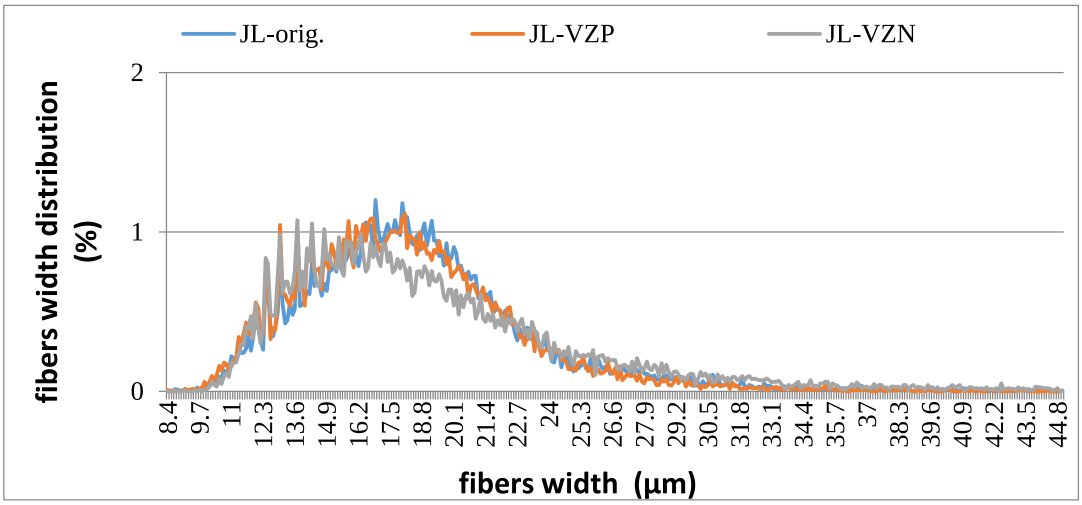


Figure 9 Fibers width of alder wood

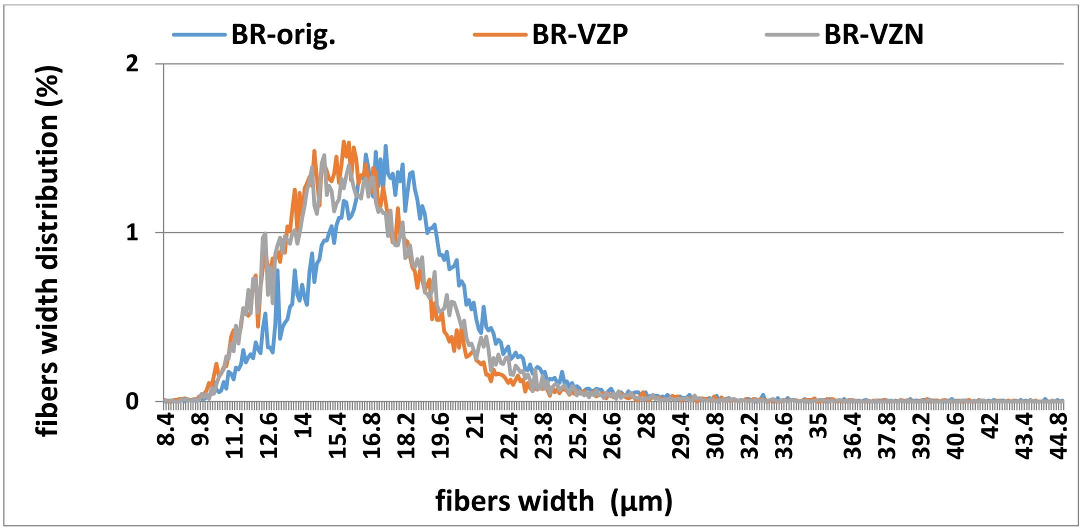


Figure 10 Fibers width of birch wood

*3.5. Shape factor*

The shape factor is a sign of straightness of fibres. Decreasing of this factor occurs e.g. at the thermal treatment the wood; fibres are twisted, become brittle and lose their strength. From the individual graphs (Figures 11 up to 15) and the Table 4, we can see the proportional decrease of more straight fibres (fraction 95.1 – 100 %) and the increase of the proportion of the fractions up to 95%.

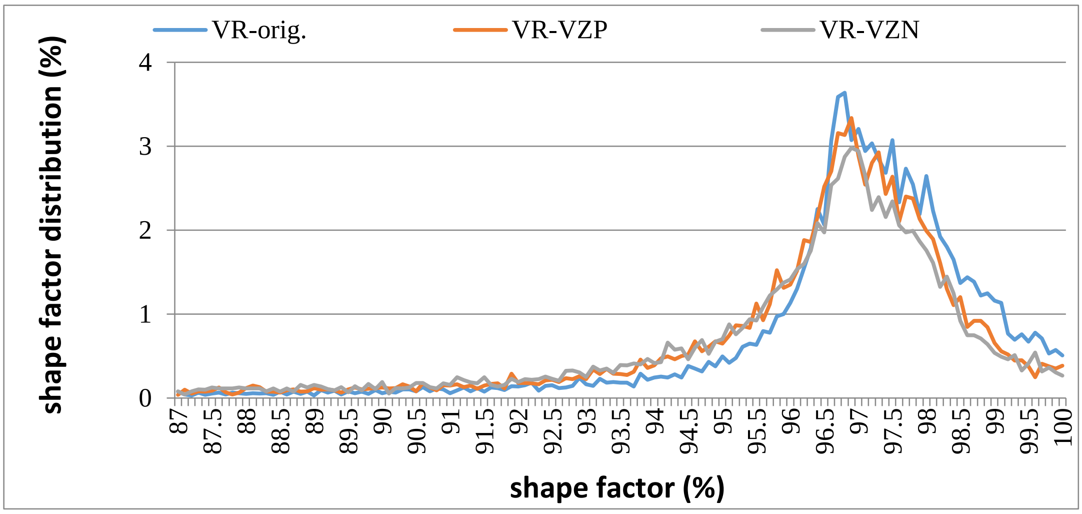


Figure 11 Shape factor of willow wood

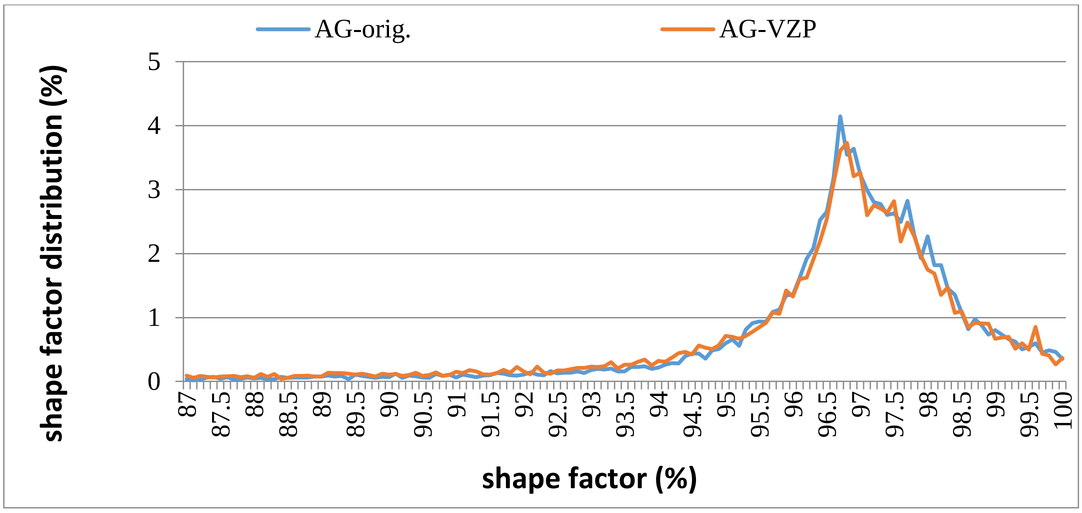


Figure 12 Shape factor of acacia wood

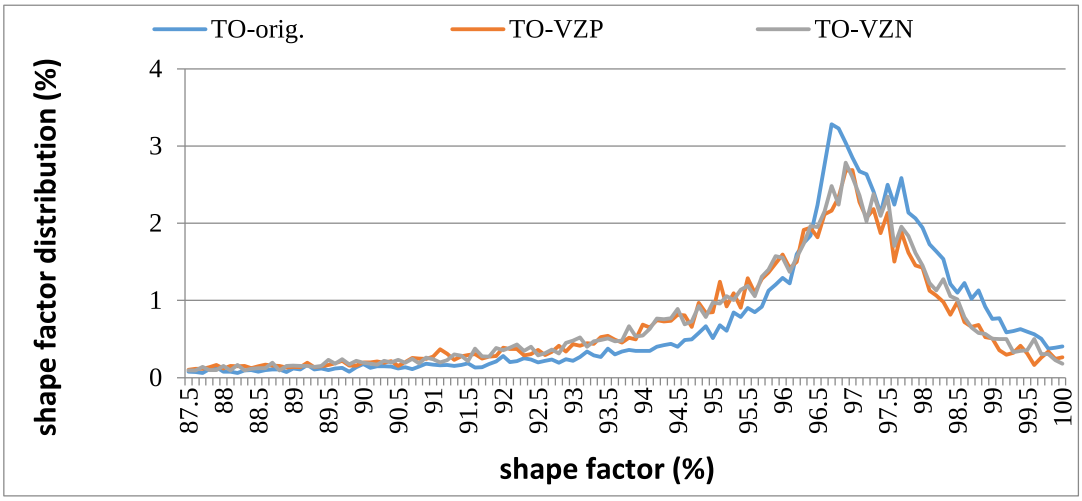


Figure 13 Shape factor of poplar wood

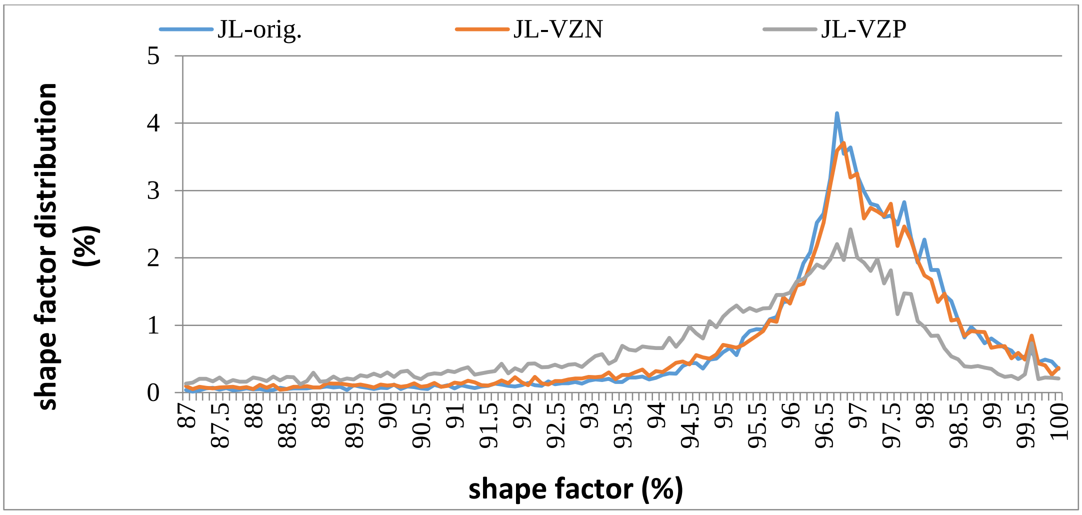


Figure 14 Shape factor of alder wood

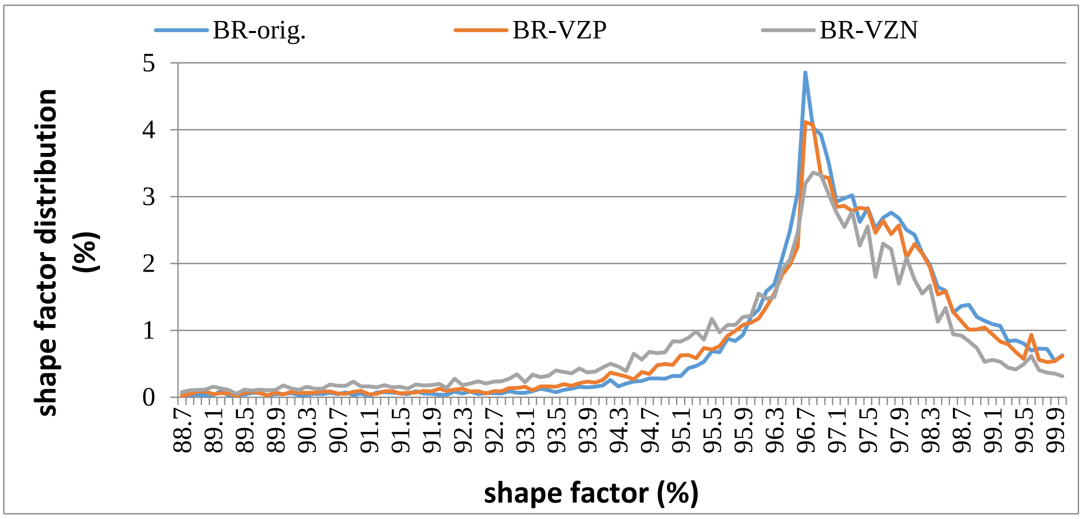


Figure 15 Shape factor of birch wood

Table 4 The percentage of fibres in each class

| Wood species (sample) | | Length classes (mm) | | | Width classes (μm) | | | Shape factor classes (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 -0.50 | 0.51-1.00 | >1.01 | 8.4 - 20.0 | 20.1 - 30.0 | >30.1 | >90.0 | 90.1 - 95.0 | 95.1 - 100 |
| VR | origin | 39.38 | 51.18 | 9.44 | 58.80 | 39.47 | 1.72 | 8.34 | 9.00 | 82.66 |
| | VZP | 71.14 | 26.00 | 2.87 | 62.90 | 35.33 | 1.77 | 10.30 | 14.06 | 75.64 |
| | VZN | 78.76 | 18.77 | 2.47 | 66.33 | 31.70 | 1.97 | 15.26 | 15.68 | 69.07 |
| AG | origin | 52.32 | 31.85 | 15.83 | 68.32 | 28.66 | 3.01 | 9.66 | 9.31 | 81.03 |
| | VZP | 62.61 | 27.46 | 9.93 | 71.29 | 26.82 | 1.88 | 11.24 | 12.05 | 76.71 |
| | VZN | - | - | - | - | - | - | - | - | - |
| TO | origin | 46.55 | 31.55 | 21.89 | 52.79 | 43.18 | 4.03 | 12.65 | 13.36 | 73.99 |
| | VZP | 90.00 | 10.00 | 0.00 | 57.71 | 37.45 | 4.84 | 16.30 | 21.44 | 62.26 |
| | VZN | 93.77 | 6.23 | 0.00 | 60.67 | 35.53 | 3.80 | 13.08 | 21.77 | 65.15 |
| JL | origin | 49.87 | 46.07 | 4.06 | 68.56 | 28.45 | 2.99 | 9.66 | 9.31 | 81.03 |
| | VZP | 52.85 | 42.46 | 4.69 | 71.51 | 26.62 | 1.87 | 11.24 | 12.05 | 76.71 |
| | VZN | 87.98 | 12.02 | 0.00 | 64.70 | 28.27 | 7.03 | 18.72 | 25.07 | 56.21 |
| BR | origin | 38.23 | 54.49 | 7.28 | 79.65 | 19.27 | 1.08 | 7.62 | 5.27 | 87.11 |
| | VZP | 53.78 | 41.49 | 4.73 | 89.79 | 9.46 | 0.75 | 10.68 | 7.98 | 81.34 |
| | VZN | 75.49 | 22.60 | 1.91 | 86.63 | 12.86 | 0.52 | 12.07 | 14.90 | 73.02 |

**4. Conclusions**

From the experimental results of ignition temperature and flash point obtained by the thermal degradation of selected fast-growing trees result following conclusions:

- the amount of lignin and cellulose increases at a higher temperature of the thermal load;
- the amount of extractive substances in willow, acacia and birch plants, respectively, at the VZP temperature is higher compared to that in thermal non-loaded timber; but in the char timber (at the VZN temperature) the decrease of those occurs; on the other hand, in poplar and alder plants quantity of extractives with a high temperature thermal loading declined;
- polysaccharide proportion (holocellulosis) significantly degraded due to the thermal load up to the VZP and VZN points by more than 20 %;
- cellulose trends to charring, which together with a condensed lignin occurs in its the increased amount in the thermally degraded wood at determination according to Seifert method;
- length of the fibres of the thermal loaded trees is reduced, which led to a reduction of the proportion of longer fibres and increasing the proportion of shorter fibres in the fractions (0.05 mm to 0.50 mm).

In terms of fire-technical characteristics it can be said that the most resistant wood species against thermal exposition is acacia wood with the highest wood density. Results of physical and chemical analyses are not comparable between individual tree species due to the fact that each species reached a different temperature and flare time and ignition time, it means that there were different degrees of degradation of wood samples.

## Acknowledgments

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# A proposed mid-scale test for evaluation of vertical construction elements

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**Abstract**

Fire resistance is expressed by limit states and classification times. To determine these, the construction element must undergo specific tests in accordance to the relevant standards. The proposed mid-scale test method is considered a mid-scale method, by which vertical construction elements can be evaluated from the fire-resistance point of view. The basis of the proposed mid-scale test comes from STN EN 13501-2 and linked standards. The paper provides a theoretical background and describes the individual parts of the test apparatus, test conditions, description of the test specimen, test methodology and principles of evaluation of the limit states – thermal insulation and integrity.

*Keywords:* fire resistance, mid-scale test, vertical construction element, integrity,thermal insulation, standard time-temperature curve;

## 1. Introduction

From a fire-protection point of view, building materials are evaluated to establish their fire performance by using various standardised tests. For the construction as a whole, it is not reaction to fire, but fire resistance that is evaluated. Specific regulations and standards deal with fire resistance tests. The test methodology depends on the type and function of the construction element.

It is necessary to select an appropriate fire scenario when testing a construction element. Usually, the standard time-temperature curve is employed when evaluating the fire resistance of walls. Fire resistance is expressed in limiting states and classification times in minutes.

## 2. Evaluation of fire resistance of load-bearing construction element in accordance with current legislation

### *2.1. Theoretical basis*

The general methodology of fire resistance classification is set out in STN EN 13 501-2 [1].

The goal of determining fire resistance in accordance with 1363-1 [2] is to evaluate the performance of the construction element specimen exposed to defined conditions of thermal and mechanical loading. This method provides means for determining the ability of an construction element to resist the effects of high temperatures through a set of limit-state criterions used for evaluation of the load-bearing function, fire-barrier performance (integrity) and heat transfer (insulation), among other limit states.

The test method for evaluation of load-bearing fire walls is set out in EN 1365-1[3].

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*2.2. Standardised test apparatus*

The standardised test apparatus as per STN EN 1363-1 [2] consists of:

- test furnace for thermal exposure of test specimens,
- control device allowing furnace temperature control,
- device for furnace pressure monitoring and control,
- device for fixing and imposing loading on the specimen and monitoring of the loads imposed,
- device for measurement of test specimen deformation,
- device for evaluation of test specimen integrity,
- time-monitoring device,
- measurement of oxygen concentration in furnace.

*2.3. Standard thermal exposure*

Usually, standard time-temperature-curve thermal loading is applied in fire resistance tests. This fire scenario is internationally recognised as a uniform time-temperature course during a fire. The standard time-temperature curve is shown in Fig. 1.

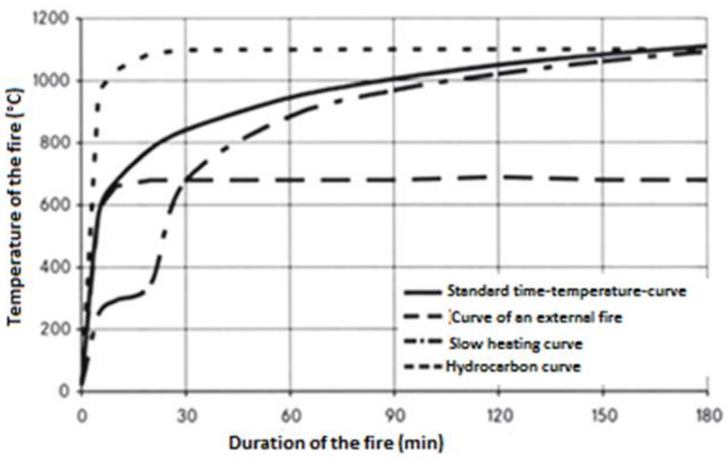


Fig. 1 Standardised time-temperature curves

The dependence which is the model of a fully-developed fire in enclosures can be expressed as:

$$T = 345 \log_{10} (8t + 1) + 20 \quad (1)$$

where
$t$ - time from the start of the test (min);
$T$ - average temperature in the furnace (°C).Werner[4]

*2.4. Test specimen*

The number of test specimens, which are to be tested, depends on the number of sides with fire resistance requirements [2]:

- in cases of load-bearing walls for which fire resistance is required only from one side, only one specimen is tested. In this case, thermal loading is applied to the side which is expected to be attacked by fire in real application.
- if a load-bearing wall is required to be fire resistant from both sides, two specimens are tested.

*2.5. Test procedure in accordance to EN 1363-1*

The general test procedure for the determination of fire resistance of vertical load-bearing construction elements is specified in STN EN 1363-1 [1], as follows:
1. Before the test, the test specimen is built into a frame placed in the test furnace.
2. The load-bearing element is put under the load at least 15 minutes before the test. Deformations resulting from the pre-test load are measured before the test.

3. 5 minutes, at the earliest, the start temperature is recorded; temperature is measured by thermocouples. The average initial internal temperature and the temperature of the unexposed specimen surface must be (20 ± 10) °C and cannot differ from the ambient temperature more than 5 °C.
4. The moment when the temperature at any of the thermocouples exceeds 50 °C is considered the start of the test.
5. The thermocouples record temperature for the entire duration of the test in intervals not exceeding 1 minute.
6. Pressure in the furnace is measured for the entire duration of the test and its values are recorded in intervals not exceeding 1 minute.
7. The deformation of test specimens is measured before and after the load is imposed by the test apparatus and during thermal exposure every 1 minute.
8. The integrity criterion of separating elements is evaluated by cotton pads, dimensions of cracks and monitoring of the test specimen for continuous flaming combustion.
9. The behaviour of the test specimen is monitored for the entire duration of the test (smoke production, cracks, melting, softening, delamination or carbonation of the test specimen), any observations are recorded.
10. The test may terminate from various reasons: lab-personnel is in danger or test apparatus may be damaged; set criteria are met; or the client requests test termination.

*2.6. Principles of integrity and thermal insulation evaluation in accordance to STN 13 501-2*

*2.6.1 Integrity*

Integrity E is the ability of the construction element, which has a fire-separating, function, to resist fire exposure from on one side without its passage to the unexposed side due to the passage of flames or hot gases. These may cause ignition of the unexposed surface or any combustible material in its vicinity(STN EN 13501-2[1]).

STN EN 1363-1 [2] considers the integrity criterion met as long as none of the following situations occur:

- Ignition of a cotton pad which is applied to the specimen for 30 seconds or until its ignition.
- Two gauges are used to evaluate any cracks or openings created during the test. The 6-mm gauge is used to check penetration through the specimen and the possibility to move along 150 mm. The 25-mm gauge is used only to check penetration through specimen. The time and place when one of the gauge was used is recorded.
- Continuous flaming combustion is evaluated visually. Its occurrence is recorded as well as its duration, and location on the unexposed side.

*2.6.2 Thermal insulation*

Thermal insulation is defined in STN EN 13 501-2 [1] as the ability of the construction element to resist fire exposure on one side without its passage on the unexposed side due to significant heat transfer from the exposed to the unexposed side.

STN EN 1363-1 [2] considers the insulation criterion met as long as none of the following situations occur:

- Average temperature increase, against the initial temperature, on the unexposed side is smaller than 140 °C, or
- Maximum temperature in any location of the unexposed side is not greater than 180 °C against the initial temperature.

## 3. Proposed mid-scale test

*3.1. Theoretical background for mid-scale test*

The mid-scale test is considered a model test. Its basis comes from STN EN 13 501-2 [1], which references to EN 1365-1[3] regarding the evaluation of load-bearing fire walls.

*3.2. Test apparatus for mid-scale test*

The test apparatus for mid-scale testing of two criteria of fire resistance – integrity and insulation, consists of the following components:

- Furnace chamber constructed of porous concrete blocks,
- Specimen sealing assembly,
- Assembly for simulation of static loading (threaded rods),
- Gas burners for creating thermal loading with holders,
- Gas flow regulators,
- Temperature recording device,

- Voltage recording device,
- Integrity test gauge,
- Clock.Dúbravská [5]

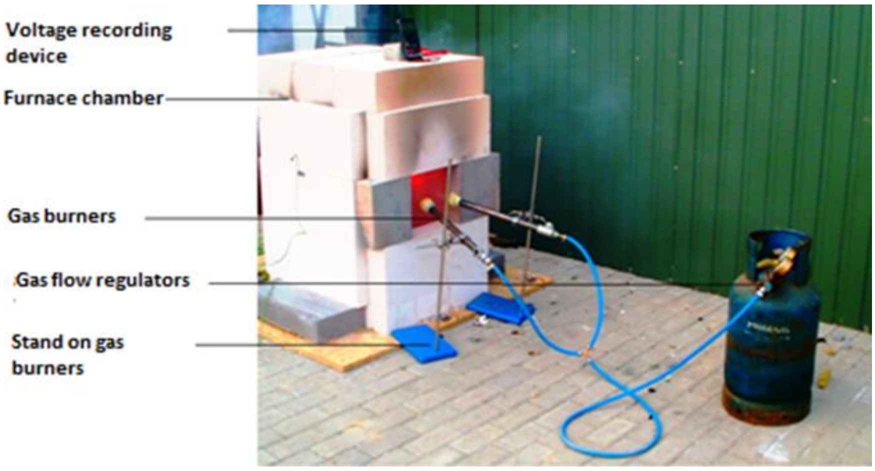


Fig. 2 Mid-scale test furnace [5]

The furnace chamber was constructed of porous concrete blocks. An opening fo 400 x 250 mm was in the middle of the front face of the furnace, into which the gas burners were placed. This opening allowed the exchange of gases into and out of the furnace. The test specimen was placed in an opening in the top segment of the rear face of the furnace (see Fig. 3).

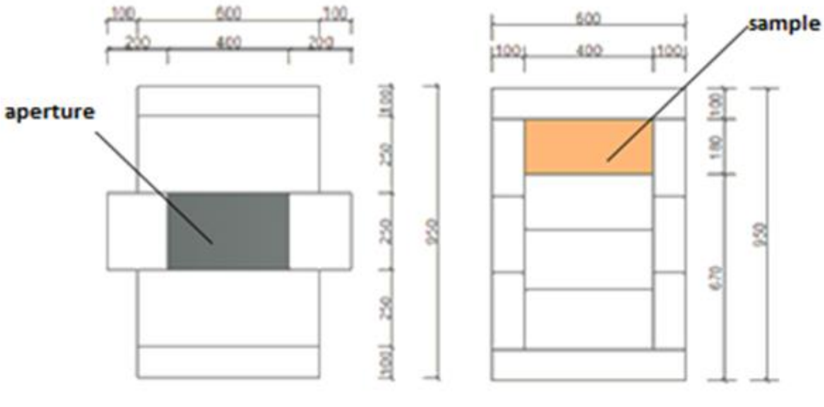


Fig. 3 Front and rear face of test furnace [5]

*3.3. Conditions during the mid-scale test*

The temperature in the test furnace was 20 ±10°C prior the test.

The temperature in the furnace depends on the required thermal loading during the mid-scale test. The standard time-temperature curve exposure was selected. The course of the temperature is measured by a thermocouple placed in the upper part of the furnace. This thermocouple is connected to a voltage-measuring device and the output voltage from the NiCr-Ni type thermocouple are converted to temperature readings using Tab. 1.

Tab. 1.Voltage – temperature conversion for NiCr-Ni type thermocouple [5]

| *°C* | *0* | *10* | *20* | *30* | *40* | *50* | *60* | *70* | *80* | *90* | *mV/°C* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***0*** | 0.00 | 0.40 | 0.80 | 1.20 | 1.61 | 2.02 | 2.43 | 2.85 | 3.26 | 3.68 | 0.041 |
| ***100*** | 4.10 | 4.51 | 4.92 | 5.33 | 5.73 | 6.13 | 6.53 | 6.93 | 7.33 | 7.73 | 0.040 |
| ***200*** | 8.13 | 8.54 | 8.94 | 9.34 | 9.75 | 10.16 | 10.57 | 10.98 | 11.39 | 11.80 | 0.041 |
| ***300*** | 12.21 | 12.63 | 13.04 | 13.46 | 13.88 | 14.29 | 14.71 | 15.13 | 15.55 | 15.98 | 0.042 |
| ***400*** | 16.40 | 16.82 | 17.24 | 17.67 | 18.09 | 18.51 | 18.94 | 19.36 | 19.79 | 20.22 | 0.042 |
| ***500*** | 20.65 | 21.07 | 21.50 | 21.92 | 22.35 | 22.78 | 23.20 | 23.63 | 24.06 | 24.49 | 0043 |
| ***600*** | 24.91 | 25.34 | 25.76 | 26.19 | 26.61 | 27.03 | 27.45 | 27.87 | 28.29 | 28.72 | 0.042 |
| ***700*** | 29.14 | 25.34 | 25.76 | 26.19 | 26.61 | 27.03 | 27.45 | 27.87 | 28.29 | 28.72 | 0.042 |
| ***800*** | 33.30 | 33.71 | 34.12 | 34.53 | 34.93 | 35.34 | 35.75 | 36.15 | 36.55 | 36.96 | 0.041 |
| ***900*** | 37.36 | 37.76 | 38.16 | 38.56 | 38.95 | 39.35 | 39.75 | 40.14 | 40.53 | 40.92 | 0.040 |
| ***1000*** | 41.31 | 41.70 | 42.09 | 42.48 | 42.87 | 43.25 | 43.63 | 44.02 | 44.40 | 44.78 | 0.039 |
| ***1100*** | 45.16 | 45.54 | 45.92 | 46.29 | 46.67 | 47.04 | 47.41 | 47.78 | 48.15 | 48.52 | 0.037 |
| ***1200*** | 48.89 | 49.25 | 49.62 | 49.98 | 50.34 | 50.69 | 51.05 | 51.41 | 51.76 | 52.11 | 0.036 |

By regulating the output of the gas burners, the required temperature in the furnace chamber is achieved, given the time step of the test. A number of specimens were tested in the mid-scale model furnace and the temperature courses for the individual tests are shown in Fig. 4. The differences among the individual tests are caused by the impact of weather, which could not be excluded entirely.

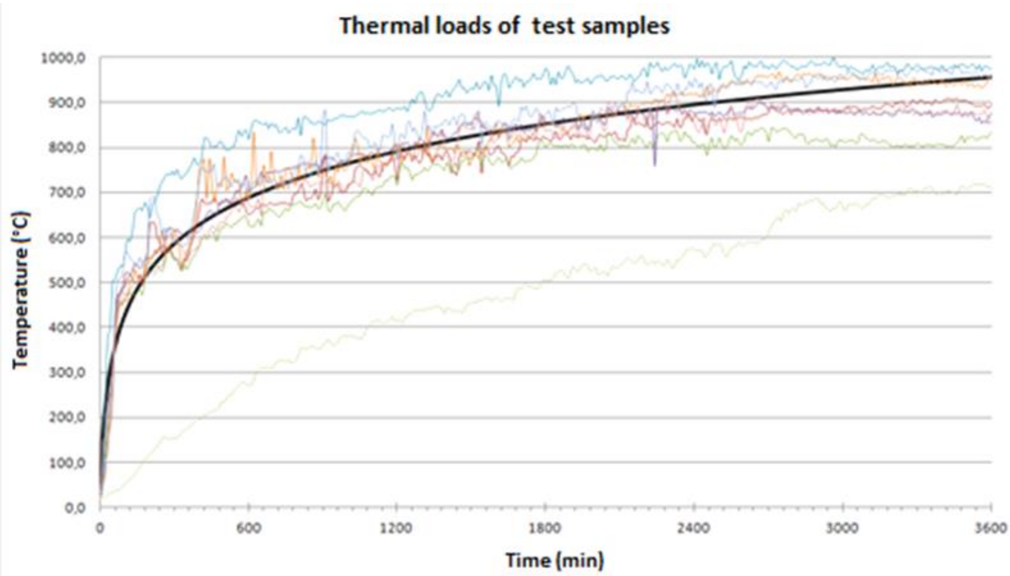


Fig. 4 Simulation of standard time-temperature curve [5]

The above is a description of temperature regulation in the furnace chamber during the model test.

### *3.4. Temperature-recording device*

The temperature is recorded by a data-logging hub with connected thermocouples. The temperature is being recorded at predefined intervals during the entire test. The temperature data are being recorded in the data logger every 10 seconds.

After the tests, the data measured by the individual thermocouples are recorded to an external storage device. From this device the data are transferred to a PC and subsequently evaluated by the ALMEMO – WINCONTROL software. It si possible to export the data into Microsoft Excel.

The data logger was connected with NiCr-Ni thermocouples which have a measurement range of -40 °C do +1200 °C.

*3.5. Test specimen*

The test specimen is fitted into the rear face of the test furnace. The dimensions of the test specimen are 180 mm height and 400 mm length. The specimen must be adequately sealed along its edges to prevent spread of fire along the gaps.

The number of test specimens to be tested by the mid-scale test is identical to STN EN 1363-1 [2].

Thermocouples are positioned into the test specimen. Their locations are as follows:

- 1 pc 5 mm from the exposed face,
- 1 pc 5 mm from the unexposed face,
- other thermocouples are uniformly placed through the specimen width.

*3.6. Test methodology*

The methodology of the mid-scale test is as follows [5]:

1. Before the test, the test specimen is placed in the rear furnace opening.
2. The test specimen is placed into a sealing assembly which prevents fire from passing along the edges of the specimen to the unexposed side.
3. The initial temperature is checked before the start of the test. The initial temperature on the individual thermocouples in the test specimen must be 20 ± 10 °C.
4. The moment when the specimen is put under thermal loading is considered the start of the test.
5. The individual thermocouples record the temperature in specified locations for the entire duration of the heating every 10 seconds.
6. The duration of thermal loading is 60 minutes.
7. The integrity criterion is evaluated during thermal loading and after the test, when the specimen is removed and let to cool.
8. The insulation criterion is evaluated during thermal loading.

*3.7. Principles of integrity and insulation*

The principles of limit state evaluation is partially based on the STN EN 1363-1 methodology [2].

*3.7.1 Integrity criterion*

The integrity criterion is evaluated:

- during thermal loading,
- after thermal loading.

During thermal exposure of the test specimen the unexposed side of the specimen is monitored continuously. Every 10 seconds, the integrity and intactness of the unexposed side of the test specimen is evaluated.

After the end of the test and a cooling period, a final visual check is performed:

- If no cracks or gaps are present on the unexposed side, the integrity criterion is met,
- If there are cracks or gaps present on the unexposed side, the following evaluation is carried out:
  - The dimensions of the individual cracks and gaps, which appeared during the test, are measured,
  - The 6 mm gap gauge test is carried out to evaluate the extent of the cracks or gaps.

*3.7.2 Thermal insulation criterion*

The thermal insulation criterion is evaluated, based on the data obtained during the test and their subsequent processing. This way, temperature profiles are obtained for the unexposed and exposed sides as well as the interior of the specimen.

The insulation criterion based on STN EN 1363-1 [2] is maintained, if:

- The increase of the average temperature in relation to the initial temperature on the unexposed side is smaller than 140 °C, or,
- The increase of the temperature in any location on the unexposed side of the test specimen is, in relation to the initial temperature, not greater than 180 °C.

The insulation criterion is evaluated on the unexposed side and thermal insulation may also be evaluated in the individual locations where thermocouples are placed.

## 4. Conclusions

The mid-scale test simulates the conditions of standardised fire resistance tests. The test is based primarily on current legislation and standards in force in the Slovak republic. From the limit states, the test is focused only on the integrity and insulation criteria.

The classification of integrity in the mid-scale tests was simplified as the cotton pad ignition is not part of the evaluation. During the test, the unexposed specimen side is monitored and after the test ends the gauge evaluation is performed.

The ability of a construction element to resist thermal loading without fire passage to the unexposed side is evaluated, based on the recorded temperatures. These represent temperature profiles in specified depths of the test specimen. It is, therefore, possible to evaluate the increase of temperature on the unexposed side as well as inside the specimen.

A number of different test specimens were tested, already and satisfactory results were obtained, despite the fact that the adverse weather effects could not be completely avoided.

## Acknowledgments

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0057-12.

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# Improvement of the reliability and safety of extrusion machine operation when forming multi-component raw materials

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**Abstract**

The article focuses on the study of the technical and structural characteristics of extrusion machines used to make multi-component waste, RDF (refuse derived fuel). It outlines the results of DEM analysis enabling to forecast the behaviour and volume distribution of multi-component material particles in the extruder to maintain the rational value of ceramic heating element temperature, optimise the speed of auger rotation, reduce emergency shutdown and extruder clogging, and prevent potential ignition of extrusion machine elements. It presents the results of the simulation done in YADE software for the distribution of particles freely leaving the hole. The participles with higher adhesion were established to stick to extrusion machine walls, while less adhesive particles are located in the centre ready to leave the extruder. ROCKY DEM software was used to model the machine body frame and particle movement inside the casing. Simulation results confirmed the need to adjust the auger heating temperature in given points as well as current gauge-assisted control. It was found that uniform heating to 400°C did not yield positive results. The experiments completed and computer models provided information on local heating sites in the extruder and the need to control a heating temperature. Research results were used to upgrade MH-3 experimental extruder by integrating controlled ceramic elements for mixture heating and heating temperature control gauges. These enhancements improved the quality of finished products.

*Keywords:* DEM of simulation, movement of particles, adhesion, clogging, auger, extrusion, parameters, automatics, thermal gauges, extrusion machine, municipal solid waste;

## 1. Introduction

The annual volumes of municipal solid waste (MSW) generated in Russia which are suitable for processing by extrusion approximate 55 million m3 (Final Report on the Waste in Russia, [1]). The high content of metals, plastic, and glass in MSW limits the use of extrusion machines (Figure 1) (Federal Law dated 24 June 1998, [2]). Furthermore, fuel elements made of such raw materials have a high ash content (Williams, [3]).


Figure 1 Composition of MSW disposed at Russian landfills

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The generation of a homogeneous material features even distribution of particles with similar physical and chemical properties (peat, coal, clays, and saw dust) in the extrusion machine body frame (Nikulin, [4]). However the target of research is waste with a multi-component composition. This task is solved by DEM analysis which enables to forecast the behaviour and volumetric distribution of multi-component materials particles in the extruder. The understanding of particle distribution across the mixing drum will enable to maintain the rational value of ceramic heating element temperature, optimise the speed of auger rotation, reduce emergency shutdown and extruder clogging, and prevent potential ignition of extrusion machine elements.

Let us consider the possibility of using RDF (refuse derived fuel) or solid secondary fuel derived from MSW as an alternative to make agglomerate fuel elements. RDF includes such high-energy components as plastic, paper, cardboard, textile, rubber, leather, wood, etc. RDF calorific value is 20,000 ± 2,000 kJ/kg (Castaldi, [5]). RDF grains are approximately 20mm to 25mm. The content of hazardous components in fuel is strictly controlled and does not exceed the maximum permissible values. The calorific value of 1.7kg of RDF corresponds to that of 1 cubic metre of natural gas (Ware, [6]).

RDF is a solid fuel produced by grinding and dehydrating MSW (Figure 2).

Figure 2 Separation of large (over 350mm) and small (smaller than 65mm) fractions at the screen

The following feed composition was selected to assess if pellets can be made of RDF:

- 14% of paper and cardboard;
- 6% of fabric and polyester;
- 18% of mixed packaging and polymers;
- 2% of plastics; and
- 60% of waster food and plants.

An operating body of the auger machine is an auger rotated by the engine through a box coupling. (Epifancev, [7]). When the auger is clogged, the pressure of a formed feed on formed stock increases and pellet compaction reaches its maximum (Chisty, [8]).

The following actions are required before forming the RDF material:

- analyse a biomass stress condition,
- study the impact of the pressure gradient on processes, and
- determine the correlation between performance and auger machine design.

The balance of forces impacting biomass cylinder elements with layer thickness $dr$ moving at a speed of $\tau z$ settles in the channel of the expansion nozzle with a round cross-section (with a radius $R$ and length $l$) where the effects of any inlet or outlet effects can be ignored (Figure 3). However, the uniform movement of the feed is limited to the impact of relevant forces. This results from the incompressibility of liquids and is based on the assumption that the liquid flows along straight parallel trajectories at a permanent speed (Kosov, [9]).

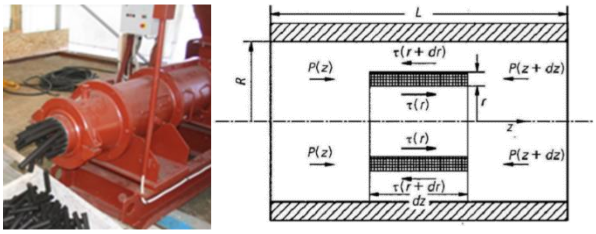



Figure 3 Balance of forces impacting the RDF mass element in the matrix where *dr* is the thickness of a feed layer, *P(z)* is the pressure on the feed layer, and τz is the shear stress of the feed element shift

When r = 0, all forces are equal to zero and the balance equation will be as follows:

$$\tau(r) = \frac{\Delta p \cdot r}{2L} \qquad (1)$$

Formula 1 is the direct consequence of the balance of forces. No assumptions were made regarding the consistent pattern in materials behaviour. It means that the linear dependence of the shearing stress in Formula 1 does not depend on the nature of a material flow. Thus, the best equilibrium state of the elements inside the expansion nozzle for feed forming will be observed with an increase in the pressure on the feed *p* and in the channel radius *r* and with a reduction in the channel length *L*.

## 2. Materials and study methods

Particle distribution with a free release from the hole (simulation of the extruder without an auger) was simulated in YADE software (Nikulin, [10]). Spillage simulation was done with density conditions for layers in line with the RDF composition we used in the extruder (Figure 4). There were particles with larger adhesion at the walls (marked with an arrow in Figure 4) with less adhesive particles which were more prone to leave located in the centre.

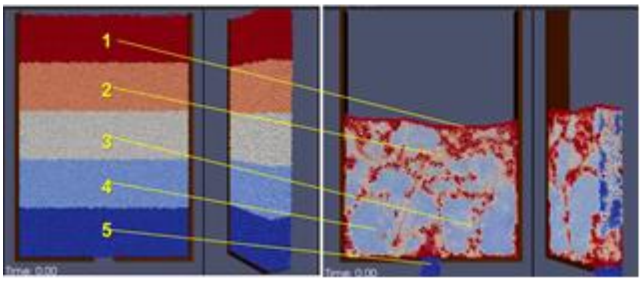
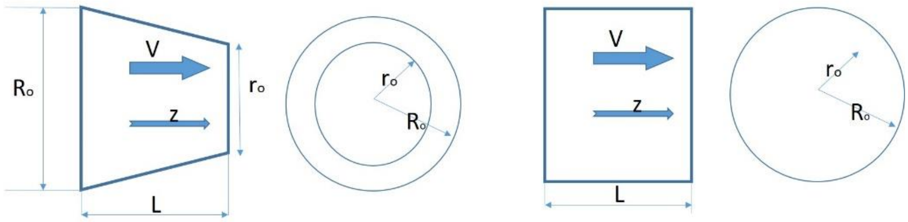



Figure 4 Simulation of interactions in RDF feed in a rectangular matrix. Designations: 1 – paper and cardboard; 2 – fabric and polyester mixture; 3 – mixed packaging and polymers; 4 – plastic;
5 – waste food and plants.

The simulation process was continued in Para-View software where a cone-shaped matrix was used. In accordance with the power law (Ostwald de Waele equation), the volume flow equation can be written as follows:

$$\dot{\gamma} = Kk\Delta p^{n} \qquad (2)$$

Formulas (9) and (10) can be considered fundamental to describe the biomass flow in the expansion nozzle channels given the flow index *n* (Figure 5).




*a* *b*

Figure 5 Geometrical parameters of main matrix expansion nozzles: *a is* a cone channel*; b is* a channel with a round cross-section.

In Figure 5 $R_0$ is the radius of the expansion nozzle lead part, $r_0$ is the radius of an expansion nozzle narrowing part, $L$ is a channel length, $z$ is a biomass direction, and $V$ is a biomass speed vector. The matrix expansion nozzle hydraulic throughput capacity for a cone channel is expressed as follows:

$$K = \frac{\pi r^4}{8L} \cdot \frac{3\left(\frac{R_0}{r_0} - 1\right)}{1 - \left(\frac{r_0}{R_0}\right)^3} \quad (3)$$

For a cylinder channel:

$$K = \frac{\pi R^4}{8L} \quad (4)$$

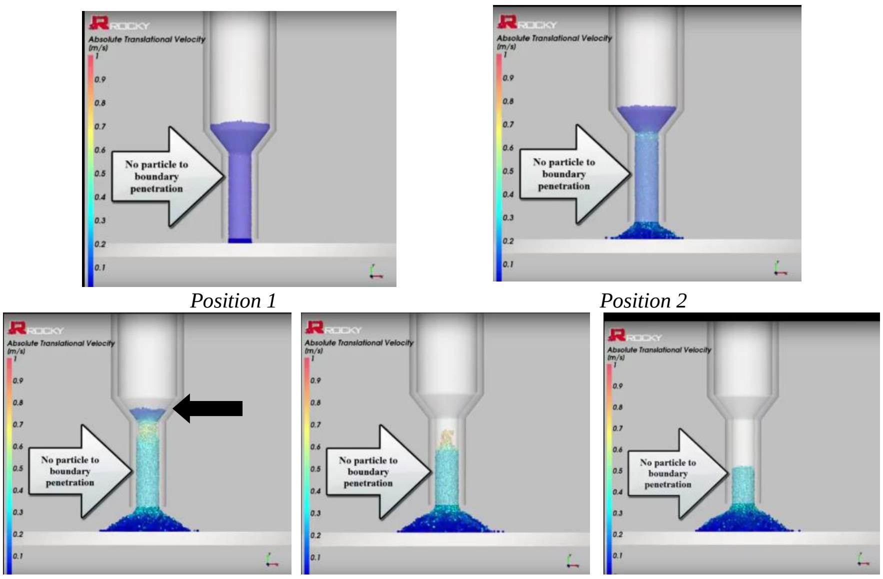
where L/R>>1.

These expressions take into account the assumptions regarding a laminar, isothermal, and stationary material flow (Bogatov, [11]). Therefore, a narrowing inlet part of the matrix expansion nozzle is responsible for material compaction. The soft entrance into the expansion nozzle fosters higher material compaction although it is difficult to make (Kocserha [12]).

Let us consider a change in the speed of particles passing through a form-making channel of the matrix with a cone narrowing section. Calculations were transferred from DEM YADE to the ROCKY DEM environment. This software is different by enabling the creation of complex non-spherical particles and the calculation of their destruction (Yanrong, [13]).

## 3. Results and discussion

Simulation results are shown in Figure 6.




*Position 1* *Position 2*

*Position 3* *Position 4* *Position 5*

Figure 6 DEM simulation of particle movement in the expansion nozzle

The speed in position 1, at the initial stage of channel filling with feed, is 0.1m/s. The speed in position 2 continues to increase the channel lengthwise to reach 0.25m/s in the transition part. A speed increase in position 3 takes place in the transition section between the cone and cylinder parts (shown by an arrow) to reach 0.51m/s. The mean particle speed in the matrix channel in position 4 is 0.34m/s. Position 5 marks the end of the experiment (Figure 7).

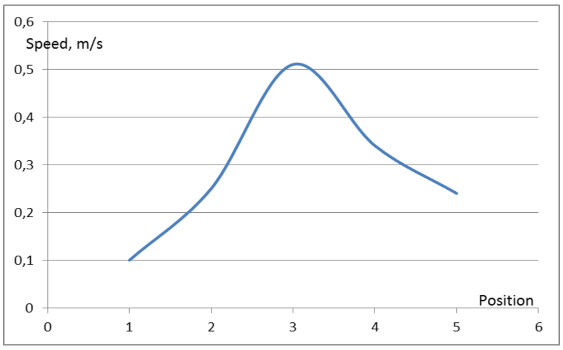



Figure 7 Speed values in positions

The experiment confirmed the pressure differential theory (Figure 5) when a significant pressure difference may result from a non-uniform feed composition and therefore, entail friability. However, if the temperature in this area of the heater is increased, a fragment will bake and move smoothly through the variation point. The internal fragment structure in this case will be uniform. The system of temperature control gauges is shown in Figure 8.

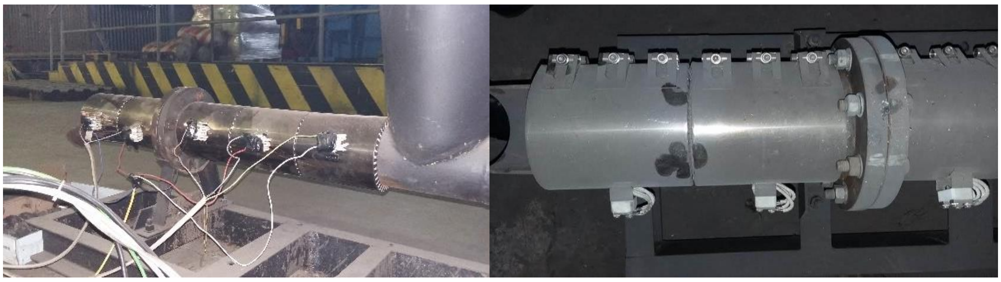


Figure 8 Temperature gauges inside the extruder

ROCKY DEM software was used to simulate the machine body frame and particle movement inside the casing (Figure 9). Simulation results confirmed the need to adjust the auger heating temperature in given points as well as current gauge-assisted control. Uniform heating to 400°C does not yield positive results. It will also facilitate timely control and prevention of granule destruction inside the extruder.

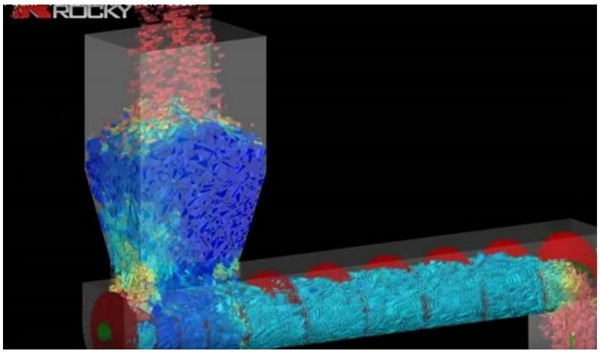



Figure 9 Results of extruder simulation in ROCKY DEM software

## 4. Conclusions

The experiments completed and computer models provided information on local heating sites in the extruder and the need to control a heating temperature. Research results were used to upgrade MH-3 experimental extruder by integrating controlled ceramic elements for mixture heating and heating temperature control gauges. These enhancements improved the quality of finished products (pellets). Figure 10 shows improved MH-3 extruder with relevant designations.

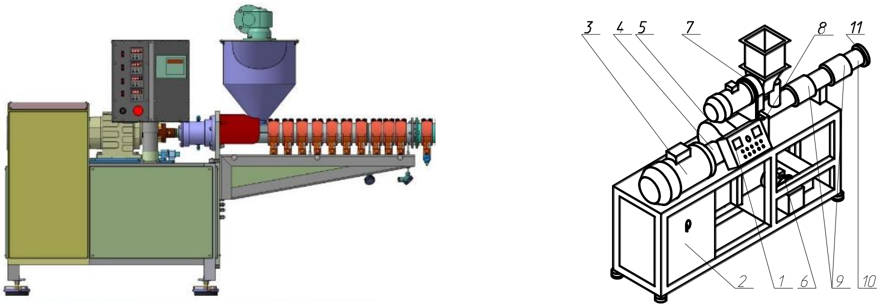



Figure 10 Extruder with integrated thermal gauges
1 – control panel; 2 – control cabinet; 3 – auger drive electric motor; 4 – coupling; 5 – reduction gear; 6, 7 – RDF dosing unit; 8 – support assembly; 9 – heaters; 10 – thermal gauge; 11 – forming matrix.

The results of the research in this area will enable to create transparent extrusion system controls to automatically manage the formation process and prevent early failures of equipment, its parts or mixture ignition.

## Acknowledgments

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# Additional thermal insulation materials and their reaction on fire

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**Abstract**

The internal lining is in building mainly used for decorative purposes, but its properties can mean some protecting load-bearing wooden structures from the effects of fire. With flammable Suspended floors belong to the permanent fire load. The aim of this work is to determine the reaction to fire coating the interior walls based on a representative sampling, recommend species and siding with the best desired properties of the reaction to fire, to evaluate the efficiency of using flame retardants.

*Keywords*: flame retardants, wood paneling, reaction to fire, scots pine;

## 1. Introduction

The design and manufacture of composite structural elements, each element must exhibit the same characteristics as the entire structure. Beam meets the requirements of fire resistance required for the specified time only if they do not damage the respective elements and substrates. The interaction of the individual elements are fire resistance of the whole structure. To increase the fire resistance of load-bearing structural elements are used mainly tiles based on wood or drywall. The lining in particular wall and ceiling, as they are most exposed to a fire. Piece Lining is effective protection against fire. It is important to correct the connection plates and the assembly of the lining, and the parameters such as the thickness, the density and the type of material of which they are made, are also a significant effect of increasing the fire resistance of the lining..

## 2. Material

*Pine wood (Pinus sylvestris)*

Pine wood has a colour-differentiated core, which is reddish brown, with distinct rings of annual growth. Sapwood is yellowish to pale pink, wide 3-10 cm. The share of the core and the sap can vary. The core of freshly felled timber is initially light brown, on the air darkens to reddish brown tint. Between the annual rings is a clear line with a sharp transition between spring and summer timber within the annual ring. Pine wood is soft, light and flexible. The fissile worse than spruce wood but with a content of resin, which increases the durability of the air and water [4].

Pine wood knot because of the greater number and higher resin content, is not as important as in the industrial processing of spruce wood. Nevertheless, its use found justification in the building, when making auxiliary, as well as the final construction and the production of frame structures prefabricated wood buildings. Is widely used as a building and construction material for outdoor construction, water works, in furniture and joinery. In the original cylindrical shape of the pine wood they create and demanding design log buildings. Lower quality pine timber is used for production of pallets and boxes. Lower quality raw pine wood is the starting material for the production of all kinds of chipboard panels. [1]

Bulk density of pine depends directly proportional to wood humidity. Pine wood has a higher strength and density than spruce, but significantly lower flash point (see Table 1).

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Table 1 Physical properties and flammability parameters (PTCH) pine wood at 15% moisture

| Pine wood | | |
|---|---|---|
| Flashpoint | | 250°C ÷ 260°C |
| Temperature of ignition | | 390°C ÷ 405°C |
| Combustion heat | | 18 ÷ 20 $MJ.kg^{-1}$ |
| Weight speed of burning | | 0,56 $m^{-2}$ |
| Compression pressure parallel to the fibre (MPa) | | 60 |
| Compression strength parallel to the fibre MPa) | | 100 |
| Volume weight of wood ($kg/m^3$) | Freshly harvested | 900 |
| | Humidity15 % | 520 |
| | Humidity 0 % | 490 |

*Finland Termowood– Thermowood®*

Termowood is definition for thermally modified wood. Thermal modification is the technological treatment process for the wood structure due to elevated temperatures to increase its resistance to pests and water. Thermal treatment is characterized by a high temperature treatment in the range 180 ° C - 280 ° C, for several hours. When hydrothermal treatment applied to wood and water. At 110 ° C the wood becomes dimensionally stable and higher temperatures multiply the effect, especially for the formation of new ester linkages in the lignin-carbohydrate constituent of wood. Due to the elevated temperature of the partially degraded hemicellulose and lignin to produce a water, formic acid, mercaptobenzimidazole, and other substances.

Thermal treatment of Thermowood is divided into three parts (Fig. 1):

– Increasing the temperature and drying: The first phase, temperature in oven growth rapidly on the value 100 ° C, late it slowly rises to 130 ° C. In this phase, the wood is dried, its moisture content will drop to almost zero.
– Heat treatment: In the second phase of the process the temperature is increased to 185 ° C - 215 ° C depending on the wood species. After the desired temperature was allowed to act on the timber 2-3 hours.
– Cooling and humidity control: In the third phase is reduces the temperature of the oven by using water spray and increases the moisture of wood into usable value of about 4% - 7% [5, 6].

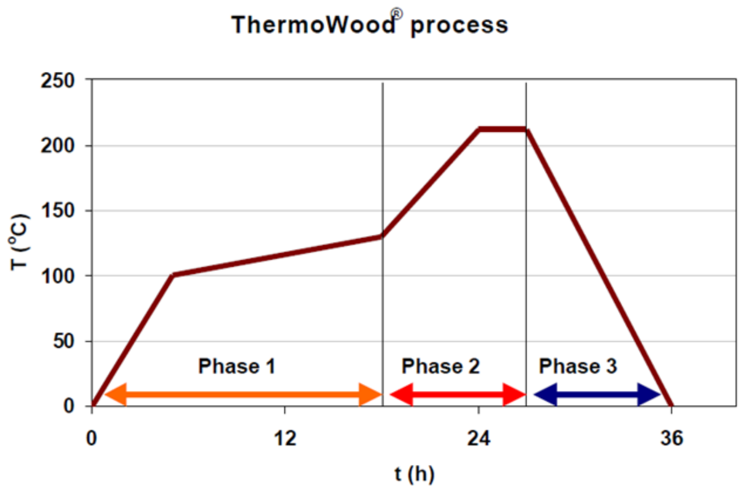


Fig. 1 Chart showing the production process ThermoWood®

There exist two basic types of thermal treatment Thermowood, which have differing temperatures in the production and physical properties:

- Thermo-S (S - Stability) - This type thermowood is stable against external influences mainly focused on resistance to rot. It is used for the production of garden furniture, shutters, saunas and building components.
- Thermo-d (D - Durability) - this type thermowood focuses on his "perseverance". It is also resistant to rot, and in particular humidity. It is used for the production of tiles, doors, floors [7].

Testing samples of pine wood are included into the category Thermo-D. This type of wood is more resistant to rot and water as Thermo-S. Manufacture is carried out at higher temperatures, and the wood to the typical dark colour. This type thermowood used for walls, floors, doors and window constructions.

*Fire retardant – Firestop special*

Flame retardant Firestop Special used during testing, is retardants based on inorganic salts, particularly phosphorous and sulphurous for example: ammonium chloride, boric acid, alkali phosphates (i.e. water glass) and sodium borate. Usually it is used for the protection of wood building materials. The basic advantage of these flame is classified good solubility in water, which is related to the improved coating surface or within the structure of the selected material. Benefits include and multi-resistance, hence the resistance to insects.

The disadvantage of these materials is retarding rapid loss of protective properties as it is soluble with water. At a time when the material is exposed to long-term weather conditions worse losing water due to the required ratio needed retardant substances. When applied to the wood can affect the mechanical properties of metallic materials and in creating causing corrosion. In the method of applying paint, coatings, these short-lived materials require more frequent maintenance. [8]

**3. Experiment**

On experiment we used two basic types of wood and in a variation of plain wood and thermowood. Used thermowood was the type of Thermo-D ThermoWood®. The samples were cut to dimensions of about 250 x 96 x 14-20 mm. The difference in the thickness is due to the procedure in the production process, wherein the different type of tile and the other dimension. Each sample was at a distance of 4 cm from the bottom edge by marking a line as lower border, where he started working flame. Since this line has been identified for each sample and the second line at 150 mm as the upper limit flame spread. During experiment was use a simple device consisting of digital scales, calipers, brushes for the application of flame retardant and test a standard furnace with a small flame. The test furnace comprises a holder for the sample, the burner and the sliding bolt with stop for adjustment of the distance of the source of ignition of the sample. In the burner was used propane.

Fig. 2 Test furnace

*Procedure*

All samples were dried before coating to a desired moisture content and weighed. The samples labelled N was applied double coating Firestop flame retardant. The samples were then allowed to dry for two weeks at room temperature. All samples were re-weighed prior to testing. After mounting samples in the frame is fastened to the support frame and the sliding bolt the flame burning at a 45 ° angle to the flow of the sample so that it only touches the bottom edge of the marked line. We first tested specimen in order to determine the appropriate distance from the sample after adjusting the flame to the test facility has been undertaken to test. [9]

The flame was allowed to act for thirty seconds, then the pushed-return. The sample was observed even sixty seconds following withdrawal of the flame. Most of the samples after delaying prevent flame, or there were only smouldering, but for some samples, the flame spread entire surface. Gradually in this way they were tested all the samples. On completion of work left to cool samples and each sample were measured values of flame propagation according to the length of char the surface layer between the fill line and the mass loss of wood after thermal stress.

## 4. Results and discussion

*Pine wood - results*

Non-retardant samples of pine forest has been categorized in terms of flame propagation in reaction to fire class E since the flame in most of the samples exceeded the limit of 150 mm (see Tab. 2).

When retarded samples reduce flame spread versus non-retardant samples. The weight loss was also by use of retarder a decreasing tendency. Pine wood contains more resin ducts and resin, which increases the flammability compared to spruce. Although he used flame positive effect, it is recommended to test a different type retarder with potentially improved properties.

Tab. 2 The results of the experiment pine wood

| | **Sample** | **Weight of sample before burning (g)** | **Weight of sample after burning ( (g)** | **Weight loss (g)** | **Spread of flamme $F_s$ (mm)** |
|---|---|---|---|---|---|
| **Non –retardant sample** | X1 | 163.83 | 162.86 | 0.97 | 150.00 |
| | X2 | 159.52 | 159.17 | 0.35 | 92.00 |
| | X3 | 164.14 | 163.85 | 0.29 | 82.00 |
| | X4 | 157.63 | 156.23 | 1.40 | 150.00 |
| | X5 | 163.67 | 162.44 | 1.23 | 150.00 |
| | **Average** | **161.76** | **160.91** | **0.85** | **124.80** |
| **Sample with fire retardant** | N1 | 180.65 | 180.62 | 0.03 | 95.00 |
| | N2 | 158.78 | 158.71 | 0.07 | 95.00 |
| | N3 | 185.43 | 185.36 | 0.07 | 110.00 |
| | N4 | 188.18 | 188.00 | 0.18 | 150.00 |
| | N5 | 168.22 | 168.16 | 0.06 | 95.00 |
| | **Average** | **176.25** | **176.17** | **0.08** | **109.00** |

*Thermowood pine wood – results*

Comparing the pine thermowood and classical wood is seen as a significant difference in weight loss as well as in spreading the flame.

When retarded samples reduce significantly the weight loss, but the flame spread was much greater (see Tab. 3).

Tab. 3 The results of the experiment thermowood pine

| | Sample | Weight of sample before burning (g) | Weight of sample after burning ( (g) | Weight loss (g) | Spread of flamme $F_s$ (mm) |
|---|---|---|---|---|---|
| Neon- retardant -ample | X1 | 190.02 | 189.69 | 0.33 | 60 |
| | X2 | 181.92 | 180.8 | 1.12 | 150 |
| | X3 | 172.42 | 172.07 | 0.35 | 70 |
| | X4 | 182.37 | 182.08 | 0.29 | 45 |
| | X5 | 195.57 | 195.25 | 0.32 | 50 |
| | **Average** | **184.46** | **183.98** | **0.48** | **75** |
| Sample with fire retardant | N1 | 191.57 | 191.44 | 0.13 | 80 |
| | N2 | 162.74 | 162.64 | 0.1 | 115 |
| | N3 | 190.03 | 189.94 | 0.09 | 81 |
| | N4 | 164.49 | 164.17 | 0.32 | 150 |
| | N5 | 162.84 | 162.75 | 0.09 | 100 |
| | **Average** | **174.334** | **174.19** | **0.15** | **105.2** |

## 5. Conclusions

In evaluating the results of the experiments we found that the flame retardant Firestop Special decreased in all types of weight loos of the test samples after heat stress. However, in the case of the surface spread of flame retarded samples of all types, this measured value has increased.

The production process thermowood is connected to the thermal stress of wood, wherein the heat-degraded hemicellulose and reduces the moisture content to 4% - 7%. Thermowood has increased resistance to rot, insects, and water. Since the retarder used is a water-soluble assume that not bind to the molecular chains, but remained on the surface, and most of the evaporated. The second assumption is perhaps the reaction retarder with certain components of wood, which has a regressive effect on the spread of flame, but the positive effect of reducing weight loss. The results show that the flame spread over the application surface of the retarder, and to a depth of less wood..

## Acknowledgments

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# Potential of recycled fabric utilization in terms of fire protection and acoustics

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**Abstract**

Materials used in constructions must meet legal and technical requirements, with an emphasis on safety in case of a fire and its ability to dampen the noise. There are new materials that are made from recycled solid waste. Materials made from recycled automotive fabrics also include STERED® board configurations, which testing from the fire and acoustics point of view focuses this paper. A non-standard heat radiation test was used for the evaluation. Weight loss and visual flame burning were detected. The measurement the sound absorption coefficient (α) was done according to STN EN ISO 19534-2 Part 2: Transfer-function method [1]. Inspite of high flammability of the textile waste, one of the boards from materials SENIZOL Ekosen, the board SENIZOL AT XX2 TL60 shows no evidence of burning when was exposed to radiant heat for 10 minutes at a distance 30 mm. This material has also the highest sound absorption coefficient.

*Keywords*: recycled fabrics, partition walls, thermal degradation, mass loss, sound absorption coefficient;

## 1. Introduction

The waste materials (mainly from textiles) can be reintroduced into the economic cycle and their use would contribute on the improvement of the life cycle assessment. Recycling textile waste has an ecological as well as the economic benefits, making it more popular in the past decades (Jordeva [13]).Theoretically, 97% of textile waste can be recycled and they can be used as a raw material for insulation materials for building industry.

There are e.g. automotive fabrics, fabric waste generated in the automotive industry, which has some properties (resistance to fire and sound insulation) that distinguish it from ordinary fabrics waste. Nowadays, when the focus is on the thermal and acoustic insulation buildings, these materials become interesting for building industry.

The latest trends in construction industry show that the share of the construction of low-energy houses (wood buildings) is increasing on the market compared with traditional materials (Karacabeyli [2]), e.g. solid wooden construction. Right in these types of constructions, there is a possibility to use recycled fabrics in the form of an insulating layer as a part of a dividing structure. The long-term goal is to create a dividing structure that includes a layer of recycled fabric material, and it is suitable both from the fire and the acoustic aspects.

## 2. Material and methods

### 2.1. Material

The tested product is a new material in the production of STERED® insulating and construction board (Krajné [3]). The STERED® thermal-insulating and acoustic material is generated by mechanical treatment of waste from fabric materials used in the automotive industry (Plesník [6]). This recycled material is characterized by resistance to moisture, mold, mechanical resistance and hygienic safety (Krajné [5]).

Four samples with dimensions of 50 x 40 x 50 mm were used for the non-standard thermal test using a radiant heat source. For the measurement of the sound

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absorption coefficient α, the four circular samples had the diameter of 100 mm and thickness of 50 mm. The distribution of the samples and their photographic documentation is shown in Figure 1.

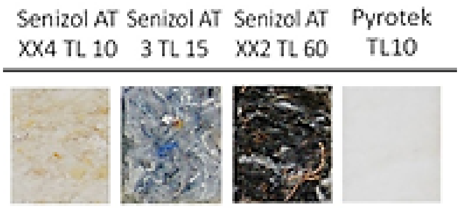


Figure 1 STERED® samples

*2.2. Methods*

In testing, there was applied the radiant heat source method and the transfer-function method [1].

*2.2.1. Method of radiant heat source*

The radiant heat source test was performed on an apparatus, the scheme of which is shown in Figure 2. The test sample was placed on a metal stand which distance from the thermal infra-red heater can be changed (by the h test = 30 mm). The ceramic infrared heater with a power of 1000 W emits radiation with a wavelength of 3 - 6 µm, the operating temperature is in the range of 300 - 750 ° C. The analytical scales Sartorius Basicplus type BDBC 200 were used to detect the weight loss.

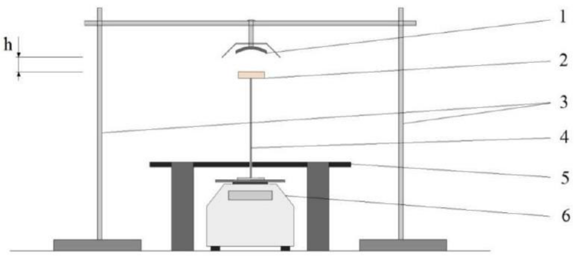


Figure 2 Testing apparatus to apply the method of radiant heat source
1 – infrared heater, 2 – sample, 3 – metal frame, 4 – stand, 5 – scales protection, 6 – analytical

The specimens were exposed to ceramic infrared emitter for 10 minutes at a distance 30 mm. Before the test and subsequently every 10 s has been recorded the mass of each specimen. The relative mass loss in the monitored intervals was calculated according to the formula mentioned in the paper "The influence of heating on thermal degradation selected wood species: (Zachar [7]).

At the same time, the occurrence of flame initiation of the sample was monitored as well as the flame retardation time and extinction time.

*2.2.2. Method of transfer function*

The measurement the sound absorption coefficient (α) was done according to STN EN ISO 19534-2 Part 2: Transfer-function method [1].

The measuring equipment consists of several parts: Bruel & Kjaer impedance tube Type 4206, the LAN module-XI Brüel & Kjær Type 3560-B-030 with two active inputs for microphones and FFT (Fast Fourier Transform) analysis, tone generator and personal computer (PC) with Pulse software (Figure 3).

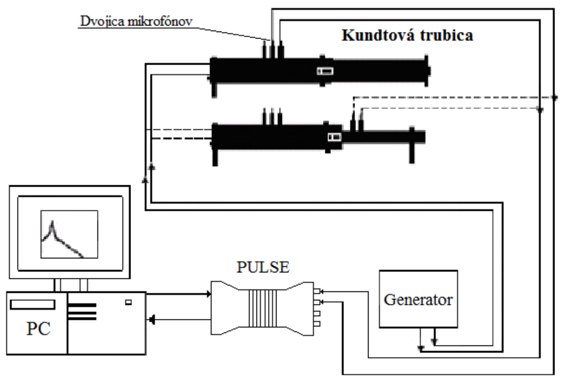


Figure 3 Scheme of the measuring apparatus

The measurement of the sound absorption coefficient was carried out in the frequency range 200 – 2 000 Hz, which corresponds approximately to the range of frequencies of noise in construction sites.

## 3. Results and discussion

The relative weight loss of the tested materials is presented in Figure 4. This parameter allows us to test the material degradation in case of a fire. High weight loss predicts extensive damage that may occur in a fire (Ozcan et al. [3]). From the experimental data, the average time of flame occurrence time ($t_i$) and the average time of flame burning ($t_f$) for each material at the logarithmic scale were calculated (Figure 5).

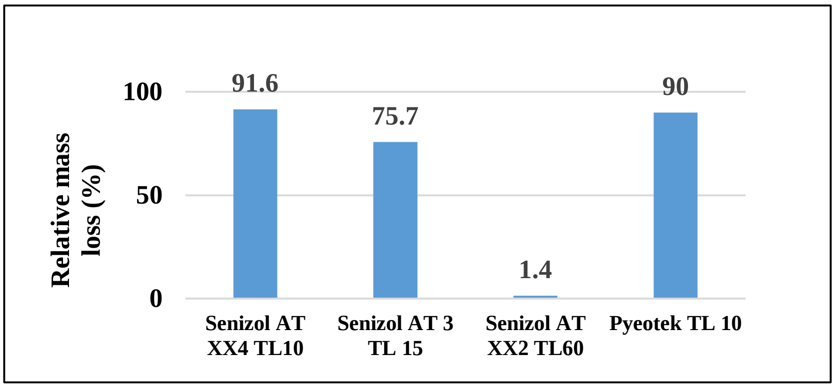


Figure 3 Relative weight loss of tested materials

From Figure 4, it is evident that the smallest weight loss was in case of Senizol AT XX2 TL 60 (average of 1.4%). With radiant heat the material started to be smelt and produced melting within 40 s on average. By the end of the test, the white smoke was released from the material in a small amount, and the weight dampened slowly at regular intervals. Senizol AT XX4 TL 10 and Pyrotek TL 10 materials showed the largest weight loss (~ 90%). Similarly, Orémusová and Hudáková [9], using the conical calorimeter method, found that the weight loss of different fabric materials exceeds 95%.

Regarding the flame burning, it can be concluded that the tested materials (except one) showed flame burning (Figure 5).

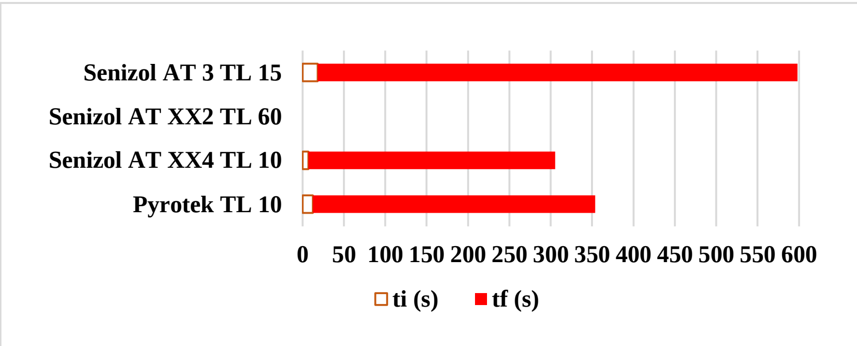


Figure 4 Čas vzplanutia ($t_i$) a doba plameňového horenia ($t_f$) testovaných materiálov

The flameless burning was carried out on the Senizol AT XX2 TL 60 sample (Figure 6), which explains why this sample reached the smallest weight loss.

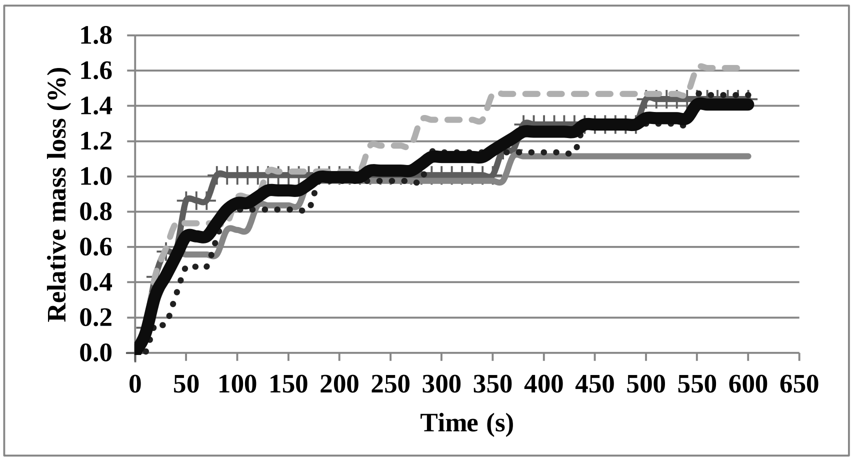


Figure 5 **The r**elative weight loss of four samples of Senizol AT XX2 TL 60

The sound absorption coefficient of commercial materials is specified in terms of a noise reduction coefficient (NRC). It is the average of four sound absorption coefficients of the particular surface at frequencies of 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz (ASTM C423 [4]). The noise reduction coefficients tested materials are given in Table 1.

Table 1 Sound absorption coefficient *α* and noise reduction coefficient NRC

| | Material | ρ (kg/m³) | α (-) | | | | | NRC (-) |
|---|---|---|---|---|---|---|---|---|
| *f* (Hz) | | | 200 | 250 | 500 | 1000 | 2000 | |
| 1. | Senziol AT XX2 TL 60 | 61.4 | 0.13 | 0.40 | 0.82 | 0.93 | 0.90 | 0.81 |
| 2. | Senizol AT XX4 TL 10 | 139.9 | 0.11 | 0.27 | 0.65 | 0.77 | 0.80 | 0.66 |
| 3. | Pyrotek TL 10 | 222.8 | 0.16 | 0.26 | 0.38 | 0.56 | 0.65 | 0.51 |
| 4. | Senizol AT 3 TL 15 | 223.9 | 0.14 | 0.24 | 0.37 | 0.52 | 0.57 | 0.47 |

From Table 1, it can be seen that the highest value of NRC = 0.81 has Senziol AT XX2 TL 60. Tiuc et al. [12] investigated the sound absorption of polyurethane insulating materials with different shares of fabric recyclate. The density of the investigated material (60 PRF), which was composed of polyurethane (60%) and recycled fabric (40%), was almost equal (60 $kg\cdot m^{-3}$) to Senizol AT XX2 TL 60 sample. The noise reduction coefficient of tested material 60 PRF was NRC = 0.59. Thus, it can be said that the evaluated material has a high sound absorption, but only this is not enough.

The material's sound absorbing properties are expressed by the sound absorption coefficient as a function of the frequency. Therefore is important to know the ability of material to absorb sound of the different frequencies of the best sound absorbing material Senziol AT XX2 TL 60. The dependence of sound absorption coefficient on the frequency is presented in Figure 7.

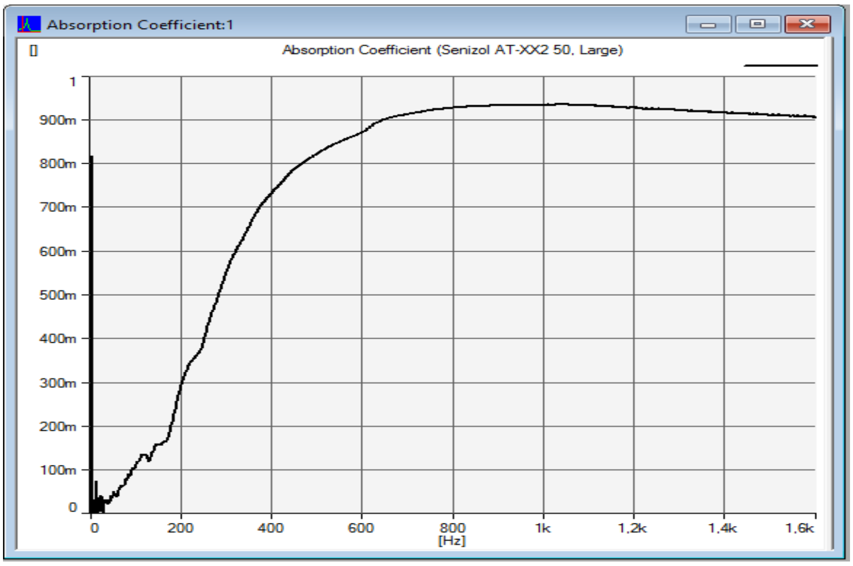


Figure 6 Dependence of sound absorption coefficient on the frequency

## 4. Conclusions

There were tested the four configurations of STERED® boards which were made from recycled automotive fabric. In the first phase of the research, the selected materials were tested from fire and acoustics aspect. The weight loss was the measured parameter. The results show that STERED® Senizol AT XX2 TL 60 was of the smallest weight loss (1.4% on average), and the highest sound absorption coefficient of noise reduction coefficient (0.81).

The results of the measurements show that the most suitable material in the dividing structure could be Senizol AT XX2 TL 60 or similar material with an approximate density of 60 kg.m-3 and a similar composition. In the next stages of research, those materials will be tested separately, as part of a construction.

## Acknowledgments

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# Close proximity and acceptable distances for selected high-capacity oil storage tanks

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**Abstract**

In the paper, there are set out the close proximities for selected high-capacity tanks according to STN 92 0201-4 and specified acceptable distance which were determined according to the methodology used in the U.S. For these high-capacity tanks for storage of crude oil were calculated the following fire parameters: energy release rate in fire and the mean height of the flame in the fire. The calculated mean height of the flame values represented the input data to determine the close proximities according to STN 92 0201-4. An objective of research was to determine and compare the acceptable distances for persons and structures in accordance to the U.S. methodology applied.

*Keywords*: mean flame height, close proximity, high-capacity storage tank;

## 1. Introduction

In the case of oil fires in large-capacity tanks radiant heat is generated, which, by its intensity, affects the surrounding area, where there are mostly other tanks, piping, structures and infrastructure. In the world, several variants of large capacity oil storage tanks are currently in operation. The storage volume of large-capacity tanks in Slovakia and abroad is now five to ten times higher compared to the tanks built several decades ago. The diameters and height of the tanks are also several times larger compared to past tanks. At the pumping station PS 4 in Tupa (Fig. 1), they are also built in places of original tanks, the storage volume of which was 10 000 m3 and 20 000 m3, which caused a rapid increase of the fire load in relation to the built-up area.

The aim of the paper is to determine and compare the distance of selected large-capacity tanks according to STN 92 0201-4 and to determine acceptable distances for people and constructions according to the methodology used in the U.S.A.

Figure 1 Crude oil pump station in Tupa

## 2. Problem

The fire hazard area of the double-shell tank with non-flammable envelope is not determined. The double-shell tank shall not be located in a fire-hazardous area of another building (Decree 96/2004).

The fire hazard arises mainly at the pumping stations, where there are several storage tanks next to each other. The storage tanks themselves are located

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at distances close to their diameter, but in some cases even shorter. In crude oil fires in large capacity tanks, a heat flux density of 105 W.m-2 is generated. The decrease in the density of the heat flux with the increasing distance is gradual and the values, that can be considered safe, are in hundreds of meters away from the fire site. In the case of crude oil fires, the thermal effect on the environment is constantly changing. This change is influenced by the course of the fire, climatic conditions and the action of human intervention (Balog, Kvarčák, 1999).

The tank construction has a major impact on the development of fire in the tanks and partly on the spread of fire. The walls of the metal vertical tank are deformed within 8-10 minutes in the case of insufficient cooling. They are more quickly subjected to deformation of the wall in the direction of the wind (Olšanský, 1976).

In case of major fire and explosion in operations or oil stations, other tanks and adjacent objects may be affected by fire, and the fire will continue to spread. This situation is called the "domino" effect. An example is a fire in Cechovice in 1971, (Balog, Kvarčák, 1999).

### 3. Methodology

Calculation of fire parameters, determination of separation distances according to STN 9202 01-4 and determination of safe distances for persons and constructions are progressively carried out on selected three sizes of large capacity tanks. Two smaller tanks of 30,000 and 70,000 m3 are currently in operation in Slovakia and larger with 125,000 m3 in the Czech Republic

*Crude oil – selected properties*

Crude oil as a mixture has no constant properties. Its properties depend primarily on the place of storage, the way it is stored, the ambient temperature and the water content.

Selected properties of Russian oil transported and stored in Slovakia:

Hazard class: I
Temperature class: T3
Explosive group: II A
Concentration limits of explosivity: lower 0.8 % obj.; upper 8 % obj.
Flash point temperature: < – 5.0 °C
Ignition temperature: 230 °C (± 2.5 °C)
Calorific value: 40 - 48MJ.$kg^{-1}$ (KBÚ, 2004).

Crude oil properties in fire (Karlsson, Quintiere, 1999):

$m''_\infty$ – area rate of burning (0.02833 $kg.m^{-2}.s^{-1}$)
$k.\beta$ – product of the radiation flow from the flame to the surface of the flammable liquid (2.8 $m^{-1}$)
$\chi$ – crude oil burning efficiency (70 %, i.e. 0.7)
$\Delta H_c$ – total combustion heat of crude oil (42.5 MJ.$kg^{-1}$ = 42 500 kJ.$kg^{-1}$)

*Large-capacity storage tanks*

The double-shell tank is a tank with two separate shells with clearance between them, the outer shell of the tank shall be made of non-combustible materials (Decree 96/2004).

Selected containers are very similar in design, the difference is mainly in their substantially different dimensions.

Storage tank with a volume of 30,000 $m^3$

The large-capacity tank (Figure 2) is a full metal welded cylindrical tank. It is standing, above ground and has a floating roof that floats on the level of stored liquid.

$D$ – tank diameter (42.8 m)
$D_h$ – diameter of emergency tank (53.6 m)
$A_f$ – horizontal burning area of storage tank (1 439 $m^2$)
$A_{fh}$ – horizontal burning area of the emergency tank (2 256 $m^2$)

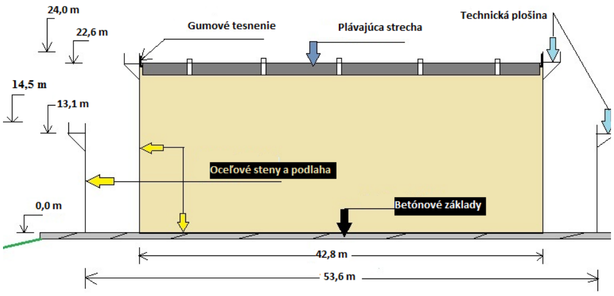


Figure 2 Profile of a tank with capacity of 30 000 **m³**

Storage tank with capacity of 70 000 m³

The substantial difference of the tank with a storage capacity of 70,000 m3 (Figure 3) compared with the tank of 30,000 m3 is in the average of storage and emergency tanks.

$D$ – tank diameter (66 m)
$D_h$ – diameter of emergency tank (80 m)
$A_f$ – horizontal burning area of storage tank (3 421 m²)
$A_{f\,h}$ – horizontal burning area of the emergency tank (5 027 m²)

Figure 3 Storage tank with capacity of 70 000 m³

Storage tank with capacity of 125 000 m³

Steel storage tanks with a steel protective emergency tank and a double-float roof at the central oil storage facility in Nelahozeves (Figure 4) are the largest of their kind in the world.

$D$ – tank diameter (84.47 m)
$D_h$ – diameter of emergency tank (90.47 m)
$A_f$ – horizontal burning area of storage tank (5 604 m²)
$A_{f\,h}$ – horizontal burning area of the emergency tank (6 428 m²)


Figure 4 Large-capacity storage tanks – Mero, ČR (www.ekonomika.idnes.cz)

## *Fire scenarios*

For double-shell storage tanks where there is a space between the emergency and storage tanks to capture the total storage quantity of crude oil, it is necessary to take into account several possible fire scenarios. When the storage tank is damaged, the most complex scenario is that the total sum of the intra-shell area and the storage tank area is affected by the fire. For simplicity, a horizontal surface with the diameter of an emergency tank is calculated, which is actually the sum of the storage tank area and the intra-shell area.

Fire scenarios which are theoretically possible:
1. Fire in the space between the tank roof and the shell of the tank - scenario S1.
2. Emergency tank and space between the roof and tank shell - scenario S2.
3. Storage tank fire - all-surface (when immersing the floating roof roof) - scenario S3.
4. Current tank and emergency tank fire (immersed floating roof of the storage tank and damaged storage tank shell) - scenario S4.
5. Fire in an emergency tank (intra-shell fire) - scenario S5.

The most complex scenarios are S3 and S4, so we will count on the selected scenarios in the calculations.

### *Speed of energy release during fire*

It is the heat released per unit of time (kJ.s⁻¹), it changes with time,

- In the case of natural tanks, the speed becomes constant,
- Depending on the diameter of the tank D,

- With a diameter above 0.2 m, the flat rate of rainfall increases with the diameter to a certain value, then it is constant m "∞,
- Depending on the constant k.β - the product of the radiation flux characterizing the fuel, which is tabulated for both liquids and thermoplastics.

When fuel in a large tank is burning, we assume that the fire will be driven by fuel, as the air access to the combustion zone should not be limited.

The rate of energy release in case of fire is calculated from the relation (1) (Karlsson, Quintiere, 1999):

$$Q^{\bullet} = A_f \cdot m''_{\infty} \cdot (1 - e^{-k \cdot \beta \cdot D}) \cdot \chi \cdot \Delta H_C \quad (\text{kJ.s}^{-1})$$

$A_f$ – horizontal burning area ($m^2$)
$m''_{\infty}$ – area rate of burning ($kg.m^{-2}.s^{-1}$)
$k.\beta$ – product of the radiation flow from the flame to the surface of the flammable liquid
$D$ – tank diameter (m)
$\chi$ – burning efficiency (%)
$\Delta H_c$ – total heat of combustion ($kJ.kg^{-1}$)

The values of the rate of fire release are needed to calculate the mean flame height at fire.

*Average flame height at fire*

The mean flame height at fire is averaging the height of the flashing flame at the time of burning.

For real fires, fuel geometry (vertical or horizontal fuel distribution), walls, ceiling, or holes must be taken into account.

The mean flame height is calculated from the relationship (2) (Karlsson, Quintiere, 1999):

$$L_f = 0.235 \cdot Q^{\bullet \frac{2}{5}} - 1.02 \cdot D \quad (\text{m}) \quad (2)$$

*Separation distance according to STN*

A fire-hazardous area is created around a burning fire section or a building where more than 18.5 $kW.m^{-2}$ of the heat flux due to a heat flux density is threatened, the risk of fire transmission by heat radiation or falling firing structures on another building (Kucbel, 1993).

The intensity of heat flux in a fire-hazardous area of a fire section decreases with a distance from a fire-exposed area. At a certain distance - at a separation distance – comes to a reduction of radiation to < 18.5 $kW.m^{-2}$, which is no longer dangerous for burnable wood-based materials (Osvald, 2005).

Separation distance is determined according to STN 92 0201-4. To determine the separation distance, it is necessary to know the parameters of the storage tanks and the flame height at fire. From the rate of energy release at fire (thermal energy) it is possible to calculate the mean flame height.

The distance from the open stores of flammable liquids is determined as a whole depending on its ground plan, landfill height and heat flux density according to Table 4 of STN 92 0201-4.

The distance from open stores can also be determined by a more precise calculation based on the reduction in the intensity of heat radiation in the burning space to 18.5 $kW.m^{-2}$, the size or the geometric shape of the open store and the assumed flame height.

When determining the separation distance, the following are considered:

a) the length of the fire section $l$ the considered side of the open store,
b) at the height of the fire section $h_u$, the average height of the stored fuel increased by an estimated flame height of at least 6 m for the high intensity of the fire,
c) the proportion of open areas.

## *Determination of distance from open technological equipment*

The distance from open technological facilities, except the pipelines and transport bridges, in which there are permanently occurring flammable substances, is determined for each fire section, depending on the dimensions of the ground planes, which can cause the decomposition of the substances processed or stored in these devices, the calculated height of temperature field and heat flux density.

The separation distance is determined by:

a) the length $l$ in meters - the side of the surface on which the degradation may occur or 0.75 of the diameter of the circle described around the area on which spillage or spillage of flammable substances may occur,

b) the height $h_u$ in meters, the equivalent height of the combustible substance increased by the assumed flame height, but not less than 6 m for the high intensity of the radiation,

c) the share of open areas (STN 92 0201-4, 2000).

As regards the storage tanks with an emergency tank, it is necessary to count the oil spill into the emergency tank (scenario S4). From the equation (3) for calculating the cylinder volume is the derived equation (4).

$$V = \pi \cdot r_h^2 \cdot v_h \qquad (m^3) \qquad (3)$$

$r_h$ – emergency tank diameter (m)
$v_h$ – maximum oil level height in emergency tank (m)

The derived equation (4) is necessary for calculation of oil level height in emergency tank for scenario S4.

$$v_h = \frac{V}{\pi \cdot r_h^2} \qquad (m) \qquad (4)$$

*Acceptable distance in the U.S.A.*

The Housing and Urban Development Department of the U.S.A. has set the boundary levels of the radiation flow for fire and radiation flow value of 31.5 kW.m$^{-2}$ for buildings and value of 1.4 kW.m$^{-2}$ for persons. As a result, an acceptable distance was established in the United States based on the analysis.

The aim of the analysis was to develop a methodology for estimating the heat flow from large fires, whether fires of flammable liquids or gases. Fire dynamics is more predictable for flammable liquids than for flammable gases, making it even easier to determine the size of the heat radiation.

A graphical representation for determining the acceptable distance (Figure 5) allows you to subtract the values directly without calculation. The values in the graph are calculated for a circular form of fire.

In Figure5 the horizontal axis shows the diameter of the fire, the acceptable axis is the acceptable distance for persons and constructions.

In the case of crude oil, area rate of burning of 0.045 kg.m$^{-2}$.s$^{-1}$ and a heat of combustion of 42,600 kJ.kg$^{-1}$ is taken into consideration.

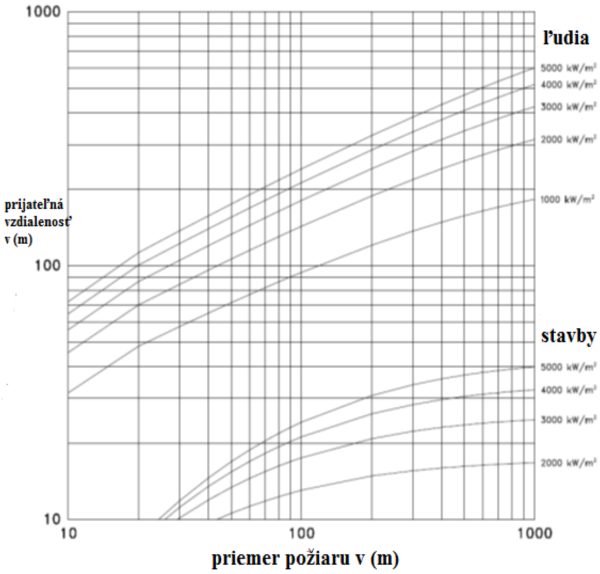


Figure 5 Graf for determination of acceptable distance at fire of flammable liquids (McGrattan et al., 2000)

From the graph in Fig. 5, it is possible to read the acceptable distance values for persons and constructions according to the diameter of the fire (in the case of flammable liquids the storage tank diameter is taken into account as the entire area of the flammable liquid which is affected by the fire) and the amount of energy released per unit area - according to the type of flammable liquid. In the case of a crude oil fire, the rate of energy release is 1,900 kW.m$^{-2}$ and the nearest value in the graph is 2,000 kW.m$^{-2}$ (McGrattan et al., 2000).

## 4. Results and discussion

Calculated selected fire parameters (heat release rate and mean flame height) of the selected fire scenarios of the described large capacity tanks are given in Table 1.

From the comparison of the values of the rate of energy release in case of fire, the direct proportion of increase in the rate of energy release in case of a fire with increasing area of fire.

When comparing the mean flame height for fire between tanks and scenarios, the differences are only in the order of a few centimeters to tens of decimetres. The largest difference (1.55 m) is between scenarios on the tank with a volume of 30 000 m3, the smallest difference (8 cm) can be seen between tank scenarios with a volume of 125 000 $m^3$.

Table 1 Calculated parameters in selected scenarios

| **Tank** | **30 000 $m^3$** | | **70 000 $m^3$** | | **125 000 $m^3$** | |
|---|---|---|---|---|---|---|
| **Calculated capacity** | **29 062 $m^3$** | | **72 803 $m^3$** | | **124 968 $m^3$** | |
| **Scenario** | S3 | **S4** | S3 | **S4** | S3 | **S4** |
| **Diameter (m)** | 42.8 | **53.6** | 66 | **80** | 84.47 | **90.47** |
| **Area ($m^2$)** | 1 439 | **2 256** | 3 421 | **5 027** | 5 604 | **6 428** |
| **$\dot{Q}$ (MW)** | 1 213 | **1 901** | 2 883 | **4 237** | 4 723 | **5 418** |
| **$L_f$ (m)** | 20.10 | **21.65** | 22.84 | **23.57** | 23.68 | **23.76** |

*Determination of separation distance for storage tanks according to STN*

When determining the separation distance, we will take the mean flame height at fire as a starting point. By adding the mean flame height and oil level in the tank, we get the required height $h_u$.

In table 2 are the recorded the separation distances determined according to STN 92 0201-4 for selected three dimensions of large capacity tanks. Separation distances are determined by two options for the most complex variant of the fire, the S4 scenario.

Explanation of the values entered in the table:

- in the bottom two rows of the table are the values determined from STN 92 0201-4 from tab. 3 and 4, by interpolation between adjacent values,
- since in tables STN 92 0201-4 the $h_u$ values are approximately half of the values introduced in tab. 2, the distance reading separation distance is underestimated,
- the highest value of the length of the fire section in tab. 3 in STN 92 0201-4 is "45 m and more" with the separation distance shown in the table, i.e. 50.3 m. The assigned separation distances (marked with*) are undervalued for large capacity tanks of 70,000 and 125,000 $m^3$.

Table 2 Parameters and separation distances determined in accordance to STN 92 0201-4

| Storage tank ($m^3$) | 30 000 | 70 000 | 125 |
|---|---|---|---|
| Calculated capacity | 29 062 | 72 803 | 124 |
| Emergency tank dia-meter $D_t$ (m) | 53.60 | 80.00 | 90.47 |
| Length | 40.20 | 60.00 | 67.85 |
| Max. height of oil in | 12.90 | 14.50 | 19.44 |
| Medium flame height | 21.65 | 23.57 | |
| Height | 34.55 | 38.07 | 43.20 |
| Share of open areas | 100 | 100 | 100 |
| Separation distance | 47.7 | 50.3 * | 50.3 |
| Separation distance | 38.9 | 45.8 | 48.0 |

*Determination of acceptable distances for persons and constructions in the U.S.A.*

Acceptable distances for buildings and persons listed in tab. 3 represent subtracted values from the graph in figure 5. The nearest readily visible values to the averages of the selected large-capacity tanks and the related distances for persons and structures have been subtracted.

Table 3 Derived acceptable distances for persons and constructions in U.S.A.

| Fire diameter (m) | Acceptable distance for | Acceptable distance for |
|---|---|---|
| 42 | 10 | 100 |
| 50 | 11 | 115 – 120 |
| 60 | 12 | 120 – 125 |
| 70 | 12.5 | 125 – 130 |
| 80 | 13 | 130 – 140 |
| 90 | 13.5 | 140 – 150 |

.

## 5. Conclusion

The separation distances according were specified in accordance to STN 92 0201-4 applying two methods. From table 3 were derived and interpolated values between the closest values of the calculated distance from the fire section, and for these two larger tanks these distances were underestimated. We can consider them underestimated because the highest value of length lu (0.75 times the diameter of the emergency tank) is in STN 92 0201-4 in tab. 3 to determine the distance of 45 m or more. From tab. 4 of the standard, there were also derived the separation distances for open stores, where they were compared with the separation distances according to tab. 3 (derived and interpolated between adjacent values recalculated) distances shorter by several meters. Given our height hu values (the sum of the maximum oil level in the tank and the calculated mean flame height at fire) in tab. 2, we can consider all the specified distances, under both possibilities of STN 92 0201-4, to be underestimated. In the above-mentioned STN in tab. 3 is the highest value → hu = 18 m and higher, in tab. 4 → hu = 15 m and more.

According to the Decree 96/2004 Coll., Section 27, paragraph 2: "The distance between the two overground tanks with floating roof must not be less than 0.6 times the diameter of the larger tank." It is unclear whether in the case of double-shell tanks this is 0.6 times the average of the storage or emergency tank.

According to Decree 96/2004, a fire hazardous area of a double-shell tank with a non-combustible shell is not specified, but the double-shell tank must not be located in a fire-hazardous area of another building. Each overhead large-capacity tank must have reinforced foundations, even recessed concrete piles deep in the ground. According to the Building Act no. 50/1976 is building a fixed connection to the ground. In addition, the Building Law defines construction in the sense that it is a building construction built by construction works of construction products that is firmly connected to the ground or whose installation requires the modification of the substrate. The construction of large-capacity tanks requires these elements. Therefore a fire-hazardous area should be designated for each of them.

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# Load bearing capacity of bonded anchors in thermally-damaged concrete

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**Abstract**

In our paper we analysed the load bearing capacity of bonded anchors placed in thermally-damaged reinforced concrete. Our primary goal was to facilitate the reinforcing techniquesof reinforced concrete structural elements damaged in fire events. For the tests, 8 mm diameter threaded rods installed with epoxy adhesive were used, with an embedment depth of 50 mm. Three levels of thermal loading (200, 300, 400 ℃) were applied to the concrete specimens , with respect to the embedment depth. The compressive strength of the concrete specimens used in the tests was fc = 44.79 N/mm$^2$.

*Keywords:* fire, concrete, bonded anchors, residual behaviour;

## 1. Introduction

In case of thermally-damaged buildings, it is typical that fastening elements should be installed in reinforced concrete structures damaged by the fire. This can include the replacement of the existing fasteners that have been damaged in the fire or the installation of a new fastener with combined function that helps the additional structural elements work together with the existing thermally-damaged reinforced concrete structural elements (e.g., column jacketing, strengthening of the tension boom, and reinforcement of the slab with sprayed concrete). There are very few experiments dealing with the determination of the load-bearing capacity of fasteners placed in thermally-damaged reinforced concrete [1, 2, 3], therefore it an actual and practically important field of research.

### *1.1. The toolbar and its menus*

The mechanical properties of concrete are changed by the effects of fire. Related research has been going on since the 1940s [4] and it is still actual. Previous studies have found that changes in the mechanical properties of concrete are caused by a variety of chemical and physical changes that occur at different temperatures [5]. The extent of such changes is higly affected by the composition of the concrete. Changes in the material structure depend on the following factors [6]:

– the type of the cement,
– the type of the aggregate,
– the water-cement factor,
– the aggregate-cement factor,
– moisture content,
– way of thermal loading.

The change in volume of the various components of concrete varies as a function of temperature. The cement stone and the aggregate react to temperature increase in a completely different way to temperature increase [7]. Consequently, the primary reason for the change in the strength of the change in the strength of concrete is the termination of the connection between the aggregate and the cement stone. This effect is amplified by the dehydration of calcium dioxide and ettringite deposited on the surface of the aggregate particles [8]. During thermal loading, as the temperature increases, the compressive strength of concrete is reduced together with the load capacity. Figure 1 clearly

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shows that the diagrams of concrete strength and deformation are getting flattened with increasing temperature. This means that lower strength values are linked to a larger deformation.

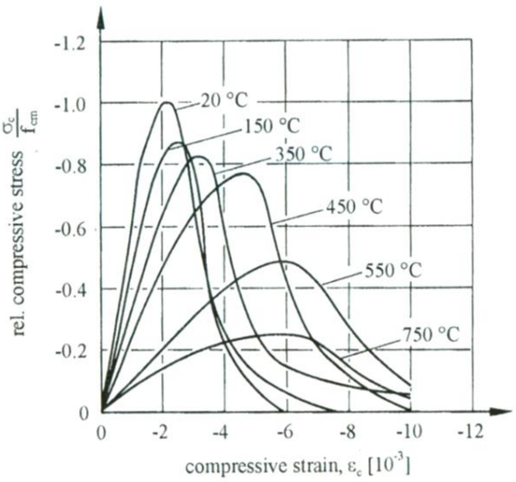



Figure 1 Stress-strain relationship for concrete with quartz gravel aggregate as a function of temperature [9]

Experience from and experiments of fire damages have shown that the delamination of the concrete surface (spalling) is typical for reinforced concrete structures at high temperatures. The reason for this phenomenon is the formation of the so-called moisture barrier in the concrete. Water present in the concrete turns into water vapor at high temperature and it is released in part to the external atmosphere through the pores; however, it starts to flow partly towards the interior of the concrete. Water vapor flowing inward reaches the colder parts where it precipitates to form water again, creating a moisture barrier. In the surroundings of the moisture barrier, the pore pressure of the concrete increases, which leads to the spalling of the concrete [10].

### *1.2. Fastening systems*

Several post-installed anchors are available with different way of load-transfer. The commercially available fastenings can transfer the load to the host material via the following mechanisms: mechanical interlock, friction or bond (Figure 2). Furthermore, the most recent techniques use combined bond and friction (e.g. bonded expansion anchors). In case of expansion anchors, the load is transferred by friction. Generally, an expansion sleeve is expanded by an exact displacement or torque applied on the anchor head during the installation process. Chemical fastenings are anchored by bond. Bonded anchors can be divided into two subgroups: capsule or injection systems. The bond material can be either organic, inorganic or a mixture of them. In this case the loads are transferred from the steel (normally a threaded rod, rebar) into the bonding material and are anchored by bond between the bonding material and the sides of the drilled holes [11, 12, 13].

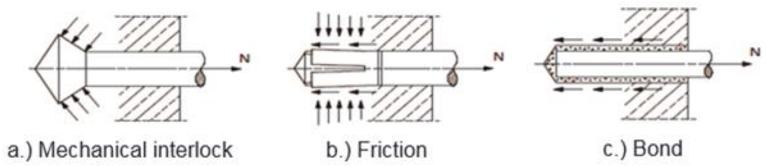



Figure 2 Load transfer mechanisms [12]

Load bearing of fastenings can be determined by taking the minimum of ultimate loads corresponding to different failure modes.

In case of tensioned anchors steel failure, concrete cone failure, pull-out failure and splitting can occur (Figure 3).

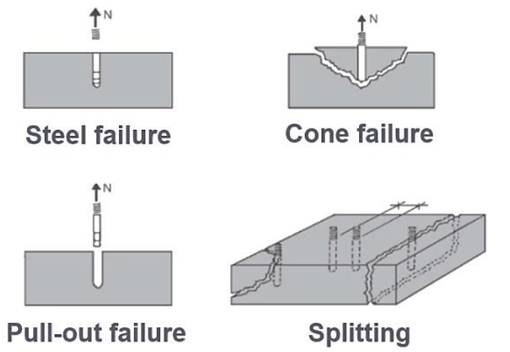



Figure 3 Failure modes [13]

Behavior of loadbearing capacity of undercut anchors in thermally-damaged concrete

There have been only few researches on the behaviour of anchors installed in thermally-damaged concrete [1, 2, 3]. In all cases only undercut anchors were examined and only concrete strength and embedment depth were altered.

Figure 4 shows the load bearing capacity of undercut anchors in case of different concrete strength and embedment depth.

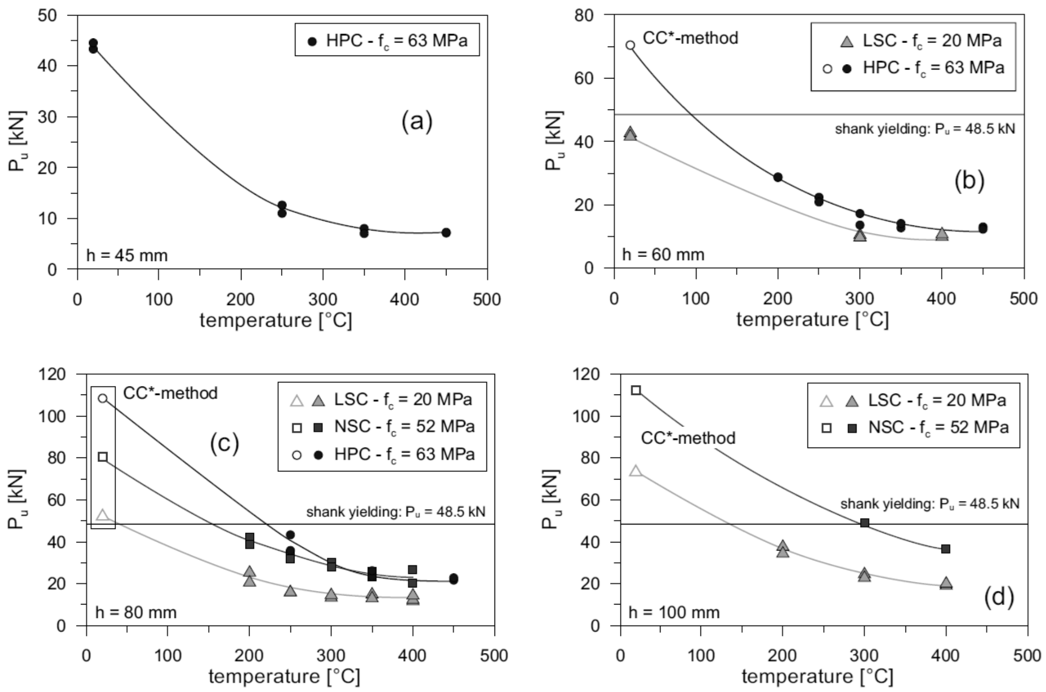



Figure 4 Behavior of loadbearing capacity of undercut anchors as a function of temperature [2]

It is visible in Figure 4 that load bearing capacity decreases as temperature increases.

This decrease is rapid below 200°C and then it becomes less intense.

## 2. Experimental part

In our experiments, we analyzed the load bearing capacity of anchors placed in thermally damaged reinforced concrete as a function of thermal load. In the tests carried out earlier [1, 2, 3], undercut fasteners were used. These studies did not address the behavior of other types of fasteners, and that is why we used bonded anchors in our investigations to test the load bearing capacity of the bonded connection and its damage.

During the experiment, the specimens prepared were exposed to fire load on one side until they reached the desired temperature, then they were allowed to cool down at laboratory temperature (20 ° C). The day after the fire load, typically after 24 hours, when the specimen had been cooled down, the fastener was inserted in the thermally damaged specimen. In order to allow the cross-linking of the adhesive, loading of the fasteners took place after a further 24 hours.

*2.1. Tested anchors*

One type of bonded anchor systems (epoxy resin) was tested. Bonded anchors were installed according to the MPII (Manufacturer`s Printed Installation Instructions). The embedment depth was $h_{ef}$=50 mm (~6d, where "d" is the diameter of the anchor), and the diameter of the threaded rods was 8 mm, the strength class of threaded rods was 10.9.

*2.2. Concrete mixture*

The mixtures were made by Portland cement (CEM I 42.5 N). The aggregates were natural quartz sand and quartz gravel and a superplasticiser of BASF Glenium C323 Mix was also used. The specimens were held under water for 7 days and then kept at laboratory temperature (20 ° C) for additional 21 days.

Compressive strength properties were tested on additional 3 cubes of 150x150x150 mm. Uniaxial compressive strength tests were carried out on concrete cubes 28 days after casting. The results were evaluated in accordance with EN 12390 -3:2009 [15] for concrete. The mean value of the mixture was fc = 44.79 N/mm$^2$.

The dimensions of concrete specimens for pull-out tests were 300x300x150 mm.

*2.3. Thermal loading*

In laboratory tests, the concrete specimens were exposed to thermal load on one side. An electric furnace was used for this thermal load, with a heat-up curve shown on Figure 5. Based on the measurement data, the curve of the furnace is different from the standard fire curve according to ISO 834-1 [16], so the experiment cannot be called a standard test. However, the heating curve of the furnace remained unchanged even after several checks, so it was well suited for the comparison of the specimens with varying degrees of thermal load, as well as for the preparation of a possible future standard test.

Thermal loading of the specimens was carried out in three different thermal steps measured at the embedment depth: 200, 300, 400 ° C (Figure 5). Temperature was measured in the embedment depth by a thermocouple, which had been placed from the "cold" side of the specimen through an inspection hole (ø 6mm). Figure 5 shows that the specimen is gradually warmed, with a significantly slower tendency than the furnace. After reaching 100 ℃ the temperature increases for a short time, then water in the concrete vaporizes and starts flowing out from the concrete. The temperature does not rise because the heat energy is entirely devoted to the change of state of the water. The arrangement for the thermal loading test is shown in Figure 6.

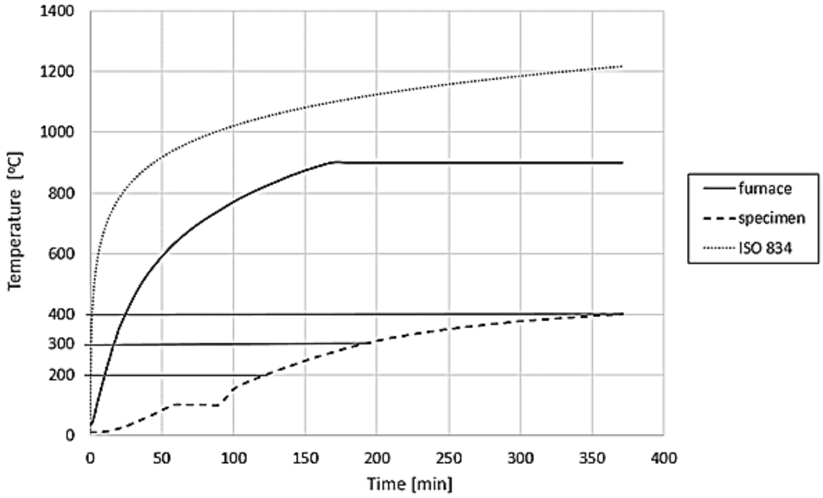



Figure 5 Temperature build-up

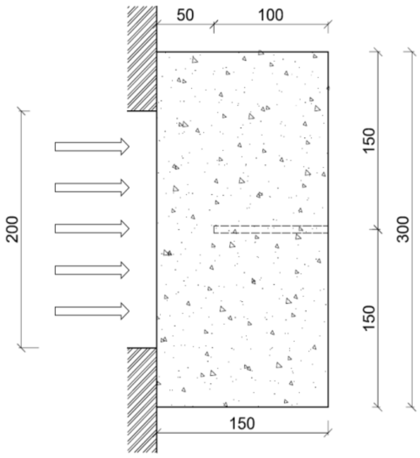
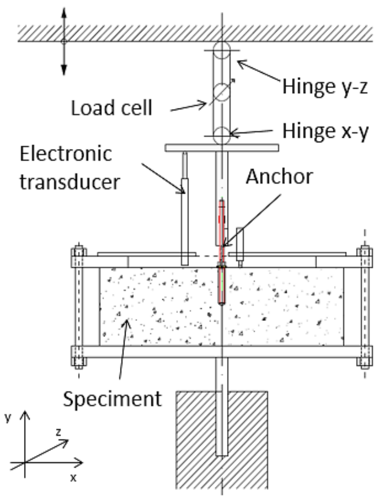



Figure 6 Arrangement of heating for the specimen

We observed no spalling of the concrete on any of the specimens during the test. This may be due to fact that water vapour generated in the concrete was not accumulated in the specimen due to the dimension of the specimen and the arrangement of the test, thus no moisture barrier was created. The steam was able to flow out freely though the test hole made for temperature measurement and the sides of the specimen. Therefore, the results of the test can be used only in cases where spalling does not occur in the reinforced concrete structure during the fire.

*2.4. Pull-out test*

Our unconfined test setup is shown in Figure 7. The loading device was a displacement controlled test apparatus, which allowed the recording of residual stresses after the failure. This setup enabled the formation of all possible failure modes, the results were not affected by the geometry of the investigated samples (thickness of the test member, critical edge, placing). The measurement setup was capable to measure, record and show the applied load and related displacement of the anchor in real-time. The perpendicular pin-joints ensured the centrality of the acting force. The displacement was measured by two electronic transducers. Three additional independent displacement transducers were used to record the deformation of the surface. The load was measured by a calibrated load cell. The tests were carried out in accordance with the instructions given in ETAG 001 Annex A. The support distance was greater than 4 $h_{ef}$ [17].



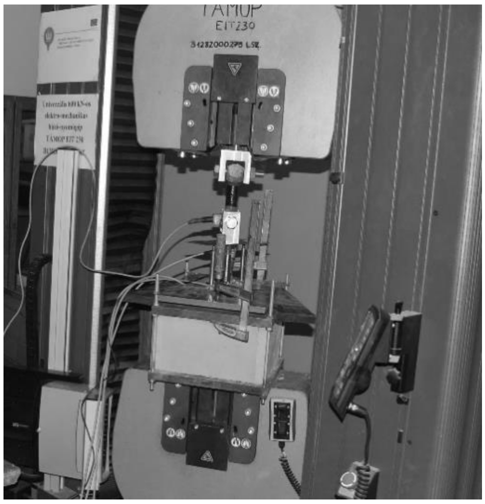



Figure 7 Arrangement of pull-out test

## 3. Test results

During the experiment, anchors have failed in all cases with concrete cone failure. These failures illustrate that an adhesive bond can be created between the adhesive and the thermally-damagedconcrete with adequate strength that caused concrete cone failure. During the tests, no specimen showed either a clear pull-out failure or the combination of concrete cone failure and pull-out failure. On the surface of the concrete cones, aggregate particles close to the thermally loaded surface had a reddish discoloration, and the ratio of discoloured particles increased with increasing temperature. This discoloration can be explained by the chemical processes that occure in the quartz gravel. In case of thermally loaded specimens, the cracks that form the concrete cone ran only in the cement stone, while aggregate particles remained intact. The aggregate particles could be easily removed from their positions as a consequence of damage of the adhesion between cement stone and aggregate.

Figure 8 shows the tensile resistance of the anchors, while Figure 9 shows the relative residual resistance values as a function of temperature.

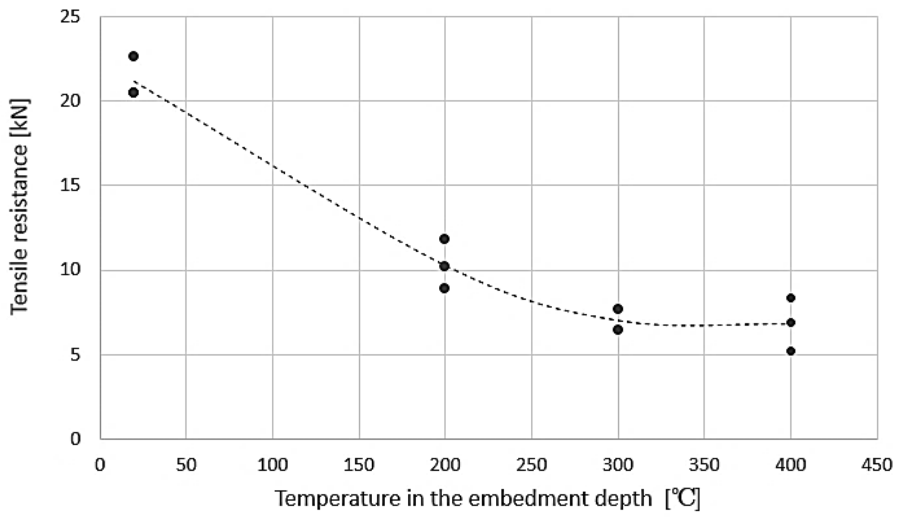



Figure 8 Relationship between the tensile resistance and the temperature in the embedment depth

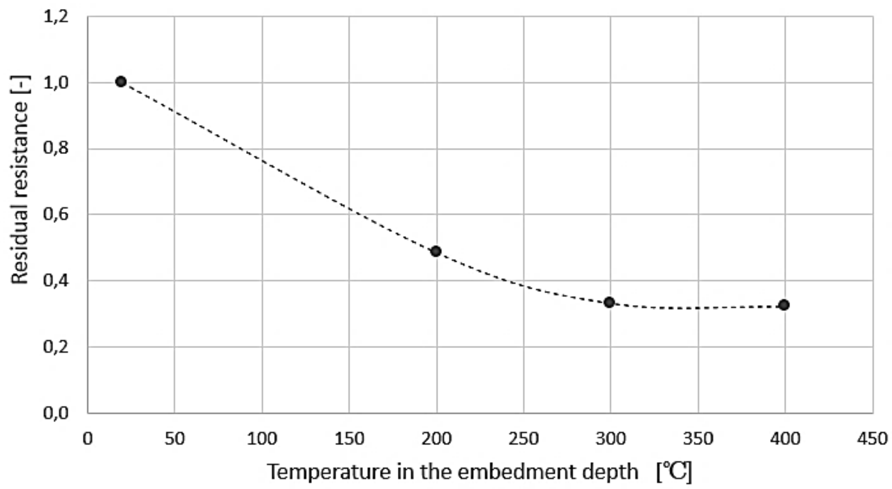



Figure 9 Relationship between the residual resistance and the temperature in the embedment depth

We used the tensile resistance of anchors bonded by epoxy resin as a standard. Tensile reist drops to 49% compared to fasteners that have not been exposed to fire if temperature reaches an average of 200 ℃-in the embedment depth. It drops to 33% when temperature reaches 300 ℃ in the embedment depth, and to 32% when temperature reaches an average of 400 ℃ in the embedment depth.

Using the test results represented in Figures 4.a and 4.b, our own results corresponding to bonded anchors are compared to the resistance values of undercut anchors. Figure 10 shows the resistance of different anchors as a function of the temperature load at the embedment depth.

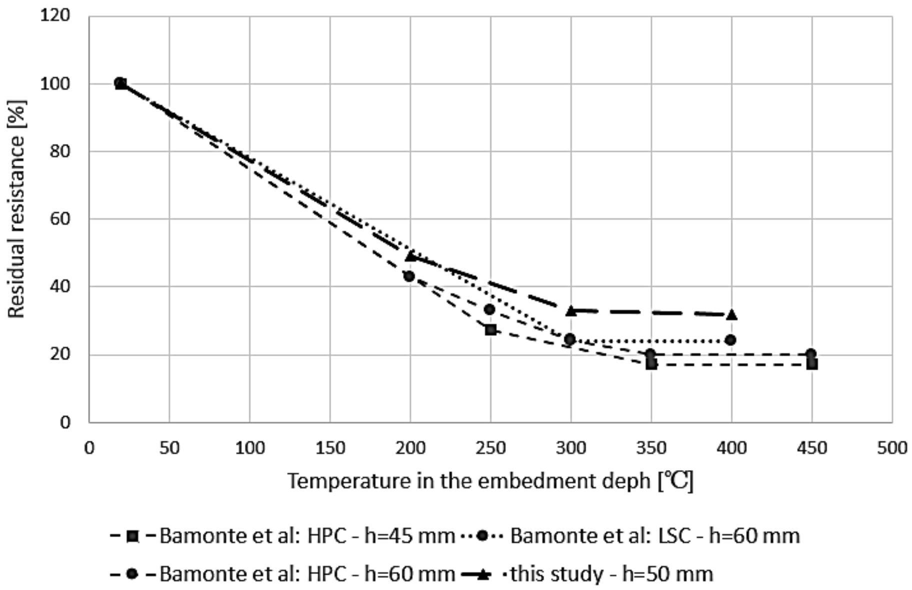



Figure 10 Resistance of undercut anchors and bonded anchors as a function of temperature measured at the embedment depth

Figure 10 shows that in case of undercut anchors there is no significant difference between the behaviour of the anchors with h=45 mm and with h=60 mm embedment depth. In case of the bonded anchors applied in our tests the decrease of the residual resistance is less intense and at higher temperatures (300, 400 °C) the bonded anchors have higher residual resistance than the undercut anchors. The reason for this behaviour is the different way of load transmission: undercut anchors works by mechanical interlock that is concentrated at the embedment depth. On the other hand in case of bonded anchors the bond transfers the load along the whole length of the drilled hole and this more evenly distributed load transfer is advantageous concerning the thermally-damaged concrete layers.

## 4. Conclusions

In our work we analysed the load bearing capacity of anchors installed in thermally-damaged reinforced concrete. Our primary goal was to aid the reinforcement techniques of reinforced concrete structural members damaged in fire events.

One concrete mixture was used to prepare the specimens. During mixing, the 28-day compressive strength of concrete was measured on 150x150x150 mm cubes. The average compressive strength of the concrete was fc = 44.79 N/mm2.

In all pull-out tests, concrete cone failure was observed. Among the failures, no specimen showed either a pull-out failure or the combination of concrete cone failure and pull-out failure. This means that the adhesive can create a sufficient bond even in thermally damaged concrete.

The load bearing capacity of anchors created with epoxy adhesive decreased with increasing temperature during thermal loading. When plotting the tensile resistance as a function of temperature, we observed that:

- if temperature reaches 200 ℃ in the embedment depth, then tensile resistance drops to 49% of the original resistance,
- if temperature reaches 300 ℃ in the embedment depth, then tensile resistance drops to 33 % of the original resistance,
- if temperature reaches 400 ℃ in the embedment depth, then tensile resistance drops to

– 32 % of the original resistance.

At higher temperatures (300, 400 °C) relative residual resistance of bonded anchors is higher than that of undercut anchors. The reason for this is the more distributed way of load transfer in case of bonded anchors than the concentrated mechanical interlock of undercut anchors at the embedment depth. The more evenly distributed loads are advantageous concerning the behaviour if thermally-damaged concrete layers.

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# Impact of fire protection on the design of energy-efficient and eco-friendly building envelopes in timber structures

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**Abstract**

Analysis of construction systems of timber structures according to their use in dependence of the fire height. Legislative limitations. Optimization of tested building envelopes in terms of the energy consumption and environmental impact on the timber buildings in the context of fire protection requirements. Fire protection of tested structures and their optimization in terms of fire resistance using calculations according to Eurocode.

Keywords: construction systems of timber structures, fire protection, legislative limitations, energy efficiency, environmental burden, fire protection of tested structures;

## 1. Introduction

The team of the Department of Building Construction and Urban Planning (KPSU) at the Research Centre of the University of Žilina work on the partial research into building envelopes and their use for low-energy timber buildings.

The building envelopes are primarily optimized in terms of the moisture diffusion within the structure and the heat loss reduction using vapour barriers and thermal insulations. Experimental load-bearing structure is a timber framework having five fields of the same width. The paper focuses on the evaluation of thermal insulations in timber buildings with different construction system in terms of the currently valid legislation and the fire protection requirements.

## 2. Analysis of the load-bearing systems in timber buildings

The use of wood in building constructions is wide - from supporting systems including partition walls and ceilings to the final furnishing. Timber buildings are the buildings with the wood-based supporting system and may be divided into log buildings, half-timbered buildings, timber-framed buildings (Balloon-Frame, Platform-Frame), skeletal structures, and panel structures. Usability of the tested compositions is in the last three above-mentioned systems.

Nowadays, the timber framework structures are the most used ones in constructing low-storey houses. The timber framework may be interrupted at the ceiling, or continuous along its entire height. If the wall load-bearing framework is interrupted in the ceiling, i.e. the wall of the next floor is fastened directly on the ceiling structure - it is a platform-frame structure. In the balloon-frame structure, the pillars go continuously along its entire height. Pre-engineered timber buildings are similar to this system.

Timber skeleton frame structures are the counterpart of the buildings made of solid timber and framework. The buildings of solid timber and framework have the linear load-bearing construction and the load from the roof and ceiling is transferred by supporting peripheral and internal walls. The load from ceilings and roofs in skeletal systems is transferred by pillars. These buildings have a more variable layout. The timber load-bearing members are typically made of glued laminated wood with the steel joint elements embedded. The building envelope, anchored to them, is generally designed as a lightweight sandwich self-supporting panel structure, e.g. the timber framework with thermal insulation. It may be placed in front of the load-bearing system, or embedded in the pillars - the ideal solution in terms of thermal protection. As for

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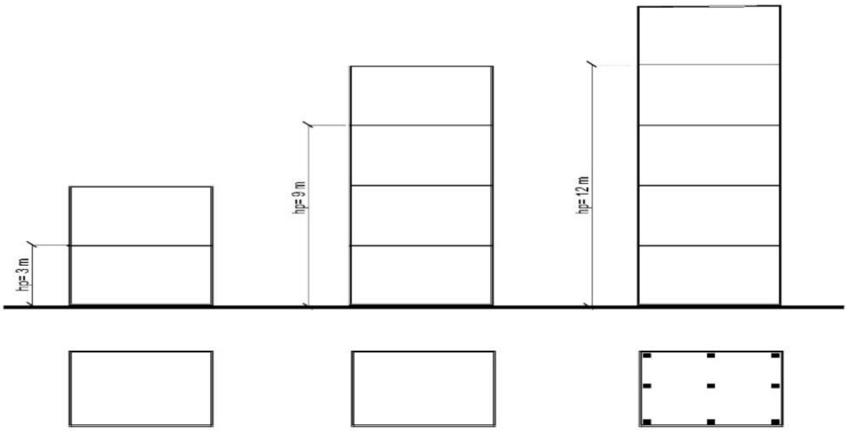
fire protection, the building envelope is generally designed as a fire-compact structure with the required fire resistance EI, or EW for wood-based ones.

Panel buildings with timber framework are the most commonly used for the construction of wooden buildings. Being pre-engineered, they are quick to assemble. They are produced as small-sized panels, 1.2 - 1.8 mm wide, or as big-sized ones, 12 -16 m long. The framework is made of spruce or fir and is covered with large wood-based or plasterboard materials.

*2.1. The toolbar and its menus*

All of the above wood-based construction systems are in terms of fire safety classified as combustible structural units. The fire height of the buildings with the timber supporting system according to legislation valid in Slovakia is limited to maximal 9 m, excepting the buildings intended for housing and accommodation (typically four-storeyed). This goes provided that the fire load calculated in the most critical fire section of such buildings is up to 60 kg/m2. If the fire load is higher than 60 kg/m2, the maximal allowable fire height is 4 m (see Fig. 1b). The requirement for maximal fire resistance of the load-bearing members is REI 90. According to the currently valid standards, residential buildings and houses may contain wood-based load-bearing systems up to the second floor (see Fig. 1a). At the present time, the modification of STN 920201-2 is being approved; it will allow using wood-based construction systems for upper floors. The fire resistance requirement for the first level of fire safety is REI 30.




1a 1b 1c

Fig. 1 Height-zoning of buildings where the wood-based load-bearing systems are allowed to use: a/ maximal height of wood-based buildings intended for housing and accommodation, b/ maximal height of wood-based buildings with $p_v$ up to 60 kg/m$^2$ without the functional use of accommodation, c/ buildings of non-combustible supporting skeletal structure with timber sandwich peripheral walls

Considering the above limitations, the non-combustible construction system, e.g. the concrete skeleton, is combined with the envelope made of timber sandwich panels. The use of this system is limited by the requirement for non-combustible fire sections to be situated between the fire areas in both vertical and horizontal direction. This system is allowed to be used in buildings with the fire height of 12 m where the fire sections are not required (see Fig. 1c). It does not go for the residential buildings where the fire sections are always required.

**3. Requirements and design solutions for the envelopes of timber buildings in terms of energy performance**

*3.1. Legislative requirements*

Current legislative conditions to optimize the energy performance of buildings are set in STN 735040-2: 2012 Z1 - 2016 so that the building would be supposed to meet the global indicator required - primary energy consumption in kWh/($m^2$.a) in the energy performance class A1. The limit values are defined depending on the building´s category - its main functional use. As of 2020, all the buildings designed, including those for housing (family houses and apartment buildings), will have to meet the national requirements for energy consumption in the category of nearly-zero-energy buildings within the limit of the global indicator - primary energy consumption in kWh/($m^2$.a) in the energy performance class A0 [2]. The energy performance of a building is a function of the parameters of a model describing thermo-technical properties of structures and effectiveness of technical systems at its intended operating under the specific climatic conditions, including the urban impact. In terms of the heat loss reduction, the current standard requirement for heat transfer through the building envelope is 0.22 W/$m^2$K.

*3.2. Construction solutions of wood-based envelopes in terms of thermal protection*

Nowadays, the construction of wood-based buildings often uses the load-bearing systems of timber framework. The framework in low-storey buildings serves as a building´s supporting system and at the same time as a load-bearing structure for the envelope. The load-bearing structure for the envelope consists of vertical wooden pillars with an air gap filled with thermal insulation. Its exterior side may be covered with vapour permeable formwork of thermal insulation (Fig. 2), or it may be covered with OSB boards, subsequently thermo- insulated and finished with a thin-layer plaster. Its interior side may be covered with OSB boards having vapour barrier with a grid and a pre-wall of plasterboard fastened to it. Technical wiring may be situated in the air gap between the pre-wall and plasterboard. The plasterboard thickness is designed according to the fire resistance requirements for the supporting wall and the envelope itself. The pre-wall also makes the acoustic insulation better.

*3.3. Optimal thermal insulation for the sandwich envelopes of timber buildings in terms of energy intensity and fire protection requirements*

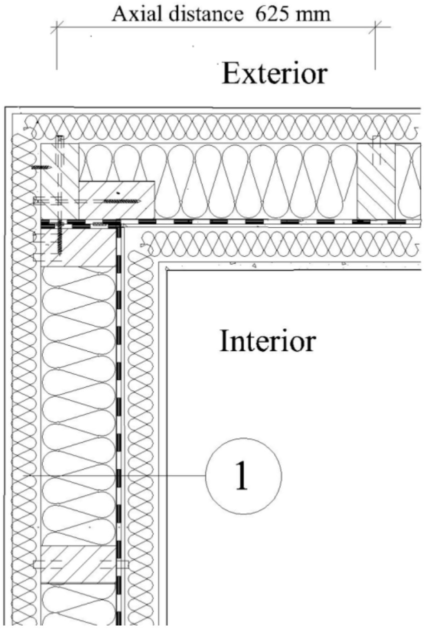
Choosing the thermal insulation for sandwich timber structures is conditioned by its thermo-insulating efficiency, combustibility class, durability, and recyclability. The building envelope and timber load-bearing framework must be designed so that the water condensation would not occur on joints of timber elements. As for hygienic demands, the layers of thermal insulation and its physical parameters must be designed to keep the minimal surface temperature of the interior wall above the critical surface temperature for mould growing, depending on the boundary environmental conditions and the type of heating. The type and thickness of thermal insulation is essential for the fire resistance of a timber panel. Its melting temperature should be above 1000 ° C and a minimal mass weight should be above 30 kg/ $m^3$. Thermal insulations m based on mineral-wool or glass-fibre meet these physical parameters.

Table 1 Optimization of a timber panel - thermal insulation in terms of heat loss for structures built by 2020 considering the fire protection and environmental requirements.

| Thermo-insulating material | λ W/mK | ρ [kg/m³] | Combustibility class | Melting temperature °C | Hr. TI [m] | $U_v \leq 0{,}22$ W/(m².K) | Δ fire resistance min. | m´ kg/m² | $\Delta OI3_{KON}$. |
|---|---|---|---|---|---|---|---|---|---|
| Gypsum plaster board, at plant | 0.22 | 750 | A1 | | 0.015 | | 28,5 | 28,5 | 5,95 |
| Isover Woodsil<br>+ vapour barrier<br>in the grid of an installation pre-wall | 0.038 | 37 | A1 | >1000 | 0.06 | | 17 | 2.22 | 3,73 |
| Oriented strand board at plant | 0.130 | 650 | E | | 0.015 | | 13,4 | 9,75 | 7,5 |
| **Variant 1** Isover Woodsil | 0.038 | 37 | A1 | >1000 | 0.12 | | 25 | 4.44 | 7,46 |
| **Variant 2** fibreboard soft, at plant | 0.400 | 55 | E | <1000 | | | 8 | 3,3 | 5,12 |
| **Variant 3** blown cellulos | | | E | <1000 | | | 0 | | 19,6 |
| Fibreboard soft, at plant | 0.043 | 55 | E | <1000 | 0.06 | cca 0.17 | - | 2.20 | |
| Thin-layer plaster with reinforcement fabric | 0.75 | 1600 | A1 | | 0.001 | | - | 1,80 | 5,3 |
| Sawn timber, softwood, raw, kiln dried, u=10% | 0,018 | 300 | E | | | - | - | 7,56 | 3,0 |

λ - heat conductivity coefficient – calculation values, ρ - mass weight, m´- basis weight, Δ - fire resistance gain

Note: In the lightweight sandwich structures - timber panels, the currently convenient thickness of thermal insulation based on mineral wool, fibreboards, blown cellulose, or sheep wool is about 220 mm, depending on the mass weight and heat conductivity coefficient. As of 2020, the requirement for the thickness of thermal insulation of building envelopes in the passive houses will be a quarter higher.




**Composition 1 -**from the interior side
- Gypsum fiber board thickness of 12,5 mm
- Mineral wool thickness of 60 mm in the installation cavity
- Vapor barrier
- OSB boards thicknesss of 15 mm
- Supporting Wooden columnar structure 60/120 mm inserted in the air gap insulation thickness of 120 mm
- Fibreboards insulation thickness of 60 mm
- Exterior plaster thickness of 10 mm

Fig. 2 Composition of timber panel optimized in terms of higher fire resistance

**4. Fire resistance of the timber sandwich panels**

The required time of fire resistance and the criteria for limit states of timber load-bearing elements of external walls are directly related to the static load. In case of frameworks, the timber vertical elements are part of the supporting walls and are linked up by the horizontal ceiling or roof supporting elements. These structures, including all those of bracing and anchor elements, must meet the REI criterion.

The composite supporting elements of the fire-separating structures, as well as all the elements related to the supporting ones in terms of load, are required to meet the criteria for the fire resistance time. The interaction of all the elements provides the fire resistance of the whole structure. In case of timber supporting elements, the value of fire resistance can be determined by calculation methods depending on the static load using STN EN 1995-1-1 (Eurocode 5). The fire resistance of timber or wood-based load-bearing and construction elements depends on the burning and charring speed.

Methods to calculate fire resistance of structures in terms of Eurocodes employ the analytical approach to design buildings considering the fire effect. It takes into account the function of a structural system at higher temperatures in terms of static load of fire separating structures as well as increases in thermal protection by active or passive elements of fire protection systems. When designing or assessing load-bearing fire barrier according to EN 1991-1-2, the appropriate model of fire situation is chosen. Subsequently, the corresponding fire scenario is determined. According to standard temperatures in the affected fire zone, it is calculated temperature course in load-bearing structural elements which are stressed both statically and thermally. The resulting static load of a structure in a critical fire situation is calculated and the cross-section is evaluated - whether it meets supposed thermal stress in the required time.

The mechanical behaviour of statically stressed structures during fire depends on thermal load defined by fire risk, thermal effects on material properties - flammability, indirect mechanical load (release or fall of facing etc.), and direct effects of static load. Thermal analysis is carried out according to STN EN 1991-1-1-2 [11]. Static analysis is made according to STN EN 1991-1-1-2 and other STN, depending on the material type.

In accordance with the procedure, specified in STN EN 1991-1-1-2, the model fire situation was determined on the basis of an estimation or calculation of fire risk. The model (normative) fire in a fire sector (FS) is determined for the model fire situation. It is always considered only for one FS in given time; in this case the entire object is one fire sector. When assessed fire resistance of a structure, calculations considered the model (normative) fire with nominal fire curves.

The charring depth and the subsequent static weakening of the cross-section must consider all the surface elements directly exposed to fire. Surface charring need not consider the surface of the timber load-bearing elements protected during the calculated fire load by other elements. Likewise, it need not be considered at the elements protected by the fire facing provided that: $t_{pr} \geq t_{fi,req}$; where tpr is the time to break the protective plate or other protective material and $t_{fi,req}$ is the time required for fire protection at standard fire load.

The timber load-bearing elements of frameworks have typically double-sided covering with boards and the air gap is filled with a thermal insulator. The OSB or other wood-based boards are used for covering. Since their surface is burning more slowly than that of solid timber, they increase the fire resistance of the load-bearing elements.

Most board materials that are construction elements of the supporting system of the envelope may be also used as an additional fire protection of timber load-bearing members. They also serve as reinforcing wall elements and a foundation for the final finishing. If they are considered as a protective fire facing, the time when the breakage occurs must be determined. In such cases, the time to break is the time within the temperature on the non-radiated side of the fire barrier will increase by more than 180 K in combustible materials and by more than 500K in non-combustible materials. These time limits are being determined by tests.

*4.1. Fire resistance of the tested timber sandwich envelopes*

The testing of envelope compositions considers covering using OSB boards on the interior side and fibreboards with a thin-layer plaster on the exterior side.

Before completing the structure, the plasterboard pre-wall with an installation gap will be fastened on a wooden grid on the interior side. After wiring, the gap will be filled with mineral wool. This adjustment will also serve as a passive fire protection of the timber elements in the load-bearing system.

The time to break a fire protection by these structures up to the surface of timber supporting elements will be the sum of the partial values of the time when the fire damage occur.

The time to break the timber and wood-based fire-protecting boards may be determined using the tests according to the relation.

$$t_{pr} = t_p/\beta_0 - t_r \text{ [min] [5]} \qquad (1)$$

$\beta_0$ - charring speed
$t_p$ - thickness of the facing
$t_r$ = 4 mm; it is the reserve to prevent boards from falling down or to prevent fire from spreading into cavities (e.g. installation gaps)

The multi-layer fire facing must always be anchored to the protected supporting element.

The time to break OSB boards in the composition tested (see Fig. 2) is 15/0.86 = 17.44 - 4 = 13.4 min.

The time to break the non-flammable facing and boards is the time when the temperature of the surface that is not exposed to fire rises by more than 500K.

For F-type plasterboards, 15 mm thick, with increased cohesion of the core at the high temperature, it can be determined according to the relation:

$$t_{pr}=1{,}9.\ \xi\ .\ t_p \text{ [5]} \qquad (2)$$

The time to break F-type plasterboards is 1.9 · 1.15 = 28.5 min

The time to break non-flammable insulation materials, more than 20 mm thick with mass density above 30 kg/m$^3$ that remain compact to 1000 ° C, can be calculated according to the relation:

$$t_{pr} = 0{,}07(t_{ins} - 20)\ .\ \sqrt{\rho_{ins}} \text{ [5]} \qquad (3)$$

$t_{ins}$ - thickness of the insulation material in mm
$\rho_{ins}$ - mass weight of the insulation material in kg/m$^3$

In this case, mineral wool with a specific weight of 37 kg/m$^3$ is used in both the pre-wall cavity.

Supporting fire barrier wall - **option 1a**

$$t_{pr} = 0{,}07\,(60 - 20)\ .\ \sqrt{37} = 17 \text{ min [6]} \qquad (4)$$

The resultant value of Σtprj for verified composition is 55 minutes. The condition corresponds to the fire resistance of a filling wall REI 30.

Curtain framework - **option 1b**

$$t_{pr} = 0{,}07\,(180 - 20)\ .\ \sqrt{37} = 68 \text{ min [6]} \qquad (5)$$

The resultant value of $\Sigma t_{prj}$ for verified composition is 109 minutes. The condition corresponds to the fire resistance of a filling wall EI 60.

The resultant value of $\Sigma t_{prj}$ for verified composition is 109 minutes. The condition corresponds to the fire resistance of a filling wall REI 30.

If the air gap in the framework is filled with a combustible thermal insulation with the melting temperature of 1000 °C - **option 1b, 2, 3**. $t_{pr}$ = 0.07 (60 -20). √37 = 17 min. The solution corresponds to the fire resistance of a supporting wall REI 30.

Criterion I. - verification of the temperature rise on the side that is not exposed to fire, up to 140K:

$\Sigma t_{prj} \geq t_{fi,req} + 5$ = 109 > 60 +15...EI 60... option 1b, 2,3. (6)

$\Sigma t_{prj} \geq t_{fi,req} + 5$ = 55 > 30 +15...REI 30... option 1a. (7)

Criterion II. - verification of the maximal temperature rise in any spot is limited up to 180°C, the condition is met if the inequation is true:

$\Sigma t_{prj} \geq t_{fi,req} + 5$ = 80.8 > 60 +5…EI... option 1b, 2,3. (8)

$\Sigma t_{prj} \geq t_{fi,req} + 5$ = 45.5 > 30 +5…REI... option 1a. (9)

## 5. Optimal choice of thermal insulation for a building envelope in terms of the environmental burden

The next important aspect is the impact of the production and disposal of thermo-insulating materials on the environment and the possibility of their recycling. It is determined by the embodied energy consumption and emissions produced throughout their life cycle. The aspect of embodied energy consumption is monitored - the energy consumed throughout the life cycle of a product given in MJ/m$^2$ PEI and the amount of emissions produced in the production, use, and disposal of a product:$CO_{2,akv}$ - GWP (global warming potential), $SO_{2,akv}$ - AP (acidification potential), PO4,akv - EP (eutrophication potential), R-$11_{akv}$ - ODP (ozone depletion potential), $C_2H_4$ - POCP (ground-level ozone formation potential).

Generally accepted equivalent for the assessment of the impact of construction materials on the environment is the environmental index of a structure known as $OI3_{KON}$. It refers to 1 m$^2$ of a structure and considers third weights of eco-indexes drawn on 1 m$^2$ of a structure. Table 1 gives the data for all the variants considered. Option 1 is an optimal solution in terms of both fire safety and the environmental burden. The concrete composition "1" has $OI3_{KON}$ = 33.

## 6. Conclusions

The increasing thickness of a thermal insulation, in terms of energy performance optimization, causes increasing fire resistance of the building envelopes where the non-combustible thermal insulation with the melting temperature of 1000 °C is used. Low-storey panel buildings, as well as kit homes with framework systems, are provided with the adequate fire-resistant load-bearing members of a building envelope when choosing interior thermal insulation optimally. In timber skeleton frame structures, where the timber load-bearing members are not fire-protected, it is possible to achieve the fire resistance by overdimensioning the cross-section of load-bearing glued timber elements according to EC:5 methodology. The conditions valid for the envelope in the panel buildings are similar to those valid for wood-based filling masonry.

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# Electrophysical method of improving the fire-extinguishing and heat-shielding characteristics of water-based materials

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**Abstract**

There are a data of changes of water molecular structure due to electro-physical effects as a results the research of distilled water using Raman spectroscopy and laser spectrofotometry: the offset of the valence bands of O-H vibrations in the direction of large values was detected, indicating a decrease in the average strength of the hydrogen bonds; the decrease of water cluster sizes as a result of an effect of an alternating frequency-modulated potential (VFMP) was shown. A decrease of water density and dynamic viscosity and an increase of surface tension under the influence were detected during the researching of physical properties of distilled water. An increase of heating time of water and modified hydrogels and a decrease of the fire class "A" extinguish period were detected during the researching of the thermophysical and fire properties of tap water and hydrogel, modified by electrophysical effects.

Keywords: electrophysical impact, variable frequency modulated capacity, water, hydrogels, extinguishing and heat-shielding properties;

## 1. Introduction

Water is a universal extinguishing substance. Its physical-chemical characteristics such as thermal stability, large heat of vaporization, the high value of specific heat capacity and a low viscosity, non-toxicity for living organisms and accessibility, make it indispensable in fire extinguishing, human lives and property saving. However, modern fire extinguishing tactics put forward new requirements for fire-extinguishing substances (FES). There are the need to reduce consumption FES to increase the efficiency of fire extinguishing settings and reduce damage in case of fire, reducing the time of fighting fires and reducing the impact of dangerous fire factors (DFF) on escape routes, including high temperatures.

The use of water in combination with other substances, including surface-active, fire-extinguishing powders, etc. allows the increase the efficiency of fire suppression, however, there is a need to use specialized fire-technical equipment, the increase of CTE cost, and there is a risk of negative impact of substances on the human body and the environment. There are technologies of reagentless change of water, water liquids and suspensions features, allowing to change their physical-chemical and operational characteristics.

There are the results of a research of properties of modified hydrogels and water used for fire protection and protection against high temperatures.

## 2. Statement of research problem

In the main,the water characteristics determined by its structure`. The structure of liquid water has been studied well. In accordance with the Pople model, each water molecule has 4 H-bonds with other molecules, that allows to build three-dimensional net of binding, unlike other molecules that even can be make only linear or closed chain H-bonds [1] using strong H-bonds.

Some molecules are bound between 1 to 3 H-bonds in liquid water, but a part has a crystalline structure with 4 H-bonds. H-bonds that hold together the clusters, which are weak enough (about 10% of the strength of the average ionic or covalent bonds),

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seeing which constructed clusters are in constant transformation (connection and decay) with a period of about $10^{-8}$ c. The presence of hydronium ions in water (water molecules with an extra hydrogen atom), that create an ionized molecular clusters in connection with oxygen atoms of the water molecules, allows the water to keep a liquid state under normal conditions and determine its ability to self-organizing dynamic system under different physical effects [2].

The size and shape of water molecule change upon excitation rotational, vibrational and electronic degrees of freedom . Raman spectrum of water absorption represented by different bands in the interval from 60 $cm^{-1}$ to 3756 $cm^{-1}$, with the most pronounced band near 3440 $cm^{-1}$, caused by changes in the bond lengths of O-H in water molecule [3].

As a rule, there are conditions for the occurrence of electric fields by effect magnetic field in the water systems: conductive water system moves in electric fields, or magnetic fields change in time. In addition, water systems test combined electromagnetic action, and the electric and magnetic components in the process have leading role depending on conditions. At electromagnetic impact on water systems change their properties correspond to heterogeneous systems and phase transitions, whereby insignificant energy parameters exposure can lead to changes, many times increasing effect [4].

In particular, we could [5] observe a significant increase of intensity and shift of some peaks in Raman spectra under an effect of magnetic field with induction of 600 – 4000 Gs on distilled water at 25 °C in the range 20 – 1900 $cm^{-1}$ and 2000 – 9000 $cm^{-1}$. In [6] the calculation of the radial distribution function of the molecules it is concluded that a structure of water under the effect of magnetic field is more stable and the ability of water molecules to create hydrogen bonds is increased by apposition of a magnetic field. In addition, it was observed a decrease of the coefficient of self-diffusion of water molecules.

Some physical water characteristics change in conditions of electrophysical effects. The increase of pH values and conductivity of the water after exposure [7] detected in research of pH changes and conductivity of distilled water under effect of constant magnetic field with induction 1.5 T.

Thus, when determining the optimal parameters of electrophysical influence, there is a possibility of changes in the physico-chemical properties of the water in terms of electrical effects, which in turn, modifies the operating characteristics of water and water-based FES, for fire protection and protection of the DFF.

## 3. Research materials

As materials for the experiments, we used distilled and tap water, and hydrogels based on Recoletos acrylic polymer (RAP) mark "Carbopol ETD-2020".

As electrophysical method of exposure was used the method of structure control in the substance at the interface of phases with an alternating frequency-modulated potential (VFMP). The method consists of effecting VFMP that characterized by nonlinear electric distorted signal with two intervals of heterogeneity with an operating frequency of 50 to 160 Hz and capacity from 56 to 220 V. Structuring and ordering of water molecules are during effect at the water and water liquids, results are changes of physical-chemical characteristics, including some thermodynamic [8].

## 4. Research of the structure and characteristics of distilled water in conditions of electrophysical effect

Research of the structure of distilled water in conditions of effect VFMP (220 V, 50 Hz) during 60 min. was made using Raman spectroscopy with a laser wavelength of 532 nm. The research showed a persistent increase in the intensity spectrum, the observed frequency shift of the band O – H in the range of 3100 … 3600 $cm^{-1}$ to 30 … 50 $cm^{-1}$ (Fig. 1). Shift the frequency of oscillation of the valence bands of O-H in the direction of its large value indicates a decrease in the average strength of hydrogen bonds [9].

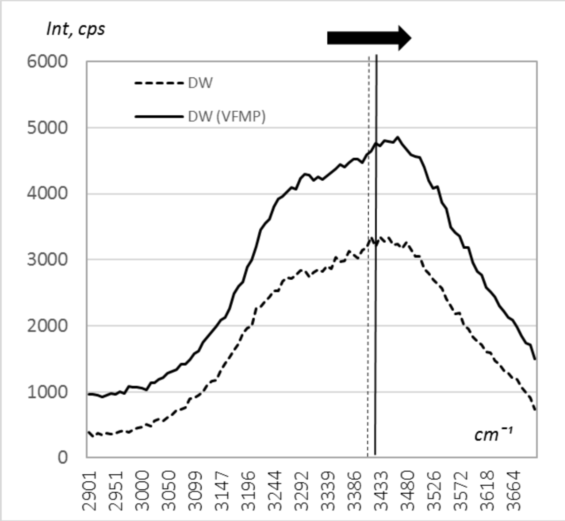
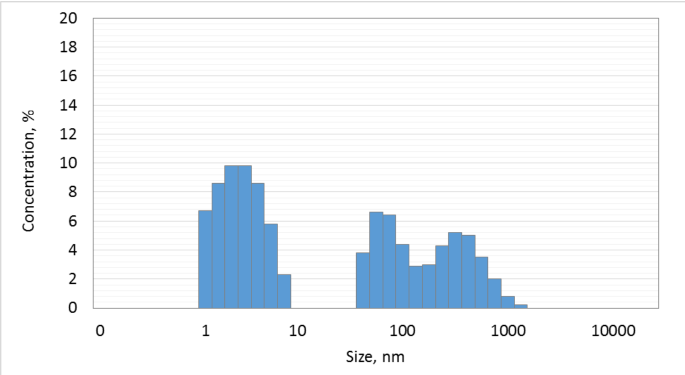
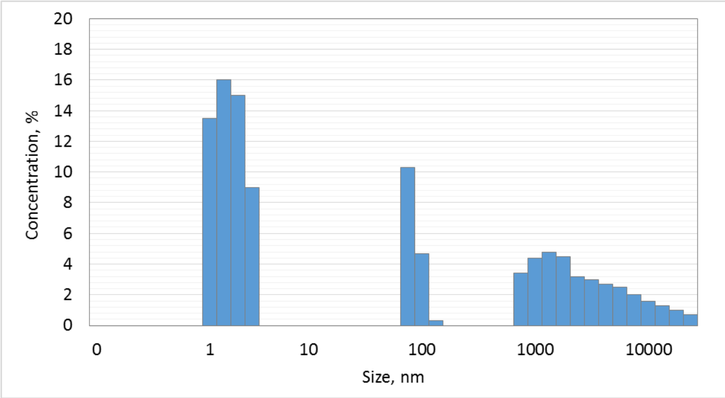



Figure 1 Raman spectrum of distilled water in the range of 2900 … 3700 cm$^{-1}$ in conditions of electro-physical effects (a) and control sample (b)

In the research of cluster structures of distilled water using the method of laser spectrofotometry based on the determination of the spectral characteristics of quasi-elastic scattered light is a helium-neon laser with a wavelength of 632 nm and a power output of 2.5 mW when passing through the liquid with a particle size of 1 ... 2000 nm [10]. The result is that the data confirm the decrease in the size of water clusters in the conditions of electro-physical effect (Fig. 2).




a)




b)

Figure 2 Dynamic light scattering distilled water clusters in terms of electro-physical effects (a) and control sample (b)

**5. Research of the physical characteristics of water in conditions of effect VFMP**

The research of changes in the physical characteristics of distilled water, depending on time of electrophysical effects, was made by measuring density, dynamic viscosity and surface tension of the liquid in conditions of electrophysical effects in the interval from 10 to 60 min, when the air temperature is 20-25 °C, atmospheric pressure and humidity no more than 80 %. Density measurement of water was made by pycnometer method using glass pycnometer Gay-Lussac [11]. The research showed that in conditions of the electrical effects it strong decrease in the density of distilled water during the first 20 min of effect. Significant changes to the density of water was not observed anymore (Fig. 3).

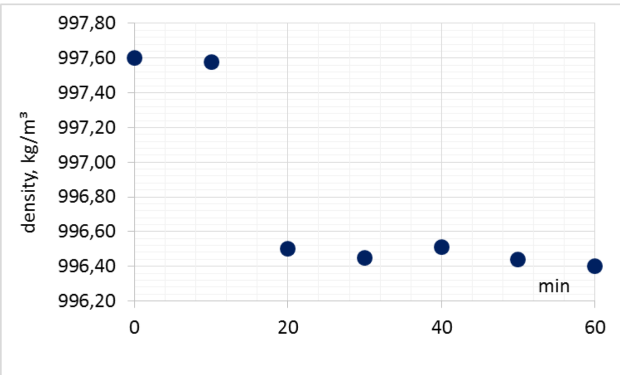



Figure 3 Change in the density of distilled water in terms of electro-physical effects for 60 min

Measurement of dynamic viscosity of water was carried out using a viscometer VPI-2m "Labtex" [12]. It is shown that the effect VFMP the dynamic viscosity of water decreased by 2 %, and the greatest change in values recorded during the first 30 min (Fig. 4).

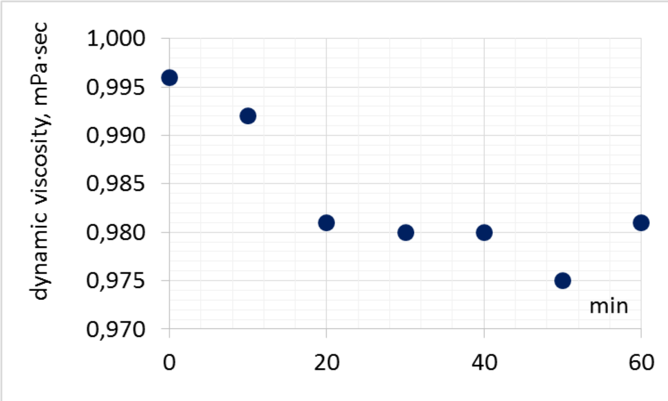



Figure 4 Change of dynamic viscosity of distilled water in terms of electro-physical conditions for 60 min.

Change the value of the surface tension of water under electro-physical effects was made using the method of droplet detachment [13]. The water was treated VFMP before measurements. As a result, the surface tension increased by 40% during the observed time (Fig. 5).

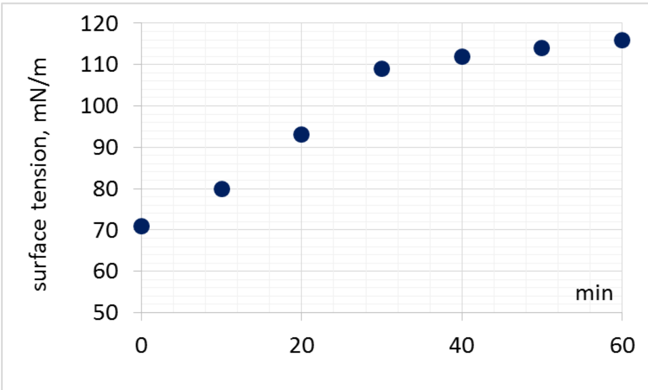



Figure 5 Change in the surface of distilled water in terms of electro-physical effects for 60 min.

**6. Research of heat protective and fire-extinguishing water and water-gel formulations in conditions of electro-physical effects**

To research the mechanism of heating and boiling of water-gel compositions (WGC) and determine the dependence of thermal conductivity on the method of modification of WGC and the concentration of RAP was used a laboratory installation for the study of surface and bulk boiling of liquids. The system includes a fluid container with a volume of 0.2 l, electric heater fixed power of 100 W, thermocouples, two-channel temperature data logger, exhaust blower for removal liquid vapor. The volume of the gel in the container was 100 ml. Changes in liquid temperature inside the tank at the thermocouple located at a distance of 50 mm from the bottom of the tank were recorded during the research.

The results show the increasing time of heating of water and hydrogel in conditions of electrical effects. Also of note is the fact that the hydrogel with the mass concentration of RAP 0.25 masses. % modified in conditions of the electrophysical effect did nt heated to a temperature above 85 °C, that allows to use it as an effective means of thermal protection in case of fire.

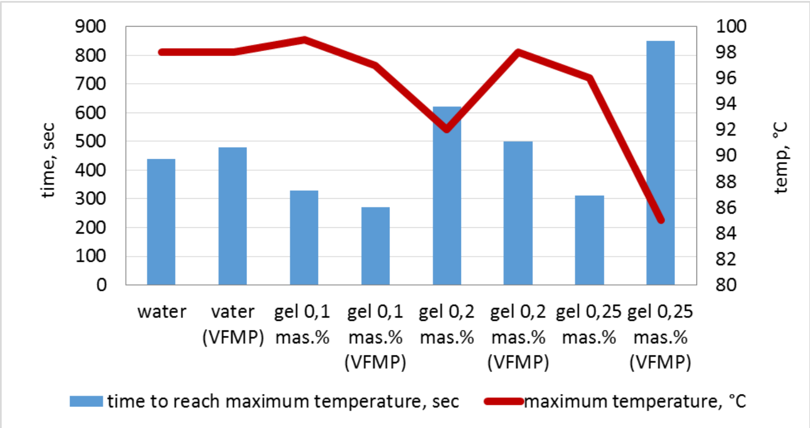



Figure 6 Time to reach and the maximum temperature of tap water and hydrogels at a concentration of RAP from 0.1 to 0.25 mass % in conditions of exposure VFMP

Evaluation of extinguishing characteristics of water and hydrogel in conditions of effect VFMP was made in accordance with [15]. As combustible material used bars of softwoods section (40±1) mm humidity 10 to 20 %. According to test results we can conclude about a significant reduction in the time of the extinguishing of the model seat fires of class "A" water modified 50% modified hydrogels by 12 – 15 % (Fig. 7) [16, 17].

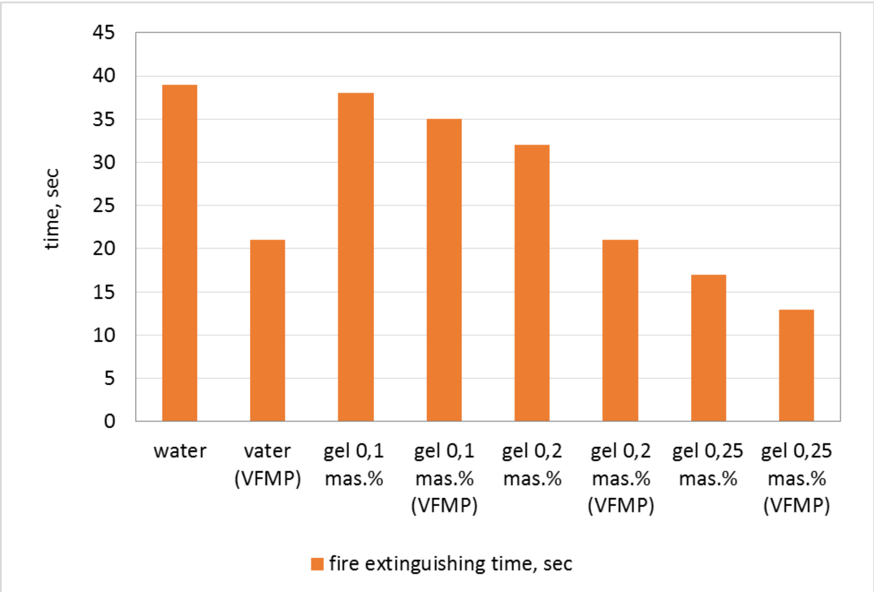



Figure 7 Extinguishing time of the fire class "A" model seat and hydrogels in conditions of effect VFMPFire resistance of the timber sandwich panels

## 7. Conclusions

1. When exposed VFMP there is a change in the water molecular structure, thereby change its physical characteristics, such as density, dynamic viscosity, surface tension. It allows for a short time (10-20 min.) to change the operational characteristics of FES on the basis of water.

2. Modified hydrogels under the effec VFMP have great insulating characteristics in comparison with control samples, that allow to use more efficient for protection from heat effects of fire.

3. The total change in thermo-physical and operational characteristics of FES leads to the reduction of extinguishing time of the fire class "A" model seat [15].

4. The use of electrophysical method does not require a significant upgrade of fire equipment and considerable energy costs, that makes it promising for use on most types of fires.

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# Review of Dust Deposition and Dust Explosion Proofness in Mine Workings

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**Abstract**

The article addresses the key items of Russian, U.S., Australian, and European regulations that govern the dust explosion proofness system at coal mines. It contains the review of parameters of main aerotechnogenic processes in mine workings related to a dusting factor. The article reviews the impact of the following dust parameters on dust explosion proofness in a coal mine. They include dust concentration, lower explosive limit, volatile yield, ash content, rock moisture content, coal wettability, and distribution of dust particles in a dust cloud. Dust particles sized up to 831µm (1,000µm) at blast wave speeds of 335 tp 435m/s or higher are demonstrated to be capable of being suspended and involved in explosions. An important indicator governed by applicable Safety Rules During Coal (Shale) Enrichment and Pelletising is a rock dusting standard which means the lowest non-combustible content when coal dust mixed with inert one does not explode. The article lists key measures aimed at mitigating a dust explosion probability at a mine. Mine working rock dusting is proposed as the most efficient technology to reduce dust release and promote dust explosion proofness. Rock dusting involves adding inert dust to make a mine working explosion-safe. The article presents methods to determine such additives in Russian and U.S. mines. Rock dusting standards were calculated for the coal mines in the Kuznetsk Basin. Results were compared with the relevant indicators for U.S. and Australian mines. The shale dust with a weight of 2.41kg/m was established to entail inert dust distribution in a 80–150µm layer when distributed across a line metre of the mine workings (covered area of 15 to 20$m^2$), however there are almost no technologies to implement this. Rock dusting frequency is based on a dust deposition intensity review.

*Keywords:* dust, dust generation, dust explosions, rock dusting, explosive limit, coal, mine, dust explosion proofnes;

## 1. Introduction

One of the key issues during bituminous coal production is dust release which not only adversely impacts mine workers' health by affecting their respiratory system but often causes explosions (Qingqing [1, 2]).

Russian regulations and technical references related to coal dust explosion issues consider particles sized up to 1,000µm. The U.S. Safety Regulations classify all particles that pass through screen # 20 (831µm) as dust deposits, and Russian, U.S., and Australian codes classify particles that can pass through screen # 200 (74µm) as floating dust (Mineral Resources [3-5], Coal Mine Safety Rules [6]). Particles sized up to 831µm (1,000µm) at blast wave speeds of 335-435m/s or higher can become suspended and be involved in explosions (Lindenau [7]).

These parameters demonstrate that it is essential to take into account other properties of host rock, a dust/gas cloud, and mine working geometry to select an efficient technology that would ensure dust explosion proofness in a coal mine (Yinlin [8]).

## 2. Materials and Study Methods

### *2.1. Coal Dust Properties that Determine Its Explosive Potential*

The studies of dust explosibility involve the identification of dust lower explosive limit (LEL,$\sigma_{lo}$), which is the maximum permissible quantity of deposited dust

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per unit of the mine working volume when an explosion cannot spread across the dusty area. The lower explosive limit is expressed in g/m3 (Coal Mine Safety Rules [6]).

Since the difference between LEL and floating dust concentrations ($C_\beta$) in the air with most process operations is 103 or 104 times, it is not feasible to compare $\sigma_{lo}$ (g/m$^3$) and $C_\beta$ (mg/m$^3$). The mine working hazard level related to its explosion potential is therefore identified by comparing $\sigma_{lo}$ with dust deposition $P_t$ (g/m$^3$*day) in the reviewed period (day). This determines dedusting, dust consolidation, and rock dusting time.

LEL depends on dust properties, such as: volatile yield, ash content, moisture content, and wettability, as well as the distribution of dust particles in released coal dust. An important indicator governed by applicable Safety Rules During Coal (Shale) Enrichment and Pelletizing (State Mining and Technical Inspection, Russia) (N, %) is a rock dusting standard which means the lowest non-combustible content when coal dust mixed with inert one does not explode.

It should be noted that European standards differ (Lebecki [9], EN 13205 [10], EN 481 [11], ISO 7708 [12]) from the Russian safety rules. Coal dust explosibility in the EU is determined by the following parameters:

– lower explosive limit of a dust cloud;
– minimum fire point of a dust layer;
– minimum fire point of a dust cloud;
– minimum ignition energy of a dust cloud;
– maximum explosion pressure; and
– maximum explosion pressure rise rate.

Pyrolysis intensity is characterised by a volatile yield ($V^{daf}$). Dust explosion hazards are related to coal layers with a volatile yield of $V^{daf} \geq 15\%$. With $V^{daf}$ increase, dust explosibility increases.

Ash ($A^{daf}$) as a non-combustible coal component reduces a dust explosion potential. Heat resulting from an explosion is partially consumed to heat the ash content. This factor along with the capability of non-combustible aerosols to reduce an explosive particle concentration and promote reaction chain breaking under the "wall principle" at the pyrolysis stage (Neceplyaev [13]) substantiates inert dust use to prevent and contain coal dust explosions.

A coal moisture content reduces the explosibility degree (Xiaochun [14]). Coal moisture content and wettability also remote adhesion meaning dust particle sticking to different surfaces and self-adhesion which means particles sticking together. Researchers from Makeevsky Research Institute (Makeevka, Ukraine) established that a 12% or higher increase in the moisture content of coal dust deposits prevents dust suspension and involvement in explosions.

Dust distribution impacts dust explosibility as follows: finer dust means easier conversion of deposits into an explosive suspension. Researchers from Makeevsky Research Institute and Central Mining Institute (Katowice, Poland) found out a significant increase in explosive properties of fractions sized up to 15μm as compared to fractions sized up to 75μm (Krzystolik [15].

*2.2. Method Used to Assess Dust Explosion Protection Parameters at Coal Mines*

In accordance with the Coal Mine Safety Rules applicable in Russia, dust explosion protection of coal mines includes the following activities:

– identification of explosive properties of coal dust;
– identification of dust deposition intensity in mine workings;
– selection and performance of explosion protection measures to reduce dust formation and deposition;
– prevention and containment of explosions; and
– dust explosion prooofness control in mine workings.

The Coal Mine Safety Rules applicable in Russia stipulate a lower explosive limit ($\sigma_{lo}$, g/m$^3$), dust deposition intensity ($P_t$) in mine workings (g/m$^3$*day), and rock dusting (*N*, %). The rock dusting standard is determined by the formula below:

$$N = \frac{A^{daf}(100 - D)}{100} + D \quad , \qquad (1)$$

where D is added inert dust required based on periodical lab tests or the graphic chart (Dust Control and Dust Explosion Protection Guidelines for Coal and Shale Mines [16]).

International standards may be taken for comparison (Mineral Resources [3-5]). The U.S. Safety Regulations (30 CFR 75.403, Maintenance of incombustible content of rock dust) and similar Australian standards stipulate that the incombustible content in dust samples must be at least 65% in fresh air and at least 80% in return air (including moisture and process ash). Every 0.1% of methane content in the mine air increase the rock dusting standard by 1% in fresh air and by 0.4% in return air. Given the permissible CH4 concentrations in the mine air, the U.S. standard value range for rock dusting is:

– N = 60% to 70% in fresh air in mines;
– N = 80% in fresh air in non-gas mines; and
– N = 80% to 84% in fresh air in gas mines.

The U.S. Regulations may be presented mathematically as follows:

$$D = N - A^{daf} - W, \quad (2)$$

where D is added inert dust to ensure explosion safety in the mine working, %;

N is a rock dusting standard determined according to (1).

D parameter for Russian mines is determined in the graphic chart which can be replaced by such linear equations as:

$$D = N_{\max} - kA^{daf}, \quad (3)$$

where $N_{\max}$ is the maximum rock dusting standard corresponding to $A^{daf} = 0$;

$A^{daf}$ is the actual ash content between 0% and 38%;
$k$ is the linear approximation factor ($k \approx 0{,}30$).

$N_{\max}$ value in current standards (Mine Coal Safety Rules [6], Mine Coal Safety Rules [17]) is 71 to 90. In Russian coal-mining companies producing high-octane coal grades with a volatile yield of $V^{daf} \geq$ 37% (at least 50% of the total produced coal), $D$ parameter is 90–0.3 $A^{daf}$. The general equation (3) for other coal grades remains unchanged. Therefore, complete dependency of the rock dusting standard from ash content can be presented as follows (4):

$$N = N_{\max} - (0{,}01N_{\max} - 0{,}7)A^{daf} + 0{,}03(A^{daf})^2$$

## 3. Results and Discussion

### *3.1. Review of the Estimated Rock Dusting Standards for Kuzbass Mines*

Calculations for Kuzbass mines show that the rock dusting standard with an error rate of less than 1% is a permanent value (Table 1) and the ash content used in (2) or (4) $A^{daf}$ has a low impact on N.

Inert dust consumption for rock dusting per 1m of a mine working ($q_{sh}$, kg/m) is determined by the formula below:

$$q_{sh} = \frac{0{,}001N\sigma_{dep}S}{100 - N}, \quad (5)$$

where N is the rock dusting standard, %; $\sigma_{dep}$ is dust LEL, g/m$^3$; S is the area of the mine working cross-section in the clear, m$^2$.

Table 1 Inert dust consumption for rock dusting of 1m of a mine working in Russia

| **Consumption** | | | | **Standards as per Safety Rules of the Russian Federation** | | |
|---|---|---|---|---|---|---|
| **Mine** | $A^{daf}$, **%** | $V^{daf}$, **%** | **LEL ($\sigma_{lo}$), g/m³** | **Added inert dust (*D*), %** | **Rock dusting standard (*N*), %** | **Inert dust consumption ($q_{sh}$), kg/m** |
| Kirova | 23.0 | >37 | 23 | 82.6 | 86.6 | 1.95 |
| Komsomolets | 14.4 | >37 | 23 | 85.4 | 87.5 | 1.93 |
| Krasnoyar-skaya | 23.0 | >37 | 28 | 82.6 | 86.6 | 2.30 |
| 7th November | 20.1 | >37 | 25 | 83.6 | 86.9 | 2.65 |
| Posylaevskaya | 12.0 | >37 | 29 | 86.2 | 87.8 | 2.54 |
| Taldinskaya-Zapadnaya 1 | 11.0 | >37 | 22 | 86.5 | 88.0 | 2.92 |
| Taldinskaya-Zapadnaya 2 | 11.2 | >37 | 24 | 86.4 | 87.9 | 3.15 |
| Kotinskaya | 12.0 | >37 | 20 | 86.2 | 87.8 | 3.03 |
| No. 7 | 13.5 | >37 | 25 | 85.7 | 87.6 | 2.77 |
| Average value | | | | | 87.3 | 2.41 |

Table 2 presents similar standards for design dust explosion protection parameters pursuant to the Australian and U.S. regulations.

Table 2 Inert dust consumption for rock dusting of 1m of a mine working in Australia and the United States

| **Averaged standards for the United States and Australia** | | | |
|---|---|---|---|
| **Development mine workings** | | **Working area** | |
| **Inert dust consumption ($q_{sh}$) per daily advance, kg/m** | **Conventional rock dusting standard (*N*), %** | **Inert dust consumption ($q_{sh}$) per 50m of the air roadway, kg/m** | **Conventional rock dusting standard (*N*), %** |
| 20.00 | >80 | 25.71 | >80 |
| 20.00 | >80 | 10.29 | >80 |
| 20.00 | >80 | 13.14 | >80 |
| 20.00 | >80 | 20.00 | >80 |
| 20.00 | >80 | 10.29 | >80 |
| 40.00 | >80 | 14.29 | >80 |
| 40.00 | >80 | 28.57 | >80 |
| 40.00 | >80 | 16.00 | >80 |
| 26.67 | | 16.57 | |

The shale dust with a weight of 2.41kg/m will entail inert dust distribution in a 80–150 µm layer when distributed over a line metre of the mine workings (covered area of 15 to 20m$^2$), however there are almost no technologies to implement this.

Significantly higher inert dust consumption per mine working line metre $q_{sh}$ results in higher emergency tolerance of mines and the recommended values are $q_{sh}$ calculated as follows:

– first, calculations based on applicable regulations;
– then, determination of increased $q_{sh}$ values based on international practices; and
– lastly, selection of $q_{sh}$, the largest of the said values as a final result.

Increased (recommended) standards taking into account international practices:

- $q_{sh}$ = 20kg/m for the development mine working section developed during the shift with a cross-section of up to 16m2;
- $q_{sh}$ = 40kg/m for the development mine working section developed during the shift with a cross-section between 16 and 25m2;
- $q_{sh}$ = 20kg/m for the air roadway section 50m long from the face end or $q_{sh}$ may be calculated based on the consumption of 100kg of inert dust per every 1,000 tons of coal produced; and
- $q_{sh}$ in 50-metre sections of conveyor mine workings (adjoining the coal handling sites) increases twice or thrice above applicable standards.

Inert dust consumption in mines is shown in the Figure.

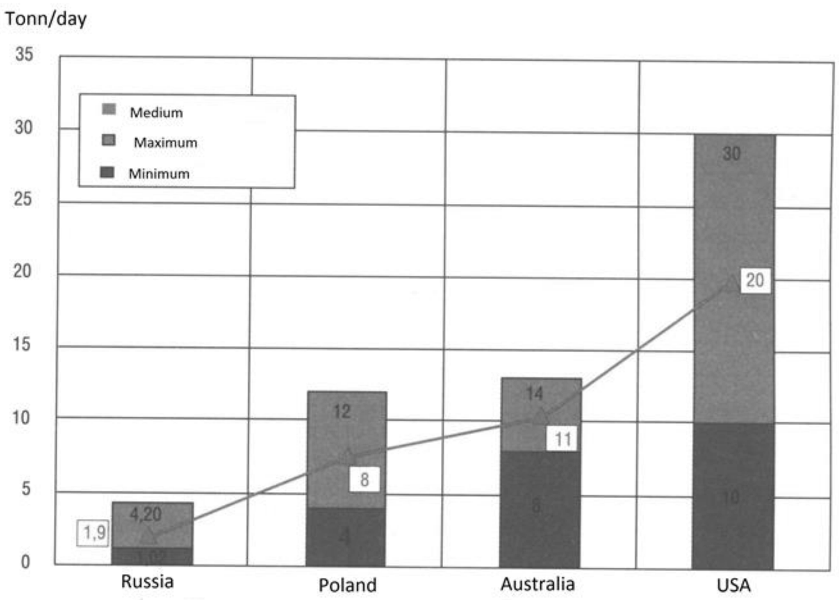


Figure 1 inert dust consumption (tpd) in mines with a capacity of 2 to 3 million tons per year

**Studies of Rock Dusting Frequency**

Rock dusting frequency is based on dust deposition intensity. It is recommended to determine $P_t$ (g/m$^3$*day) based on the difference between dust concentration in two cross-sections of a mine working: $C_1$ and $C_2$ (provisionally, 10m and 50m from the dust formation source) according to (6). A sample calculation of inert dust consumption in the development heading (based on current and recommended increased standards). $q_{sh}$ values for SUEK-Kuzbass mines are between 2.16 and 3.19kg/m. Therefore, increased standards (20 to 40kg/m) are taken based on the cross-sections of mine workings. The recommended (increased) daily consumption of inert dust in the development heading (kg) will be:

$$Q_{sh} = q_{sh}L \qquad (6)$$

where $L$ is a daily advance in the development heading, m.

The relevant calculation for the Kuzbass mines is shown in Table 3.

Table 3 Recommended daily consumption of inert dust in the Kuzbass mine development heading

| Mine | $q_{sh}$, kg as per SR | $q_{sh}$, kg/m | Advance, m | | $Q_{sh}$ | | Rock dusting time (daily), min |
|---|---|---|---|---|---|---|---|
| | | | per day | per year | per day | per year | |
| Kirova | 1.98 | 20 | 55 | 17,774 | 1.1 | 355.480 | 5 |
| Komsomolets | 1.93 | 20 | 16 | 7,790 | 0.32 | 155.800 | 22 |
| Krasnoyarskaya | 2.30 | 20 | 20 | 8,712 | 0.4 | 174.240 | 9 |
| 7th November | 2.65 | 20 | 14 | 6334 | 0.28 | 126.680 | 6 |
| Posylaevskaya | 2.15 | 20 | 10 | 4,787 | 0.2 | 95.740 | 14 |
| Taldinskaya-Zapadnaya 1 | 2.92 | 40 | 30 | 10,181 | 1.2 | 407.240 | 30 |
| Taldinskaya-Zapadnaya 2 | 3.15 | 40 | 26 | 5,645 | 1.04 | 225.800 | 30 |
| Kotinskaya | 3.03 | 40 | 26 | 11,331 | 1.04 | 453.240 | 5 |
| No. 7 | 2.77 | 40 | 31 | 5,266 | 1.24 | 210.640 | 27 |

Sample calculation of inert dust consumption (kg) in an air roadway, where A is daily production, t.

$$Q_{sh} = q_{sh} A \quad (7)$$

The results of the relevant calculations for the Kuzbass mines are shown in Table 4.

$$P_t = \frac{C_1 - C_2}{\Delta x S t} q \quad (8)$$

where $\Delta x$ is the distance between measuring points, m; S is the average area of the mine working cross-section, m$^2$; $t$ is a measuring period, day; $q$ is an air volume passing through the mine working during measurement, m$^3$.

With a physically correct approach, the calculations according to formula (6) are unacceptable in many cases due to a high error rate for $C_1$ and $C_2$ (Pozdnyakov [18, 19]).

A more acceptable option to be used in practice is the determination of $P_t$, measurement of the weight of the dust depositing on the base. The total area of the bases (2 to 4 units) ($S_{base}$) is 0.1% to 0.01% of the dust deposition area in the mine working. Dust deposition intensity (g/m$^3$*day) seen on the bases during measurements applies to the part of the mine working 30 to 50m long as is shown in Table 4.

Table 4 Recommended daily consumption of inert dust in the Kuzbass mine development heading (estimated based on a production volume)

| Mine | $q_{sh}$, kg as per SR | $q_{sh}$, ton per 1,000 tps | Production, ton | | Recommended inert dust consumption, ton | | Rock dusting time (daily), min |
|---|---|---|---|---|---|---|---|
| | | | per day | per year | per day | per year | |
| Kirova | 1.98 | 0.0001 | 12,475 | 4,500,000 | 1.248 | 450 | 5 |
| Komsomolets | 1.93 | 0.0001 | 6,693 | 1,800,000 | 0.669 | 180 | 25 |
| Krasnoyarskaya | 2.30 | 0.0001 | 7,550 | 2,300,000 | 0.755 | 230 | 17 |
| 7th November | 2.65 | 0.0001 | 12,894 | 3,500,000 | 1.289 | 350 | 28 |
| Posylaevskaya | 2.15 | 0.0001 | 2,460 | 1,800,000 | 0.246 | 180 | 17 |
| Taldinskaya-Zapadnaya 1 | 2.92 | 0.0001 | 8,152 | 2,500,000 | 0.815 | 250 | 25 |
| Taldinskaya-Zapadnaya 2 | 3.15 | 0.0001 | 11,554 | 2,500,000 | 1.155 | 250 | 27 |
| Kotinskaya | 3.03 | 0.0001 | 19,530 | 5,000,000 | 1.953 | 500 | 8 |
| No. 7 | 2.77 | 0.0001 | 10,400 | 2,800,000 | 1.040 | 280 | 23 |

$$P_t = 4{,}34\frac{bM}{SS_{noд}t} \quad (9)$$

where $b$ is the width of the mine working across soil, m; $M$ is a dust weight on bases, g.

The calculations by formulas (8) or (9) are accepted for a 50-metre air roadway section adjoining the longwall. A 3.5-fold smaller value is taken for calculations for the next 150m (Fes'kov [20,21]).

The dust deposition intensity ($P_t$) is used to determine $T_W$, frequency of whitewashing, rock dusting, washing, and other operations aimed at securing dust explosion proofness. Globally, rock dusting with $T_W$ (day) calculated by the formula below is widely used:

$$T_{П} = \frac{K_{CH_4}\sigma_{lo}}{P_t} \quad (10)$$

where $K_{CH_4}$ is the factor that takes into account a methane content in the mine working for stipulated concentrations of 0.5%; 0.75%, and 1.0%, which equals 0.75; 0.60, and 0.50, respectively.

The formula above (9) does not include a protective action coefficient of 1 for rock dusting.

Earlier provided correlations stipulate an annual inert dust demand for each mine working:

$$Q_{sh} = 10^{-3}q_{sh}L\frac{365}{T_{П}} \quad (11)$$

where $L$ is a mine working length, m.

## 4. Conclusions

The full annual demand for inert dust at a mine is determined by adding up the quantity of dust required to process all mine workings subject to rock dusting and to load all stone-dust barriers in place subject to replacement frequency.

All of the above methods disregard the continuous relocation of a dusting source (cutting loader in the longwall or a development working) against immobile bases. This relocation of dust sources (6 to 20m/min for cutting loaders) results in changes in the size-consist of dust depositing on the immobile bases.

Determination of reliable dust deposition functions along the mine working is a challenging process. It requires planning of a representative sampling process.

Current dust explosion proofness standards and calculation methods at mines need to be improved. It is recommended to apply increased rock dusting standards at Russian mines to guarantee dust explosion proofness performance.

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# Prediction of wood and wood products behaviour under real fire conditions

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**Abstract**

Presented paper deals with the description of methods used in prediction of time to flashover and reaction to fire class of wood and wood products. Described methods have been applied to prediction of time to flashover and reaction to fire class of selected wood. All described methods predicted the time to flashover and reaction to fire class from data measured by the cone calorimeter according to testing procedure in accordance with ISO 5660-1:2015 at heat flux of 50 kW $m^{-2}$. Majority of described methods calculate the time to flashover also from the density of the sample in addition to data measured by the cone calorimeter. Samples of White Birch wood (Betula verrucosa Ehrh.) with dimensions of 100x100x20 mm were investigated. The samples were dried at temperature of 103 ± 2 °C to water content of 0 wt% prior to testing on the cone calorimeter. The density of investigated samples (at water content of 0 wt%) was 558.4 ± 12.2 kg $m^{-3}$. The calculated time to flashover of investigated birch wood lied in interval from 120 s to 600 s in most cases of used methods. The predicted reaction to fire class of investigated birch wood was C.

*Keywords*: Cone calorimeter, fire investigation, fire risk, flashover category, flashover prediction, reaction to fire prediction, time to flashover, White Birch wood;

## 1. Introduction

The behavior of materials under fire conditions is reflected by the fire characteristics. According to the phase of the fire, in which is the behavior of the material assessed, are the fire characteristics divided into flammability characteristics describing the initiation of fire, fire development, fully developed fire and the whole course of fire.

The tendency of the material to ignition is expressed by flash ignition temperature, spontaneous ignition temperature and critical heat flux. Characteristics describing the development of fire are divided to flame spread rate and time to flashover. Rate of flame spread is characterized by the development (spread) of local fire, while the time to flashover expresses the tendency of the material to develop from a local to fully developed fire. Fully developed fire is mainly characterized by heat release. Among characteristics important for the entire duration of the fire are primarily heat release rate, total heat release and toxicity and the optical density of the combustion products. Fire resistance is important feature for building constructions with support or fire barrier function. The fire resistance is usually designed for fully developed fire conditions, but some materials (e.g. steel) are susceptible to destruction not only at maximum temperatures of fire (achieved at the stage of a fully developed fire), but also at rapid cooling. Therefore, the fire resistance is the fire characteristic, which reflects the behavior of the material (structures) throughout the whole fire development phase.

Most of the mentioned fire characteristics are known for most of the tree species today. The least exanimated and clarified fire characteristic of wood and wood products is time to flashover. According to Osvald et al. [1] the only test method evaluating the tendency of the material or product to promote fire in

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flashover phase is test according to ISO 9705 [2]. Test according to cited technical standards is costly and time-consuming. Therefore, several methods of time to flashover prediction from data obtained both financially and less time-consuming test method on cone calorimeter according to ISO 5660-1 [3] have been developed.

Among the above mentioned, most widely used and by professional community most widely accepted methods include methods by Ostman and Tsantaridis [4], Kokkala et al. [5], Hansen and Hovde [6] and Xu et al. [7]. Time to flashover of construction products can also be estimated from the reaction to fire class and data in Annex A to EN 13501 + A1 [8].

The aim of presented paper is to describe the methods used to predict the time to flashover and reaction to fire class and subsequent prediction of time to flashover and reaction to fire class of White Birch wood (Betula verrucosa Ehrh.).

## 2. Theory and calculation

The simplest method to predict the time to flashover is the method by Ostman and Tsantaridis [4]. This method calculates time to flashover using equation (1). The method according to Ostman and Tsantaridis [4] was developed for wood and wood products.

$$t_{\mathrm{FO}} = 0.07 \cdot \frac{t_{\mathrm{i}} \cdot \rho^{1.7}}{\mathrm{THR}_{300}^{1.3}} + 60 \quad (1)$$

Where: $t_{FO}$: time to flashover (s); $t_i$: time to ignition (s); ρ: sample density (kg.m$^{-3}$),; $THR_{300}$: total heat released in time interval from $t_i$ to 300 s after $t_i$ (MJ)

The method of Kokkala et al. [5] is the most abundant and most widely accepted in the scientific community. Before calculating the flashover category by this method, it is necessary to calculate the ignition index using equation (2) and the heat release rate index using equation (3). Flashover category is then calculated by inequalities (4-7). The material or product during test in accordance with ISO 9705 [2] reaches the stage of flashover in 120 s (if inequality 4 is true), between 120 to 600 s (if inequality 5 is true), between 600 to 1200 s (if inequality 6 is true) or does not reach the flashover at all (if inequality 7 is true). The time of ignition based on the visual observation is not used as ignition time ti in equations (2 and 3), but instead the time at which the heat release rate reaches value of 50 kW.m$^{-2}$ is used.

$$I_{\mathrm{IG}} = \frac{1}{t_{\mathrm{i}}} \quad (2)$$

Where: $I_{IG}$: ignition index (min$^{-1}$); $t_i$: time to ignition (min)

$$I_{\mathrm{Q}} = \int_{t_{\mathrm{i}}}^{t_{\mathrm{end}}} \left[ \frac{\mathrm{HRR}(t)}{(t - t_{\mathrm{i}})^{\mathrm{m}}} \right] \mathrm{d}t \quad (3)$$

where: $I_Q$: heat release rate index (-); HRR(t): heat release rate in time t (kW.m$^{-2}$); t: time (s); m: empiric constant (two values are considered during calculation 0.34 and 0.93) (-)

$$I_{Q(m=0.34)} > 6800 - 540 \cdot I_{IG} \wedge I_{Q(m=0.93)} > 2475 - 165 \cdot I_{IG} \quad (4)$$

$$I_{\mathrm{Q(m=0.34)}} > 6800 - 540 \cdot I_{\mathrm{IG}} \wedge I_{\mathrm{Q(m=0.93)}} \leq 2475 - 165 \cdot I_{\mathrm{IG}} \quad (5)$$

$$I_{\mathrm{Q(m=0.34)}} \leq 6800 - 540 \cdot I_{\mathrm{IG}} \wedge I_{\mathrm{Q(m=0.93)}} > 1650 - 165 \cdot I_{\mathrm{IG}} \quad (6)$$

$$I_{\mathrm{Q(m=0.34)}} \leq 6800 - 540 \cdot I_{\mathrm{IG}} \wedge I_{\mathrm{Q(m=0.93)}} \leq 1650 - 165 \cdot I_{\mathrm{IG}} \quad (7)$$

Another method of prediction of flashover category was described in scientific paper by Hansen and Hovde [6]. The cited method is based on the fact that the flashover category is determined particularly by the density of material, total heat released during the first 300 s of the test and by maximum value of the ratio of heat release rate to time when the respective value of the heat release rate was measured in the process of classification of materials and products. The material or product is classified into four flashover categories according this cited paper based on the equations (8-11), wherein the material is classified into category which equation has maximum value.

$$F_{\mathrm{FO1}} = 0.01789 \cdot \rho - 0.06057 \cdot \mathrm{THR}_{300} + 0.971 \cdot \ln\left(\frac{\mathrm{peak(HRR)}}{t_{\mathrm{peak}}}\right) - 7.910$$

(8)

$$F_{\mathrm{FO2}} = 0.01492 \cdot \rho + 0.03354 \cdot \mathrm{THR}_{300} + 1.877 \cdot \ln\left(\frac{\mathrm{peak(HRR)}}{t_{\mathrm{peak}}}\right) - 7.418$$

(9)

$$F_{\mathrm{FO3}} = 0.008589 \cdot \rho + 0.409 \cdot \mathrm{THR}_{300} + 2.721 \cdot \ln\left(\frac{\mathrm{peak(HRR)}}{t_{\mathrm{peak}}}\right) - 13.406$$

(10)

$$F_{FO4} = 0.0000256 \cdot \rho + 0.347 \cdot THR_{300} + 3.621 \cdot \ln\left(\frac{peak(HRR)}{t_{peak}}\right) - 9.215$$
(11)

Where: $F_{FO1}$, $F_{FO2}$, $F_{FO3}$, $F_{FO4}$: flashover category, $F_{FO1}$: (flashover phase does not occur during the whole test), $F_{FO2}$: (time to flashover is between 600 - 1200 s), $F_{FO3}$: (time to flashover is between 120 - 600 s), $F_{FO4}$: (flashover does not occur until 120 s from the beginning of the test); peak(HRR)/$t_{peak}$: maximum value of the ratio of the heat release rate to time when the respective value of the heat release rate was measured (kW m$^{-2}$.s$^{-1}$)

The latest, highly sophisticated method of calculating flashover category was described in scientific paper by Xu et al. [7]. Cited collective of authors, by comparing the Pearson, Spearman and Kendall correlation coefficient for HRR-CO, HRR-$CO_2$ and CO-$CO_2$, for a variety of materials, loaded by heat flux of 25, 35 and 50 kW.m$^{-2}$ during the tests on cone calorimeter proved, that Pearson correlation coefficient for HRR-CO (for material irradiated by heat flux of 50 kW.m$^{-2}$) may be used for classification of materials in to four flashover categories:

- FO1: <Pearson correlation coefficient for HRR-CO 0 to 0.3),
- FO2: <Pearson correlation coefficient for HRR-CO 0.3 to 0.5),
- FO3: <Pearson correlation coefficient for HRR-CO 0.5 to 0.7),
- FO4: <Pearson correlation coefficient for HRR-CO 0.7 to 1>.

In addition to the described methods, the flashover category of wood and wood products can be predicted on the bases of reaction to fire class and from the data in the annex of EN 13501-1 + A1 [8]. This cited technical standard show, that products in reaction to fire class E reach flashover in 120 s, in reaction to fire class D reach flashover in between 120-600 s, products with reaction to fire class C reach flashover in between 600-1200 s and products in reaction to fire class B, probably tested in accordance with ISO 9705 [2] will not achieve flashover. Products in reaction to fire class A1 and A2 will not achieve the flashover phase.

Reaction to fire class of wood and wood products can be, according to Hansen and Kristoffersen [9] predicted from test results on a cone calorimeter (samples loaded by heat flux of 50 kW.m$^{-2}$) based on the equations (12 to 14). The product is classified to reaction to fire class, which equation (12-14) has a maximum value. The method according to Hansen and Kristoffersen [9] was developed specifically for wood and wood products.

$$F_B = -0.503 \cdot THR + 0.10 \cdot \rho + 2.04 \cdot ML - 86.177 \quad (12)$$
$$F_C = -0.313 \cdot THR + 0.071 \cdot \rho + 1.767 \cdot ML - 66.596 \quad (13)$$
$$F_D = -0.648 \cdot THR + 0.098 \cdot \rho + 2.268 \cdot ML - 105.250 \quad (14)$$

Where: $F_B$, $F_C$, $F_D$: reaction to fire class (FB: reaction to fire class; B, $F_C$: reaction to fire class C, FD: reaction to fire class D) (-); ML: total sample mass loss (%).

### 3. Material and method

Samples of White Birch wood (Betula verrucosa Ehrh.) with dimensions of 100x100x20mm were examined. Surface of samples was scraped. The samples were dried prior to testing to the water content of 0 wt%, at a temperature of 103 ± 2 ° C. Before testing, the samples (after drying) were conditioned in a desiccator at 20 ± 1 ° C, for 24 hours. The density of the samples (at a water content of 0 wt%) was 558.4 ± 12.2 kg.m$^{-3}$. Orientation of the samples during the test was horizontal.

The samples were examined by cone calorimeter. Cone calorimeter and the test procedure were in accordance with the requirements of ISO 5660-1 [3]. During the test, the samples were loaded by heat flux of 50 kW.m$^{-2}$.

Time to flashover was predicted from data obtained by tests on cone calorimeter according to methods of Ostman and Tsantaridis [4] Kokkala et al. [5], Hansen and Hovde [6] and Xu et al. [7]. Reaction to fire class was predicted by the method according to Hansen and Kristoffersen [9]. Time to flashover was predicted from reaction to fire class based on data in annex A to EN 13501 + A1 [8].

### 4. Results and discussion

Values needed to calculate the time to flashover according to method of Ostman and Tsantaridis [4] and Kokkala et al. [5], together with the resulting values of time to flashover are listed in Tables 1 and 2.

Table 1 Time to flashover of White Birch wood according to Ostman and Tsantaridis [4] and input values for the calculation

| $t_i$ (s) | $\rho$ (kg m$^{-3}$) | THR$_{300}$ (MJ m$^{-2}$) | Time to flashover (s) |
|---|---|---|---|
| 23 | 558.4 | 42.77 | 630 |

Table 2 Time to flashover of White Birch wood according to Kokkala et al. [5] and input values for the calculation

| $I_{IG}$ (min$^{-1}$) | $I_{Q(m=0.34)}$ (-) | $I_{Q(m=0.93)}$ (-) | Time to flashover (s) |
|---|---|---|---|
| 2.61 | 24269 | 1628 | 120 to 600 |

Input values for time to flashover calculation (except for input values listed in Table 1), together with final value of time to flashover determined by the method according to Hansen and Hovde [6] are listed in Table 3.

Table 3 Time to flashover of White Birch wood according to Hansen and Hovde [6] and input values for the calculation

| peak(HRR)/$t_{peak}$ (kW m$^{-2}$ s$^{-1}$) | Time to flashover (s) |
|---|---|
| 7.4 | 120 to 600 |

The absolute value of the Pearson correlation coefficient of HRR-CO of birch wood was 0.602. According to Xu et al. [7] materials and products with a Pearson correlation coefficient in the range from 0.5 to 0.7 have time to flashover in the range of 120-600 s.

Mass loss of birch wood for the entire duration of the test on a cone calorimeter was 89.46%. From these figures, together with data on density and total heat released (Tab. 1) was according the equations (12-14) the reaction to fire class determined to C. According to annex A to EN 13501 + A1 [8], construction products with reaction to fire class C have time to flashover in the range of 600-1200 s.

The method of the Kokkala et al. [5] is considered to be the most reliable and is most widely accepted by the scientific community. The same values for birch wood, as according to the Kokkala et al. [5] method were obtained by the method of Hansen and Hovde [6] and by Xu et al. [7]. The method of Xu et al. [7] was developed from data obtained for synthetic polymers and its reliability for predicting time to flashover of natural polymers has not yet been confirmed

The method according to Ostman and Tsantaridis [4] was developed specifically for wood and wood products. Therefore, the results obtained by this method can be the considered as the most reliable. The same results as the results obtained by the method according to Ostman and Tsantaridis [4] were obtained from the prediction of time to flashover based on the reaction to fire class.

The time to flashover and reaction to fire class significantly depend on the specific characteristics of wood, primarily on density, surface treatment, moisture content and protection by flame-retardant. Influence of fire retardants on the fire performance of wood and wood products is described in detail in the scientific work of Osvaldová and Osvald [10]. Flammability characteristics of wood and wood products also significantly depend on the form of wood (compact or dust). This issue is described in detail in the scientific work Kadlic et al. [11]. For this reason, the values may not be generalized to birch wood with a significantly different density, thickness, surface finish or birch wood that was physically (e.g. thermal) or chemically (e.g. flame retardants) treated, but the described methods may be used to predict the time it flashover and reaction to fire class of practically all wood and wood products.

## 5. Conclusions

The aim of the present paper was to describe the methods used to predict the time to flashover and reaction to fire class of wood and wood products and their subsequent application to predict the time the flashover and reaction to fire class of birch wood.

The obtained data also indicate that the method according to Kokkala et al. [5], Hansen and Hovde [6] and Xu et al. [7] show the same values for time to flashover (120-600 s). Different values for time to flashover were calculated by the method according to Ostman and Tsantaridis [4] (630 s) and from the reaction to fire class, which was predicted by the method according to Hansen and Kristoffersen [9] (600-1200 s). Examined birch wood was categorized to reaction to fire class C.

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# Impact of the limited oxygen availability on the localized fire development in a large-area building compartment

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**Abstract**

The numerical modeling results of a localized fire are presented in this paper. Such a fire may develop in a fire compartment having large area and relatively low height. It was assumed, that neither smoke vents nor any other measures to facilitate the smoke extraction were installed in the considered fire zone. Under such circumstances the efficient ventilation is rather impossible, especially in the areas distant from the permanently open doors and windows. This limits the availability of oxygen, affecting the fire intensity. The modeling was performed using the FDS computer program. The development of potential fire with three different fire origin locations was considered. The considered locations differed in the distance to the existing ventilation openings and to the external walls de-limiting the fire compartment. The obtained results, and especially the distributions of maximum temperature in the smoke plume specified in the selected cross sections of the analysed zone were compared with the temperature distributions estimated based on the analytical models recommended in the professional literature. The comparison is complemented by the thermal maps illustrating the specifics of the forecast fire development in the boundary zone near the walls.

*Keywords*: localized fire, fire modelling, ventilation conditions, oxygen availability, fire suppression, exhaust gas temperature;

## 1. Introduction

When the fire resistance of building object's bearing structure is estimated in the engineering practice, it is usually assumed, that the model of a fully developed fire with the uniform exhaust gas temperature in the whole volume of the fire compartment is authoritative. This is true only in the case of relatively small zones, limited in size, in which the potential fire development would be driven by the potential fuel supply and not by the effective ventilation. Fire compartments of this type usually have sufficient number of relatively large window and door openings to ensure the unlimited availability of fire sustaining oxygen in even the farthest areas of the compartment. In such zones fires develop without constraints, until burnout of all available flammable materials. However, in the contemporary building practice one may have to deal with structures having fire compartments of completely different character. These are large area fire compartments, relatively low and poorly ventilated. The fire initiated in such compartments would not reach the flashover point, and with high probability would remain at the stage of localized fire, with limited intensity and affected zone. The salesroom of a typical mall may be considered an example of such compartment. The observation indicates, that usually the hall of this type is devoid of windows, and access is possible only through the limited number of gates and small size doors. Of course, the fire compartments of this type should be equipped with smoke vents, sprinkler installations, smoke curtains and many additional active fire protection systems as provided by law. Unfortunately, the provisions of law are not always fully enforced, especially in the case of old buildings, only provisionally adapted to the current usage. The expert evaluating the fire resistance of the bearing structure located in the fire compartment of this type is thus authorized to assume that the localized fire scenario, with limited heat output and fire affected zone

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would be authoritative in the analysis. The consideration of highly improbable under such circumstances fully developed fire would result in the recommendation of relatively expensive fire protection resources, not justified from the point of view of safety guaranteed to the users. In the contemporary professional literature one may find many, more or less complex, formal models describing the development, intensity and reach of localized fires. Here we intend to turn the reader`s attention to the fact, that these models do not take into account the potential fire development limiting factor, when the availability of fire sustaining oxygen is limited by the distance and size of window and door openings. Such models also do not take into account the precise location of the fire origin, i.e. whether it is located more or less in the centre of the fire compartment or in the boundary zone adjacent to the wall. The consideration of such characteristic cases, undoubtedly important from the practical point of view, constitutes the objective of this paper.

## 2. Description of the analysed model

A large area shopping hall depicted in Fig. 1 and 2 constitutes the fire zone considered in this paper. The hall is characterized by the following parameters: horizontal dimensions of 135.00m x 60.00m and a constant height of 6.50m. In order to simplify the model, it is assumed that the smoke vents are not installed. However, existing constantly open entrance gates: one large having the dimensions of 10.00m x 4.50m, and three smaller having the dimensions of 2.50m x 2.50m each are included in the analysis. The locations of these gates are indicated in the Fig. 1 and 2. The sheathing of the hall is modelled as made of the typical sandwich panels having the thickness of 15 cm with mineral wool filling. The properties of the insulating material, dependent on the external temperature, are assumed according to Wang et al. [1]. The bearing structure of the hall is made of carbon steel, for which the relationships between the material temperature and the specific heat and heat conductivity are assumed according to the recommendations of the code EN 1993-1-2 [2]. It is also assumed that before the initiation of the fire the temperature within the hall was constant and equal to 20°C. At first three alternative locations of fire source, denoted by symbols F1, F2 and F3 in the Fig. 1, respectively, are considered. These sources differ in the location with respect to the hall centre, and thus the distance between the flame axis and the external walls in both the longitudinal and the transverse directions relative to the main symmetry axis of the hall. For each of these three locations, according to the recommendations contained in Fan Shen- Gang et al. [3], it was assumed that the maximum rate of heat release is equal to Qmax = 25MW. This in turn, after assuming the heat release rate at the level of RHRf = 500 kW/m$^2$ [2] led to the computational fire area equal to:

$$A_{fire} = \frac{Q_{\max}}{RHR_f} = \frac{25MW}{500\,kW/m^2} = 50m^2 \qquad (1)$$

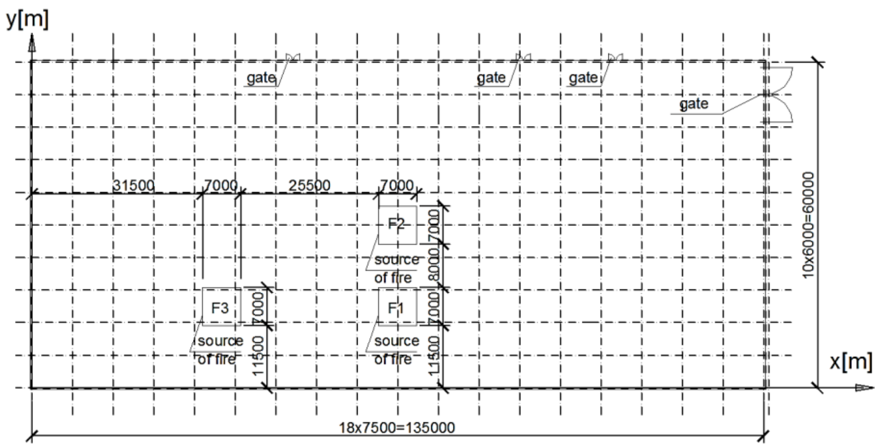


Figure 1 Horizontal dimensions of the hall considered here including the analyzed locations of fire source denoted by symbols F1, F2 and F3

Let us note, that this assumption is more restrictive with respect to the recommendations of the code EN 1991-1-2 [4], according to which the value of $RHR_f$ = 500 kW/$m^2$ is recommended for the public services buildings, such as libraries, cinemas and theaters, while a halved value of $RHR_f$ = 250 kW/m2 is recommended for use in the case of shopping malls. This halved value would result at the same heat release in the area $A_{fire}$ = 100 $m^2$. The Fire Dynamics Simulator (FDS) code (McGrattan et al. [5]) is used to analyse the fire development in each of the locations listed above. In each case the circle circumscribing the fire source, and having the area of $A_{fire}$ = 50 $m^2$ is replaced by a square of the same area. The chemical composition of the burning material is modelled in a simplified manner, with the values of functions describing the generation of carbon monoxide and soot equal to: CO_YIELD=0.063 and SOOT_YIELD=0.163, respectively. The fire growth phase is described by the so called t-square function [4], identifying the relationship between the energy dissipated during the fire and duration of that fire. Thus the following formula is applied for the energy dissipated:

$$Q(t) = \begin{vmatrix} 10^6 (t/t_\alpha)^2 & \text{dla} \quad t < t_p \\ Q_{\max} & \text{dla} \quad t \geq t_p \end{vmatrix} \tag{2}$$

The time $t_p\,[\mathrm{s}]$ denotes the end of fire growth phase, while the parameter $t_\alpha\,[\mathrm{s}]$ denotes the time corresponding to the energy dissipation at the 1 MW level. It follows directly from the Eq. (2) above, that after the limit time $t_p$ has passed, the heat dissipation rate does not increase any more. The assumed $Q_{\max}$ = 25MW and $RHR_f$ = 500 kW/$m^2$ accompanied by the limit time value $t_\alpha = 150\,[\mathrm{s}]$ associated with the heat release per square meter [4] unequivocally determine the value of $t_p = 750\mathrm{s} = 12.5\,\mathrm{min}$. The considered hall, as analyzed by FDS, is schematically depicted in the Fig. 2.

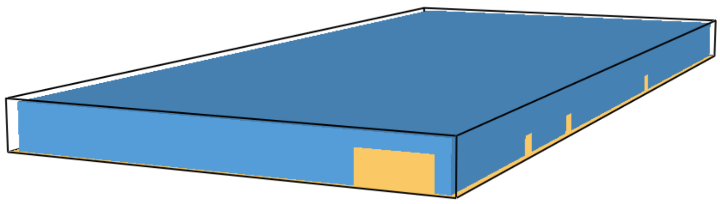

Figure 2 Model of the considered hall as applied in the FDS code

Virtual temperature sensors were located in the hall for each of the considered fire source locations. Application of these sensors allow for the creation of thermal maps along the longitudinal direction parallel to the main axis of symmetry of the hall, as well as along the transverse direction perpendicular to this axis. The sensor distribution line axes in each case intersect at the location of the fire source.

## 3. Distributions of fire plume temperature values in the transverse cross sections of the analysed hall

The distributions of fire plume temperature values along the selected cross sections of the hall analysed in this example after one hour of fire exposure, and arrived at after detailed analysis, are shown in the Fig. 3. Let us note, that the location of these cross sections is coincident in the case of scenarios F1 and F2, while the cross section corresponding to the fire scenario F3 is offset by the distance of 32.50 m towards the depth of the hall with respect to the preceding ones. Assuming the origin of the coordinate system at the bottom left hand corner of the hall floor depicted in the Fig. 1, and treating the longitudinal coordinate of the considered cross section as the indicator, these cross section will be denoted in the following considerations as:.

$$F1_{\perp}(67.50) \quad F2_{\perp}(67.50) \quad F3_{\perp}(35.00)$$

Comparison of the figures presented above leads to the conclusion that the maximum values of fire plume temperature determined directly above the fire source in the case of locations F1 and F2 are very similar, while the temperature obtained for the fire source location F3 is significantly lower.

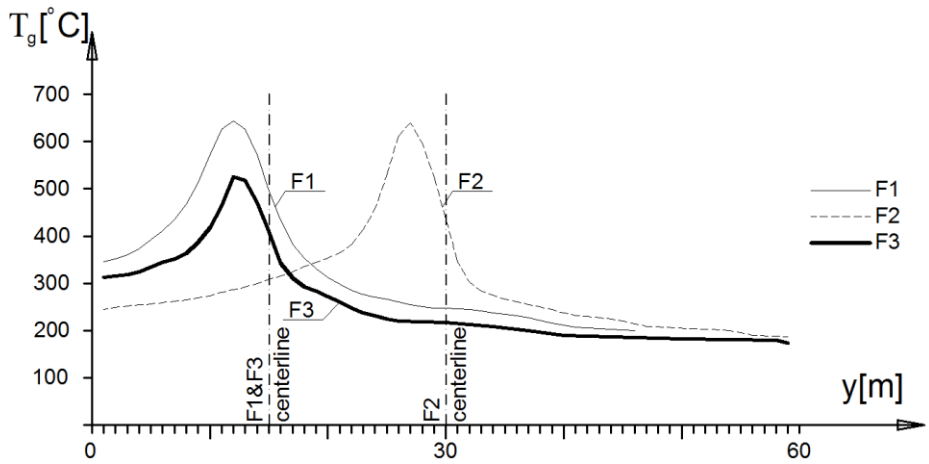


Figure 3 Distributions of the fire plume temperature values obtained for various locations of the fire source in the cross sections of the considered hall after one hour of fire exposure

The source of this difference will be explained later in detail. The differences in the shape of fire plume thermal distribution are clearly visible in the Fig. 3 as well. These differences are mainly due to the fact, that in the case denoted as F2 the fire centreline coincides with the hall centre (coordinate of this axis is equal to 30.00 m), while for the locations F1 and F3 these axes are offset with respect to the longitudinal axis of the hall by 15.00 m in the direction towards the external wall (fire axis coordinates are equal to 15.00 m in both cases). As a result of this offset, the temperature values reached near the external wall for the location F2 are substantially lower than in the case of the two remaining scenarios. This is quite obvious, as a result of a larger distance between the wall and fire source. Let us note as well the lack of symmetry in the thermal distributions with respect to the fire centrelines. The extreme values of fire plume temperature values are clearly offset with respect to these lines, towards the external wall. This offset is induced by the lack of symmetry in the distribution of external gates, forming the vertical ventilation openings.

## 4. Distributions of fire plume temperature values in the longitudinal cross sections of the analysed hall

The analogous distributions of fire plume temperature values obtained after one hour of fire exposure along the selected longitudinal cross sections of the hall, parallel to the main axis of the building, are depicted in Fig. 4. This time, the longitudinal cross section corresponding to the fire location F2 and coincident with the main axis of symmetry of the whole structure, and mutually identical cross sections corresponding to the locations F1 and F3, offset with respect to the preceding one by a distance of 15.00 m towards the external wall of the hall, stand out. Treating the coordinate in the global coordinate system as the indicator of the cross sections selected above, the denotations of:

$F1_{II}(15.00)$ , $F2_{II}(30.00)$ and $F3_{II}(15.00)$ , will be assigned to these cross sections in further deliberations, respectively.

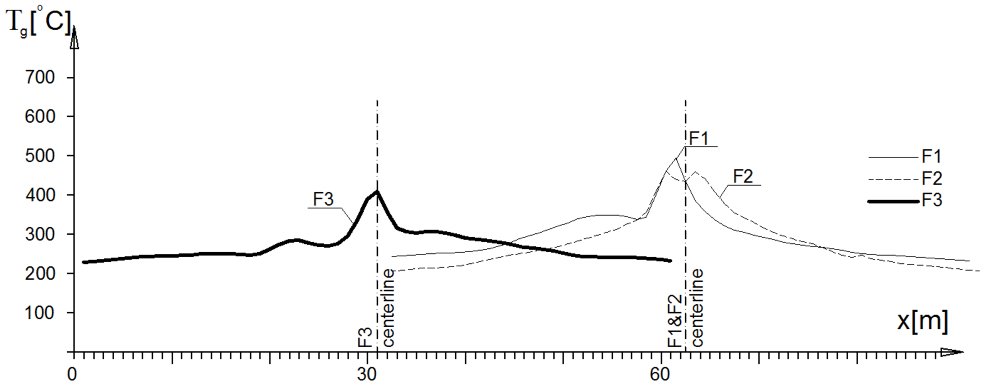


Figure 4 Distributions of fire plume temperature values obtained for various locations of fire source in the longitudinal cross sections of the hall after one hour of fire exposure.

Significantly lower temperature of the fire plume for the fire source location F3 with respect to the remaining two locations is clearly visible here. This is similar to the phenomenon observed previously for the fire plume thermal distributions in the transversal direction. The influence of the distance to the external wall is visible as well, resulting in the significantly higher fire plume temperature for the fire source located at F3 close to this wall . The fire plume thermal distributions lack symmetry with respect to the corresponding fire centrelines as well, though this lack of symmetry is substantially less pronounced than in the case of transversal cross sections. In general it is clearly visible only in the case of the fire source location F1. In this case the maximum value of fire plume temperature is offset with respect to the fire centreline towards the inside of the building.

**5. Specifics of fire development with the fire source location at the external wall of the hall**

While showing the differences in development of fire for the fire source located far away from the external wall (in our analysis this corresponds to the fire location F2) and the one, for which the fire source was located close to this wall (if transversal cross sections of the hall are considered, both F1 and F2 fire source locations conform to this) one has to analyse the thermal plots developed for each of the compared fires. In the Fig. 5 the plot of this type obtained after one hour of simulated fire exposure for the fire source located at F2 is shown in the middle. Of course this plot corresponds to the cross section $F2_{\perp}(67.50)$ .

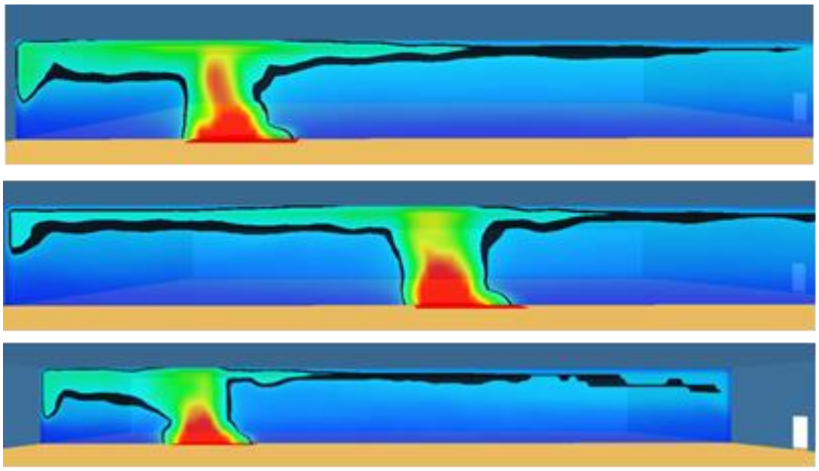

Figure 5 Thermal plans obtained after one hour of fire exposure in the considered cross sections of the hall: on the top – for the fire source located at F1, in the middle – for the fire source located at F2, on the bottom – for the fire source located at F3. The contour line in black corresponds to the fire plume temperature equal to 200°C

The black contour line denotes here the fire plume temperature of approximately 200□C. Above this contour line the fire plume temperature is higher, and below lower than this boundary value. In the following deliberations, by convention, this contour line will be treated as the line separating the zone occupied by hot gases developing directly below the ceiling of the hall and the zone of air unaffected by the fire near the floor. One may easily observe, that the zone occupied by the hot gases is relatively thin, and more importantly, distributed quite evenly along the whole width of the hall. A comparison of this plot with a plot prepared for the fire location at F1 and related to the cross section shows an important difference. This second plot is shown in the Fig. 5 on the top. If the fire source is located at F1, the fire plume is clearly unsymmetrical with respect to the fire centreline. The plume is obviously thicker at the boundary area next to the wall, and quite thin on the

other side of the fire centreline, where obstructions to the hot gas redistribution are absent. This distribution of temperature in fire plume undoubtedly results in the quicker filling by the hot gases of the whole available hall volume in the boundary area and at the same time slower heating of the remaining part of the building. However, in this analysis we did not observe any pronounced difference in the maximum temperature of fire plume at the fire centreline, if the fire source locations F1 and F2 are considered. Let us note as well, that on both plots the fire is deflected towards the inside of the hall. This confirms the earlier observations of the fire plume temperature spatial distributions lacking the symmetry with respect to the fire centrelines.

## 6. An issue of fire damping for fire located at F3

Let us compare the plots described above with a plot specified for the fire origin located at F3, and the cross section corresponding to this location. This plot is depicted in the Fig. 5 on the bottom. Here the zone of hot fire plume directly below the ceiling at the right hand side of the fire centreline is hardly visible, and the height and temperature of the flame are substantially lower than in the other scenarios. The fire initiated in this location is damped by the limited availability of oxygen sustaining the combustion. In order to prove this the temporal evolution of maximum fire plume temperature at the fire centreline, measured 5.00 m above the floor, is depicted in the Fig. 6 for all three considered fire scenarios. The temporal evolution of these changes for the location F3 differs significantly from the evolutions specific to fires originating at F1 and F2. During the first phase of the fire the temperature values determined for each considered fire origin increase in a similar manner and reach comparable values. After reaching the peak value, for each considered scenario the fire plume temperature decreases. This is a direct result of restricted gas exchange with the surrounding area. The intensity of fire damping for the location F3 is substantially higher than for the remaining two fire locations. In a notable difference, the fire in this location develops in a kind of oscillatory manner, passing through subsequent damping and revival phases.

Let us note that the location F3 is selected deep in the inside of the hall, close to the corner and far away from the gates, functioning as the ventilation openings. Near vicinity of the external walls on three sides and a relatively low height of the hall constrain the air circulation substantially. Thus the fire developing in such location will undoubtedly be a so called fire controlled by the ventilation. Interestingly, after one hour of fire exposure, the temperature of fire plume reached similar values in all the considered fire scenarios.

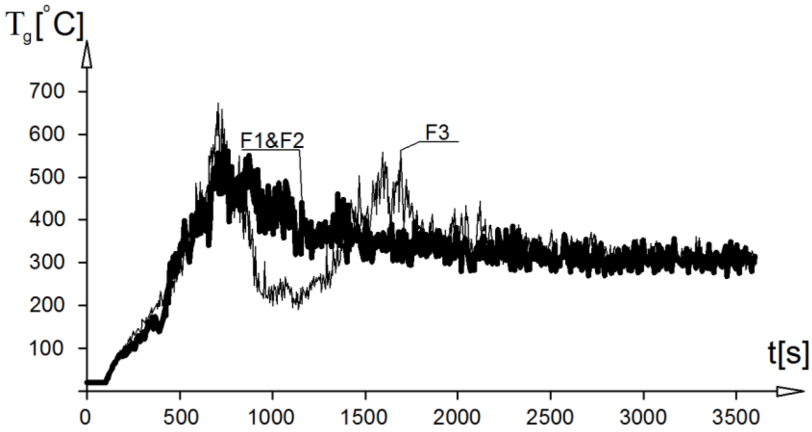


Figure 6 Temporal evolution of fire plume temperature during the fire, measured at fire centreline for various locations of fire source (F1, F2 and F3, respectively)

## 7. Comparison of the results with the results obtained by application of the classical analytical models

The results of the numerical simulations presented above are related below to the results obtained under the same initial assumptions by the analytical models available in the literature. The following analytical models were selected by the authors for the purpose of this comparison:

*Model A1* – presented in *Fan Shen-Gang et al.* [2] - the relationships allowing for the determination of the flame height $L_f$ [m] and flame temperature $T_m(z)$ [°C] at the height of z [m] above the floor are as follows:

$$L_f = 0.235 Q_{\max}^{0.4} - 1.02D \quad (3)$$

$$T_m(z) = T_a + 119.5 Q_{\max}^{2/3} (z + z_0)^{-5/3} \quad (4)$$

where $D$ [m] is the fire diameter, $T_a$ [°C] - ambient temperature at the fire initiation, while $z_0$ [m] denotes location of the virtual fire centreline, such that:

$$z_0 = 0{,}25 Q_{\max}^{0.4} \quad (5)$$

In this model the temperature of fire plume $T_g(z,r)$ [°C] at the height of $z$ [m] above the floor level and at the horizontal distance of $r$ [m] from the fire source is determined according to the formula (6):

$$T_g(z,r) = T_a + 119.15 f(z,r) Q_c^{2/3} (0.86H + z_0)^{-5/3} \quad (6)$$

where:

$$f(z,r)=\begin{cases}\exp[\frac{-(r-0.5D)^{1.6}}{(0.5D)^{1.6}}-\frac{0,693z_0^2}{(z+z_0)^2}] & \text{for} \quad r>0.5D\\ \exp[-\frac{0.693z_0^2}{(z+z_0)^2}] & \text{for} \quad r\le 0.5D\end{cases}$$

(7)

The variable $H\,[\mathrm{m}]$ denotes the height of analysed fire compartment, while $Q_c\,[\mathrm{kW}]$ - the convectional part of the heat release rate, assumed as equal to $Q_c=0.8Q_{\max}$ in simplification.

*Model A2* – presented in *Fan Shen-Gang et al.* [2] as well – constitutes a development of the model A1. It is supplemented by correction coefficients $\gamma_s$, $\gamma_t$ and $\gamma_a$ which are to cover the influence of fire zone area $A_{tot}\,[\mathrm{m}^2]$ and the duration of fire $t\,[\mathrm{s}]$, such as:

$$\gamma_s=1+Q_c^{0.2}\exp(-0.1A_{tot}^{0.5}/H^{0.3}) \tag{8}$$

$$\gamma_t=1-0.8\exp(-\mu t)-0.2\exp(-0.1\mu t) \tag{9}$$

$$\gamma_a=1-\exp(-0.0012t\sqrt{H/A_{tot}}) \tag{10}$$

The factor $\mu$ is a parameter depending on fire intensity and fire compartment area. When the parameters indicated above are introduced into the formulas (4) and (5) respectively, the final form of these formulas applied to determine the temperature of fire plume in the area adjacent to the ceiling is as follows:

$$T_g(z,r,t)=T_{jet}=$$
$$=T_a+119.15\gamma_s\gamma_t[\gamma_a+(1-\gamma_a)g(z,r)]Q_c^{2/3}(0.86H+0.25Q_c^{2/5})^{-5/3} \tag{11}$$

$$g(z,r)=\begin{cases}\exp[-(r-0.5D)^{1.6}/(0.5D)^{1.6}-\frac{0.693z_0^2}{(z+z_0)^2}] & \text{for} \quad r>0.5D\\ \exp[-0.693(r/(z+z_0))^2] & \text{for} \quad r\le 0.5D\end{cases} \tag{12}$$

*Model B* – presented in detail in *Zhang Guo-Wei et al.* [6] – is the so called *Alpert* model (*Alpert* [7]), where the flame height is determined according to the formula:

$$L_f=-1{,}02D+0.083Q_{\max}^{0.4} \tag{13}$$

and the distribution of temperature $T_{jet}\,[^{\circ}\mathrm{C}]$ in the fire plume zone adjacent to the ceiling is determined according to the following:

$$T_{jet}=\begin{cases}16.9\frac{Q_{\max}^{2/3}}{H^{5/3}} & \text{for} \quad r/H\le 0.18\\ 5.38\frac{Q_{\max}^{2/3}}{(r/H)^{2/3}H^{5/3}} & \text{for} \quad r/H>0.18\end{cases}$$

(14) (14)

The same denotations as in the model A1 hold here.

*Model C* – presented in *Li Guo-Qiang et al.* [8] – the temperature of the combustion gases $T(x,z,t)\,[^{\circ}\mathrm{C}]$, determined at the spatial location having the horizontal coordinate of $x$ and vertical coordinate of $z$, and determined after the time $t$ of fire exposure, is calculated according to the following formula:

$$T(x,r,t)=T_a+T_m(1-0.8e^{-\beta t}-0.2e^{-0.1\beta t})[\eta+(1-\eta)e^{-\frac{x-0.5D}{\mu}}] \tag{15}$$

where the value $T_m\,[^{\circ}\mathrm{C}]$ is a tabulated value of temperature at the fire centreline, and coefficients $\beta$, $\eta$ and $\mu$ are empirically determined.

*Model D* – presented in *Yu Zhi-Chao et al.* [9] – is a development of the well-known model describing the so called BFD fire (*Barnett* [10]). The distribution of fire plume temperature values $T_g(t)\,[^{\circ}\mathrm{C}]$ determined after the fire exposure time $t$ is prescribed here by the following formulae:

$$T_g(t)=\begin{cases}T_a+T_me^{-(\ln t-\ln t_d)/\omega_1} & \text{for} \quad t\le t_d\\ T_a+T_me^{-(\ln t-\ln t_d)/\omega_2} & \text{for} \quad t>t_d\end{cases} \tag{16}$$

where the time $t_d\,[\mathrm{s}]$ corresponds to the initial cooling phase of the fire associated with the burn out of 80% of the potential fuel gathered in the analysed fire compartment, and the parameters $\omega_1$ and $\omega_2$ are shape coefficients. The maximum value of the temperature $T_g$ is determined by the following formula:

$$T_g^{\max}=(\frac{Q_{\max}}{50}+80)-(\frac{4Q_{\max}}{10000}+3)H+\frac{100\cdot(52Q_{\max}/1000+598)}{A_{tot}} \tag{17}$$

while the temperature $T_{jet}$ directly below the ceiling is determined as:

$$T_{jet} = T_g^{\max} k_{zm} \quad (18)$$

where $k_{zm}$ is the so called localization coefficient, determined according to:

$$k_{zm} = \begin{vmatrix} \eta + (1-\eta)e^{(D/2-x)/7} & \text{for} \quad x \geq 0.5D \\ 1 & \text{for} \quad x < 0.5D \end{vmatrix} \quad (19)$$

and the factor $\eta$ is an empirically calibrated parameter.

Model E – described in the code EN 1991-1-2 [4] and further developed in *Heskestad et al.* [11] and *Zhang Chao et al.* [12] – is an extension of the classical code approach, where flame height in a localised fire is determined according to the formula:

$$L_f = -1.02D + 0.0148 Q_{\max}{}^{0.4} \quad (20)$$

and the temperature $T_m(z)$ computed along the flame centreline, and depending on the height $z$ above the fire source according to the formula:

$$T_m(z) = \min(20 + 0.25 Q_c{}^{2/3} (z - z_0)^{-5/3}; 900) \quad (21)$$

where:

$$z_0 = -1.02D + 0.00524 Q_{\max}{}^{0.4} \quad (22)$$

This specification, applied in the scenarios, where the flame does not reach the ceiling is complemented in [13] by a formula proposed in [12] to determine the temperature $T_{jet}$ $\left[{}^{o}\mathrm{C}\right]$ of fire jet in the zone located directly below the ceiling. This formula is expressed as:

$$T_{jet} = T_g \left\{ 1.92 (\frac{r}{b})^{-1} - \exp[1.61(1 - \frac{r}{b})] \right\} \quad \text{for} \quad 1\mathrm{m} \leq r \leq 40\mathrm{m} \quad (23)$$

where the symbol $b\,[\mathrm{m}]$ denotes the radius of hot fire jet measured at the ceiling level.

The distribution of temperature in fire jet after one hour of fire exposure has been determined according to each of the analytical models listed above, subject to the assumptions enumerated in the first part of this paper. For the purpose of comparison, all these results have been plotted on the Fig. 7. As in the analytical models of the type considered here the location of external walls with respect to the fire source is not taken into account, the obtained results may be compared with results of numerical simulations performed by the authors, regardless of the case (i.e. for all three scenarios considered). One has to note as well, that the temperature distributions in the fire jet, in all the analytical models considered here, are axially symmetrical with respect to the fire source. Because of that only one half of the respective thermal plots is presented in the Fig. 7, as this sufficiently describes the considered phenomenon.

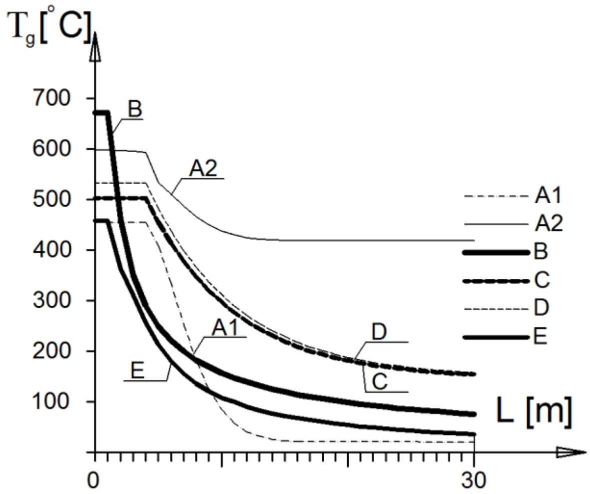


Figure 7 Comparison of temperature distributions in fire jet specified for the hall cross sections considered in this paper, according to the analytical models presented above

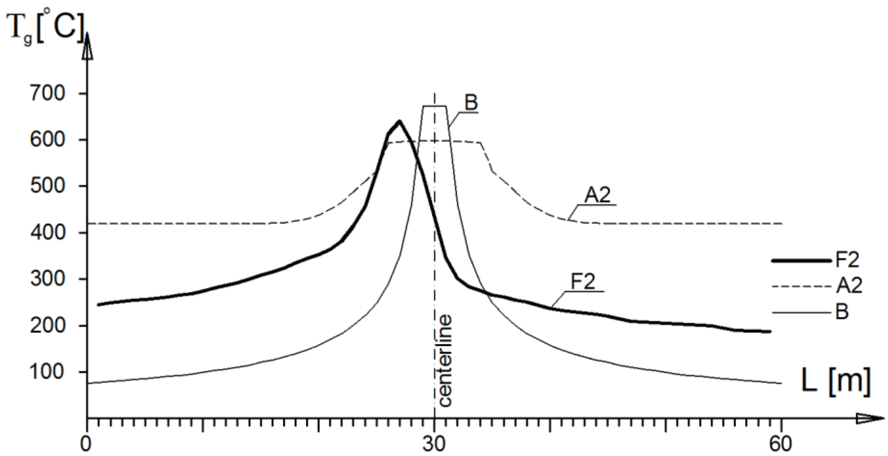


Figure 8 Comparison of fire jet temperature distribution in the transversal cross section of the considered hall obtained using numerical modelling for fire source location at F2 with corresponding distributions obtained for analytical models denoted in the text as A2 and B

Commenting the results presented in the Fig. 7, one should stress the substantial differences in fire jet temperature values. The maximum values of this temperature determined at the fire centreline for each of the analytical models considered differ, and this difference in extreme cases reaches up to 215°C. In general, the distributions obtained may be grouped in two categories. Those for which the forecast fire jet temperature is relatively high not only in the direct vicinity of fire source, but also at the distance constitute one category. Based on the results presented in the Fig. 7, one may assign fires modeled using approaches A2, C and D to this category. Application of the models B and E leads to the opposite conclusion, and thus these models may be assigned to the second category. There the high temperature of fire jet is reached only in the vicinity of fire centreline. In those models the temperature rapidly decreases with growing distance to the fire source. Model A1 seems to be the intermediate one in this classification. During the numerical simulation conducted by the authors, for fire source locations F1 and F2, the extreme values of temperature in fire jet exceeded 645°C. Let us note, that only the model B forecast the higher temperature of fire jet. However, due to the forecast spatial distribution of temperature, the numerical results are better approximated when the analytical model A2 is applied. Respective results are depicted in the Fig. 8. According to our opinion, a more general ascertainment is instructive. It has been found out, that analytical models recommended in professional literature in many cases underestimate the fire jet temperature, which may be reached, and thus may lead to overly optimistic assessment of fire growth rate for a given hall geometry and potential fire risk.

## 8. Conclusions

In the analysis performed above the Authors tried to prove, that the mode and development speed of a localised fire initiated in the large area shopping mall to a large extent depends on the fire source location. Change of this location substantially affects the circulation conditions of fire jet. The differences in development speed are aggravated, if the fire source is located in a hardly accessible area, far away from the ventilation openings, and thus the considered fire is increasingly controlled by the ventilation conditions. These conclusions pertain not only to commercial buildings, but also to fire zones having large horizontal dimensions, relatively low and badly ventilated. They are valid in every location, where probability of fire initiation and growth to the stage of fully developed fire is insignificant, and thus the localised fire is authoritative to estimate the real safety level of buildings and people inside those buildings. These conclusions seem quite obvious at the first sight, however, according to the Authors' opinion, assure the potential reader that the analytical fire models existing and recommended for application in the professional literature should be refined. So far, the existing models, in spite of increasing complexity, do not reflect sufficiently the real conditions determining the development of fire, and thus do not describe the fire development process precisely enough. Many factors are still neglected in the analytical models, for instance the control of fire by availability of adequate ventilation or fuel is completely absent. The localised fires forecast analytically still exhibit radial symmetry, modelled locally, without taking into consideration the real boundary conditions. Thus the shape of such fires is not influenced by the geometrical constraints imposed by the surroundings.

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# The use of sodium silicate to create fire retardant woods

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**Abstract**

The demand to use wood and wood-based products for applications in both residential and non-residential building construction has been increasing over recent years. However, due to the inherent flammability of such products, they often contribute to unwanted fires, resulting in numerous injuries and fatalities

Treatment of wood with flame retardants is one of the strategies to increase fire protection. The aim of flame retardants is to prevent or delay the ignition and to diminish the effects of combustion.

The aim of this paper was to determine the resistance to flame action of wood coated with protective material alkaline silicates (water glasses).

*Keywords*: wood, combustion of wood, fire retardants, sodium silicate, water glass;

## 1. Introduction

Wood is a renewable, sustainable and easily workable material that has been used in the building industry for thousands of years. Its use remains widespread, ranging from structural frames to floors, paneling, doors, interior and exterior woodwork, and furniture. However, its disadvantage is the fact that it is flammable. The combustibility of timber is one of the main reasons that many building regulations strictly limit the use of timber as a building material. As fire safety is an important criterion for the choice of building materials, the main precondition for an increased use of timber as a building material is adequate fire safety.

The use of wood is, therefore, limited by various safety requirements and regulations pertaining to its flammability and spread of fire characteristics.

Within EU member states, fire safety is an essential requirement in the event of fire, specified in the Construction Products Directive (Directive 89/106/EEC [1]).

Fire safety in case of construction products is defined by their reaction to fire and fire resistance. Construction products are divided into groups (classes) depending on how they affect ignition, flame spreading and smoke development. Test methods for the classification of these products are also defined.

A new classification system for the reaction to fire properties of building construction products has recently been introduced in the EU (Commission Decision February 2000). It is often called the Euroclass system and it consists of two sub systems, one for construction products excluding floorings, i.e. mainly wall and ceiling surface linings, see Table 1, and another similar system for floorings. Both sub systems have classes A to F of which classes A1 and A2 are non combustible products [2, 3].

Wood properties such as density, thickness, joints and types of end use including different substrates have been studied thoroughly and are included in the classification. Most wood products fall in classes D-s2, d0 or Dfl-s1 (for floorings). If wood is treated with fire retardants, it can be placed in class B.

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Fire retardants for wood usually act in the early (initial) stage of the fire, when they can postpone its occurrence or even stop its spreading.

## 2. Wood burning

Cellulose, hemicellulose and lignin are the three polymeric materials that constitute the wood cells. Cellulose is a polymer with alternating repeat units of glucose. Cellulose derived from wood pulp has an average of 3,000 repeat units. The large number of hydroxyl groups on the sugar molecule, which leaves the polymer as water molecules during decomposition, result in char formation. In the wood structure, cellulose forms the cell walls, and provides the tensile strength of the wood matrix. Hemicelluloses grow around the cellulose fibres and are a group of non-structural, low molecular weight, mostly heterogeneous polysaccharides. Lignin is an aromatic polymer, which allows trees to grow upright by imparting rigidity to the wood: it cements the cells together, thus accounting for the compressive and shear strengths of wood [4].

When wood is progressively heated at raised temperatures, changes begin to occur in its structure, accelerated by further increase in temperature. The three polymeric components in the wood begin to thermally decompose to a mixture of volatile gases, tar (levoglucosan) and carbonaceous char. The decomposition is often regarded as the superposition of the individual constituent's decomposition mechanisms: hemicellulose decomposes first 180-350°C, followed by cellulose 275-350°C, and lignin 250-500°C [5, 6].

Cross-linking reactions dehydrate cellulose and the re-polymerized levoglucosan begins to yield aromatic structures, becoming graphitic carbon structures at around 500°C. This decomposition process is called pyrolysis. Wood pyrolysis has been the subject of extensive research over the last years. Such studies have shown that whilst the charred surface of wood can have temperatures of 800°C, the main pyrolysis of wood begins at temperatures above 225°C and ends below 500°C [4]..

When an appropriate volatile fuel-air concentration is reached, oxidation of the pyrolysis gases leads to flaming combustion. In contrast, oxidation of the remaining char produces glowing or smouldering combustion [7, 8].

Table 1 Overview of the European reaction to fire classes for building products excluding floorings (Östman, Mikkola [2])

| **Euroclass** | **Smoke class** | **Burning droplets class** | **Requirements according to** Non comb flame | SBI | Small | **FIGRA W/s** | **Typical products** |
|---|---|---|---|---|---|---|---|
| **A1** | - | - | x | - | - | - | Stone, concrete |
| **A2** | s1, s2 or s3 | d0, d1 or d2 | x | x | - | ≤120 | Gypsum boards (thin paper), mineral wool |
| **B** | s1, s2 or s3 | d0, d1 or d2 | - | x | x | ≤120 | Gypsum boards (thick paper), fire retardant wood |
| **C** | s1, s2 or s3 | d0, d1 or d2 | - | x | x | ≤250 | Coverings on gypsum boards |
| **D** | s1, s2 or s3 | d0, d1 or d2 | - | x | x | ≤750 | Wood, wood-based panels |
| **E** | - | - or d2 | - | - | x | - | Some synthetic polymers |
| **F** | - | - | - | - | - | - | No performance determined |

SBI = Single Burning Item test (EN 13823), main test for the reaction to fire classes for building products;

FIGRA = FIre Growth RAte, main parameter for the main fire class according to the SBI test

## 3. Fire retardants

Treatment of wood with flame retardants is one of the strategies to increase fire protection with the aim to prevent or delay the ignition and to diminish the effects of combustion. Improvement of the behaviour of wood exposed to fire can extend the use of timber products in the building sector. The most usual way to improve the fire performance of wood is by treating it with fire retardants that can be applied to wood composite products during manufacture, pressure impregnated into solid wood or wood products or added as a paint or surface coating. Fire retardants cannot make wood non combustible, they are formulated to control ignition, flame spread on the wood surface and to reduce the amount of heat released from wood.

According to the main theories, the role of fire retardants consists in reducing the flow of heat to prevent from further combustion, quenching the flame, or modifying the thermal degradation process. In wood fire retardancy, the use of fire retardants increases the following mechanisms [9]:

- Create a liquid or glassy layer, forming a barrier or insulation that prevents the exchange of air and flammable products at the combustion zone;
- Form coatings, glazes or foams insulating the surface and restraining the pyrolysis by reducing/preventing access of air;
- Increase the thermal conductivity allowing heat to be dissipated faster than it is supplied by the ignition source;
- Create endothermic chemical and physical changes that absorb heat at a level that prevents ignition conditions; and
- Form non-flammable gases which dilute the flammable gases and form less flammable gaseous mixtures, reducing the combustible matter.

Horrocks and Price (2001 [9]) based on the experience of many years of studies and the results of the most recent research demonstrate that an ideal fire retardant should have the following properties:

- High fire protection effectiveness (an amount not exceeding 10% of total weight of protected material);
- Chemical stability at normal service conditions;
- No effect on mechanical strength and a esthetics of protected materials; No emission of toxic and corrosive substances during their use;
- No increase of emission of toxic products of thermal decomposition and combustion;
- Easy application;
- Insecticidal and fungicidal effectiveness;
- Resistance to water and UV degradation; and
- Relatively low price.

Today, many impregnation compositions for timber have been developed, with different sets and proportions of low-molecular inorganic substances and derivatives of organic compounds demonstrating fire-retardant properties. The fire-retardant impregnation compositions used include of inorganic substances various derivatives of phosphorous and phosphoric acids, boric acid, ammonium and sodium tetraborates, ammonium salts of sulfuric and hydrochloric acids, chlorides of alkaline-earth metals and polyvalent transition metals, sodium and potassium carbonates. Many of the indicated substances have a polyfunctional effect on the chemical constituents of timber. For example, they have the properties of catalysts for etherification of both hydroxyl-containing macromolecules of timber components by phosphorus acids and of agents of cellulose dehydration. In this way, they promote directional change of timber thermal decomposition reactions toward reduction of flammable volatiles through increased yield of char residue. Ammonia and hydrogen chloride generated in thermal decomposition of the employed salts may function as inert flame diluents and inhibitors of radical oxidation reactions in the gas phase. As the temperature rises, the product of thermal decomposition of phosphorous and phosphoric acids derivatives – orthophosphoric acid – turns into pyro-, tri-, and polymetaphosphoric acids, which have low volatility. Upon melting they may form a glassy protective layer on the charred surface. It works as a physical barrier against oxygen diffusion into the carbonized product. An important feature of phosphorus compounds is their unique ability to suppress smoldering combustion reactions in timber. Boric acid and other boron compounds have a similar effect. The above mentioned substances making up part of impregnation compositions are hygroscopic and soluble in water. That is why in an atmospheric environment with moisture above 70 % or in direct contact with water, the fire protection efficiency of timber impregnations may be totally or partially lost. To prevent this, it is recommended to apply additional water-resistant covering varnishes and paints or use fire-protected timber materials only inside the buildings. Another way to enhance moisture resistance of fire-protected timber is introduction of organic and organoelemental substances with low viscosity and water-repellent properties into impregnation compositions. A combination of organic binders and liquid glass is also used for intumescent fire-retardant coatings. These same derivatives of various acids serve as effective intumescent agents for coatings by emitting a lot of incombustible gases ($NH_3$, $CO_2$, HCl, H2O). These intumescent agents belong to typical gas developing agents, which generate incombustible vapors and gases as a result of chemical decomposition reactions when the substances are heated. Physical agents that generate intumescent fire-retardant coatings include vermiculites and thermally expandable graphites [10].

Nowadays, there is a growing concern about the environmental and toxicological impact of building materials. The addition of performance chemicals, such as halogenated fire retardants, can be expected to have environmental effects. There is a current contentious toxicity problem with boron and as such, a need for wood products to move away from boron based fire retardants is recognized.

The choice of fire retardant chemicals is most important for the environmental profile of the final wood product. Environmental risks are also associated with degradation products during normal product use and during fire conditions [11].

In order to apply a protective surface coating to wood, it is typically painted, sprayed or dipped into a solution of fire retardant. Superficial treatments, such as paints, are often thought to be attractive for the ease with which they can be applied, and for the comparatively small amount of material required for fire protection. However, the associated re-application requirements and surface damage possibilities are considerable problems for the end-user [6].

### *3.1. Liquid sodium silicate – water glass*

Sodium silicate is the common name for a compound sodium metasilicate, $Na_2SiO_3$, also known as water glass or liquid glass.

Water glass is a compound containing sodium oxide (Na2O) and silica (silicon dioxide, SiO2). The higher the ratio of SiO2 to Na2O and the higher the concentration of both ingredients, the more viscous is the solution. Viscosity is a product of the formation of silicate polymers, the silicon (Si) and oxygen (O) atoms being linked by covalent bonds into large negatively charged chain or ring structures that incorporate the positively charged sodium ions as well as water molecules [12].

The use of sodium silicate as a timber treatment for pressure-treated wood actually began sometime in the 19th century. Since 1998 scientists have researched methods for rendering sodium silicate insoluble once the lumber has been treated with it. With or without the additional process, treating wood with sodium silicate preserves wood from insects and possesses some flame-retardant properties.

Liquid sodium silicate (water glass), applied to the surface of various products, can impart fire retardant properties. In the presence of fire, the sodium silicate forms foam-like crystals that help to provide an insulating barrier between the product and the flame, and thus slows down the spread of fire. Wood and other products become less flammable when treated with sodium silicate. The foam-like product appears to be more than a mere change in form of the sodium silicate. It is believed that the foam-like material is the product of a chemical reaction, and also imparts fire retardant properties to the material treated with sodium substrate.

Wood products treated with sodium silicate can be used simultaneously to impart flame resistant properties to wood and to cause the wood to become termite resistant, providing an environmentally friendly method for long term termite control.

As a result of the application of heat, the sodium silicate undergoes dehydration (loss of water) and a process of polymerization that forms increasingly larger moieties of $(SiO4)_{n-1}$ while still maintaining an overall charge of −1 that forms an association with the free sodium. As the material polymerizes the resultant material increases in size to the point that it is no longer able to dissolve in water, thus becoming insoluble [13].

## 4. Experimental Part

*4.1. Experimental Methods*

In order to test the flammability of materials the firing tube method is used [14, 15]. It is a rapid method for determining the flammability of the group of solid materials.

The firing tube (Fig 1), is a vertically disposed metal tube (diameter 50 mm, height 165 mm), fixed to the tripod and provided with a holder for the sample. To monitor the behaviour of the material in the examination there is a mirror placed. The ignition source is the propane-butane gas, temperature 950±10°C. The tested sample is placed in the cylinder so that the lower end is 5 mm beneath the lower edge of the cylinder. The gas burner is ignited and the flame height is adjusted to 55 mm. Then, the burner is fed under the sample so that the flame acts in the middle of the lower end of the sample. At the same time the stopwatch is started. After 2 minutes, the ignition source is extinguished. After cooling the sample to the room temperature, it is re-weighed and the weight loss as a percentage of the original sample weight is marked.

If after removing the external source of ignition the material supports independent flaming or glowing combustion that is evaluated for smoke emission, and thus there is a weight loss of more than 20%, then the tested material is in the combustible group.

The selected wood samples for the experimental testing belong to the kinds of wood used as construction materials and for furniture elements, and they are as follows:

– White Ash (Fraxinus excelsior) – it is hardwood used in industry for the manufacture of massive slabs, veneers, furniture elements, for the preparation of garden furniture, musical instruments, ships, as well as for fuel. Wood is thermally treated at 100°C for three weeks.

– Firs (Abies) – wood used as a construction material for internal installation, making pillars, furniture, musical instruments, in the cellulose and paper industry, in the industry of fiber in the manufacture of wooden packaging, etc.

– Beech (Fagus) – primarily used in construction, in the manufacture of furniture, veneer parquet, plywood and fiber boards, for the cellulose and as firewood.

– Walnut (Juglans) – important for its attractive timber, which is hard and dense, used to manufacture the cut and peeled veneer, then in the manufacture of furniture and for interior cladding of buildings, for the manufacture of fiber boards and parquet flooring.

– Medium-density fibreboard (MDF) is an engineered wood product made by breaking down hardwood or softwood residuals into wood fibres, combining it with wax and a resin binder, and forming panels by applying high temperature and pressure. It is made up of separated fibres, but can be used as a building material.

The samples are dimensioned according to the test method to 35 × 150 mm, thickness not more than 10 mm.

Wood and wood products are treated with the 36% concentration of liquide sodium silicate – water glass, purchased in retail.

To determine the fire resistance of the used coating agent in the experimental conditions, serial tests are carried out:

I series – control series with untreated samples;
II series – samples coated with two layers of water glass;
III series – samples coated with three layers of water glass;
IV series – coated samples treated in water;
V series – coated samples heat-treated, kept in the kiln for x hours in the temperature of x °C.

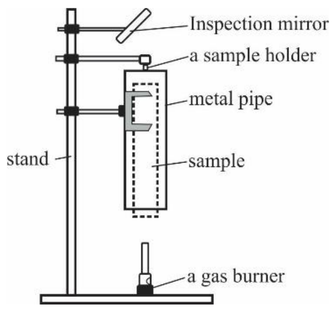


Fig 1 Firing tube

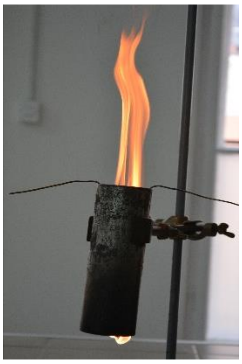

Fig 2 Untreated sample

*4.2. Results and Discussion*

*I series – control series with untreated samples*

***The wood is weighed before (m1) and after testing (m2). The loss of mass is calculated from the following equation:***

$$\% = \frac{(m_1 - m_2)}{m_1} \cdot 100$$

The results of the experiment are given in Table 2.

When flame is first applied to the sample, the fire propagates quickly and starts to spread up the sides of the sample. The fire soon quickens, and begins to spread to other parts of the sample.

The flames on the wood rise, and begin to consume the whole sample. The flames extend above the sample, and the sample begins to lose shape quickly. The flames continue to burn the sample even when the gas burner is turned off.

The samples are completely charred and some are completely disintegrated. The values entered in Table 2 are mean values of three repeated tests. All wood samples lose more than 20% by weight; they burn down completely and belong to the combustible group.

*II series – samples coated with two layers of water glass*

The tested wood samples have been measured before and after coating to determine thus the mass of the applied water glass coating (0.99 to 1.59 g).

It is noted that sodium silicate residues form bubbles providing a physical barrier against the flame and reducing access to flammable materials by oxygen; hence, as heating continues, the sample becomes incandescent. It has been shown that in the samples with the sodium silicate, the wood remains unchanged by flame. Similar observations on the behavior of cellulosic materials treated with water glass are presented in the works of Slimak [13], and Kalbskopf [16].

The loss of mass is from 4.49 to 14.33%, which is significantly less than 20%. All tested samples are classified as non-flammable. The test results and observations are given in Table 3.

*III series – samples coated with three layers of water glass*

The mass of the coating applied to the wood samples is in the range of 1.57 to 2.31g. This amount of protection has not permitted to come to the fire of the samples. The loss in mass of 3.71-7.41% shows that a high degree of resistance to the action of the flame is achieved; hence, all the test samples are classified in the group of non-flammable.

The experimental results obtained during the testing are listed in Table 4.

*IV series – coated samples treated in water*

Water glass is soluble.

To confirm the fact that sodium silicate is soluble in water, the wood samples have been previously coated with the solution, liquid sodium silicate, immersed in the water for 24 hours, dried at room temperature and then examined in the experimental conditions.

The results are given in Table 5. Based on the obtained results, it is evident that the protective coating has lost its role, and the samples burn similarly to those without any protection, the loss of mass is from 43.43 to 87.88%.

In the investigation conducted by Slimak [13], it was found that there was evidence of leaching of sodium silicate from the wood, with approximately 50 % of the sodium silicate removed after one year of exposure to the weather conditions.

## 5. Experimental Part

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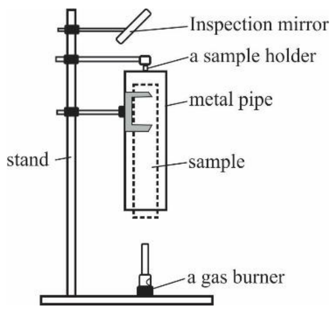


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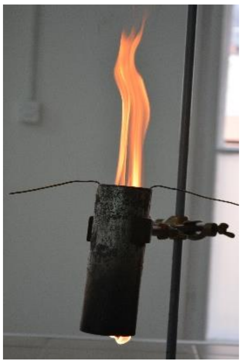

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It is noted that sodium silicate residues form bubbles providing a physical barrier against the flame and reducing access to flammable materials by oxygen; hence, as heating continues, the sample becomes incandescent. It has been shown that in the samples with the sodium silicate, the wood remains unchanged by flame. Similar observations on the behavior of cellulosic materials treated with water glass are presented in the works of Slimak [13], and Kalbskopf [16].

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In the investigation conducted by Slimak [13], it was found that there was evidence of leaching of sodium silicate from the wood, with approximately 50 % of the sodium silicate removed after one year of exposure to the weather conditions.

Table 2 Results for the control series with untreated samples

| Untreated samples | Mass of coating (g) | | Mass loss | | Observations |
|---|---|---|---|---|---|
| | Before combustion | After combustion | (g) | (%) | |
| WHITE ASH | 28.863 | 3.881 | 24.98 | 86.55 | Ignition occurs in 20-30 s, burns intensively with the occurrence of black smoke, extinguishes by itself after 3:15-5:54 min. Parts fall off during combustion. |
| FIR | 15.318 | 3.028 | 12.29 | 80.33 | The sample ignites between 15-28 s, burns with red and orange flames with black smoke, extinguishes after 2:41–3:04 min. Parts fall off during combustion. |
| BEECH | 27.982 | 3.547 | 24.43 | 87.31 | The sample ignites after 40-55 s, burns bright with red and orange flames with black smoke, extinguishes after 3:40-3:44 min. |
| WALNUT | 25.578 | 4.09 | 21.48 | 84.01 | The sample ignites after 30-34 s, burns with red and orange flames with black smoke, extinguishes after 3:35–3:49 min. |
| MEDIUM-DENSITY FIBREBOARD (MDF) | 29.038 | 7.065- | 21.97 | 75.66 | The sample ignites after 22-33 s, burns with yellow flame (height 35 cm), with black smoke, extinguishes after 4:20–4:30 min. The sample completely burned. |


Fig 3 Charred remnant


Fig 4 The swollen layer of water glass

Fig 5 Samples with fire resistant coating after examination

Table 3 Results for samples coated with two layers of water glass

| Water glass coating in two layers | Mass of coating (g) | Mass loss | | Observations |
|---|---|---|---|---|
| | | (g) | (%) | |
| WHITE ASH | 0.99 | 11.89 | 14.33 | On the site of operation of the burner, the sample is glowing, with a lot of smoke, but after removing the burner the sample extinguishes. |
| FIR | 1.21 | 2,01 | 12,81 | The sample ignites after 100-115 s, but extinguishes after 2:25 – 3:00 min, the occurrence of white smoke. |
| BEECH | 1.18 | 2.42 | 8.64 | The sample ignites within the first minute, and extinguishes after 2:00-2:50 min, the occurrence of thick white smoke. |
| WALNUT | 1.32 | 1.22 | 4.56 | On the site of operation of the burner the occurrence of flame that soon extinguishes, the occurrence of white smoke. |
| MEDIUM-DENSITY FIBREBOARD (MDF) | 1.59 | 1.40 | 4.49 | On the site of operation of the burner the occurrence of small flame that quickly extinguishes, the occurrence of white smoke. |

Table 4 Results for samples coated with three layers of water glass

| Water glass coating in three layers | Mass of coating (g) | Mass loss | | Observations |
|---|---|---|---|---|
| | | (g) | (%) | |
| WHITE ASH | 1.57 | 4.85 | 6.39 | No ignition occurs, the appearance of white smoke. |
| FIR | 2.31 | 1.37 | 7.14 | On the site of operation of the burner the glowing sample does not burn with flame, the occurrence of white smoke. |
| BEECH | 2.22 | 1.13 | 3.71 | The sample does not ignite, the occurrence of thick white smoke. |
| WALNUT | 1.96 | 1.06 | 3.85 | On the site of operation of the burner the glowing part does not burn with flame, the occurrence of white smoke. |
| MEDIUM-DENSITY FIBREBOARD (MDF) | 2.31 | 1.33 | 4.24 | The sample does not ignite, the occurrence of thick white smoke after removing the burner. |

*V series – heat-treated coated samples*

The tested wood samples are coated with sodium silicate and kept in the kiln for 24 hours in the temperature of 150 °C. Physical changes are observed on the surface of samples, which is no longer shiny or smooth.

The samples are then exposed to the flame action and the obtained results are shown in Table 6. It is evident that there is no ignition of the samples other than the appearance of the glowing at the point of the flame, but it stops shortly after the flame removal. The loss of mass is within the range of 2.52% to 11.89%. Consequently, the samples are classified as non-flammable. Thus, the protective coating has not lost its role due to exposure to elevated temperatures. Similar observations and results were obtained in our previous experiments [17].

Table 5 Results for coated samples treated in water

| Samples with water-glass – dipped in the water | Mass of coating (g) | Mass loss | | Observations |
|---|---|---|---|---|
| | | (g) | (%) | |
| WHITE ASH | 0.31 | 24.59 | 86.07 | The sample ignites after 26-46 s, and extinguishes after 2:50-3:29 min. |
| FIR | 0.24 | 12.02 | 78.64 | The sample ignites after 27-30 s, and extinguishes after 2:20-2:48 min. |
| BEECH | 0.68 | 23.76 | 88.78 | The sample ignites after 50-70 s, and extinguishes after 3:14-3:28 min, parts fall off during combustion. |
| WALNUT | 0.53 | 20.16 | 82.33 | The sample ignites after 25-36 s, and extinguishes after 2:57-3:28 min. |
| MEDIUM-DENSITY FIBREBOARD (MDF) | 0.14 | 12.17 | 43.43 | The sample ignites after 35-45 s, and extinguishes after 3:31-3:40 min. |

Table 6 Results for heat-treated coated samples

| Samples with water glass, heat-treated | Mass of coating (g) | Mass loss | | Observations |
|---|---|---|---|---|
| | | (g) | (%) | |
| WHITE ASH | 0.31 | 3.53 | 11.89 | The sample ignites within the first minute, and extinguishes after 3:50, the occurrence of white smoke. |
| FIR | 1.34 | 0.86 | 4.92 | No ignition occurs, the appearance of white smoke after removing the burner. |
| BEECH | 0.76 | 0.97 | 3.42 | No ignition occurs, the appearance of white smoke after removing the burner. |
| WALNUT | 0.43 | 4.79 | 6.65 | On the site of operation of the burner the sample burns, but extinguishes after removing the burner, the occurrence of white smoke. |
| MEDIUM-DENSITY FIBREBOARD (MDF) | 0.52 | 7.48 | 2.52 | On the site of operation of the burner the sample burns, but extinguishes after removing the burner, the occurrence of white smoke. |

## 6. Conclusions

Liquid sodium silicate (water glass), applied to the surface of various products, can impart fire retardant properties. In the presence of fire, the sodium silicate will form foam-like crystals that help to provide an insulating barrier between the product and the flame, and will thus slow down the spread of fire.

Even though the wood will burn in areas in direct contact with hot flame, the flames will not spread. This will help to keep small fires from spreading into large ones.

Increasing the fire resistance time of wooden constructions is one of the most common applications of intumescent coatings. The advantage of this protection method is that the structure of wood remains visible which is often desirable for architectural reasons. Intumescent coatings in fire resistance applications have also some drawbacks, for example their sensitivity to humidity. The subsequent/repeted treatment may increase its resistance and allow it to be used, not only for the protection of interior surfaces, but also for external purposes.

It can be concluded that water glass is an effective fire retardant when applied as a coating, then it could be an important finding since it is virtually non-toxic, safe to use, relatively cheap, readily available and can be easily used by the homeowner.

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# Effect of flame retardants on selected fire parameters of spruce wood

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**Abstract**

The paper deals with the issue of the protection of wood. It brings the results of experimental works focusing the assessment of the chemical substance with fireproof function application effect on the thermal resistance of spruce wood. The experiments results show the change in effect of the protective substance at varying concentration and method of application (coating, retting), and thus also the different values of observed variables (weight loss, time of ignition) of tested spruce samples.

Keywords: wood, coating, retting, flame retardant, weight loss, ignition time;

## 1. Introduction

Wood is one of the oldest building materials and is still an important element in the construction industry. The main reason for its wide application is its advantageous design, thermal insulation and soundproofing properties, long life, but also ecology, because wood is one of the few building materials that have the ability to regenerate naturally.

The current trends in the use of wood in construction industry include prefabricated family houses, lightweight roof structures, mixed constructions made of wood, steel and concrete structures, easy machinability and woodworking, which opens wide options in selection of construction systems (wall, skeletal or mixed) [1].

The great disadvantage that significantly affects the use of wood in the building is its flammability. Wood is a natural material, the core of which the wood cells are, consisting of organic polymers (cellulose, hemicellulose, lignin). These play a major role in the degradation processes that wood is subjected to at higher temperatures. By acting on the activating energy (flame, spark, etc.), the polymer breaks down and flammable gases are formed. At high enough temperature they react with oxygen in various thermo-oxidation reactions of exothermic nature, releasing considerable amount of energy needed for further heating and pyrolysis of wood [2]. Due to this feature according to the current PBS regulations, it wooden constructions up to two above-ground floors, respectively. After fulfilling specified conditions, it is possible to build them up to a fire height of 9 m [3].

For this reason, there is an attempt to eliminate this negative property, which can now be implemented with a number of fire-fighting measures (depending on the area of use) during the construction and installation of individual wood elements.

One way is also the chemical treatment of wood, by the preparations containing flame retardants. Although those substances also have their limitations, e.g. their effect is lost at high heat flows (at later stages of the combustion process), in spite of this they have an important place in the fire protection area. Their significance is in the fact that, by their application, they effect as a support for formation of a char layer, prevent the burning into the depth of the material, or as the additives, they bind the free radicals, and thereby break the chain reaction mechanism [4].

In the following part of the contribution we are also addressing the above mentioned method of protection of wood - chemical protection and we present concrete

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results of experiments which investigate the effect of the selected protective agent on the fire resistance of spruce wood.

## 2. Experiment

### *2.1. Material*

The experiment was carried out on samples of spruce wood (with density of about 0.467 g.cm-3), as the representative of the most frequently used wood species in building constructions. The samples with humidity of 10% did not have any anatomical shortcomings, and were sized to 50 x 40 x 10 mm. The protective agent - *Bochemit Antiflash* - was then applied in two ways - by coating and soaking. On the coating application, the substance was applied in three layers in 24-hour time span. The soaking was carried out with complete immersion of the samples for 24 hours. The quantities and concentrations used are shown in Table 1. Five representative samples were prepared for one test set.

Table 1The quantities, concentrations, and methods of application of Bochemit Antiflash

| **Application** | **Concentration** | **Dilution (Bochemit + water)** | **Layer** |
|---|---|---|---|
| Coating 3x | 50 % | 1:1 | 250 $g.m^{-2}$ |
| | 100 % | - | 300 $g.m^{-2}$ |
| Soaking 24 h | 50 % | 1:1 | - |
| | 100 % | - | - |

**Bochemit Antiflash** - water-borne agent designed to reduce reaction of wood, wood-based materials, wooden building structures and elements built in the interiors of buildings to fire. The substances contained in the Bochemite Antiflash agent are decomposed on non-flammable gaseous substances, which take oxygen needed for the oxidation of wood. They also support the rate of formation of a char layer, which has a significant thermal insulation effect and prevents further heating. The active substance of the Bochemite Antiflash agent is boric acid. In accordance with EN 13 501-1 [5], after the treatment with 50% dilution of Bochemit Antiflash agent, the wood material meets the requirements of the Fire Reaction Category C, when applied the 100% dilution of the agent, it meets the requirements of Fire Rating Class B. The agent is also suitable for the protection of wood against wood-destroying fungi and insects [6]

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Figure 1 Bochemit Antiflash – an agent with fungicide-insecticidal and anti-fire function [6]

### *2.2. Testing method*

A non-standard test method (Figure 2) was used, which consists in investigating the weight loss of the test material over time. During a set time of 600 seconds, the test bodies are subjected to loading of a 1000 Watt thermal infrared heater (see Tab. 2) at a distance of 30 mm from the surface of the heater. At regular 10-second intervals, weight loss is recorded and any ignition is observed.

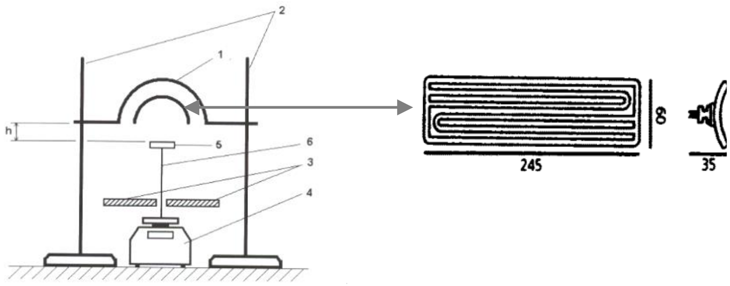


Figure 2 Scheme of a test method for testing the weight loss with detail of a ceramic radiant body
1 – infrared heater, 2 – supporting metal frame, 3 - protective frame, 4 - electronic scales,
5 - test specimen, 6 - metal stand

Table 2 Parametre charakterizujúce žiariče typu F.T.E.

| | | | | |
|---|---|---|---|---|
| Power [W] | 250 | 500 | 750 | **1 000** |
| Average surface temperature [°C] | 418 | 560 | 670 | **750** |
| Minimum wavelength [microns] | 4.9 | 4.0 | 3.5 | **3.0** |
| Surface loading [W/cm$^2$] | 1.7 | 3.4 | 5.1 | **6.8** |

The experimental evaluation criterion was the relative weight loss according to the given relationship [7] and the ignition time.

$$\delta_m(\tau) = \frac{m(\tau_0) - m(\tau)}{m(\tau_0)} * 100 \quad (\%) \tag{1}$$

Where:

$\delta_m$ - Relative weight loss in time $(\tau)$ [%]

$m(\tau_0)$ - original sample weight [g]

$m(\tau)$ - sample weight in time $(\tau)$ [g]

## 3. Results

The results of the evaluated criteria (weight loss, ignition time) were processed in tables and charts for better clarity. Through them we are able to compare thermal resistance of retardant unprotected and protected samples of spruce wood as well as assess the effect of protective agent Bochemit Antiflash by changing its concentration and the method of its application.

Table 3 Comparison of weight loss and the time of ignition of spruce samples as a function of varying the concentration and method of application of protective agent Bochemit Antiflash

| **Evaluation criteria** | **Agent concentration** | | **Application method** | |
|---|---|---|---|---|
| | | | Coating | Soaking |
| Weight loss (%) | No application | 92.48 | - | - |
| | 100 % concentration | | 26.74 | 52.57 |
| | 50 % concentration | | 77.36 | 58.93 |
| Ignition time (s) | No application | 151 | - | - |
| | 100 % concentration | | no ignition | 131 |
| | 50 % concentration | | 126 | 121 |

Note: In the Table, there are introduced the average values obtained from five tests

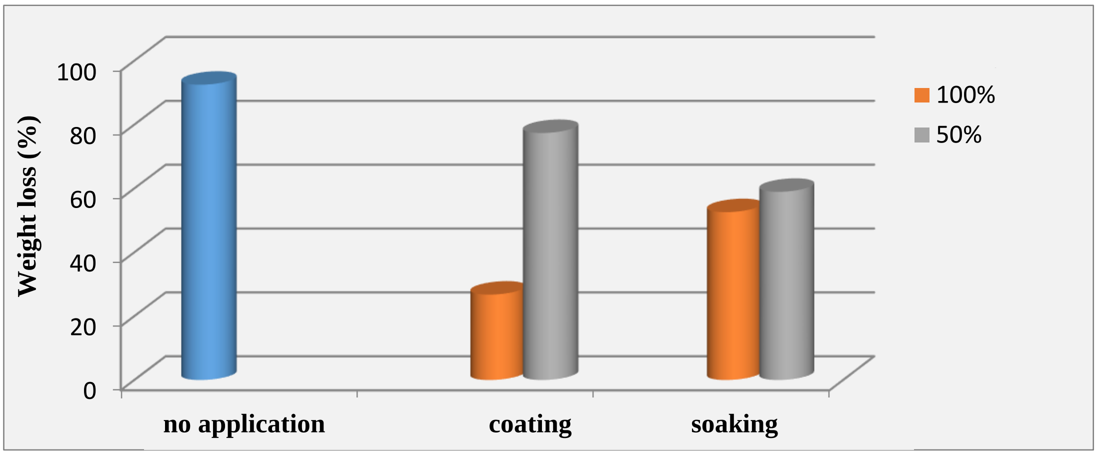


Figure 3 Final weight loss values of unprotected and retarded spruce samples

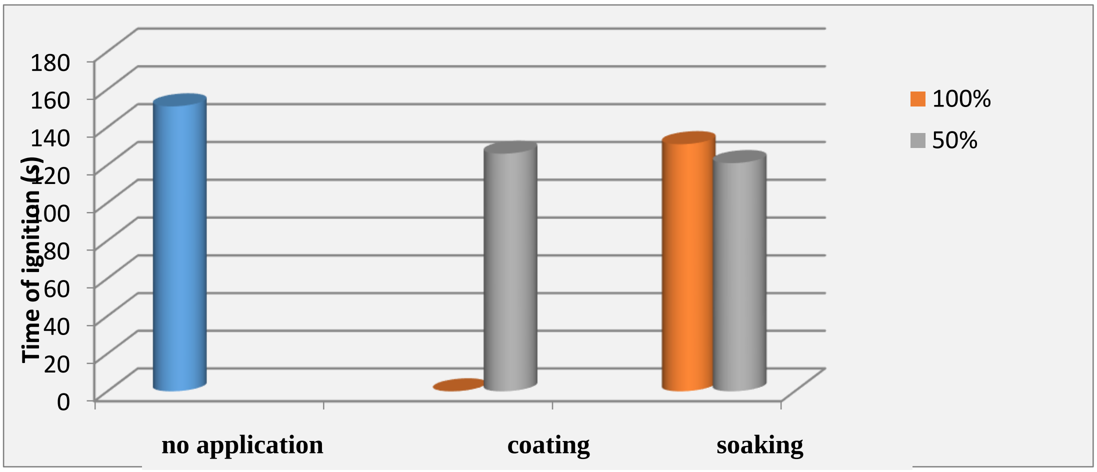


Figure 4 Time of ignition of unprotected and retarded spruce samples

The results of our experiments (Table 3 and Figures 3 and 4) aimed at evaluating the effect of Bochemit Antiflash agent on the thermal resistance of spruce wood confirmed the retardation effect of this agent, which was reflected in lower values of weight loss of treated samples compared with untreated. The results also indicate that the effect of the agent depends on the concentration in which it is used and then on the manner of its application.

The results show that Bochemit Antiflash agent achieves a better effect in a non-diluted form, at 100% concentration. In accordance to application manner (coating, soaking) on the effect of the agent, the results show that:

• At the 100% concentration, the application by coating was more advantageous (as compared to soaking, the sample was not ignited using this treatment and the weight loss was about 26% less than the soaked samples);

• At the 50% concentration, the more appropriate application was by soaking (although the ignition time is comparable, but the weight loss of the soaked samples is about 18% lower than that of the covered samples).

This difference is explained by the fact that if the agent is used in undiluted form and is applied in three layers, it creates a stronger protective layer on the surface of the samples than the soaking, which, when the heat is applied, is charring and prevents the heat to penetrate the material.

If the agent is diluted with water, on the other hand, better results are achieved with soaked samples. It is due to the fact that water and total immersion of the samples into the agent contributed to better saturation of the protective agent into the structure of the material, which was eventually reflected in a lower weight loss compared to the coated samples.

## 4. Conclusion

Despite all the positive aspects of wood, the flammability is a property that significantly affects its use in construction. However, experts in this field agree that, when applying suitable fire preventive measures, this material may also be a fire safe. At present, wood protection is given considerable attention where a significant role has protection using the chemical agents. The results of our experiments also show the usefulness of the use of those protective agents, and also indicate that, in addition to the chemical composition, their protective function also depends on the concentration and the manner in which they are applied to the wood material. In the case of the tested Bochemit Antiflash agent, the results point to the fact that if the substance is used at 100% concentration, it is more convenient to apply the coating. If it is used in a 50% concentration, it is preferable to apply it by soaking.

## Acknowledgments

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# Comparison of the effectiveness of sorption materials for a variety of lubricants and their applicability

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**Abstract**

One of the negative effects from an environmental point of view is leak of crude oil and petroleum hydrocarbon products, caused whether negligent action or various accidents. As a precautionary measure or intervention, different types of sorption materials are used. In this paper, sorption substances in the bulk phase were investigated, because of their quantitative use. The samples were chosen due to their general appearance of the Fire and Rescue Corps and in the private sector (3mon, Absodan plus, Cansorb, Chezacarb, expanded perlite, PeWaS Sorb, sorptive brash Reo and Spilkleen Plus). Sorbents were tested for sorptive capacity, hydrophobicity, spatial and weight demands. Selected sorbent samples were tested for different used operating fluids, such as motor oils, gear oils and hydraulic ones. Sorptive capacity was measured by a standard test method for determination of sorption properties of adsorbents in the short-term standpoint. The measurement determined the best average sorptive capacity of the sorbent sorptive Reo brash with a value of 16.85 g/g of adsorbent treated with a hydrophobic treatment. The PeWaS Sorb sorbent was determined as the most compact sorbent having sorptive capacity 1003.35 liters/m3 volume. From the last comparison in term of the most effective sorbent, the sorbent Reo brash with a volume of 18.72 l/kg was determined.

*Keywords*: sorbent, hydrocarbon lubricants, sorptive capacity;

## 1. Introduction

Environmental pollution belongs among the most watched events in the present. One of the most serious types of flora and fauna pollution, include pollution by petroleum hydrocarbon products. A leak of dangerous substance in a road accident even in small quantities can result under certain circumstances in serious damage to the particular components of the environment: water, soil and air (Coneva 2010). Petroleum is processed and transformed into a variety of products using various methods and technologies. Among the most famous products processed from crude oil, belongs wide range of oils, lubricants and fuels such as diesel, petrol, motor and gear oils. In practice, we can be challenged by spills of petroleum hydrocarbon products in common operations as well as in negligent acting, different disasters and traffic accidents. In the case of traffic accidents associated with leakage of hazardous substances, it is also an ecological intervention dealt by members of the Fire and Rescue Corps (FRC). An important task of intervening firefighters is an environmental protection (Coneva 2011). As means of removal and insulation of these pollutions caused by petroleum products, sorption agents are used. In case of general leaks in various operation technologies, loose as well as textile sorbents are used. They are widely used only for the prevention of leakage from technological equipment. Leaks out of technologies are considered as a different accidents as well as negligent acting. The paper deals with sorptive agents that are used for disposal of such accidents. The benefit of the paper consists on knowledge concerning sorptive substances currently used and on information relating the newest sorptive substances on the Slovak market.

Authors in various publications deal with sorptive materials and their properties, e.g. (Markova 2006), (Zachar 2009), (Coneva 2013) and others.

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Sorptive substances and their use is characterized in many articles and publications. General review of the available sorptive materials, however, is missing and the reason is that new types of sorptive materials suitable for the disposal of hydrocarbon products are placed and promoted on the market. there is a great amount of sorptive substances; the paper concerns selected sorbents, which are currently used in the FRC or are approved for use. Legal acts relating to the activities and the use of sorbents in the FRC are: the Act of the National Council of the Slovak Republic No. 314/2001 Coll. on fire protection, as amended, the Act of the National Council of the Slovak Republic No. 315/2001 Coll. on the Fire and Rescue Corps as amended, the Act No. 129/2002 Coll. on Integrated Rescue System, Tactical and Methodological Methods for carrying out interventions issued by the Presidium of Fire and Rescue Corps, guidelines of the President of the FRC, and standard test method for determination sorptive properties of adsorbents (ASTM F 726, 2006). The data were drawn from research papers, placement sheets of sorption materials, various publications and open access sources.

Sorbents are substances prevailingly in a solid state, which by their chemical and physical composition separated gaseous or liquid substances. A characteristic feature of sorptive material is the ability to absorb a certain amount of fluid in relation to its own weight (Ankowski, 2011). Sorbents are most often found in loose form or as a textile fabric. The most important characteristic of sorbents is their structural composition. Sorption substances are formed by different channels, capillaries and pores.

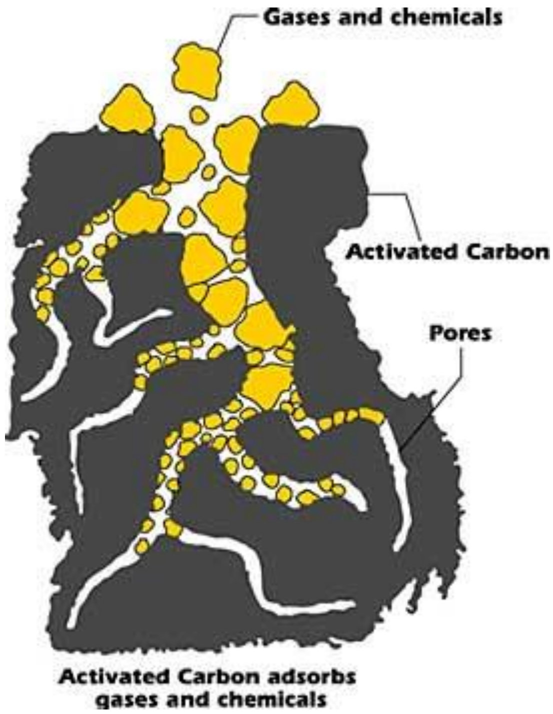


Fig. 1 Sorption in pores and capillaries (Internet, 2016)

Due to structural composition, sorbents have a large surface area. The capacity of the sorbent depends on the amount of surface area to which oil may adhere, as well as on the type of surface (Fingas, 2010). The size of the sorbent, so-called specific surface area is expressed in area units (m2) per mass unit (g, kg). Good adsorbent has a surface area of about 1,000,000 $m^2.kg^{-1}$. (Zachar, 2010). Due to these properties, sorbents have ability to chemically and physically bind substances of organic or inorganic origin on their surface and also in mentioned pores, capillaries and channels.

The principle of sorption materials can be described as follows: multiple processes run during adsorption. In particular, a soaking of another substance on the surface and into pores which are located directly in the grains or granules of sorbent; and the soaking between several granules. In the case of single molecule layer adsorbing, only a small amount of liquid can be captured on a solid particle surface. The amount of liquid can be heightened by increasing the surface of the solid particles.

In the case of bulk sorbent, the adsorbed material is also captured among beads or granules. Due to capillary forces, soaking into the pores of the grain occurs. This process smoothly continues the capillary condensation, that actually is a phenomenon between adsorption and absorption properties. The basic difference is that the capillary condensation fills the deep pores from the narrowest profile; it means that they often filled backwards (Markova 2016).

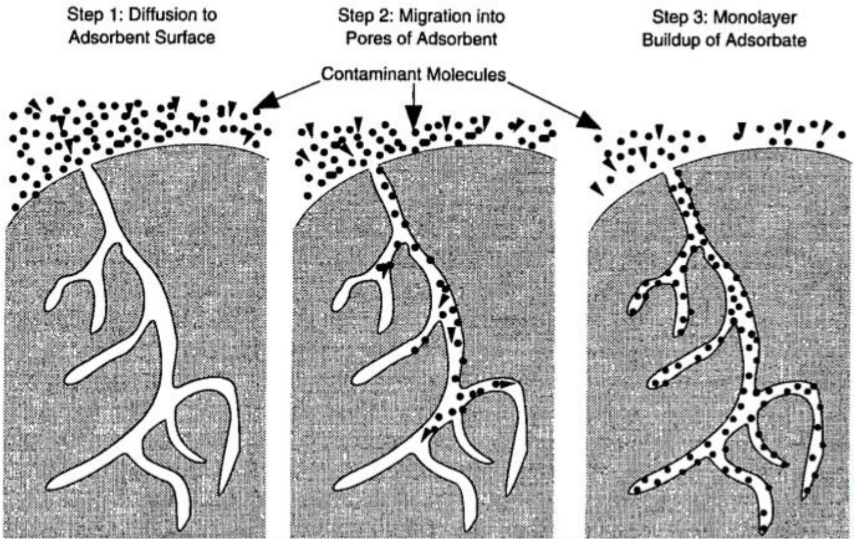


Fig. 2 Adsorption mechanism (Internet, 2016)

The sorption agents are classified according to various aspects. The essential classification of sorbents used in practice for removing various kinds of spills or environmental accidents, is based on common prevalent characteristics, as follows: natural sorbents, synthetic ones, loose, textile, oil, chemicals and maintenance ones.

Among the *natural sorptive agents* belong: sawdust, peat, sand, powdered sulphur, coal dust and other.) Typically, they have low absorption capacity and are suitable only for slight interventions (Markova 2012). Availability of natural sorbents can also be found on intervention site. However, they have low sorptive capacity for pollution caused by oil-based substances. The subsequent ecological disposal is too demanding; thus, the use of natural sorbents abandoned and synthetically prepared and manufactured sorptive agents are preferred. Natural sorbents can be treated by so called hydrophobization, which increases absorption of the non-polar liquids (Orinčák 2012); such as oil, petroleum products and others.

Among the first *synthetic sorbents,* we can include ash and coconut powder that was not intended for sorption purposes (Markova, 2003). Absorption of oil-based or water-based liquids was only the side effect due to their structure containing pores. These by-products of the production processes begun to be treated on high sorption materials. Later, rock-based substances (perlite, clay, and limestone), cellulose and plastic (polypropylene, polymers) started to be produced. They are purposefully produced and treated for removing oil products and chemical pollutions. Like natural sorbents, they are chemically modified, for example by the hydrophobization. This modification makes the sorbents hydrophobic and oleophilic substances. Their use can be found in the private sector as well as in terms of the FRC.

*Loose sorbents* are solid state substances. There are substances made from natural or synthetic materials. Loose form of sorbents varies; they are either in the form of fine powder or granules. Granules, grains or other shapes have a size from 0.1 mm up to 5 mm, depending on the manufacturer (Zachar 2009). The structure is porous, having a variety of cracks and pores. They have a large surface area and adsorb large amounts of liquid even being in small quantities. They are used to remove pollution on large and rough surfaces. They can be treated by hydrophobization. Their disadvantage is dustiness and limited use in high winds.

*Textile sorptive agents* are most often made of polypropylene and polyethylene with the admixture of various additives. They are produced in the form of fibres, nonwoven textiles, fibre structures and other textile modifications. The use of textile sorbents is similar to the loose ones. One of the biggest advantages of textile sorbents is a possibility of reuse. The fabric is wrung out and can be used again until the adsorption capacity of the textile material is exhausted. Another advantage is the possibility to use them in bad weather due to the compact splice of fibres and dust-free characteristic.

*Oil sorbents* are treated for sorption petroleum-based materials. They have special treatment by the hydrophobization. Hydrophobization alters the properties of the sorbent and then it acts oleophilic and hydrophobic, i.e. it absorbs oil products and repels water. The oil sorptive agents are used for collecting the oil products on the water surface and in the environment where water-soluble liquids and water are present.

*Chemical sorbents* are chemically resistant substances applicable to all kinds and types of liquids, including aggressive ones, such as chemicals. They are not suitable for use on the water surface. Textile chemical sorbents are most often made of polypropylene microfibers having a hydrophilic finish for better absorption of fluids such as acids, alkali and alcohol-based fluids. They are available in different colours to distinguish the type of absorbed material. Their use may be in chemical plants, for transportation of chemicals and handling chemicals. In firefighting practice, they are a part of emergency kits, designed for interference with the occurrence of hazardous substance (chemical).

*Maintenance sorbents* are universal sorbents. These sorbents are not as effective as sorbents designed for specific oil (Fingal 2010). Use of maintenance sorbents is wherever leakage of petroleum products occurs as well as escape of various coolants and less aggressive liquids. They are unsuitable for collecting spillage on water surface. They are used mainly as a precaution means against escape in diverse work activities.

Leaks or accidents where hazardous materials are present, are characterized by a diversity of terrain and weather. Just due to this fact, selecting a suitable sorbent is important. The use of a certain sorbent type depends on the physical form of the sorbent, conditions of its use, its quality, the circumstances and the size of the leaked substance (Doerffer 2013).

The aim of this paper is to compare the sorptive capacity, hydrophobicity, spatial and mass performance of selected loose sorbents, which are often used in intervention activities of the FRC as well as sorbents used in the private sector.

## 2. Materials and methods

For determination of the sorptive capacity, sorbents have been repeatedly exposed to various hydrocarbon lubricants. Choice of hydrocarbon lubricants was due to their frequent occurrence at traffic accidents of passenger motor vehicles, which are most often present in road collisions. Choice of sorbents was influenced by information concerning the quantitative use of sorbents in the private sector as well as in terms of the FRC.

Sorptive substances chosen for testing were:

*3mon* – 3mon sorbent is a hydrophobic Calcium Hydroxide with other natural compounds on the plant basis. Very fine grains - 5 microns.

*Absodan plus* – Products Absodan plus are based on material named MOLER by thermal processing (ignition). Particle size is 1.5 – 3 mm.
*Cansorb* – It is loose natural organic material of brown colour having origin in Canada. Particle size is 0.5 – 15 mm.
*Chezacarb* – Highly conductive soot Chezacarb is produced as a product of gasification of heavy oil residues. Particle size is 0,5 – 2.5 mm.
*Expanded perlite* – Expanded amorphous alumina silicate of volcanic origin in a grainy form. Particle size is 0.5 – 2.5 mm.
*PeWaS Sorb* – It is formed by polymeric solid particles having size 0.5 – 4.5 mm.
*Sorptive brash Reo* – Hydrophobic sorptive brash is produced from healthy friendly non-toxic polypropylene in the form of crushed microfibers. Particle size is 0.5 – 15 mm.
*Spilkleen plus* – Oil sorbent Spilkleen plus is a by-product of paper processing industry with multiple sorptive ability when compared with common granules. Particle size is 0.5 – 10 mm.

Selected sorbents: 3mon, Absodan plus Cansorb, Chezacarb, expanded perlite, PeWaS Sorb, sorptive brash, and Reo Spilkleen plus, respectively, were subjected to the influence of hydrocarbon lubricants.

The first test took place with engine oil 10W 40 that is generally used for combustion engines (petrol) or ignition (diesel) engines. Provided oil was from vehicle having run 15,453 kilometres.

The second lubricant sample was hydraulic oil MOL Hydro HV 46 commonly used for hydraulic drives and systems.

The penultimate sample was gear oil PP 80 from a motor vehicle Skoda Felicia; this oil had not been changed during operation 193 583 km.

Last hydrocarbon lubricant provided for the test, were mixed in a ratio of 2 : 4.5. This ratio is common for passenger cars. Passenger vehicles were selected because of their frequency is highest in normal traffic and they are vehicles that cause or are involved in an accident the most often. Two mixture parts represent two litres of gear oil, and 4.5 parts represent content of the oil filling for combustion engines, i.e. 4.5 litres.

The sorptive capacity was determined by a standard test method for determination of sorptive properties of adsorbents (ASTM F 726 2006). The mass and spatial demandingness was measured by small-sized procedure with the laboratory scales and graduated cylinder. The sorption capacity of individual sorbents in loose form is referred in the table and graphical comparison hereinafter below.

The mentioned test method covers the laboratory tests describing properties of adsorbents at the removal of petroleum substances and other floating water-immiscible liquids, which do not form emulsions, from the water surface. According to the method, adsorbents Type II (loose) were tested. All test specimens were conditioned at 23 ± 4 ºC and at relative humidity 70 ± 20 % for at least 24 hours prior the testing in a completely exposed state without overlapping samples in order to obtain equilibrium with the laboratory environment (ASTM F 726 2006). The test method describes the short-term test of adsorption of petroleum products, according to which the samples were tested in a laboratory at the Technical University in Zvolen. Used adsorbents as well as oils were ecologically disposed.

Calculation of adsorbed substance mass in the adsorbent – $a_1$ [g] according to the equation (1):

$$a_1 = a_2 - a_3 - a_4 \quad (1)$$

Where:
$a_1$ - mass of adsorbed petroleum substance [g]
$a_2$ - mass of wet basket, bowl and wet adsorbent [g]
$a_3$ - mass of wet basket with bowl [g]
$a_4$ - mass of dry adsorbent [g]

Calculation of mass adsorption of the petroleum product per mass of adsorbent – $a_5$ [g/g] according to the equation (2):

$$a_5 = a_1 / a_4 \quad (2)$$

Where
$a_5$ - mass adsorption of the petroleum product per mass of adsorbent [g/g]
$a_1$ - mass of adsorbed petroleum substance [g]
$a_4$ - mass of dry adsorbent [g].

## 3. Results and discussion

Sorptive substances were exposed to various hydrocarbon lubricants.


Fig. 3 Sorbent 3mon in a loose form

Fig. 4 Sorbent 3mon after use


Fig. 3 Cansorb in a loose form

Fig. 4 Cansorb after use


Fig. 9 Chezacarb in a loose form

Fig. 10 Chezacarb after use


Fig. 5 Ex perlit in a loose form

Fig. 6 Ex perlit after use


Fig. 13 PeWaS sorb in a loose form

Fig. 14 PeWaS sorb after use


Fig. 7 Sorptive brash Reo in a loose form

Fig. 8 Sorptive brash Reo after use


Fig. 9 Spilkleen + in a loose form

Fig. 10 Spilkleen + after use

Each sample was conditioned and weighed on the weight of 5.00 g. According to ASTM F 726 - 2006 three measurements with each sample sorbent were carried out (ASTM F 726 2006). Obtained values were re-calculated using the formula for calculating the mass of the substance adsorbed on the adsorbent and an average mass of adsorbed petroleum product on the adsorbent was calculated. Using the ratio of the mass of adsorbed petroleum substances and the mass of the dry adsorbent, the mass adsorption of the petroleum product per mass of adsorbent was calculated.

Table 1 Mass capacity of adsorbents for different oil types

| Sorptive substance name | **3mon** | **Absodan plus** | **Cansorb** | **Chezacarb** | **Ex perlit** | **PeWaS Sorb** | **Sorptive brash Reo** | **Spilkleen plus** |
|---|---|---|---|---|---|---|---|---|
| Mass $a_4$ [g] | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Mass $a_5$ engine oil [g/g] | 0.46 | 1.13 | 5.67 | 10.86 | 3.33 | 4.37 | 14.98 | 1.44 |
| Mass $a_5$ hydraulic oil [g/g] | 1.29 | 1.89 | 6.05 | 10.84 | 3.12 | 4.34 | 17.62 | 1.88 |
| Mass $a_5$ gear oil [g/g] | 0.84 | 1.02 | 6.07 | 10.53 | 2.44 | 4.7 | 17.33 | 1.3 |
| Mass $a_5$ engine and gear oil mixture [g/g] | 0.49 | 1.26 | 5.93 | 11.53 | 3.24 | 4.97 | 17.47 | 2.1 |
| Hydrophobicity | YES | NO | YES | YES | NO | YES | YES | NO |

$a_4$ – mass of dry adsorbent [g]
$a_5$ - mass adsorption of the petroleum product per mass of adsorbent [g/g]

The mentioned table shows the diversity of sorption agents and their mass adsorption in terms of used engine oil, hydraulic oil, gear oil, and engine and gear oil mixture with the ratio of 2 : 4.5 for the average values of measurements. The table contains also information concerning the hydrophobic treatment and the dry weight of the samples.

The first measurement shows the difference of adsorption among diverse sorptive materials for the case of used motor oil. The best sorbent is the sorptive brash Reo with the mass capacity 14.98 grams of the substance adsorbed per 1 g of adsorbent. The second measurement relating to the use of hydraulic oil showed that the sorptive brash Reo has the best mass capacity 17.62 g of the substance adsorbed per 1 g of adsorbent. Based on the third comparing measurement with gear oil again the best adsorbent is the sorptive brash Reo with the mass capacity 17.33 grams of the substance adsorbed per 1 g of adsorbent. The last measurement shows the difference of adsorption in case of engine and gear oil mixture with the ratio of 2 : 4.5. Similarly, as in the first three measurements, the sorptive brash Reo reaches best mass capacity 17.47 g of the substance adsorbed per 1 g of adsorbent.

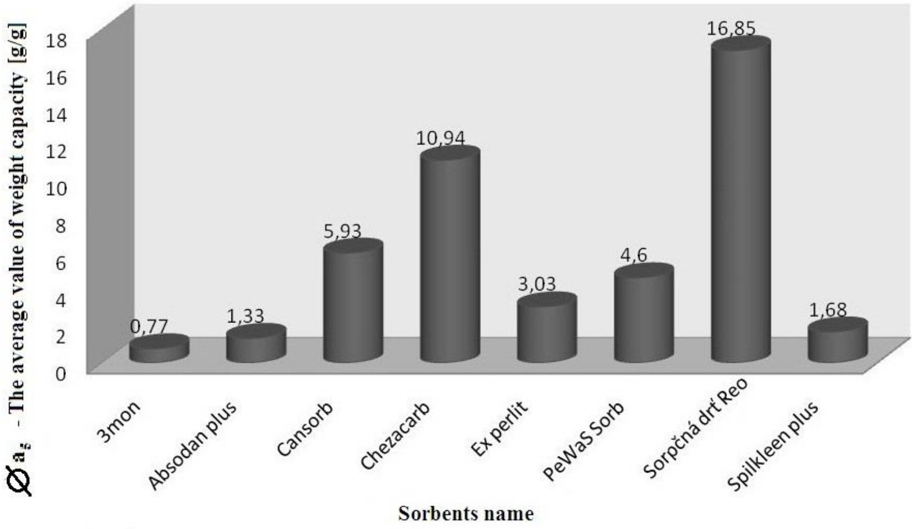


Fig. 11 Average value of the mass capacity in terms of used oils [g/g]

From the Figure 11 follows, that the sorptive brash Reo with the average mass adsorption 16.85 [g/g] is the most effective adsorbent. Sorptive brash Reo is treated with a hydrophobic finish and is suitable as an intervention agent at leakage of hydrocarbon lubricants in a humid environment or on water surfaces directly. During the measurements according to test method, it was found that the measured data do not correspond to the values stated by the manufacturers. The reasons of these variations are different conditions for testing, hydrocarbon lubricants diversity and heterogeneity of tests. The test of short-term adsorption of petroleum products leads to data concerning the maximum possible sorptive capacity and idealizes exposure time of sorbent influencing the hydrocarbon lubricant and sorptive ability not affected by the presence of water.

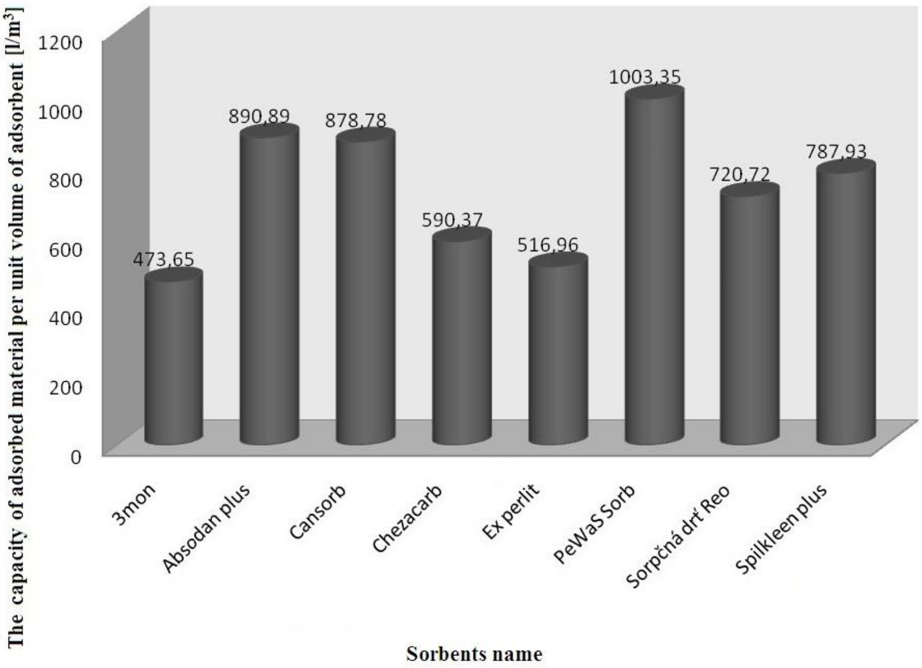


Fig. 12 Volume of the adsorbed substance per volume unit of adsorbent

Figure 12 shows a comparison of selected sorptive agents and their sorptive capacity per volume unit of the adsorbed substance. As regards firefighting practice, we meet many kinds of firefighting equipment designed for different situations and different interventions. Fire-fighting engines contain a lot of material equipment and tools. For this fact, almost every vehicle is often overloaded by equipment. These facts describe the need of sorbents with the highest sorptive capacity in terms to the spatial requirements. PeWaS Sorb was determined as the most compact sorbent. Its sorption capacity is 1,003.35 litres of absorbed petroleum substances per 1 m3 of sorbent volume. Even a small amount of PeWaS Sorb is able to absorb large spills of leaked petroleum substances.

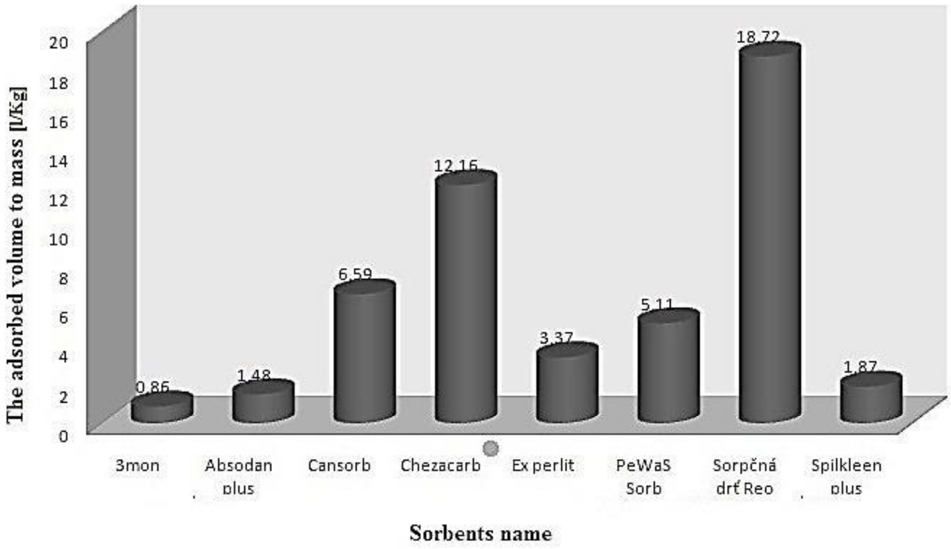


Fig. 13 Volume of adsorbed substance per volume unit of adsorbent

The last graphical Figure 13 compares the mass load of dry sorptive materials. As mentioned, the FRC vehicles are many times overloaded by technical equipment for an intervention activity. The mass of sorbents and their effectiveness may also play a role in choosing the appropriate sorptive means to eliminate the leakage of hydrocarbon pollution. The Figure shows that the sorptive brash Reo is in terms of its mass the most effective one reached the value 18.72 litres of adsorbed material per 1 kg of dry adsorbent.

## 4. Conclusions

The leaked hydrocarbon materials have a large adverse environmental impact. Sorbents play a role in the disposal of the petroleum spills. The paper compares the sorptive capacity, hydrophobicity, spatial and mass demandingness according to the test method and our own comparison. The results of the measurements show the appropriateness of their use in the FRC interventions. Based on defined goals, it was found that each analyzed sorbent has different parameters and therefore different possibilities of its utilization.

By comparing the properties of selected sorbents, it was found that the best sorptive properties reached sorptive brash Reo. This sorbent is treated by a hydrophobic finishing that improves its properties and the possibility of using the water surfaces. It is also the least onerous in terms of its mass relative to the amount of oil that it can capture by its own mass.

Spatial demandingness in fire trucks, which was taken into account, revealed different results for selected sorbents. The least spatial-consuming sorbent is PeWaS Sorb. When choosing sorptive substances, not only basic features are important. Sorbents can also be chosen according other aspects such as flame resistance, dustiness, particle size, environmental friendliness, ability to extinguish etc. Sorptive substances have different applications and therefore it is important to deal with research of new types thereof that will meet a number of criteria, namely not the least queue the environmental impact and degradability.


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# Determination of selected fire-technical and safety characteristics of food dusts

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**Abstract**

The goal of the paper is determination of selected fire-technical characteristics of food dusts. Selected samples are processed in the food processing industry and in the agriculture in mills which are dusty technologies and there exists a real risk of fires and explosions. We put samples of dust particles of the smooth wheat flour and cornstarch to the sieve analysis, thermal analysis by determination of TG (thermogravimetry) and DSC (Differential Scanning Calorimetry) and next measurement was determination of minimum ignition temperature of swirled and settled dusts. Experiments have confirmed that both samples of food dusts are similarly flammable and explosive because of their fire-technical and safety characteristics, so it is necessary to observe fire prevention and provide protection against explosion to the technology.

*Keywords:* food dusts, cornstarch, wheat flour, sieve analysis, thermogravimetric analysis. settled dust, swirled dust;

## 1. Introduction

Fires and explosions of dusts are common risks that occur when handling combustible dusts in industry. Such risks include handling through processing, transport and storage of flammable substances, where exists mining and storage of coal, processing of agricultural products, organic dusts and production of metal powders [1]. For organic combustible dusts which are in operations of plants or in other facilities in the presence of aerodynamic swirling, such dust may be easily dispersed into the air and it becomes a function of variables - the density of dust particles, their diameter, shapes and their cohesive properties in mutual relations to each other and adhesive properties with regard to supporting surface. External factors such as the structure and the intensity of aerodynamic swirling, such as places of deposition of the dust layer (roofs, walls, lighting fittings, floors, shelves, etc.), geometry of surfaces and other operational parameters also affect the spreading of dust. The problem is separately contained in the system in which the dust is dispersed by design, for example, the grinder or pneumatic conveying lines, where the probability of spreading dust is expected [1].

Therefore it is important to know hazardous properties of combustible dusts in order to handle them safely and prevent possible fires or explosions. The most reliable way how to obtain information regarding the fire and dust explosion is to analyse the sample and describe the test results in the form of parameters known as "safety characteristics" [2].

Safety features are not physical constants, but scientists agreed on certain values; they are linked to specific test methods which should be practical enabling simple conversion of test results into practice. The scope of tests has to be determined in close cooperation between the test laboratory and users who are working on resolving this problem [3]. Parameters characterizing fire and explosion are used to assessment of probability of explosion and designing of preventive and protective measures against explosion which are set in laboratories or by large-size tests [1]. Selected safety measures depend on it to prevent fires and explosions or at least to limit consequences of explosions [2].

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Dust explosions in industry may arise from many ignition sources, including static sparks, friction and from flaming or smouldering materials. Dust may explode if following factors are met: dust has to be flammable, it has to be capable to uplift, it has to be capable to spread the flame, the dust concentration has to be within the range of explosiveness, an ignition source has to be present and the atmosphere has to contain enough of oxygen to support and sustain combustion. [3]

It is possible to describe the danger of settled and swirled industrial dust from the point of view of flammability and explosiveness by following parameters: the minimum ignition temperature of settled dust and swirled dust, the relative speed of flame spreading on the layer of settled dust, the lower limit of explosiveness, the minimum initiatory energy ignition of swirled dust, the maximum explosive parameters [4].

The reaction burning rate of settled dust is affected by: dimensions of dust particles, amount of oxygen absorbed on the dust surface, the dust temperature, the shape and area where the dust is located, the dust moisture and the dust composition [5].

Each fire of combustible dust can easily go into explosion and vice versa. The half of swirled dust may burn in optimal case, in case of dust explosion, the rest of not reacted dust may burn further. When large amount of oxygen was spent during explosion, the fire need not to follow after explosion [6].

Industrial explosions of dust usually occur in the sequence - the primary explosion in pre-spread out the dust cloud, followed by one or more secondary explosions. Continual repetition of this process results in a considerable overpressure causing larger damages of buildings and facilities [1].

Silos serve as containers for storage of bulk materials or dust in wood processing industry and in agriculture. Volumes of silos range from several cubic meters of supplying silos up to several thousand cubic meters for storage of grain or sugar.

There exist silos having cylindrical shape or silos having rectangular cross-section. Preconditions of fire and explosion are permanently present in silos where combustible and bulk materials are stored. The sensitivity to combustion of material depends on its chemical structure and physical properties such as particle size, porosity and moisture content [5].

It is necessary to determine and define physical and chemical properties of materials relating to bulk materials because they were a cause of large amount of fires.

It is necessary to consider five different factors in analysing of risk:

- the danger having relation to the bulk material and to its handling,
- the danger having relation to technology device,
- risks having relation to the regime of operation and maintenance,
- the speed of spreading the fire,
- expected losses in case of fire or explosion [9].

Assessment of such factors leads to the concept for prevention and protection against fires and explosion. Technical and organisational measures are possible.

## 2. Methodology and material

We selected methods for determination by sieve analysis, thermic analysis and measurement of minimum ignition temperature of samples in settled and swirled dusts for determination of selected fire-technical and safety features of wheat smooth flour and cornstarch.

### *2.1. Material*

Organic dusts from the food industry, smooth wheat flour and fine cornstarch were selected as test samples of dusts.

**Wheat**

Chemical content of the wheat grain is various. It contains starch, proteins, fats, sugars, cellulose, ash, phospholipids, vitamins, ferments and other substances. [10].

About 70-75% of proteins of the wheat grain are localised in the endosperm. There is the layer of aleurone cells between the endosperm and cover layers representing about 6 - 7 % of the weight of grain. There is a high content of proteins, lipids and vitamins creating the protein complex in cells of aleurone layer. About 14 – 15 % of the weight of grain represent cover layers. They contain the most mineral substances, vitamins, especially B - vitamins and fibre from entire grain [11].

The spectrum of content of mineral substances is in relation of app. 1.4 - 3 %. It is possible to identify on average 450 mg of phosphorus, 380 mg of potassium, 160 mg of sulphur, 140 mg of magnesium, 60 mg of calcium, 30 mg of sodium, 5 mg of iron, 4.5 mg of manganese, 3 mg of zinc, 2.5 mg of boron, 0.7 mg of copper and per 100 g of dry matter and in small amounts others [12]..

Table 1 The chemical composition of wheat in % [13]

| | **Ash matter** | **Fat** | **Proteins** | **Starch** | **Fiber** | **Pentosans** |
|---|---|---|---|---|---|---|
| Whole grain of wheat | 1.92 | 2.2 | 14.1 | 66.2 | 2.5 | 7.,9 |

The composition of combustible dust of the smooth wheat flour which is crushed from inner part of the grain containing identical components obtained by grinding from the wheat grain belongs to the most important factors.

Table 2 Fire technical characteristics of selected food and their dust [14]

| **Type of food** | **Begin development of after-damp (°C)** | **Flashpoint (°C)** | **Fire point (°C)** | **Ignition point (°C)** |
|---|---|---|---|---|
| Flour | 140 -145 | 170 - 180 | 230 - 240 | 265 - 270 |
| Starch | | | | 470 - 640 |
| Wheat dust | | | 380 | 205 |
| Corn dust | | | | 850 |

**Corn**

The corn is the most important raw material for industrial production of the starch. The starch is created by grinding from grains from dry corn. The sweetcorn is the most cultivated species, the corn is consumed fresh, canned or frozen. It is characterized by its grain containing a high percentage of sugar in the stage of lactic ripeness, when it is suitable for processing in kitchen. It is dried to the moisture of 15 % for production of the *starch*.

*Composition of the starch*

The cornstarch is a polymer of glucose (C6H10O5)2, located as a reserve substance. The cellulose is another type of polymer of glucose. The starch in comparison to cellulose is made up of alpha-glucosidic bonds which form helical molecules. The cellulose is made up of beta-glucosidic bonds, which create long, straight molecules having the fibre structure. The starch in the plant occurs in the grainy form having the diameter of 1-140 μm.

The cornstarch mostly consists from 25 % of amolyse and 75 % forms amylopectin. The two components are made up of long rows of molecules of glucose and it also contains lipids, proteins and water. The high content of amylopectin is associated with higher viscosity and stability against temperature and pH. The starch of amylo-corn does not gelanitise in usual way and it is used in the textile industry, in production of adhesives and also in the food industry.

*2.2. Methodology of the experiment*

**Sieve Analysis of Dust Samples**

The sieve analysis is the method of finding out the size of particles of solid substances. This method belongs to the so-called. fractionation or separation techniques of analysis of particles size. The sieve analysis is based on using of a set of sieves having known size of apertures which is set in direction of gravity transport of analysed substance into the block with gradually lowering the size of apertures. Certain part of the original sample containing particles within the limits determined by size of apertures of the upper and lower sieves remains on the each sieve after completion of fractionation. The rest on the sieve is weighted and the result is assessed as the weight of fractions with defined interval of the size of particles. The result of sieve analyses in the form of mass content of particular fractions as well as gain of real sample with defined size of particles belong to the greatest advantages of this method. It was necessary to make a sieve analysis of samples before measurement of minimum ignition temperature of dusts in settled and swirled states. The sieve analysis was performed on the device marked as RETSCH AS 200 lasting 10 minutes. The duration of the sieve analysis was selected upon the size of particles of dust sample.

The amounts of samples of the smooth flour and the cornstarch were measured before performing the sieve analysis which were placed on the sieve having the largest size of apertures (500 μm). The weight of each fraction was measured on analytical scales (KERN PLT 450-3M) after performing the sieve analysis; it provided us an information about the size and percentage representation of particles which were present in examined samples.

**Thermic Analysis of Dust Samples**

The thermogravimetry, differential thermic analysis, differential scanning calorimetry, thermic dilatometry and enthalpiometry belong to the most important methods of thermic analysis.

Samples of the dust of the wheat flour and the cornstarch were analysed by thermogravimetry (TG) and differential scanning calorimetry (DSC).

The thermogravimetry (TG) is the method of thermic analysis which studies the course of thermolysis and combustion of polymers. It follows also changes of the weight of heated sample. The thermogravimetry, according to method of the heating the sample, may be either isothermic (suitable to monitoring of self-heating and self-ignition processes) or dynamic, in which, the temperature varies according to predetermined programme [15].

The method of thermic analysis, differential scanning calorimetry is often used at present, also referred to as enthalpy thermic analysis (DSC - Differential Scanning Calorimetry). It is process, through which the difference between the heat flow (energy) supplied into the test sample and the reference sample is measured as a function of temperature and / or time, while the test and the reference samples are exposed to selected temperature programme.

The DSC uses an additional source which balances the temperature difference between uniformly heated sample and compared substance. The energy consumed to this balancing is measured directly beside it. The advantage is particularly simple, direct determination of specific reactional heats [15].

Thermogravimetry - thermal decomposition of dust samples of the flour and the starch will run in three stages at constant heating rate of 10 °C.min$^{-1}$.

**Determination of minimum ignition temperature of dusts in settled and swirled states**

The minimum ignition temperature in the settled state $t^{u}_{min}$ and ignition temperature in the swirled state $t^{r}_{min}$ are obtained upon the Slovak Technical Standard STN EN 50281-2-1. Electrical devices for use in premises with presence of flammable dust Part 2-1: Test methods. Methods to determination of minimum ignition temperatures of dust [16].

Samples of dusts were stabilized and treated equally. The height of settled dusts was 5 mm. The principle of determination was applying the dust sample on hot surface of the metal plate on which was placed thermocouple measuring the temperature of the hot surface. Another thermocouple was placed 1 mm below the surface of the dust sample; the thermocouple was reading its fluctuating temperatures. Whether it was ignition (heating or smouldering) was concluded on visual appearance of the sample.

It is stated in above mentioned standard, that thermocouple reading the temperature of the surface of the settled dust sample have to pass through entire diameter of testing ring where the dust sample is placed. Because of absence of such thermocouple, the measurement was performed with the thermocouple having its end placed in the middle of the ring. But measured values are relevant and comparable with measurements in which the thermocouple is passing through entire diameter of test ring would be used.

Determination of ignition temperature of dusts in swirled state trmin rests in creating combinations of charge of the sample, furnace temperature and chamber pressure containing technical air which swirls the sample. Determination of minimum ignition temperature of swirled dust influences the weight of charge of the dust sample, temperature of the hot surface of furnace and pressure of technical air swirling the dust sample and transferring it into furnace.

We used charges having the weight 0.1; 0.3 and 0.5 g and the pressure of technical air of 10, 20 and 50 kPa in determining the minimum temperature of ignition of swirled smooth flour and cornstarch. After positive response, (i.e. an ignition happened), we reduced the temperature of the furnance to such a value at which an ignition of any combination did not come on.

## 3. Results

### *3.1. Results of the sieve analysis*

We obtained results shown in the Tab. 3 by the sieve analysis of samples of solid particles of the smooth wheat flour and the cornstarch. Particles having the size of 90 μm have the largest representation in the sample of the cornstarch. Particles having the size of 71 μm have the largest representation in the sample of the smooth flour. An important finding is that the value of the overflow through all screens to the bottom in the case of the cornstarch was 1.463 g; this value is much higher in comparison to the smooth flour, because the value of the overflow of the smooth flour is 0.032 g. We can conclude from shown measured values of percentage representation of solid particles of samples according to size of sieves that solid particles of smooth wheat flour have finer fractions than cornstarch.

Table 3 Measured values of flour and corn starch by sieve analysis

| **Mesh size (μm)** | **Corn starch** | | **Flour** | |
|---|---|---|---|---|
| | Weight (g) | Percentage | Weight (g) | Percentage |
| **500** | 0.208 | 0.73 | 0.202 | 0.70 |
| **250** | 3.394 | 11.94 | 1.243 | 4.32 |
| **200** | 2.895 | 10.19 | 1.513 | 5.26 |
| **150** | 3.387 | 11.92 | 1.518 | 5.28 |
| **90** | **9.771** | **34.38** | 9.172 | 31.88 |
| **71** | 5.313 | 18.69 | **11.569** | **40.21** |
| **56** | 1.598 | 5.62 | 3.376 | 11.73 |
| **45** | 0.393 | 1.38 | 0.148 | 0.51 |
| **Bottom sieves** | **1.463** | **5.15** | **0.032** | **0.11** |

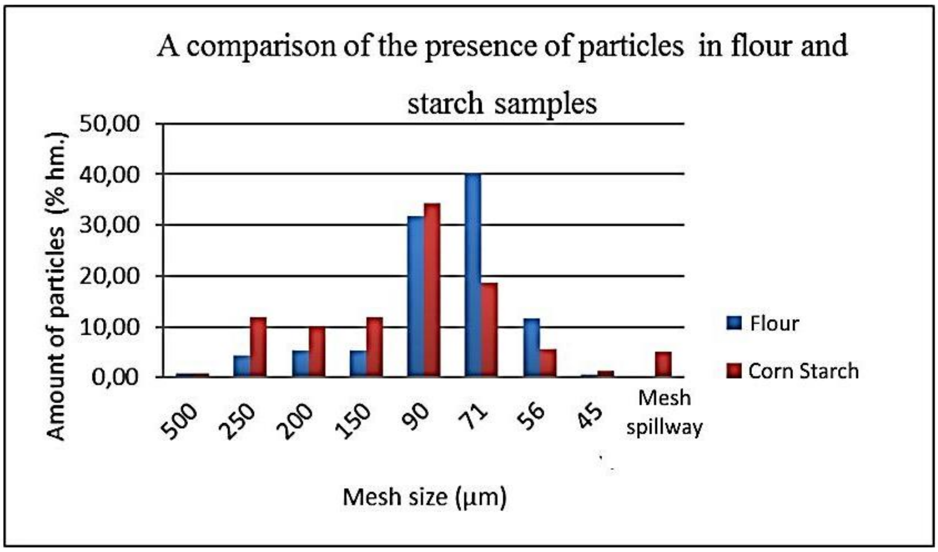


Figure 1 Comparison of the presence of particles in flour and starch samples

The percentage of representation of the size of samples of smooth flour and corn starch by sieve analysis is shown at the Figure 1.

*3.2. Thermic analysis of dust samples*

We found out by experiments of samples by thermogravimetric analysis that the shape of the curve that represents the dependence of the change of the weight on increasing temperature is similar in both of samples of dust particles. The course of thermic decomposition of the smooth wheat flour is shown at the Figure 2 and the corn starch is at the Figure 3.

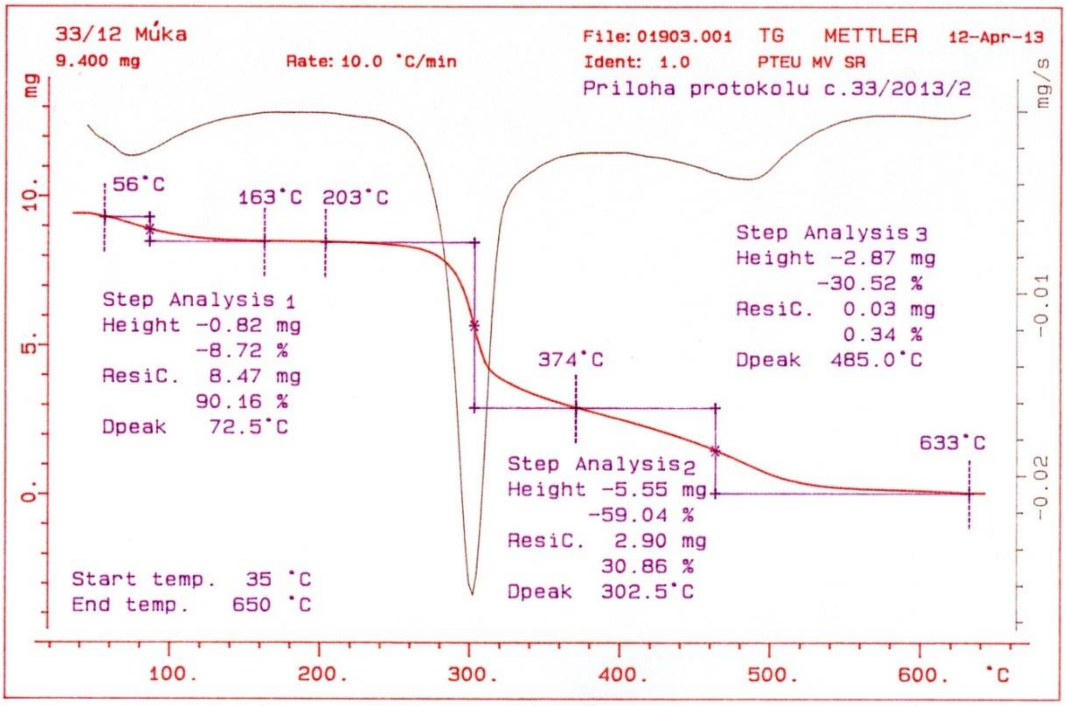


Figure 2 TG analysis of wheat

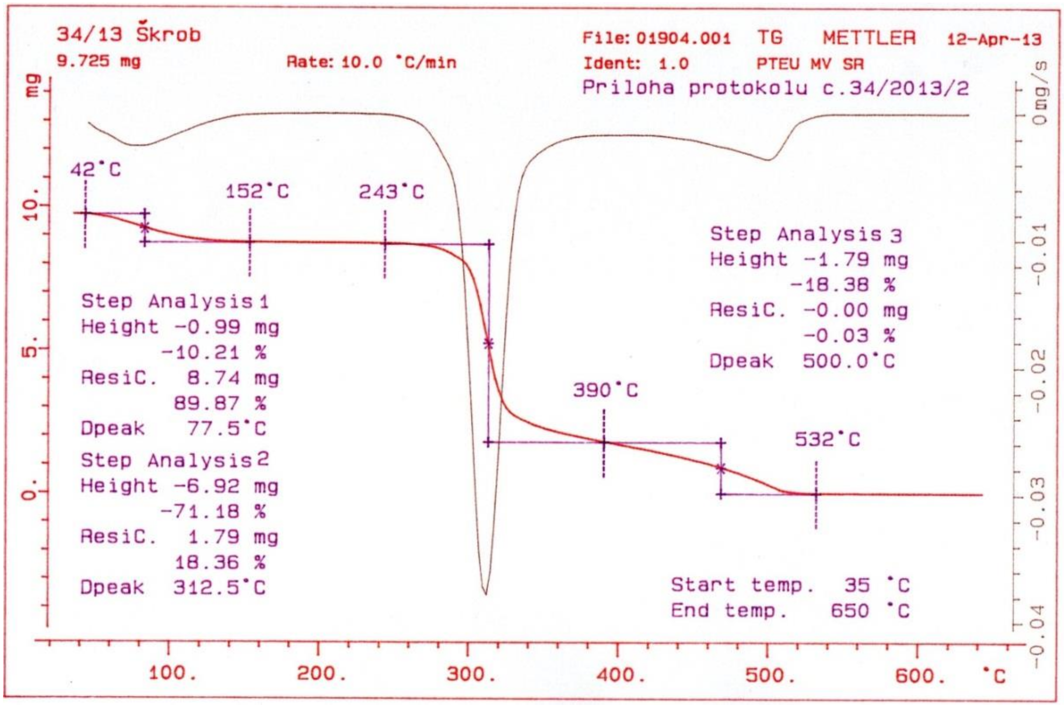


Figure 1 TG analysis of corn starch

Data obtained from graphic courses of the dependence of the change of the weight on increasing temperature of both of dust samples are shown in Table 4.

Table 4 Thermal characterization of the various stages of dust samples decomposition with TG analysis

| **Sample, sample weight** | **Intermediate stages of decomposition** | **Temperature range (°C)** | **Weight loss (%)** | **The temperature at max. rate of decline (°C)** | **Resistant Carbon (%)** |
|---|---|---|---|---|---|
| **Flour 9,400 mg** | I. grade | 56 – 163 | 8.72 | 72.5 | 90.16 |
| | II. grade | 203 – 374 | 59.04 | 302.5 | 30.86 |
| | III. grade | 374 – 633 | 30.52 | 485.0 | 0.34 |
| **Corn starch 9,725 mg** | I. grade | 42 – 152 | 10.21 | 77.5 | 89.87 |
| | II. grade | 243 – 390 | 71.18 | 312.5 | 18.36 |
| | III. grade | 390 - 532 | 18.38 | 500.0 | 0.03 |

It results from the Table 4 that dust samples of the smooth wheat flour and cornstarch are behaving differently during particular stages of thermic decomposition. The first stage of decomposition represented the phase of final drying, the weight loss of the flour was at this stage of decomposition 8,72% and 10,21% in the case of the starch. It is not possible to see significant differences kn behaviour of dust samples n the first stage of thermal decomposition; but it is not the case in the second and third stage. It is possible to observe the significant loss of the weight of both samples. It is the value of 59,04 % in the case of flour and 71,18 % in case of the starch; it represents an essential difference between theses dust samples. So, the cornstarch has much lower resistance against the thermic degradation in this stage of decomposition.

The third stage of decomposition proceeded in the sample of the wheat flour up to temperature of 633 °C and in the sample of the starch up to temperature of 532 °C. The active phase of decomposition of the cornstarch finished at a lower temperature than in the case of the wheat flour, which is associated with a different composition of dusts. The decrease of the weight of the flour was 30,52 % and of the starch was 18,38 % in the third stage of decomposition. We can therefore conclude that the amount of the dust, that was not subject of degradation in the second stage of the thermal decomposition, was decomposed in the third stage at much higher temperatures. The higher decrease of the wheat flour in the third stage of decomposition was caused only due action of higher temperatures than in the case of cornstarch.

The result of differential scanning calorimetry analysis of samples of food powder particles with this method is information on endothermic and exothermic processes during controlled thermic decomposition. The dependence of the reaction enthalpy of the sample of the wheat flour on increasing temperature is shown at the Fig. 4 and the cornstarch at the Fig. 5.

Temperature intervals with significant changes of endothermic and exothermic reaction enthalpies were observed in both of tested samples of dust. The endothermic process run within the range of temperatures from 35 °C to 129 °C and the exothermic process run within the range of temperatures from 240 °C to 600 °C in the case of the smooth flour. The endothermic process run within the range of temperatures from 35 °C to 132 °C and the exothermic process run within the range of temperatures from 250 °C to 600 °C in the case of the cornstarch. There are predominantly dehydrating processes in temperature ranges of the endothermic process in both of dust samples. The exothermic process on both of dust samples is characterized by a rapid increase of the change of the reaction enthalpy. The rapid increase of temperature is documented by ongoing oxidation.

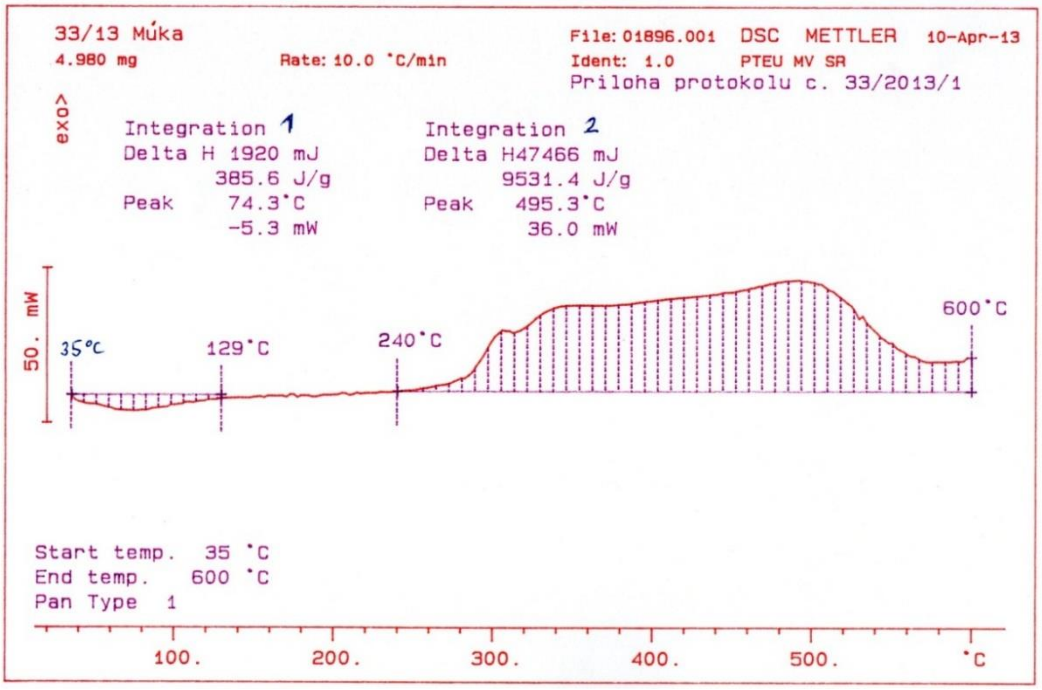


Figure 4 DSC analysis of flour

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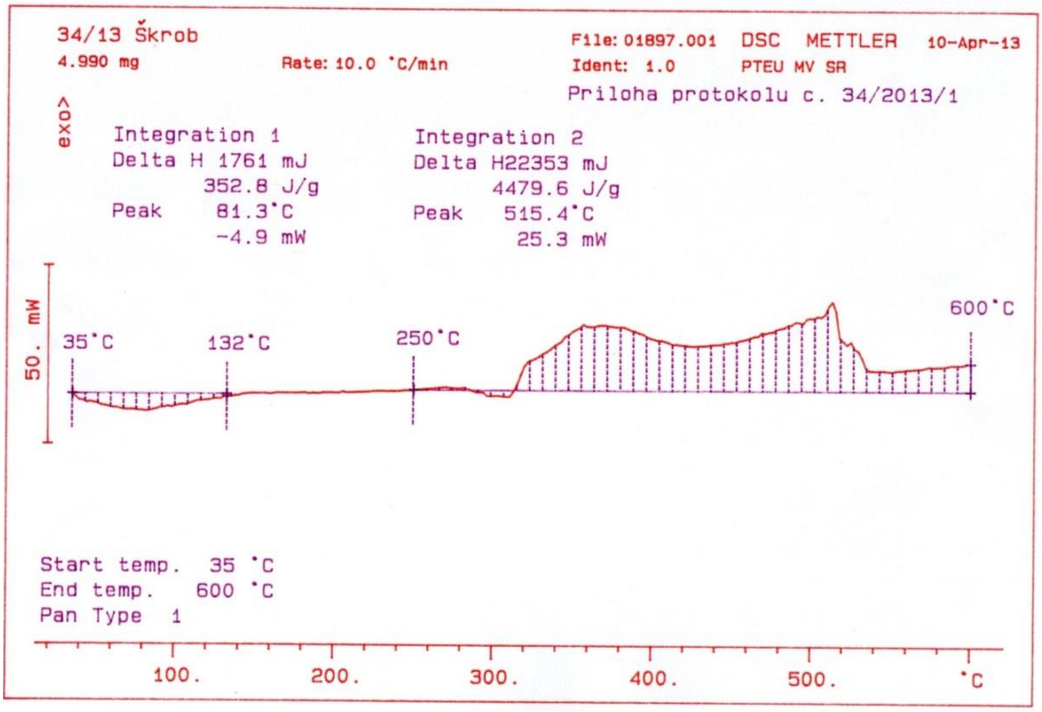


Figure 5 DSC analysis of corn starch

Data obtained from graphs of the reaction enthalpies of the two samples of dust from the rising temperatures are summarized in Table 5.

Table 5 Dependence of enthalpy reaction of dust samples (DSC analysis)

| Sample, sample weight | Temperature range (°C) | Change of enthalpy reaction ($J.g^{-1}$) | Temperature at max.peak (°C) |
|---|---|---|---|
| **Flour 4.980 mg** | 35 – 129 | 385.6 (endo) | 74.3 |
| | 240 – 600 | 9531.4 (exo) | 495.3 |
| **Corn starch 4.990 mg** | 35 – 132 | 352.8 (endo) | 81.3 |
| | 250 – 600 | 4479.6 (exo) | 515.4 |

It is clear from graphic courses shown at the Fig. 5 and 6 that the larger area of exothermic peaks at dust samples than endothermic peaks are, the more significant process of thermic degradation is. It results from the Tab. 4, that reaction enthalpies of dust samples of the flour and starch in endothermic processes running within the range of temperatures 35 - 129 °C are from each other very different.

*3.3. Determination of minimum ignition temperature of dusts in swirled state*

It results from tables 6 and 7 that temperature in which the dust-air mixture of the smooth flour was still ignited is 450 °C and 440 °C in the case of the cornstarch. The minimum ignition temperature of swirled dust is determined according to Slovak Technical Standard STN 50281-2-1 so from the temperature at which the air-dust mixture still ignites is deducted value of 10 K (or 10 °C). It means, that the minimum ignition temperature of swirled smooth flour is 440 °C a cornstarch is 430 °C.

Measurements, where the condition of negative feedback was present, (especially from the point of vie of low pressures, low weights and lower temperatures), were not repeated at all. Other measurements were repeated three times.

Table 6 Determination of the minimum ignition temperature of turbid wheat flour

| Weight (g) | Pressure (kPa) | Temperature (°C) | Status (Y/N) | Note |
|---|---|---|---|---|
| **0.1** | 10 | 450 | N | - |
| | 20 | 450 | N | smoke |
| | 50 | **450** | **A** | flame |
| | | 440 | N | Intensive smoke formation |
| | | 430 | N | smoke |
| **0.3** | 10 | 450 | N | smoke |
| | 20 | 450 | N | smoke |
| | 50 | **450** | **A** | Intensive flames |
| | | 440 | N | Intensive smoke formation |
| | | 430 | N | smoke |
| **0.5** | 10 | 450 | N | - |
| | 20 | 450 | N | smoke |
| | 50 | **450** | **A** | flame |
| | | 440 | N | Intensive smoke formation |
| | | 430 | N | smoke |

Table 7 Determination of the minimum ignition temperature of turbid cornstarch

| Weight (g) | Pressure (kPa) | Temperature (°C) | Status (Y/N) | Note |
|---|---|---|---|---|
| **0.1** | 10 | 450 | N | - |
| | 20 | 450 | N | smoke |
| | 50 | 450 | N | smoke |
| **0.3** | 10 | 450 | N | - |
| | 20 | 450 | N | - |
| | 50 | 450 | A | flames, slower ignition speed |
| | | **440** | **A** | flames |
| | | 430 | N | smoke |
| **0.5** | 10 | 450 | N | - |
| | 20 | 450 | A | flames, more intensity |
| | | 430 | N | - |
| | 50 | 450 | A | Intensive flames |
| | | **440** | **A** | flames, smaller intensity |
| | | 430 | N | smoke |

*3.4. Determination of minimum ignition temperature of dusts in settled form*

It results from tables 8 and 9, that the temperature of the hot surface, when the sample of the settled dust of the smooth flour is still ignited is 310 °C and 320 °C in case of the corn starch. The Slovak Technical Standard STN EN 50281-2-1 states that the minimum temperature of the settled dust is determined in such a way, that from the minimum temperature that still ignites the sample of settled dust is deducted value of 10 K (or 10 °C). It means, that minimum ignition temperature of the dust in settled form for the smooth wheat flour is 300 °C and 310 °C for the corn starch.

Table 8 Determination of minimum temperature of flour ignition

| Layer thickness | Surface tempera- | Result of a test | Note | Period of igni- |
|---|---|---|---|---|
| **5.0** | 410 | ignition | glowing | 4 min. |
| | 360 | ignition | glowing | 9 min. |
| | **310** | ignition | glowing | 16 min. |
| | 300 | without ignition | - | - |
| | 290 | without ignition | - | - |
| | 280 | without ignition | - | - |

There is significant difference in the form of courses of temperatures of examined samples in determination of minimum ignition temperature of settled dust from the point of view of comparing examined dust samples. Comparison of courses of temperatures both of examined samples of the smooth flour and cornstarch in determination of minimum ignition temperature is shown at the Figure 6.

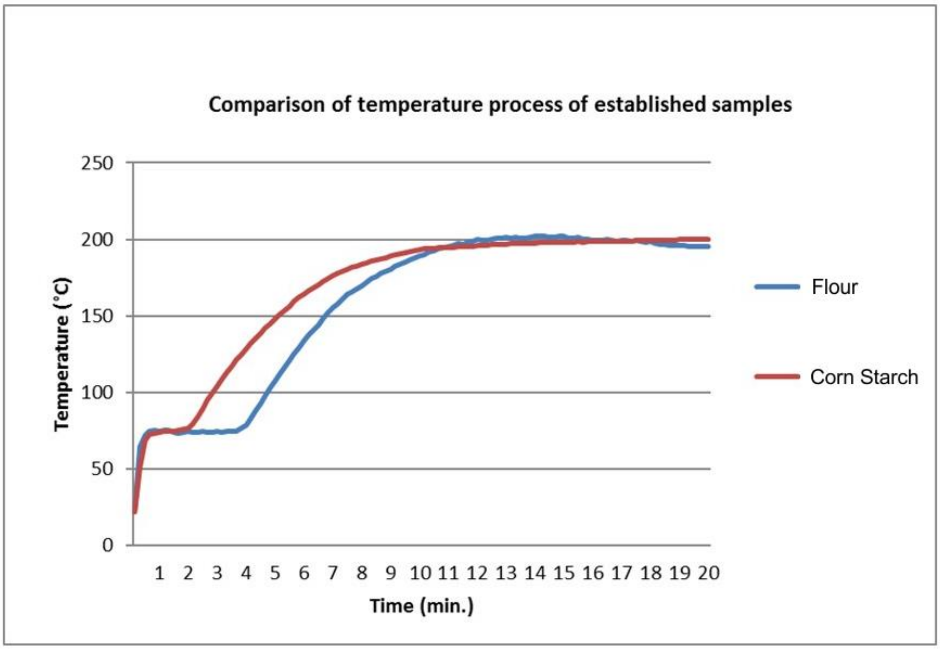


Figure 6 Comparison of temperature processes of sedimented flour and starch samples

It is clear from the courses of temperatures of the smooth flour and the cornstarch, that the sample of the smooth flour has a slower increase of temperature in comparison to the sample of the cornstarch what has relation to composition of samples.

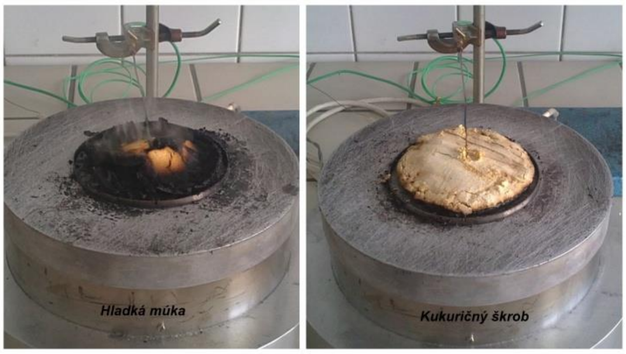


Fig. 3 Dust sample in sedimented form at 410 °C


Fig. 4 Limit states of sample ignition in sedimented form

Manifestations, on which the limit, when the sample of the dust was still ignited, was determined, are shown at the Figure 8.

### *3.5. Evaluation of results*

The TG and DSC analysis shows that the smooth flour has higher resistance against the thermic degradation than it is in the case of cornstarch. The sieve analysis itself also shows to different composition of particular fractions of samples. We observed in determination of the minimum ignition temperature that the flour behaved in similar way at each tested temperature. Its surface did not remain compact even once (cracks were created) and the layer of the flour increased after exposition to hot surface.

We observed in determination of minimum ignition temperature of the corn starch that the sample of the starch behaves specifically after exposition to the hot surface, also in the same way like the flour. The surface of the sample of the starch remained compact in most cases. Although the small cracks also appeared at the surface, but the sample always remained compact and its thickness, similarly as in the case of the flour increased due to effect of temperature. There are shown at the Figure 7 demonstrations of examined samples in settled form at the temperature 410 °C.

Both dust samples simulated real conditions in operations and therefore in determining the minimum ignition temperature was not used the representative fraction, but sample of all factions.

## 4. Conclusions

We can formulate results obtained by testing samples of smooth flour and starch as follows:

- By evaluation of sieve analysis of dust particles we state higher percentage representation of finer fraction of particles in smooth wheat flour then in cornstarch; we can assume the lower limit of explosiveness and higher reactiveness in the smooth wheat flour due to it.
- The TG analysis shows that the dust sample of the corn starch is less resistant to thermic degradation and it degrades at lower temperatures than wheat flour.
- The sample of the wheat flour had higher value of reactive enthalpy from DSC in exothermic process in both intervals of temperature than the sample of cornstarch; we can conclude from it, that more intensive process of thermic degradation run in case of sample of wheat flour then in case of the sample of cornstarch.
- The minimum ignition temperature of swirled smooth wheat flour is 440 °C and 430 °C in case of swirled cornstarch.
- According to observed values and the course of behaviour of dust samples during determination of minimum ignition temperature of settled samples we can state that the smooth flour is subject of ignition at lower temperature compared to cornstarch and its demonstration of carbonisation were more conspicuous.

Dust samples of the wheat flour and the cornstarch, which have been subject of experiment in order to obtain the fire-technical and safety parameters, namely determination of sieve analysis, subjected to thermic analysis and determination of the minimum ignition temperature of swirled and settled dust declare unequivocally, that it is a case of combustible organic food materials that represent the risk of fire and explosion in the food industry. By their nature, they are classified as grain and other crops, i.e. they are flammable substances. In addition to it, they have a tendency to self-ignition. Mixtures of dust with air and its sediments are especially dangerous and that is reason why it is necessary to assess the risk of fire and take effective measures against the fire and explosion in operations with their presence.

## Acknowledgments

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# Use of 3D laser scanning system for using during fire investigation

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**Abstract**

The paper deals with the utility of 3D laser scanning system at the scene of the fire. This is a relatively new and progressive method of documenting and digitizing location of the fire seat. The output is very detailed pictorial and surveying, topographic documentation, including a record in the infrared spectrum. Outputs can be further implemented to fire technical expertise.

*Keywords:* 3D documentation, search, fire and technical expertise, seat of the fire, scanning, investigating causes of fire;

## 1. Introduction

The Population Protection Institute created an expert group designed to perform expert activities during fire investigations. The group operates nationwide and helps to determine cause of fires at the scenes of the fires. This assistance can be imagined as an aid in inspecting and evaluating a fire scene, taking samples for laboratory examination, suggesting causes of the fire and the actual laboratory examination. Subsequently, the results are processed into the fire-technical expertise in the form of expert opinion.

A 3D laser scanning system, specifically an ultra-portable laser scanner Focus3D X130 from an American manufacturer FARO, has been acquired for this workplace to improve quality of its findings when conducting fire investigations.

Scanners of this type are commonly used in the construction, archaeology, geodesy and other industries. During the 2016, the author in collaboration with Mgr. Zdenek Marek from the Police Academy of the Czech Republic in Prague, was verifying usability of the scanner and the subsequent incorporation of gain data into the fire rescue practice because the scanning system offers a wide range of utilization within the Fire Rescue Service of the Czech Republic. It is possible to use the system within both the State Fire Supervision (when performing tasks of supervising the fire safety in construction, inspections in fire prevention and identification of the causes of fire) and the Fire Rescue Units for intervention when dealing with emergencies, and preparing for them during the training of modelling and simulation.

## 2. Brief introduction of the spatial digitization methods

Spatial scanning is a geodetic method of measuring spatial coordinates. It is based on automatic and precise tracking of a large number of points that define the area in the tri-axial coordinate system. These points are generally called a point cloud, where every point is defined by coordinates X, Y, Z. The system is capable of obtaining up to 976,000 spatial points per second from the surrounding area. In this way it is possible to define an object, room, multileveled house, street, and even an entire city. The measuring, using this type of scanner, is performed at a distance of 130m from its location and it focuses everything within its direct visibility. The scanner is stationary and during scanning it is statically placed on a tripod and can be ejected up to 4,5 meters high.

The spatial scanner operates in a contactless manner. It emits a laser monochromatic beam at a wavelength of about 1550 nm. The beam falls on a rotating oblique mirror; the angle of incident is 90°, which ensures scanning the area in the vertical direction. Scanning in the horizontal direction is provided by rotating the scanner around its own vertical axis. The laser

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scans the area horizontally (360 degrees) and vertically (305 degrees), or a sector specified by the operator. The scanner is also able to scan in an inverted mode by 180 °, i.e. upside down, and thus digitize the space underneath.

The accuracy of the data collection directly depends on the reflectivity of the materials the scanned objects are made of. The worst precision of the scanner is defined as +/- 2 mm at a distance 25 m at 90% reflectivity of the surface. During average applications the scanner manages an average accuracy of +/- 0.8 mm.

The outputs are standard 3D data appearing in the infrared spectrum in a shade of gray. The scanner has a built-in internal camera, which is also able to document colour information from the visible electromagnetic spectrum. The resulting colour photograph, which is when processed applied to the 3D data, is then at a resolution of up to 70 million spatial points (megapixels).

The scanner is equipped with additional internal sensor technology such as GPS sensor, digital compass, thermometer, altimeter, digital spirit level and more. These sensors operate mainly automatically and at the time of scanning they provide to the 3D data with other necessary information. A more detailed description of the method, used by the laser scanning system was described in the conference papers "Fire Protection in 2016" [1].

To scan complete data, location scanning is performed, where the resultant data are combined into a single project. The output is in the form of an accurately documented incident site (seat of fire), creation of 3D digitizing incident site, and virtual measurements of acquired 3D data. It is also possible to simultaneously perform scanning of surfaces and cubature. After a few minutes of semiautomatic work, a topographic documentation is available. A fire investigator then obtains accurate 2D plans with a scale, orthogonal views, 2D sections and section plans. This scanning system can greatly increase inspection efficiency of the seat of fire as there is then no need for measuring the rooms, the technologies at the scene of the fire, and manually drawing them in the surveying sketches.

The comprehensive visual information, which is represented by a virtual tour in a standard form of an HTML webpage forms another output. It is therefore not necessary to install any imaging software, viewers. The virtual tour operates both from a DVD in the so-called off-line mode, or it can also work through the Intranet without any limits of computing power of the computer terminal. Is it possible to protect it with a password, so that it is then accessible only to people with the knowledge of the correct password. This option is used mainly abroad where the data is shared on the Intranet.

## 3. Practical experience in using laser scanning system abroad

Spatial scanners have been used in various fields such as industry, mining and geodesy since 1999, but only during the last few years these systems became more affordable and thus they are no longer considered special and expensive applications. They are now available as common devises in construction, industry and other areas.

The scanning system has been implemented in criminology since 2012, when the Swiss police bought the system and applied it to selected cases of the crime scene documentation. In 2014, other countries such as Germany, Great Britain, France and Norway followed. However, none of the above states adopted a blanket approach to usage of this method. Nevertheless, a special unit has been created within all those police structures with a defined territorial scope, which provides a complete service to under units conducting examination and investigation of the crime scene. Since 2014 further other states and territories has started using this method. [2]

We can find possibilities of using the laser scanning system at the scene of the incident in foreign literature [3]. It presents examples of scanning a forest fire scene using firearms and collapsed road bridge. Virtual tours of the fire scene, and mapping of the fire scene location in 2D and 3D forms the output of the scanning. The system allows to upload files via "hot spots" of photos, notes, laboratory examinations. The system enables measuring sizes of an object, distances, scanning in the dark, taking photos, processing plans, and recording damage caused by fire in the infrared spectrum. The output data can be inserted into CAD systems to create a physical model. Another option is to create websites with virtual tours.

Dr. John Dehaani, the author of the aforementioned literature, in his article [3] describes the main benefits of this method. He has become one of the leading protagonists of 3D scanning methods in the forensic field. The traditional manual collection of spatial data or measurements has many limiting factors. Exterior explosion sites are among the most challenging ones, because explosion fragments - forensic clues are scattered tens to hundreds of meters away. Using traditional methods used to make this examination very demanding in terms of speed, quality, and quantity of data collection. It often occurs that the data, collected in a traditional way are fragmented and incomplete, even though it is important to locate the exact position of forensic evidence and efficiently, comprehensively document it. Deploying the new 3D scanning methods prevents specialists from making fundamental errors in the documentation of inspected fire scene and above all the investigators can virtually return to the site of an explosion at any time and repeat any measurements. The author states that this is a huge shift in investigating the causes of fires and explosions.

## 4. Practical experience of the Population Protection Institute with using the laser scanning system

In terms of the security forces of the Czech Republic the laser scanning system has been used since 2016 only by the pyrotechnic services and now also by the Population Protection Institute. During the 2016, possibilities of the laser scanning system were tested for the purposes of fire cause investigations.

The first place where the scanner was used, was the building of a former children's clinic, which is in terms of documentation and creation of topographic documentation complexed and dissected. Due to the abandonment of the object, there have been several fires in different places inside it in recent months. In this particular case a total of 20 exterior scans and 48 interior scans of the building were generated. On account of the vastness of the building and individual unrelated outbreaks of fire, only the scenes of fire were documented and other unrelated rooms were not scanned. Effectiveness and usefulness of the 3D data was verified on specific fire scenes. Accurate 2D maps with a scale and orthogonal views form the output of the obtained data. In the virtual model dimensions of the furniture and fittings damaged by the fire were consequently scanned, and a scale of the damage caused by radiating heat was determined

Furthermore, the method verified applicability of the method in case of multiple outbreaks of unrelated fires which originated at different times and places. Produced virtual tour, which formed the outcome of this scan, clearly showed details of various seats of fires which were spaced apart and occurred on different days and months. The user, while not being physically at the scene of fire, could gain an impression of the event. This virtual tour also allowed users to take measurements (Figure 1) anywhere at any time, e.g. to measure sizes of the rooms, fixtures, areal dimensions of charred seats. The data were processed both in so called black and white version, which corresponds to the depiction in an infrared spectrum (Figure 2 and Figure 3), and in colour thus in the standard visible spectrum.

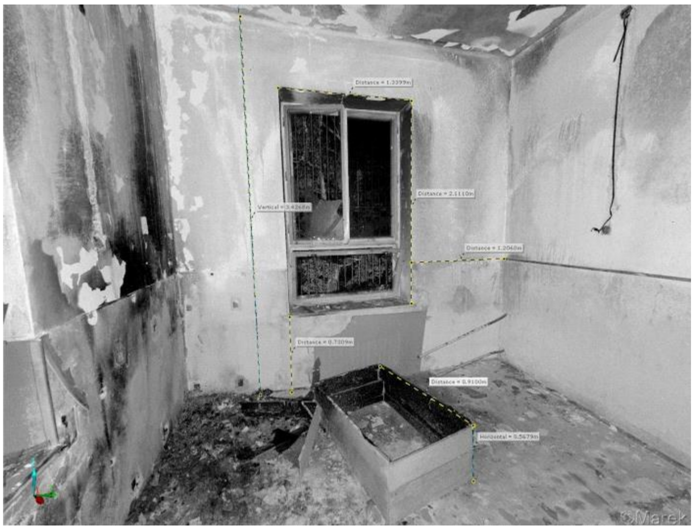

Figure 1 Demonstration of measuring objects of interest at the fire scene - 4th fire scene [1]

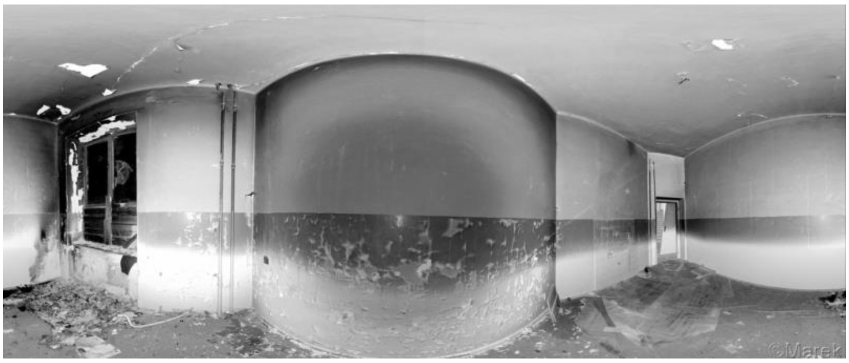

Figure 2 Infrared 3D scan - spherical view- 1st fire scene [1]

Figure 3 Infrared 3D scan - spherical view - 2nd fire scene [1]

Another study to verify the scanning system used a training area designated for crime scene investigation training belonging to the Police of the Czech Republic in Pardubice. The scanner was deployed to digitize a fire scene. There have already been several fires in that area, and therefore several seats of fires.

Generally, a 3D scan of one fire scene can take from 1 minute to 2 hours, depending on the setting and desired preciseness of a 3D scan. Three scans were performed in a metal shed with no windows. In this case the scanner was set in a way that it took 8 minutes to complete one scan. In the Fugure 4 there is infrared 3D scan in a spherical view nad Figure 5 colour 3D scan in a spherical. This setting was chosen to verify whether the specified quality is sufficient for given space. Based on the obtained data it was proven that some areas were not sufficiently scanned (the scanner reads only objects in the direct line of sight), but this fact did not negatively affect the overall output, since the scanner operator placed the scanner in the way that it always documented the center of fire and focal signs.

Topographic documentation - 2D maps with a scale, orthogonal views, 2D sections and ground plans formed the output from the obtained data (Figure 6, Figure 7, and Figure 8). Embedded dimensions of objects that were measured in the virtual project are seen in the photos bellow.

Figure 4 Infrared 3D scan in a spherical view [5]

Figure 5 Colour 3D scan in a spherical view [5]


Figure 6 Ground plans of the shed [5]

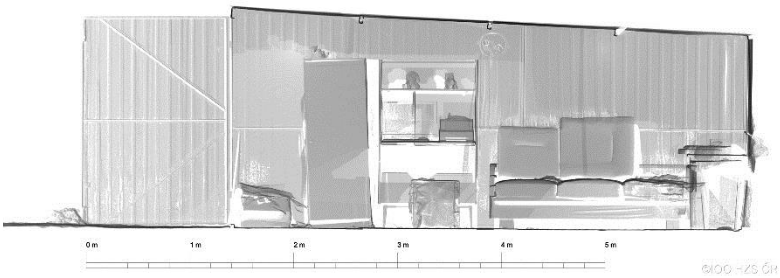


Figure 7 Sections of the shed in the IR spectrum [5]


Figure 8 Sections of the shed in the visible spectrum [5]

Another part focuses on verification of focal signs of vehicle fires. Also in this case eight scans of the scene around the vehicle and one scan of the vehicle's interior were taken. At one point only a sector specified by the operator was scanned. If there is a lack of time, it is possible to perform minimal quantity of 3 scans, but this is at the expense of the quantity of data obtained from scene of the fire. After downloading the obtained data a connection of individual scans into a single project was performed and then a realistic model of the vehicle after the fire was drafted. From the obtained 3D model it is possible to get an overview of the places with the greatest intensity of fire (Figure

9), and of the direction the fire spread. It is also possible to perform measurements of individual points of interest, and 2D maps with a scale, orthogonal views, 2D sections and ground plans also formed the output.

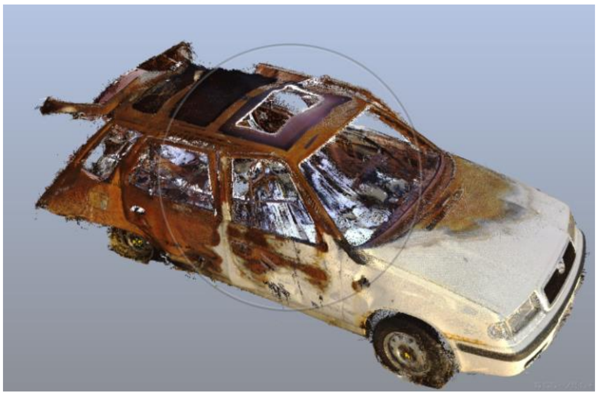

Figure 9 3D model of the vehicle [5]

Figure 10 Photographs of the burning vehicles - the date of acquisition is the date of the fire [6]

Figure 11 Photographs of the vehicles after the fire - the date of acquisition is the date of the fire [6]

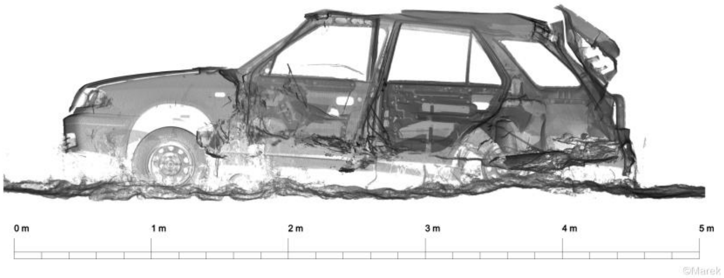


Figure 12 Comparison of an image captured by the scanner in the IR spectrum and the visible spectrum - the date of acquisition is about 3 months after the fire [5]

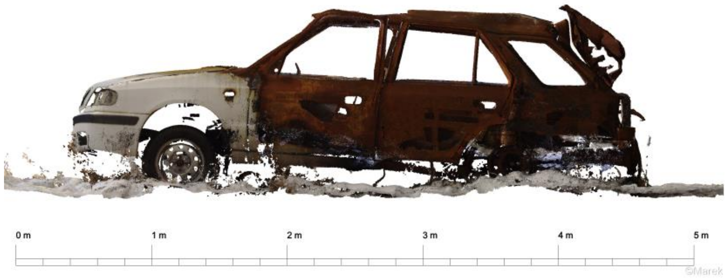


Figure 13 Comparison of an image captured by the scanner in the IR spectrum and the visible spectrum - the date of acquisition is about 3 months after the fire [5]

In January 2017 the 3D laser scanning system was already used for explaining causes of the real fires when the outputs were attached as an appendix to the fire technical expertise.

## 5. Conclusions

Spatial ground laser scanning method is a suitable and proven method in the Czech Republic of a precise, detailed and well documented scene of fire. Spatial data acquisition is not complicated in practice, scanning is quick and it is easy to operate the device. It is possible to create a standardized and automated process to document the scene of fire. Captured 3D data form an enormous source of information and they are further usable in forensic sciences. It is possible to reuse the data and then verify the findings of previous analyses using different approaches.

The obtained data always reflect the real state at the time of scanning. Scanning is possible even in low or no light, or even at night. The obtained information - the data are not only of the visible light spectrum as commonly used documentation methods offer today (e.g. photographs), but also of the IR spectrum.

Processing the collected data is cost efficient as everything is done in a virtual environment. The output forms automatically generated topographic documentation (plans, projections, sections), including cross projections, cylindrical alignment, etc.

It is possible to create a virtual tour in HTML format, import the data into a common CAD and modelling software and create videos.

Disadvantages of this method include higher financial one off acquisition cost of a scanner and a purchase of specialized software to form large-volume data. It is necessary for a trained person to operate the scanner in order to obtain and process quality data. Subsequent processing of the data requires high demands on knowledge of processing and simulation software and time-consuming process and production of analyses.

The above described method is ready for deployment within the fire and forensic practice and is particularly suitable for precise documentation of larger fire scenes, multiple fire scenes within a single building, hard to reach places, intricately shaped and spatially demanding objects..

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# Research of the methods to enhance extrusion pellet machine performance by using automated load controls and its safety

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**Abstract**

The annual municipal solid waste (MSW) generation in Russia totals 55 to 60 million tons [1] with an average of up to 400kg of waste per person per year. The growth of waste generation is closely associated with increasing welfare of the society, which means that there is a correlation between GDP per capita and per unit generation of waste. Lack of appropriate measures might result in a substantial environmental footprint in the MSW sector.

Waste recycling in Russia merely reaches 5% to 7% versus up to 60% of MSW in Slovak Republic and EU, and over 90% of waste in Russia is delivered to waste landfills and unauthorised dumps so that waste accumulation is increasing [2].

This environmental situation is a national priority. The Decree of the President of the Russian Fed-eration dated 5 January 2017 announces 2017 the Year of Ecology in Russia. Most environmental reforms stipulated by amendments to laws are enacted from 1 January 2017. These are primarily measures aimed at emissions and discharges control using best available technologies and break-through provisions of the Industrial and Consumer Waste law [3]. The Clean Country, priority pro-ject of the Russian Government, will be implemented from 2017 to 2025 with the key aim of reduc-ing the environmental footprint from municipal solid waste disposal and mitigating environmental risks of an accumulated environmental damage [4]. The priority project involves the construction of five environment-friendly facilities for the thermal processing of municipal solid waste (waste incineration plants), four of them to be built in the Moscow Region and one facility to be built in the Republic of Tatarstan.

An alternative to waste incineration is municipal waste recycling by moulding in extrusion machines to make pellets to be further used in the fuel or construction industries. The profitability of a waste recycling facility is dependent on a sound choice of extrusion equipment with the best value for money [5].

*Keywords*: extrusion machine, clogging, auger, matrix, palletising, feed, moulding parameters, automatics, gauges, pressure;

## 1. Introduction

An increase in the reliability of extrusion machines used to shred and extrude refractory materials (plastics, hard food waste, and couched paper) is subject to rational use of the extrusion force inside the machine frame. It requires automatic gauges and mechanisms capable of seamlessly increasing or reducing the effort and rotation speed at the right time to preserve the engine life and prevent failures.

When producing fuel pellets or construction materials from waste, an extrusion machine is exposed to significant loads on its main operating elements such as: inside the frame, on the auger shaft, coupling, connecting auger to the engine shaft, and inside the matrix.

The most common extruder failure in the extrusion process is matrix clogging with a moulded stock (Fig. 1), formation of a tight clog impeding auger rotation, loss of efficiency, and engine emergency shutdown. A failure response takes one to two hours to dismantle and clean the auger.

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Figure 1 Clogged matrices reduce palletising to 50% matrix holes

The above loads need to be reduced to not only minimise machine assembly wear but to reduce power consumption, and enhance the reliability of the engine which accounts for 30% of the ma-chine value. Currently, the set-up of a waste recycling facility requires a thorough review of power consumption per 1kg of product. Energy saving on the machine makes extrusion equipment more affordable in regions with high energy cost.

An operating body of the auger machine is an auger rotated by the engine through a box coupling. Clogging increases pressure from a moulded feed both on a welded auger head (Fig. 2) and on the box coupling. These are main machine operating elements, and a reduction in their strength will result in the production of defective pellets (less tight and more friable).

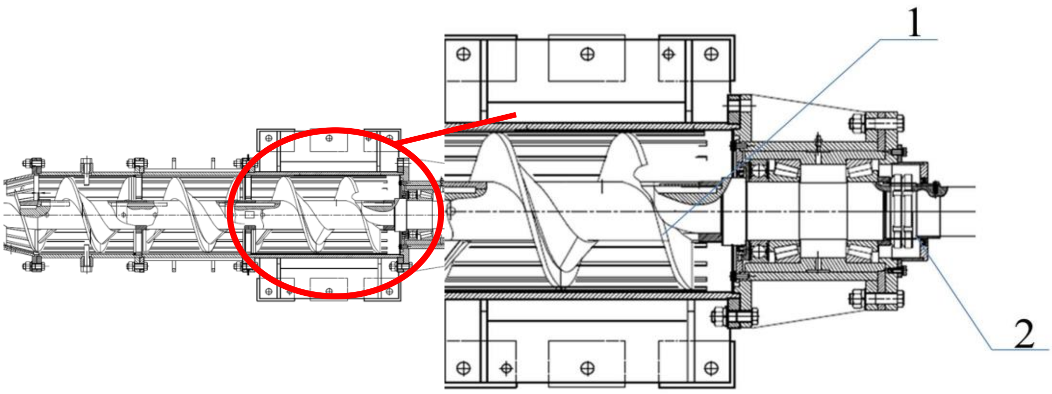


Figure 2 The most common deformed elements of the auger machine when clogged: 1 – weld location of an auger head and shaft, 2 – box coupling on the rotation shaft

Statistically, without engine emergency shutdown, these elements develop microcracks and are deformed. Twisting deformation can be assessed as twisting of a beam with a non-round cross-section. If we consider an auger to be a circle with a flattened surface, the maximum effort is applied at the middle of the flat cut: $\tau max = h/2$ [6,7], i.e. the maximum effort is in the middle point at the location where the auger diameter changes and the auger has a cone shape.

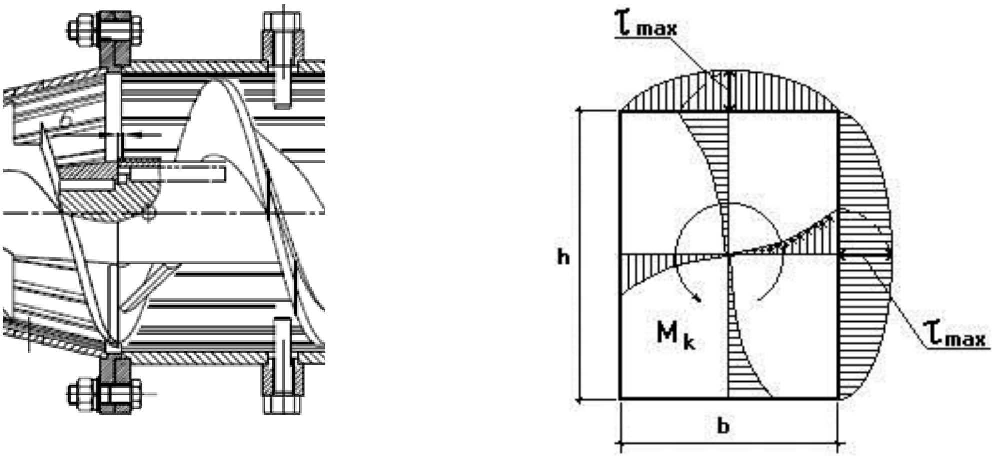


Figure 3 Curve showing shaft moment of resistance with auger narrowing, h=115mm, b=113

We will calculate the moment of resistance for the maximum overload force at the shaft when it is clogged and a contingency situation develops [8].

$$W_k = \frac{b^3(2,6\frac{h}{b}-1)}{8(0,3\frac{h}{b}+0,7)} = \frac{113^3(2,6\frac{115}{113}-1)}{8(0,3\frac{115}{113}+0,7)} = 297\kappa H \cdot м \qquad (1)$$

Therefore, estimates were sufficient to determine the moment of resistance as 238.04kN/m. When exceeded, the auger would be exposed to microcracks and deformation.

## 2. Materials and study methods

The extrusion moulding process was studied using waste from dumps and wastewater treatment facilities, non-marketable TPP products and wood processing waste [9]. Clogging processes were researched using a newly built auger-type machine (MN-3) with heating elements (Figure 4).

Figure 4 MN-3 extruder

The ingredients of the mixture to be palletised with a moisture content of 45% were as follows:

- 20% of cardboard;
- 15% of plastic;
- 40% of coal charge;
- 10% of sawdust; and
- 15% of waste from the wastewater treatment facilities (sludge).

The feed was loaded into the hopper of MN-3 auger-type machine which started to produce pellets 20 minutes after pre-heating of its heating elements and ramp-up. The process was going for two hours when machine performance began to decrease. The auger rotation speed was increased using a frequency converter, but that raised power consumption by 20%. After three hours of operation, a decision was made to shut the machine down since its performance was minimum with the maxi-mum rotations per minute of the engine.

During the experiment, the frequency converter helped to control engine and, therefore, auger rota-tion speed. However, speed was adjusted manually by an operator depending on pellet output. Clogging of the auger was not controlled since it was mounted in a metal frame and the process could not be seen. Such actions were random and chaotic. Temperature was not switched off, either, heating bundles were operated in the normal mode so that the edges of the clog in the auger melted and became harder. When the frame was dismantled, the cause of the loss of efficiency could be identified. It was a clog consisting of a compacted waste feed which blocked the auger and resulted in the emergency shutdown (Figure 5).

a. b.

Figure 5 Stopper clog (a – stopper clog removed from the machine when the frame was cleaned, b – pellets produced on the machine)

A decision was made to study the clog at the destructive press:

- for uniaxial compressive strength test;
- for split test; and
- to determine a normal effort at the auger shaft in ParaView software by comparing it to the estimated effort of 238.04kN and to visually monitor the clogging process.

This data was needed to determine the range of action of a pressure gauge to be later mounted in the extruder frame to alarm of the start of the clogging process. By interacting with the frequency converter, the gauge will prevent emergency shutdown which reverses the engine through a change in poles. A shaker may also be used inside the auger to reduce stock adhesion to the auger and prevent clogging.

**3. Results**

The uniaxial compressive strength test required to split the clog mechanically into two parts to pre-pare for testing at Testometric 500 press in the Geomechanics and Mining Issues Centre of the Min-ing University. The diameter and height of produced samples were duly measured (Figure 6).

Figure 6 Uniaxial compressive strength test of the clog

A cone sample (Sample 1) was compressed at the press first followed by a cylinder sample (Sample 2), (Table 1).

Table 1 Results of uniaxial compressive strength test of the clog

| Test No. | Max. load (N) | Destruction shift (mm) | L (mm) | P (kg/m$^2$) |
|---|---|---|---|---|
| **Sample 1** | 3,907.600 | 2.902 | 115 | 56.38050057 |
| **Sample 2** | 4788.900 | 14.090 | 125 | 69.09626859 |

Figure 7 shows graphically how changes in deformation (mm) depend on the load (N). Sample 2 apparently has better performance (by 881.3 N) as compared to Sample 1.

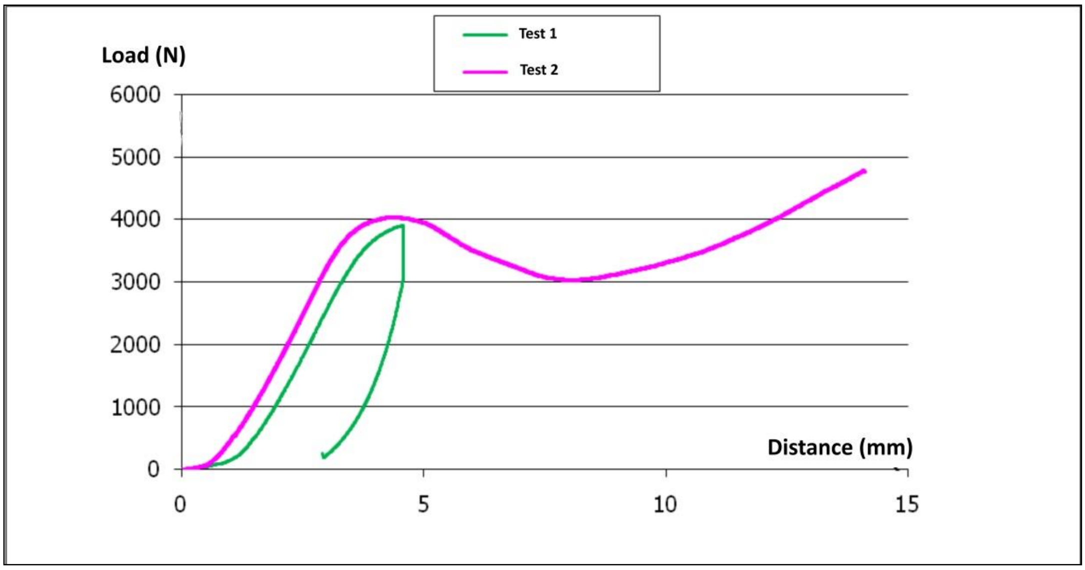


Figure 7 Deformation of Samples 1 and 2 during uniaxial compressive strength test

These were followed by the uniaxial compressive strength tests of produced pellets (Figure 8, Table 2).

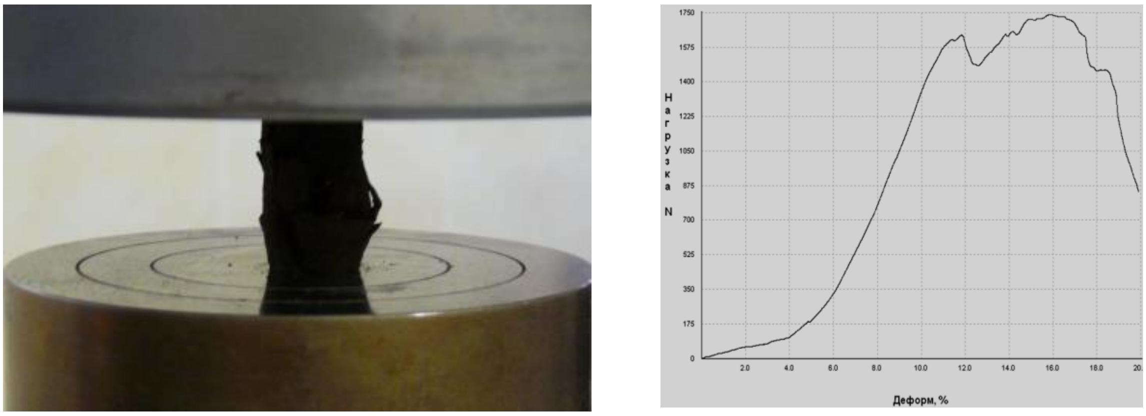


Figure 8 Uniaxial compressive strength test of the pellets

Table 2 Results of uniaxial compressive strength test of the pellets

| Item No. | D, mm | N, mm | m, g | Max. load (N) |
|---|---|---|---|---|
| 1 | 33.5 | 53.5 | 40.65 | 1720 |
| 2 | 35.5 | 51.2 | 36 | 1300 |
| 3 | 31.5 | 38 | 28 | 1400 |

Clogging was analysed then in a 3D simulation model of the extrusion machine in ParaView software. The simulation included similar machine parameters with its matrix split using the finite elements method. A type of an approximation function is randomised per element. The simplest case is linear polynomial (Figure 9).

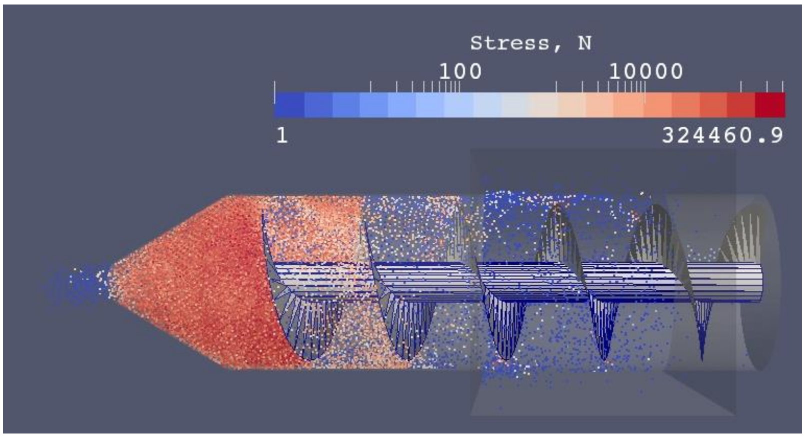


Figure 9 Simulation of the clogging process

## 4. Discussion of Results

The studies completed revealed several important parameters required to set automatics cutoff values:

- Moment of resistance of the auger according to Formula 1 is 297kN/m. When it is exceeded, the auger is subject to microcracks and deformation. When simulated in ParaView software, the moment at the auger shaft during clogging reaches 324.46kN. In this case, we will take the effort range between 297 and 324.460kN;
- Uniaxial compressive strength test shows the difference between the cone and cylinder parts of the auger as 3,907.6N and 4,788.9N, which demonstrates the difference of 800N and supports I.N. Chisty's theory [10,11] of pressure summation in the middle point of the cone output (P+▲P) after which the clog is hard to destroy (Fig. 10).

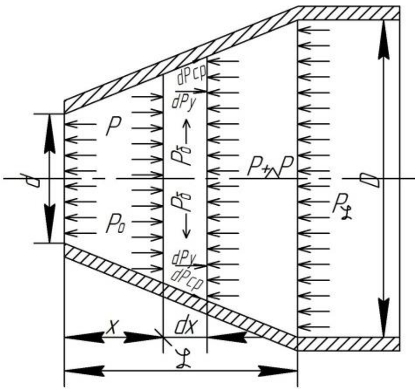

Fig. 10 Visual representation of pressure summation inside the matrix

This experiment enabled to determine the pressure summation point as 115cm – the length of the cone part of the clog (Table 1). It is the point where a leap certifying to clogging takes place.

## 5. Conclusions

The experiments facilitated the collection of information on clog location and hardness in different parts. The studies formed the basis for the upgrade of the existing MN-3 extruder which was re-equipped with pressure gauges 115cm off the matrix edge and a strain gauge capable of recognising an effort on the auger between 297 and 324.5kN. The main function of the two gauges is to start auger in the reverse for the clog to "roll away' and destroy. The auger was also upgraded with a vi-brating element reducing feed stuck to the coils and minimising clog development and matrix clogging.

This area of research will be effective means of creating "transparent" extruder control sys-tems for automatic monitoring of the clogging process and protection against machine breakdown and loss of reliability..

## Acknowledgments

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# Intermediate ceiling board - risk element of road tunnels

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**Abstract**

Tunnels are significant constructions of the road infrastructure. The tunnels in Europe put into operation at the beginning of the second half of the 20th century were designed in time when technical possibilities and traffic conditions were different as today ones and so various levels of safety in tunnels in East, North and West Europe exist. The aim of this paper is to highlight the fire safety of long road tunnels and motorways, ventilation system of which is semi-transverse or transverse. These tunnels are structurally designed with intermediate ceiling board separating the driving space from the ventilation duct. In case of fire, the intermediate ceiling is a critically thermally stressed structure. Maintaining the stability and integrity of the intermediate ceiling has a direct impact on the functionality of the ventilation tunnel.

*Keywords*: road tunnel, fire, ventilation;

## 1. Introduction

Directive 2004/54/EC [1] defines minimum requirements for road tunnels. In terms of fire hazards, as shown by a variety of catastrophic events in many European tunnels, requirements and measures for fire safety were developed, based on the specifics of the course of fire in road tunnels [2]. A fire in a road tunnel differs from a fire in open space.

Requirements for fire safety of individual countries of EU differ. RABT [3] sets fire load in tunnels depending on number of trucks in the tunnel. If transport exceeds 4000 trucks per day then it is required to construct ventilation system for fire performance of 50 MW. When transporting over 6,000 trucks per day it is required to construct power ventilation for fire power of 100 MW. By, in France [4] there is required minimum exhausted quantity of 110 $m^3.s^{-1}$ of combustion gases on the length of maximum 600 m. Control of the longitudinal air velocity must not exceed 1.5 $m.s^{-1}$ in the zone of fire. Minimum exhausted quantity must be 152 $m^3.s^{-1}$ of combustion gases on the length of maximum 600 m without a longitudinal control of air velocity. In Switzerland, the ventilation system with a concentrated exhausting even at tunnel length of 800 m is installed depending on risk factors that are the traffic intensity per one traffic lane, number of trucks per one traffic lane and longitudinal gradient of tunnel. In Czech Republic [5], the design of ventilation is based on number of trucks (TNV) for 24 hours and km for one tunnel tube. The range is 5 from mW to 50 MW of heat power. Requirements for ventilation system in the Slovak Republic require in tunnels longer than 500 m to install a ventilation system. For emergencies, it is necessary to count with an output of 50 MW. The risk analysis may lead to higher or lower respective values.

According to the Japanese standards, the road tunnels are divided into five categories depending on the length of tunnel and traffic density. For particular categories, it is defined obligatory equipment of tunnel for all modes, including fire [7].

## 2. Hazard analysis of road tunnels

### *2.1. Analysis of causes of fire in road tunnels*

From the analyses of accidents [8, 9], it is evident that the most accidents are caused by a front - rear collision (40%), the main cause of which is non-observance of safe distance. It is also evident that more accidents are caused by trucks (74%) where the cause

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is a non-observance of safe distance and bad technical condition of trucks.

By ADR classification, in tunnels of Slovak Republic [2] there are ADR classes represented as flammable liquids 78%, liquefied gases 12%, and corrosive substances 8%. Other ADR classes are represented by less than 4%.

For knowing the real conditions during a tunnel fire more large scale test were carried out. On the basis of these tests, the requirements for fire protection systems in road tunnels were defined.

*2.2. Analysis of causes of fire in road tunnels*

Large scale fire tests in road tunnels are carried out with the aim:

- to verify computational model (dynamics of fire and understanding the process of combustion,
- to verify possibility and ability of response of technological systems in crisis situations.

These tests form the basis for the following analyses and procedures within the overall concept of safety. In Table 1, there are the best known sets of fire tests in road tunnels [10, 11, 12, 13, 14].

Table 1 Survey of selected fire tests in road tunnels

| | | | |
|---|---|---|---|
| Ofenegg | Switzerland | 1965 | |
| Glasgow | Great Bri- | 1970 | |
| Zwenberg | Austria | 1975 | |
| Lappeenranta | Finland | 1985 | (VTT) |
| Repparfjord | Norway | 1990- | (EUREKA |
| Hammerfest | France | 1992 | (INERIS) |
| Charlestown | USA | 1993- | (Memorial |
| Shimizu | Japan | 2001 | |
| Rotterdam | Netherlands | 2002 | (2$^{nd}$ Bene- |
| Runnehamar | Norway | 2003 | |

To know the development of fire, intervention in a road tunnel, it is necessary to know heat output, distances and the respective temperatures of individual burning cars. EUREKA 499 [11] Test was aimed to knowing these parameters of fire in a road tunnel. In Table 2, there are selected temperatures and corresponding distances for individual sources of fire.

Table 2 Temperature on the walls of tunnel depending on the distance from a place of fire

| Type of fire | Distance from the source of fire [m] | | | |
|---|---|---|---|---|
| | 10 | 100 | 200 | 400 |
| Passen- | 400°C | 150°C | 80°C | 40°C |
| Truck | 700°C | 250°C | 120°C | 60°C |
| Petrol | 1000°C | 400°C | 200°C | 100°C |

In 2003, the fire tests were carried out in Runehamar [10], table 3, the aim of which were to answer the questions regarding heat output $Q_{max}$ of transported material on trucks.

Table 3 Description of tests in Runehamar

| Test | Description | Weight [kg] | $Q_{max}$ [MW] |
|---|---|---|---|
| T1 | Wooden and plastic(PE) pallets | 10160 (11010) | 202 |
| T2 | Wooden pallets and (PUR) mattresses | 6390 (6930) | 157 |
| T3 | Furniture and accessories + tyres | 7530 (7750) + 800 | 119 |
| T4 | Plastic glasses on wooden pallets | 2850 | 66 |

Based on real fires [15] and tests, we can say that the fastest developing of fire in tunnel [11] is within 5 minutes. At the start of fire when the whole vehicle is affected, the temperature, heat output and development of combustion gases are of fast growing character. The fast increase of temperature in tunnels leads to the conclusion that possibility of ventilation to exhaust gases of combustion and heat from the space of tunnel is important for fire control. This condition can be achieved only if all building parts of ventilation will safely withstand the effects of high temperatures. At the collapse of intermediate ceiling, the ventilation becomes dysfunctional. It is advisable to consider the thermal load of tunnels already at transport with 15% trucks. It is advisable to consider the temperature curve according to RABT directive or according to the modified HC curve, Figure 1.

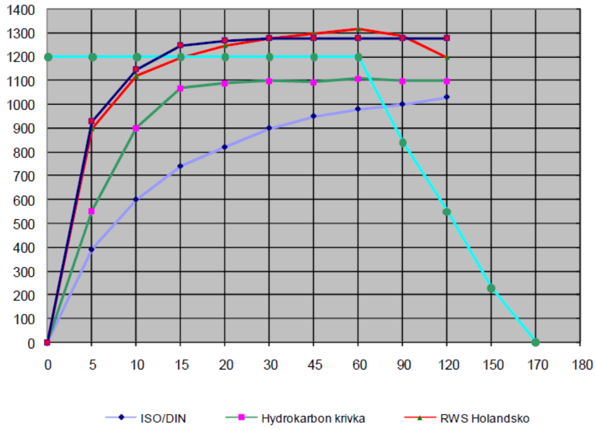


Fig.1 Comparison of individual normatives

Fire in tunnel can be characterized by the following parameters:

- ventilated space in tunnel supports very fast development of fire,
- in the space of tunnel there is a rapid spread of combustion gases and increase of their concentration due to poor possibility of their free dispersal,
- the temperature increases fast in the source of fire,
- at stopping the traffic, it occurs accumulation of vehicles and increase of risk of fast spread of fire and growth of its range,
- the users of tunnel are different persons with different level of knowledge of fire and fire protection.

## 3. Modelling of heat distribution into the building structures in a road tunnel

### *3.1. Modelling of heat conduction in intermediate ceiling board*

Basic processes of all reactions of burning are redox reactions. Physical processes during combustion are the mass transfer, energy transfer processes. In the process of burning rate of chemical reactions of the main chemical, carbon and hydrogen in the fuel and oxygen in air increases exponentially with increasing temperature. The heat from the combustion process spread to the surrounding area by conduction, flow, radiation.

Fourier equation of non-stationary heat conduction, equation 1, taking into account the internal volume of resources, is of the following form:

$$\frac{\partial t}{\partial \tau} = a.\nabla^2 t + \frac{q_V}{c_P.\rho} \qquad (1)$$

Where “a” is a factor of thermal diffusivity and has a significant impact on non-stationary heat conduction.

The most effective method of continuum mechanics is now a finite element method (FEM). For the calculation of heat conduction in reinforced concrete structure of tunnel, a computer program COSMOS M was used that solves thermal fields described by Fourier equation of heat conduction with the appropriate boundary conditions on the body surface (prescribed temperature, heat flow density). This principle uses COSMOS M at calculation of thermal field T(t,x,y,z) and function that meets prescribed boundary conditions of the first kind (prescribed temperatures on the element boundary) and which minimizes the functional,

$$E_T(T) = \int_V \left(\frac{1}{2}(\Delta T)^T \Lambda \Delta T - QT + \rho c_p T \frac{dT}{dt}\right) dV + \int_{Sq} T dS + \int_{S\alpha} \alpha \left(\frac{T^2}{2} - T T_\infty\right) dS \qquad (2)$$

meets Fourier differential equation including the boundary conditions. Finite element approximation of thermal field is selected as a linear combination of the shape functions,

$$T(x,y,z,t) = \sum_{i=1}^{N} T_i(t) N_i(x,y,z) = \vec{N}^T \vec{T} \qquad (3)$$

where symbol T designates vector of nodal temperatures (it is a function of time) and N is a vector of corresponding shape functions (it depends on spatial coordinates x,y,z). Substituting equation 3 in functional 2 and its minimization with respect to the vector of nodal temperatures T and achieves a system of ordinary differential equations for the nodal temperatures. Solution of this system of differential equations can be obtained by means of modal analysis or by direct integration of Euler method. COSMOS M program uses direct integration of Euler method.

*3.2. Geometry of intermediate ceiling board*

Figure 2 shows the system of semi-transverse ventilation in the analysed tunnel. In the event of fire, all air flaps are closed and only 5 flaps in the space above the fire and channel valve which connects the ventilation duct with upcast object remain open.

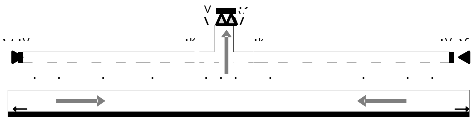

Fig. 2 System of semi-transverse ventilation of tunnel with dampers

Figure 3 shows the cross section of tunnel with intermediate ceiling board placement. Geometry of intermediate ceiling board is on the right side of Figure. Intermediate ceiling board is placed on the secondary tunnel lining.

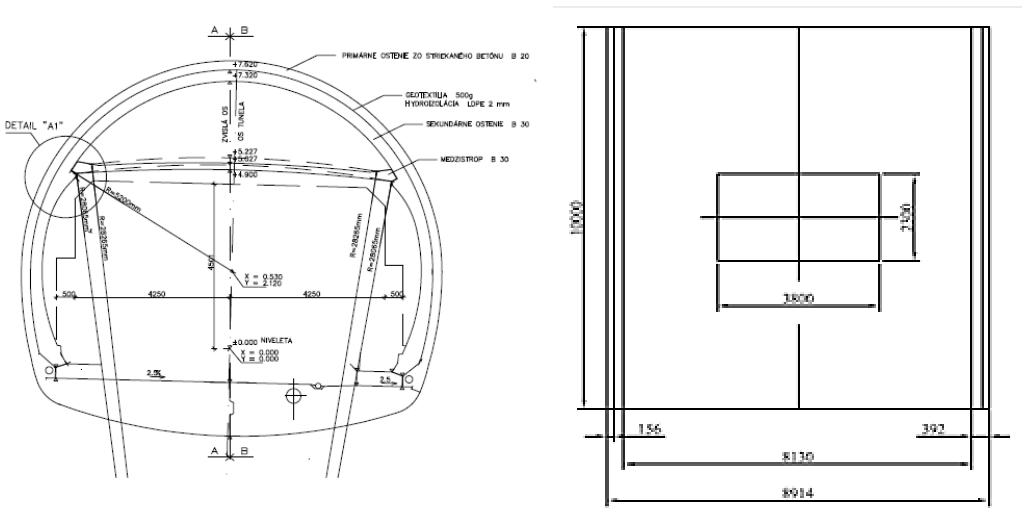


Fig. 3 Cross section of tunnel and dimensions of intermediate ceiling board with opening for ventilation flaps

Figure 4 shows ventilation duct above the intermediate ceiling board. Placement of intermediate ceiling in space of tunnel is shown on the right side of Figure.


Fig. 4 Ventilation duct and ceiling board of tunnel with flaps for combustion gases exhausting

*3.3. Material properties of structure of tunnel and their impact on fire resistance*

Safe operation of tunnel even in critical situations means that local destruction of structure must not have serious impact on tunnel as a whole. Due to the high temperatures of fire, reinforced concrete structures may lose their carrying capacity.

**Properties of reinforced concretes**

From a series of deformation properties of reinforced concrete, thermal expansion for fire safety of constructions is particularly significant. At the temperatures above 100 °C, the value of thermal expansion of concrete and steel reinforcement significantly changes. At heating of reinforcement to 200 °C, yield stress decreases. Critical temperature of reinforcement is above 500°C. Upon reaching the yield point, collapse structures occurs.

With Portland cements [16], due to the expulsion of water, shrinkage of permanent character occurs that significantly grows at the temperatures up to 500 °C. At higher temperatures, dehydration of calcium hydroxide (connective components) to calcium oxide is carried out. In this regard, the cements with high content of Al2O3 at hydration of which no calcium hydrates are created, show good properties. Volume changes of silica occur at 575 °C and subsequently at 870 °C. Concrete is melted at about 1500 °C, depending on its components.

The permeability of the concrete, the size of the concrete structure and the temperature-rising rate are also important because then determine the size of internal stresses resulting from action of the gaseous components generated by thermal decomposition. The temperature of the concrete begins to grow after removal of all evaporable water. When releasing volatilizable water from the cement stone there is a problem of rapid heating. The water content in the cement stone is high and the cement stone has a low permeability. In such case, the surface layer of concrete is crumbling as inside of the cement stone the pressure grows faster than the vapour pressure can escape to the atmosphere.

The low factor of thermal conductivity of concrete causes slow heat penetration into it. The water content in the concrete due to its high specific heat capacity, and hence a large consumption of heat for water evaporation, slows the heating.

Influence of high temperature on concrete can be reduced by selecting a suitable cement and aggregate. For the production of refractory concrete, it is necessary to use aluminous cement. For temperatures up to 1000 °C, the alkaline aggregate containing igneous rocks, such as basalt or dolerite and heat treated porous aggregate (slag, expanded shale). At higher temperatures, it is a fireclay chippings, magnesite, carbide and artificial corundum.

**Thermal expansion**

Thermal expansion is an important factor at all types of concrete structures where higher difference of temperatures can occur by impact of surrounding or operating conditions. When the internal stress caused by thermal expansion exceeds the tensile strength of concrete, the concrete cracks appear or it starts its destruction. Problems arise mainly due to the different thermal expansion of the cement paste and aggregate [17].

**Thermal conductivity**

Thermal conductivity is ability of material to conduct the heat. Thermal conductivity determines rate of heat transfer through the concrete, value of thermal gradient and thermal stress. Thermal conductivity depends on thermal conductivity of the cement stone and aggregate and their proportion in concrete. Thermal conductivity of the hardened cement paste and aggregate is affected by their porosity and humidity. The factor of thermal conductivity is influenced by its volume weight. The lightweight concretes with higher porosity have lower factors of thermal conductivity and so better thermal and insulation properties. The factor of thermal conductivity of hardened cement paste, aggregate and concrete is not affected by temperature under common climatic conditions. After evaporation of water from concrete (110 °C), the factor of thermal conductivity drops sharply. At the temperature of 800 °C, the factor of thermal conductivity has a half value in comparison with that at 20 °C [18].

**Specific heat capacity**

Specific heat capacity of hardened cement paste is significantly affected by porosity, content of water and temperature. Therefore, these factors significantly affect even the specific heat capacity of concrete [18].

## 4. Thermal and mechanical response of the intermediate ceiling board to fire

### *4.1. Modelling of heat conduction in intermediate ceiling board*

The updated computational methods are based on recognized principles and assumptions of the theory of heat transfer, as mentioned above. In the thermal response model, a real heat load, thermal and mechanical material properties, thermal profile in the reinforced concrete were considered. The mechanical response reflected changes in the mechanical properties depending on the temperature.

The simulations were carried out in a computer program COSMOS M which uses a deformation principle of FEM in calculation. 2D and 3D models were used in calculation.

**Model 1 (observation of temperatures)**

The intermediate ceiling board, Figure 3, is placed on the concrete footing. In case of fire, this binding transforms under the influence of temperature and subsequent expansion into a solid bond. By means of 2D model of the intermediate ceiling board, the time until achieving critical temperature of reinforcement at loading by defined thermal curve was observed. In these models, the elements of PLANE 2D were used enabling distribution of heat, rise of stress and deformation caused by thermal stress at parallel rise of stress and deformations caused by external load and own weight. With regard to the symmetry of board, the model was modelled in a half profile.

**Model 2 (observation of deflection)**

In case of fire in tunnel with semi-transverse ventilation, combustion gases are exhausted through the space above the intermediate ceiling board. The intermediate ceiling boards were modelled by 3D models. The models were used for observation of distribution of thermal field and deformations at fire load.

In these models, the final elements of TETRA 4 and SOLID were used enabling simulation of distribution of heat, rise of stress and deformations caused by thermal stress at parallel rise of stress and deformations caused by external load and own weight. Two types of boards were modelled, standard board, board with an opening for combustion gases exhausting. With regard to the symmetry of board around two planes, a half or a quarter of board was modelled.

### *4.2. Calibration of model*

To achieve relevant result of simulation, a verification was carried out. Within changes of final version of secondary lining of Libouchec [19], test of the sample with dimensions 2x2 m and thickness 400 mm was carried out. The sample from dense concrete C30 XF4 XD3 was for a period of 180 minutes. exposed to thermal stress according to ISO of curve, Figure 1. The course of temperatures at a depth of 100 and 200 mm is shown in  Figure 5.

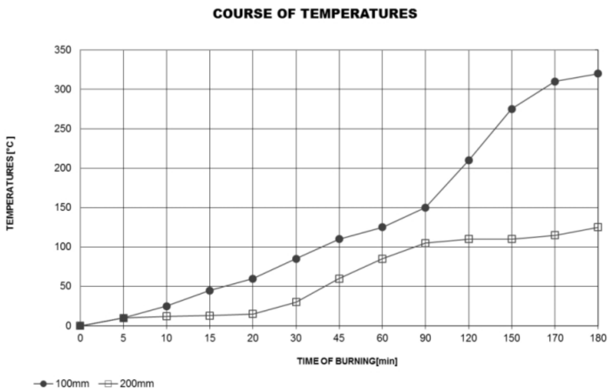


Fig. 5 Course of temperatures in a specimen of Libouchec tunnel

The results of test show that at at a depth of 100 m from the heated edge, there is a temperature of 310 ° C and in depth of 200 mm from the heated edge, it is 121 °C.

To compare and confront the results with the simulation a unitary element with a thickness of 400 mm was modelled in COSMOS M program and loaded by ISO curve in duration of 180 min.

The values of temperatures achieved by simulation at a depth of 100 and 200 mm are shown in Figures 6,7 [20].

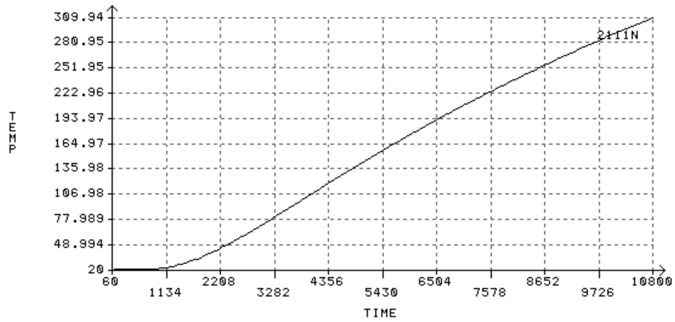


Fig. 6 Course of temperatures at a depth of 100 mm

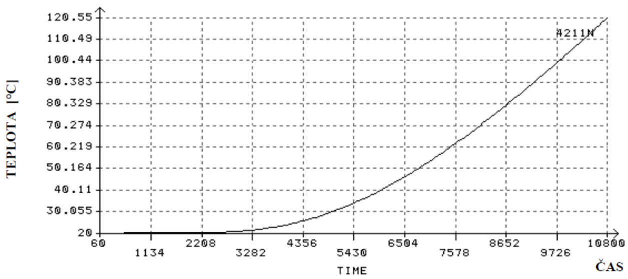


Fig. 7 Course of temperatures at a depth of 200 mm

Comparison of the test results, Figure 5, and those of simulation, Figures 6,7, shows that the results correlate. With such calibrated boundary conditions, simulation of thermal stress of the intermediate ceiling board was carried out.

*4.3. Analysis results*

**Model 1**

A finite element mesh, Figure 8, was selected and then densified so that the nodes in which the temperatures are calculated, would be placed at a depth of 40 mm below the surface of heating.


Fig. 8 Cross section and selection of nodes of the intermediate ceiling board of tunnel at modelling FEM

The results obtained from calculation are shown in Figures 9, 10 [20]. The graph in Figure 9 shows the temperature of reinforcement at a depth of 40 mm from the edge on both sides of thermally stressed intermediate ceiling board by the temperature according to ISO curve. After 120 minutes of fire stress, the temperature achieves 597 °C. A critical temperature of 500 °C is obtained by the reinforcement in the 86th minute of loading.

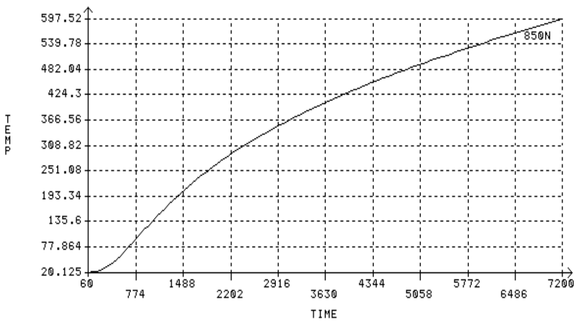


Fig. 9 Course of temperatures in the intermediate ceiling board at a depth of 40 mm loaded by the temperature from both sides according to ISO curve

The graph in Figure 10 shows the temperature of reinforcement at a depth of 40 mm from the edge of both sides thermally stressed intermediate ceiling board. The board was loaded by the temperature according to the modified HC curve. After 120 minutes, the temperature achieves 734 °C. A critical temperature of 500 °C is obtained by the reinforcement in the 54th minute from the beginning of loading.

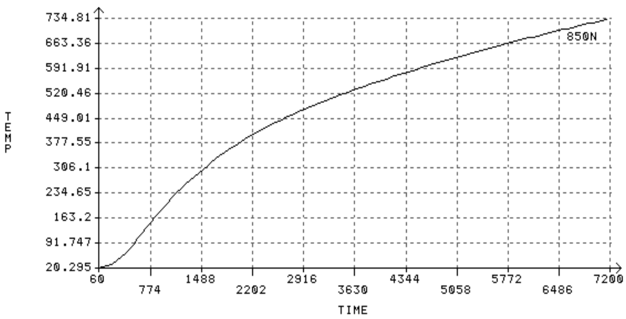


Fig. 10 Course of temperatures in the intermediate ceiling board at a depth of 40 mm, loaded from both sides according to the modified HC curve

**Model 2**

The intermediate ceiling boards are loaded by their own weight and are thermally stressed. Inside the board, a heat flow arises. Material properties of the intermediate ceiling board are changed under the influence of temperature. An increase of the temperature leads to a decrease in strength and loss of stability. The ends of boards are placed on consoles of the secondary lining. They were modelled like cantilevered on both sides. The board is thermally stressed from bellow by fire and from above by exhausted hot air. To consider the loss of stability of the intermediate ceiling board, a development of deformations in time was observed. The analysis results are shown in Figures 11,12 [20].

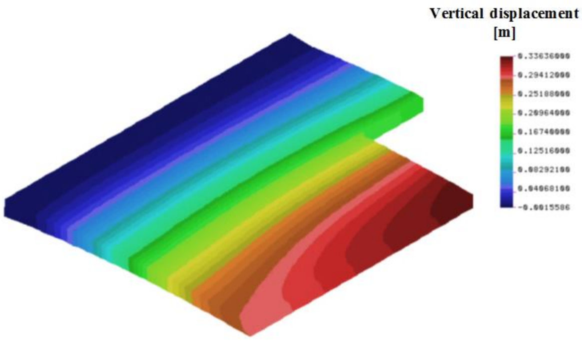


Fig. 11 Vertical displacement of the board with an opening of the intermediate ceiling board stressed on both sides by the temperature according to ISO curve

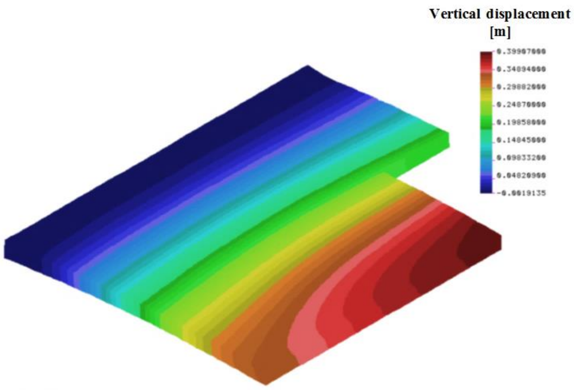


Fig. 12 Vertical displacement of the board with an opening of the intermediate ceiling board stressed on both sides by the temperature according to the modified HC curve

The boundary carrying capacity occurs at the value of deflection I/25 in the middle of the board. At the length of the reinforced concrete board of 8 914 mm, it is a deflection of 357 mm.

Based on the calculations, it was stated that the intermediate ceiling boards with a hole for combustion fumes exhausting, exposed to the temperature on both sides according to the modified HC curves do not meet the criterion of deformation during the 120 minutes of fire load.

Based on the analyses, Figures 9, 10, 11, 12, we can say that the decisive actions (evacuation) at fire must be executed within forty minutes. If the intermediate ceiling is thermally protected by barriers this time can be prolonged.

### *4.4. Model of thermal stress of the intermediate ceiling board with use of thermal barrier*

Either in one of above mentioned cases, the requirement of thermal protection according to for fire of truck E120/D1 (fire resistance of 120 minutes for structures of D1 category) was not met [6]. According to [18], we can conclude that the reinforced concrete structure keeps its mechanical properties for a long time if on contact with the barrier the temperature of concrete does not exceed 380 °C and the temperature of reinforcement does not exceed 250 °C.

Model with PROMATECT- H thermal barrier

The aim of the analysis was to set what thickness of barrier meets critical temperature of 250 °C and temperature of concrete on contact with barrier 380 °C at cover of reinforcement of 40 mm. Material values necessary for calculation were provided with the permission of the representative of PROMAT company. Conditions for different thickness of lining were modelled and it was stated that 25 mm thickness of PROMATECT-H board does not fulfil criteria of fire safety. Calculation for 30 mm thickness of board is shown in the following Figures 13,14 [20]. At this thickness of lining, required criteria were fulfilled.

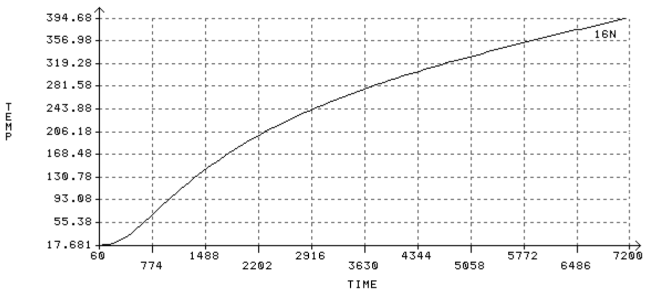


Fig. 13 Course of temperatures on the interface of a board and barrier with thickness of 30 mm stressed on both sides by the temperature according to the modified HC curve

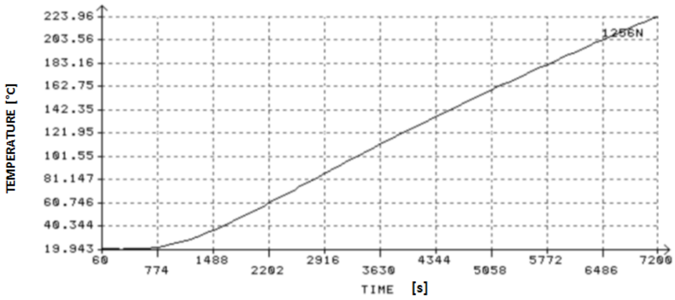


Fig. 14 Course of temperature of the reinforcement of the board at the barrier of thickness of 30 mm stressed on both sides according to the modified HC curve

## 5. Discussion

The presented model can generally be applied after solving the following problems:

1. The model is usable only in the plane of distribution of temperatures across the section for dense concretes verified by a real test. Adopting criterion for assessing the structure by determining the temperatures in a particular place of section and achievement of critical temperature of reinforcement, the model is fully applicable generally to other materials.
2. If we want to know behaviour of the structure in terms of stress and deformation at the time, the model needs to be confronted with the real experiments with actual boundary conditions. It is important accurately to determine, by means of the factor of sensitivity analysis, a coefficient of linear thermal expansion. The analysis showed that

this parameter is very strongly influencing the resulting deformation of the structure. By

changing the value of thermal expansion by the value of $10^{-6}$, resulting deformation will change by about 30 mm.

3. The parameter of thermal expansion is strongly in several properties of the concrete components. Mainly water factor, porosity and grain size of gravel used in the concrete. For general use of the model, it is necessary to carry out the model calibration with materials used in the concrete.

Despite of the fact that the road tunnels are specific structures, the theory of heat transfer can be applied even to these structures. Very fast increase of the temperature in tunnels leads to the conclusion that the ability of ventilation system to exhaust combustion gases and heat as long as possible from the space of tunnel and to provide firefighting and evacuation of the participants is very important.

It is suitable to consider thermal stress of new tunnels and if proportion of trucks is more than 15 % for the thermal curve according RABT directive or modified HC curve, Figure 1.

The decision on using the barrier is left solely to investors and developers. Even the input data of material properties of the reinforced concrete are the problem. EUROKOD 2 solves them even with the national annex conservatively resulting in different results in comparison with the experiment carried out.

In most cases, to meet stability requirements in the Slovak Republic with tunnel constructions, the concrete or reinforced concrete of class C 30/35 complies. To meet fire and technical properties of tunnel, it is necessary to equip the tunnel with thermal protection barriers that are able to withstand the thermal stress at the temperatures of 1200 °C during the period of 120 min.

## 6. Conclusions

In road accidents with a fire, high temperatures, reduction of oxygen concentration, poor visibility, the spread of smoke and toxic gases rise in tunnel because of considerably limited space conditions therefore, the extent of damage to the road users in the case of fire is much higher than on the open road.

The results from practical tests of the European programs for fire research in tunnels show that fire of the truck that is not transported dangerous goods in terms of ADR achieves heat outputs of 200 MW and more and temperatures near the fire achieve even 1300 ° C. Reinforced concrete is not able to resist such heat stress for required period as it was shown. Addition of any additives for improving the thermal and technical properties of concrete from which the tunnel is constructed does not solve the problem of penetration of heat into it and following heating of reinforcement with the collapse of individual structural parts of the tunnel.

Characteristics of thermal barriers are protected by the producers and are confidential but without them, it is not impossible to create a comprehensive model.

**Acknowledgments**

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# Evaluation of upholstery fabrics ignitability

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**Abstract**

The paper deals with the assessment of ignitability of selected upholstery fabrics used in the upholstered furniture and upholstery products, which belong among the combustible organic polymers. Upholstery fabrics are grouped into three sets, based on the origin of the fibres as a basic structure unit of fabrics. There were tested fabrics from natural fibres: herbal - cotton, animal - wool; chemical fibres: natural polymers - viscose, synthetic polymers - polyacrylonitrile, polyester, polypropylene; mixed fabrics - in specific percentage of chemical and natural fibres mixture, while the fabrics had different weight and moisture basis. Two fabrics were flame retardant treated and one with anti-soiling treatment. The ignitability was represented with the flash point temperature, ignition temperature, and the time to ignition, which belong among the fire characteristics in accordance to standardized test methods introduced in the standard EN 871. Flash point temperature ranged from 240 ° C (cotton) to 430 ° C (wool with the Scotchard anti-soiling treatment), the time to ignition was in range from 159 s (cotton) to 587 s (retardant treated polyester), the ignition temperature was in range from 360 ° C (retardant treated fabric 50% polyester / 50% polypropylene) to 530 ° C (wool with the anti-soiling treatment), the ignition time was in range from 32 s (polyacrylonitrile) to 438 s (retardant treated polyester). The retardant coating affected mainly the times to ignition. In addition, there was analysed the relationship between temperatures, times and the weight and moisture basis. The dependence has been shown to be statistically significant only for the fabrics set made from natural fibres of cotton and wool.

*Keywords*: upholstered furniture, upholstery fabrics, flash point temperature, ignition temperature, time to flash point, time to ignition;

## 1. Introduction

Upholstered furniture is the standard interior equipment of the public sector - administrative buildings, social facilities, social rooms, theaters, cinemas as well as regular households where the dominant element of the equipment is mainly living and sleeping rooms. Upholstered furniture is a complex construction consisting of a variety of materials and joints, which can be divided into main and auxiliary materials - elements (Navrátil 2015). It's a whole range of diverse materials.

Almost all components of the upholstered product (excluding, e.g. iron skeleton and springs) belong to a group of flammable organic polymers. The fire safety of living spaces is unduly influenced by the materials used to produce both upholstered furniture that are sensitive to thermal loading. Upholstered furniture can be a burdensome source of fire. Frequent is occurrences of negligent fires where the burning of materials began first. The fires in the buildings release the amount of combustion products (emissions), with the different composition, the physical state and the physicochemical properties, which depend mainly on the kind and amount of flammable material, but also on the fire conditions (Coneva 2015).

The general development of the society has also developed and expanded the fields of fire investigation. This is related to the nature, development and consequences of the fires. Today's households are filled with equipment that is easy to ignite, supports the propagation of fire and releases a considerable amount of highly toxic combustion products by their thermal degradation (Netopilová, Kristek 2015, Marková 2004). They include upholstery materials. According to the statistics of the U.S. NFPA, the upholstered furniture, either as the first object that was ignited by the initiation source or as the main object contributing to the spread of the fire, played a role in nearly a quarter

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of all deaths in house fires in recent years (Durso 2013).

Statistics show that a significant number of deaths occur in case of fire in dwellings, buildings, where the upholstered furniture is commonly used and may be exposed to accidental contact with initiation sources (Statistical Yearbook 2010 - 2013).

For the protection and safety of persons against fire in the interior it is important that the design of the upholstered furniture as a whole is safe. When assessing product safety, the issue of fire protection of interior design elements lags behind other qualitative and quantitative parameters. If we want the upholstered product to be safe as a whole, first it must be safe all the materials that enter the process of its manufacture. In particular, those are the coating materials (synthetic or natural fiber fabrics) or non-fabric (leather, leatherette) and filler fabrics (nowadays, in standard products is PUR polyurethane foam, but fluffy polyester and brush can also be used) (Orémusová 2016).

Coating materials are an essential part of every upholstered furniture that directly affects the consumer both on his purchase and then on his daily use. The coating materials are used to pull the outer surface of the padding. Their primary function is to increase the value of the product by adjusting its aesthetic appearance and increasing its life. As standard, we use the fabrics that are the subject of this paper.

The coating fabrics first come into contact with the possible source of ignition of the upholstered product, and it is therefore desirable that the research interests also be of interest in fire protection and safety. To assess the fire hazard of coating fabrics, we need quantitative and qualitative data to assess the possibility of fire occurrence and spread. Such data are the fire characteristics obtained by laboratory standardized methods but also the exact approach of their evaluation (Masařik 2003, Martinka et al., 2011, Orémusová 2006).

The aim of the paper was to evaluate the ignition properties of coating fabrics based on the determination of the flash point, the ignition temperature (fire characteristics) and the corresponding ignition times in accordance with the internationally accepted international standard STN ISO 871 (1999). The fabrics based on natural, chemical and mixed fibers of different area weight and moisture were tested.

## 2. Experiment

### *2.1. Material*

The samples for our research were selected from a wide range of coating fabrics so that fabrics based on natural, chemical and mixed fibers were represented and had different area weight and moisture. Among the tested fabrics, there are 2 samples with non-flammable (retard) treatment. The other 2 samples are with Scotchard treatment (water, grease and dirt resistance). The basic data on tested samples of coating fabrics are shown in tables 1 and 2.

Tab. 1 Basic data on tested samples of coating fabrics

| **Sample** | **Fabrics type** | **Area weight ($g.m^{-2}$)** | **Moisture (%)** | **Note** |
|---|---|---|---|---|
| P1 | Woven foliage | 230 | 5.52 | |
| P2 | Woven jacquard | 190 | 5.47 | |
| P3 | Woven foliage | 410 | 8.59 | Treatment Scotchard |
| P4 | Woven foliage | 360 | 8.75 | |
| Ch5 | Woven jacquard | 360 | 9.37 | |
| Ch6 | Woven foliage | 310 | 1.68 | |
| Ch7 | Woven jacquard | 260 | 0.51 | Non flammable treatment – Trevira |
| Ch8 | Woven foliage | 230 | 0.67 | |
| Z9 | Woven jacquard | 190 | 6.29 | |
| Z10 | Woven jacquard | 150 | 0.87 | Non flammable treatment |
| Z11 | Woven jacquard | 190 | 1.9 | |
| Z12 | Woven foliage | 430 | 9.2 | Treatment Scotchard |

Tab. 2 Continuation of basic data on tested sample

| Fiber type | | | Composition (%) | Sample |
|---|---|---|---|---|
| natural | plant | cotton (ba) | 100 | P1 |
| | | cotton (ba) | 100 | P2 |
| | animal | wool (vl) | 100 | P3 |
| | | wool (vl) | 100 | P4 |
| chemical | natural polymer | viscose (Vs) | 100 | Ch5 |
| | synthetic polymer | polyacrylonitril (PAN) | 100 | Ch6 |
| | synthetic polymer | polyester (PES) | 100 | Ch7 |
| | synthetic polymer | polyester (PES) | 100 | Ch8 |
| mixtures | chemical/ chemical | viscose / polypropylene (Vs / PP) | 61/39 | Z9 |
| | | polyester / poly-propylene (PES / PP) | 50/50 | Z10 |
| | chemical/ natural | polyester / cotton (PES / ba) | 61/39 | Z11 |
| | | viscose / wool (Vs / vl) | 60/40 | Z12 |

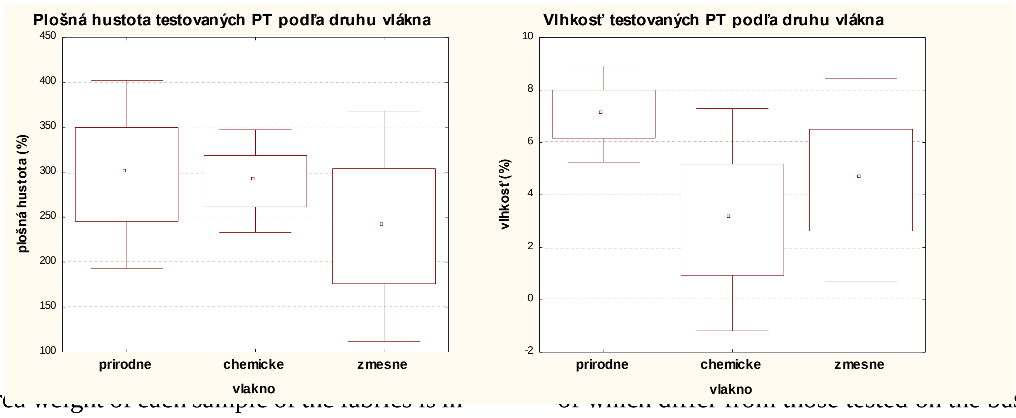
### *2.2. Testing method*

The methodology was elaborated according to international standard STN ISO 871 (1999). The principle of the test is that the material sample is heated in a hot-air oven at various temperatures. The flash point temperature is determined by adding a small ignition flame directed to the furnace cover opening to ignite the released gases. The ignition temperature is determined in the same way as the flash point but without the ignition flame. Samples consisted of squares of fabric (20x20) mm stacked on and weighing (3 ± 2) g. Before the test, the samples were conditioned at a temperature (23 ± 2) ° C and relative humidity (50 ± 5) % for at least 40 hours in accordance with ISO 291 (2006). Furthermore, the individual temperature and time dependence on the area weight and moisture content of fabrics was determined. Dependency was evaluated in STATISTICA by the method of single factor analysis of ANOVA scattering (Šmelko, Wolf 1998, Klein et al., 1999).

## 3. Results

The results of the tests are presented in the form of column and box graphs, where samples of individual coating fabrics (PT) are arranged in three sets based on the type of fiber P - natural, Ch - chemical and Z - mixed. In the case of box graphs, it is not a matter of the results, but above all, it is evident, where the average of the values of the individual characteristics of the three sets of coating fabrics is based on natural, chemical and mixture fibers.

Before we did the fire characteristics tests themselves, we determined the moisture and the area weight of the textiles shown in the basic sample data in tab. 2 and the variability analysis graph is in Fig. 1.




The area weight of each sample of the fabrics is in the range of 150 g.m$^{-2}$ (Z10) to 430 g.m$^{-2}$ (Z12). Both samples belong to a set of mixture fabrics, the values of which differ from those tested on the basis of natural and chemical fibers. The lowest variance between the area weight values is for chemical samples.

The moisture content of the fabric samples is dependent on the origin of the fiber. The moisture value

Fig. 1 Variability analysis a) area weight b) moisture of the natural fiber fabrics differs significantly from the moisture values of the chemical and mixture fiber sample sets and is evidently higher. However, the highest moisture value is obtained by the Ch5 sample (100% Vs), the chemical substance of which forms the natural polymer - cellulose (chemically treated). A comparable value of moisture is Z12, the basis of which is 60% viscose and 40% wool. A slightly lower value is the Z9 sample, which contains 60% viscose and 40% polypropylene. Samples based on chemical synthetic polymers achieve very low moisture values.

### *3.1. Results of the determination of the flash point temperature and the flash point time of the coating fabrics*

For each determination of the flash point temperature of the individual fabric, it was necessary to prepare a sufficient number of samples (at least 10 pieces). A graphical representation of the resulting average values of the flash point temperatures of individual samples of the coating fabrics is shown in Fig. 2 and 3.

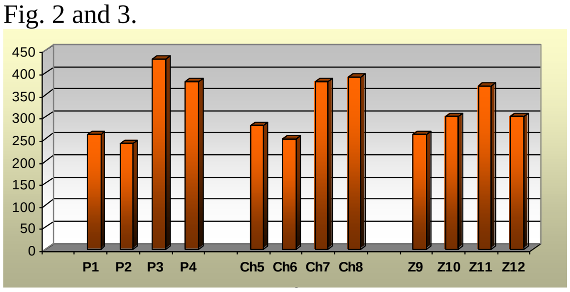



Fig. 2 Resulting values of PT flash point temperature

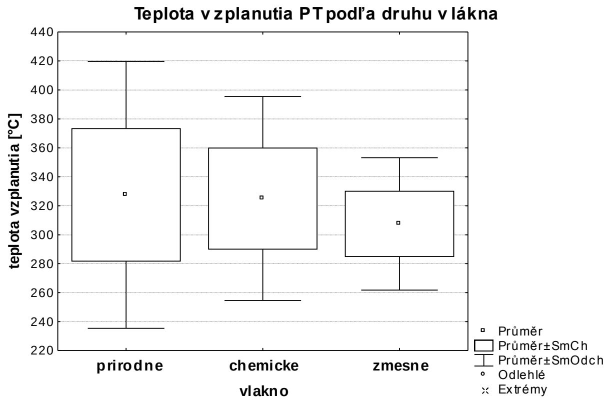



Fig. 3 Variability analysis related to flash point temperature of PT

The flash point, which represents the lowest temperature at which the gaseous decomposition products of the substance in the mixture with air ignite, is the temperature at which the ignition initiator is ignited in the test fabrics ranging from 240 °C in sample P1 (100% ba) to 430 °C in sample P3 (100% wool/wool). Both textiles are based on the natural fibers with the highest temperature range. The smallest temperature range was achieved by mixture fiber fabrics. The second lowest flash point temperature after cotton achieved the sample Ch6 based on chemical fiber (100% PAN) at 250 °C. Ch5 sample (100% Vs), the chemical substance of which forms cellulose, similar to that of cotton fabrics, reached a higher flash point of 20 °C compared to the P1 or P1 samples or by 40 °C compared to sample P2.

Comparable temperature values with wool fabrics reached Ch7 and Ch8 samples, both based on 100% PES, but the Ch7 sample is non-combustible. This test method did not meet the expectations that Ch7 and Z10 treated samples would have significantly higher flash-point temperature values than other fabrics. Sample Ch7 reached a lower value of 10 °C over Ch8 (PES without retardation), but a significant difference compared to another sample with Z10 flame retardant, which has a flash point of up to 80 °C lower. A relatively high flash point temperature reached the Z11 sample (61% PES, 39% b) and 370 °C.

Fig. 3 shows that the average values of the flash point temperature for the different groups of coating fabrics do not differ significantly.

When determining the flash point temperature, the time to flash point of the individual test samples is also monitored by some authors, which is also referred to as the induction time. The graphical representation of the resulting flash time values is shown in Fig. 4 and the analysis of the variability of the times to the flash point according to the kind of fiber of the individual coating fabrics is shown in Fig. 5.

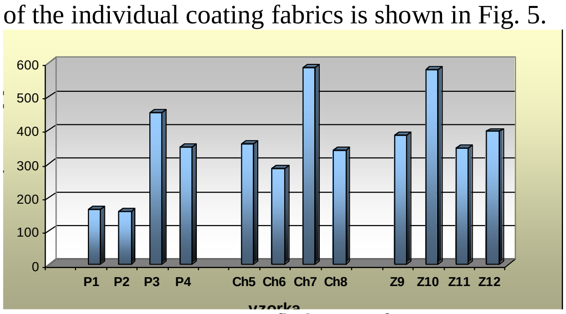



Fig. 4 Time to flash point of PT

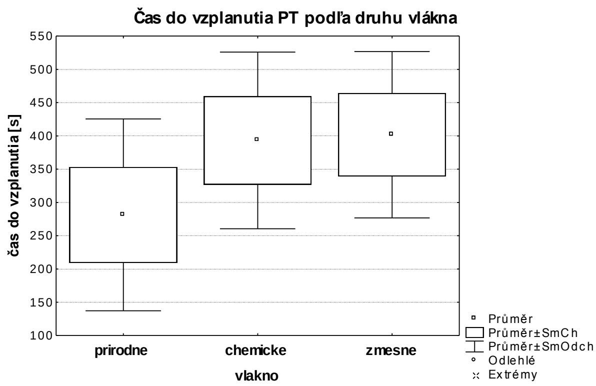



Fig. 5 Variability analysis of a time to flash point of PT

While at the flash point temperature it may appear that the temperature of the individual samples is relatively little different, and the retardation treatment did not fulfill the role of non-combustion treatment, otherwise it is at the time to reach the flash point temperature. From the fire safety point of view, it is important that the flash point time values are as high as possible. Those have just obtained the Ch7 and Z10 flame retardant treated samples (587s and 580s). The time difference between them is minimal.

Fig. 5 shows that the values of the flash point times of natural fiber fabrics are noticeably different from those of chemical and mixed fibers that do not differ significantly from one another.

The time values of the individual samples range from 159 s (P2) to 587 s (Ch7). The time values of the individual samples range from 159 s (P2) to 587 s (Ch7).

Cotton samples P1, P2 reached the lowest flash point times of 164 and 159 seconds. A much higher value of time has the Ch5 sample, the basis of which is regenerated cellulose chemically processed until the cotton is mechanically processed. Wool samples of fabrics, the chemical substance of which forms the protein - keratin, have an incomparably higher flash point time (451 s and 351 s) compared to natural cotton fabrics. Samples P3 and P4 have a higher area density and also moisture than samples P1 and P2.

At the lowest values of the time to flash point of cotton fabrics, the Ch6 (287 s) sample is based on chemical fiber (100% PAN). Other samples reached values up to 300 seconds.

### *3.2. Results of the determination of the ignition time and the ignition time of the coating fabrics*

The conditions for determining the ignition temperature were the same as at the flash point temperature, but the ignition initiator changed according to the standard (no flame attachment, the sample ignited the hot air). Graphically the ignition temperatures are shown in Fig. 6 and the analysis of the variation of the ignition temperature by type of fiber is shown in Fig. 7.

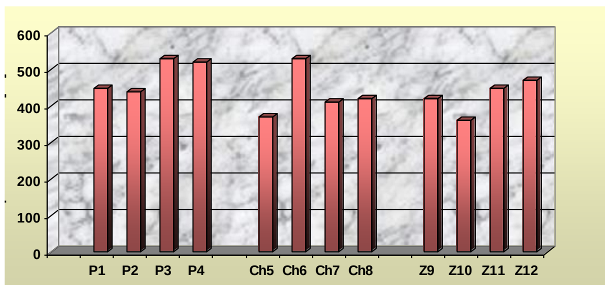



Fig. 6 Ignition time of PT

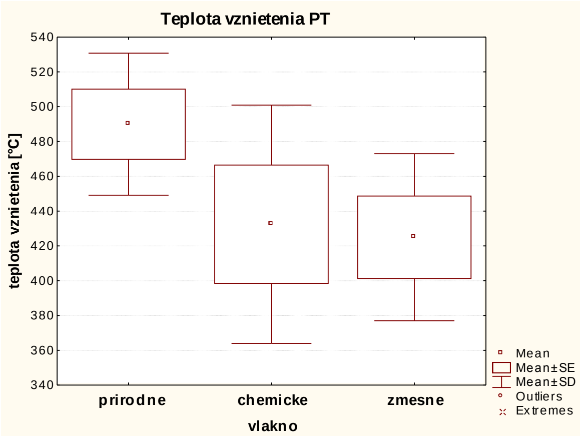



Fig. 7 Variability analysis related to ignition temperature of PT

The ignition temperature, representing the lowest temperature at which the decomposition products of the substance are ignited in the absence of the ignition initiator, ranges from 360 °C (Z10) to 530 °C (P3, Ch6) in the test samples. In the case of natural fiber fabrics, unlike the results of the flash point temperature, the average value of the ignition temperature visibly differs compared to the chemical and composite textiles, is significantly higher.

The test method for determining the ignition temperature has showed a surprising result in terms of both the height of the values of natural materials (especially cotton) and, in particular, the results of non-combustible textiles. While Ch7 sample based on 100% PES with retardant treatment reached a 10 °C lower value than the Ch8 sample, which is also based on 100% PES but without retardation, the Z10 sample, which is a mixture of 50% PES and 50% PP, reached the lowest ignition temperature (360 °C) not only from the mixed fiber sample but also from the set of samples of all tested textiles. This value significantly affected the chemical composition of the sample. Although polypropylene with flame-retardant finish in combination with polyester, this fabric did not achieve a 100% PES ignition temperature value. One of the highest ignition temperature values was Ch6 (100% PAN), in contrast to the flash point temperature, where the sample was among the lowest-weighted fabrics.

For composite textiles, the ignition temperature for sample Z11 (61% PES, 39% cotton) is equal to cotton fabrics even though it contains more polyester than cotton in its chemical content. For sample Z12 (60% Vs, 40% w / w), the ignition temperature is between the values of fabrics having a 100% composition of one polymer, i.e., of wool or viscose (samples P3, P4 and Ch5), and these samples are also comparable to the area weight and moisture content. In contrast, the Z9 (61% Vs, 39% PP) ignition temperature is higher than the Ch5 sample of 100% viscose.

As with the flash point temperature determination method, the ignition temperature is followed by the ignition time. The resulting values of ignition times are shown in Fig. 8 and analysis of the variability of ignition times by the type of fiber of the individual samples is shown in Fig. 9.

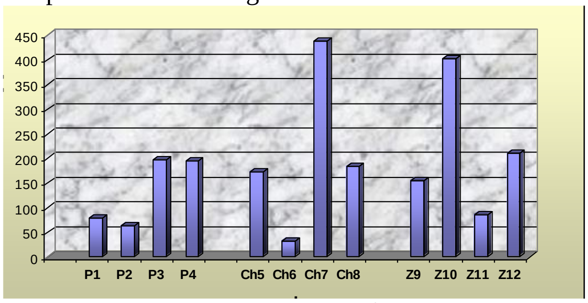



Fig. 8 Time to ignition of PT

By natural fabrics, the scattering of the time values to ignition is the smallest. The average time values of these materials differ from the average values of time to ignition of the chemical and mixed fabrics, with the average time values of the fabrics based on chemical and mixed fibers not significantly different. The greatest dispersion of values was seen in chemical fiber fabrics. In the time of ignition, the role of flame-retardation has largely manifested itself. Both flame retardant samples reached ignition times over 400 seconds. By the Ch7 sample the ignition time was extended by 254 seconds compared to the Ch8 specimen, while the ignition temperatures of these samples varied by only 10 °C. The lowest value of ignition time reached the Ch6 sample (PAN). This fabric was ignited in 32 seconds.

From the point of view of fire safety, it is important that the values of the flash point and ignition temperature are as high as possible, but also the values of the time to flash and ignition are as high as possible.

*3.3. Statistical evaluation of particular characteristics dependency on area weight and moisture*

Area weight and moisture are important physical properties that affect the properties of the materials. We have therefore tested the dependence of the tested characteristics on these properties. Even with one characteristic for a whole set of samples, there was no statistically significant dependence, so we evaluated the correlation for each set of samples based on natural, chemical and mixed fibers. The linear regression model evaluated by STATISTICA was used to evaluate dependence. Since the correlation between independent variables has been confirmed and the regression models are not multi-channelarity, one-dimensional regression has been used. The statistical significance of the whole model was tested by the F-test.

The dependence between the flash point temperature and the area weight by fiber type is as follows:

- natural – area weight: flash point temperature: $r^2 = 0.9947$; $r = 0.9974$, $p = 0.0026$; $y = 65.5087988 + 0.8806*x$
- chemical – area weight: flash point temperature: $r^2 = 0.7125$; $r = -0.8441$, $p = 0,1559$; $y = 626.836735 – 1.0408*x$
- mixtures - area weight: flash point temperature: $r^2 = 0.0073$; $r = -0.0854$, $p = 0.9146$; $y = 314.817073 – 0.0305*x$

In the case of natural coating fabrics with increasing area weight, the temperature of the flash point temperature increases. Dependency severity measured by the correlation coefficient reaches 0.99, which is almost a functional dependency. The relationship of the flash point temperature to the area weight is statistically very significant. This is confirmed by the F test coefficient of determination F = 376.79 (critical value F = 18.51 applies to all observed dependence on area weight and moisture for $\alpha = 0.05$). On the basis of the test, we can state at the level of significance $\alpha = 0.003$ that the coefficient of determination is statistically significantly different from 0. The dependence between the area density of the natural fabrics and the flash point temperature can be expressed by the following linear regression function: flash point temperature = 65.51 + 0.88 * area weight.

For chemical fabrics with increasing area weight the flash point decreases (r = -0.84). The reason for negative regression dependence is probably the fact that for higher-weighted fabrics, the proportion of light-weight substances is higher. Due to the low number of measurements, the dependence on the significance level $\alpha = 0.05$ is statistically insignificant (F = 4.96).

For mixed textiles, the relationship dependency of the flash point temperature and the area weight was not statistically significant (F = 0.015, $\alpha = 0.91$). Dependency severity measured by the correlation coefficient is very low r = 0.085, indicating the fact that the ignition temperature is not primarily dependent on the area. It is an interesting scientific problem that goes beyond our research. In the future, it will be necessary and useful to address this problem on a wider set of data. There were four measurements to find the relationship between the flash point temperature and the area weight for natural fabrics. This is not in the case of chemical and mixed fabrics. I consider this statement to be an important partial research result.

The dependence between the flash point time and the area weight is as follows:

- natural - area weight: time to flash point: $r^2 = 0.9722$; $r = 0.9860$, $p = 0.0140$; $y = -124.028309 + 1.3623*x$
- chemical - area weight: time to flash point: $r^2 = 0.1021$; $r = -0.3196$, $p = 0.6804$; $y = 608.382653 – 0.7418*x$
- mixtures - area weight: time to flash point: $r^2 = 0.0314$; $r = -0.1771$, $p = 0.8229$; $y = 443.262195 – 0.173*x$

Similarly to the dependence of the flash point temperature on the weight of the natural textile fabric and the flash point time dependence on the weight of these materials, a statistically significant dependence was confirmed. This is confirmed by the F test coefficient of determination F = 69.93. Based on the test, we can state at the level of significance $\alpha = 0.014$ that the coefficient of determination is statistically significantly different from 0. The dependence between the weight of the natural fibers and the time to flash point can be expressed by the Linear regression function:

flash time = 608.38 – 0. 74 * area weight.

For the fabrics based on chemical fibres, the time to flash point decreases (r = -0.32) with the increasing area density. The studied dependence on the significance level α = 0.05 is statistically insignificant. F = 0.228, which is substantially less than the critical value of 18.51.

For mixture fabrics, the dependency between the time to flash point and the area density was not statistically significant (F = 0.06, α = 0.82).

The dependence between the ignition temperature and the area weight is:

- natural - area weight: ignition temperature: $r^2$ = 0.9831; r = 0.9915, p = 0.0085; y = 353.435348 + 0.4422*x
- chemical - area weight: ignition temperature: $r^2$ = 0.0072; r = -0.0851, p = 0.9149; y = 462.091837 – 0.102*x
- mixtures - area weight: ignition temperature: $r^2$ = 0.5289; r = 0.7273, p = 0.2727; y = 359.634146 + 0.2724*x

The ignition temperature of natural fiber fabrics with increasing area weight is increasing. Relationship severity measured by the correlation coefficient reaches 0.99, similar to the dependence of the flash point temperature on the area weight. The ignition temperature dependence is statistically very significant (F = 116.49). Based on the test, we can state at the level of significance α = 0.008 that the coefficient of determination is statistically significantly different from 0. The dependence between the area weight of the natural textiles and the ignition temperature can be expressed by the following linear regression function: ignition temperature = 353.44 + 0.44 * area weight.

In the case of chemical fibers with an increasing surface density, the ignition temperature decreases (r = -0.08), up to one so-called extreme value (Ch6 sample). The studied dependence is statistically insignificant (F = 0.015) at the level α = 0.05 (due to the low number of measurements). Similarly, the dependence on mixed-fiber fabrics is statistically insignificant, where the calculated value of F = 2.246.

Dependency between ignition time and area weight:

- natural - area weight: time to ignition: $r^2$ = 0.9617; r = 0.9807, p = 0.0193; y = -68.3534813 + 0.6777*x
- chemical - area weight: time to ignition: $r^2$ = 0.1574; r = -0.3967, p = 0.6033; y = 546.806122 – 1.1735*x
- mixtures - area weight: time to ignition: $r^2$ = 0.0248; r = -0.1574, p = 0.8426; y = 253.896341 – 0.1673*x

The time-to-ignition and area weight dependence is statistically significant, as in the previous cases by natural fabrics, which is confirmed by the F test coefficient of determination F = 50.21. At the level of significance α = 0.02, the dependence between the area weight and the ignition time for natural fabrics can be expressed by a linear regression function: time to ignite = -68.35 + 0.68 * area weight. For chemical and mixture fiber fabrics, the dependence is statistically insignificant (chemical F = 0.37, mixed F = 0.051). Dependence was also evaluated for the additional physical parameter – moisture, because the results were comparable with the results of the dependence of the given characteristics on the area weight. Even in relation to the tested characteristics on moisture, the dependence was confirmed by the F test. Critical value F obtained from tables = 18.51. In order to confirm the statistically significant dependence, the calculated Fr value must be greater than the critical value.

Dependency of the tested characteristics of the coating fabrics on moisture is as follows:

- natural - moisture: flash point temperature: $r^2$ = 0.9284; r = 0.9635, p = 0.0365; y = -15.3229797 + 48.4042329*x; F = 25.941
- chemical - moisture: flash point temperature: $r^2$ = 0.2820; r = -0.5310, p = 0.4690; y = 351.986574 – 8.8263528*x; F = 0.786
- mixtures - moisture: flash point temperature: $r^2$ = 0.2302; r = -0.4798, p = 0.5202; y = 333.301371 – 5.65199794*x; F = 0.598

Statistically significant was only the dependence of the flash point temperature on moisture by natural materials to a significance level of 0.04, where the rise in the moisture increased the temperature.

- natural - moisture: time to flash point: $r^2$ = 0.8994; r = 0.9484, p = 0.0516; y = -246.735977 + 74.5479671*x; F = 17.887
- chemical - moisture: time to flash point: $r^2$ = 0.0695; r = -0.2637, p = 0.7363; y = 418.475686 – 8.25042887*x; F = 0.149
- mixtures - moisture: time to flash point: $r^2$ = 0.1994; r = -0.4466, p = 0.5534; y = 467.407446 – 14.3827921*x; F = 0.498

With the dependence of flash point time on moisture, the relationship was not confirmed as statistically significant in one set of textiles.

- natural - moisture: ignition temperature: $r^2 = 0.9790$; r = 0.9894, p = 0.0106; y = 307.177571 + 25.1072967*x; F = 93.199
- chemical - moisture: ignition temperature: $r^2 = 0.2570$; r = -0.5069, p = 0.4931; y = 457.537906 – 8.18901244*x; F = 0.692
- mixtures - moisture: ignition temperature: $r^2 = 0.4472$; r = 0.6687, p = 0.3313; y = 387.289916 + 8.26069744*x; F = 1.618

At the ignition temperature, the statistically significant dependence on moisture in the natural fiber sample set was confirmed. This is confirmed by the higher values of the statistical characteristics ($r^2$, r) and the lower significance level p = 0.01. In chemical and mixture textiles, the dependence on the tested number of samples was not confirmed as statistically significant, but it should be noted that this is mainly due to the extreme values of the Ch5 and Z11 samples.

- natural - moisture: time to ignition: $r^2 = 0.9926$; r = 0.9963, p = 0.0037; y = -144.163864 + 39.1689183*x; F = 268.28
- chemical - moisture: time to ignition: $r^2 = 0.0570$; r = -0.2388, p = 0,7612; y = 235.605874 – 9.51950099*x; F = 0.121
- mixtures - moisture: time to ignition: $r^2 = 0.0890$; r = -0.2983, p = 0.7017; y = 261.497428 – 10.4594584*x; F = 0.195

As statistically very significant, the dependence between ignition time and moisture in natural textiles was confirmed, where they reached a coefficient of determination and a correlation coefficient of the highest value compared to all the observed moisture dependency characteristics. In the case of chemical and mixture fabrics, the relationship was not confirmed, while by the mixture materials this depencency was interferred in particular with the remote vales of sample with retardation treatment Z10.

### 4. Discussion

Methods for obtaining the flash point and the ignition temperature are also called ignition tests (STN ISO 871). Tests carried out under the conditions of this method may be of considerable importance when comparing the relative fire initiation characteristics of the various materials in our case with different coating fabrics. The values obtained represent the lowest ambient air temperature at which ignition of the material occurs under the test conditions. The measured values allowed us to organize fabric coating materials according to their susceptibility to ignition under normal conditions of use.

The results of the research show a considerable differentiation of ignition properties of individual coating fabrics. It has been confirmed that the evident influence on flammability as such has, in particular, the chemical composition of the material. The lower values of the flash point temperetaures reached the samples whose chemical substance is cellulose. These are the cotton-based samples, but also viscose-based samples. From the two mixed samples Z9 and Z12, where the viscose has a majority presence, has benefited, both from the flashpoint and from the flash point time, the wool combination. Wool-based samples averaged the highest values of flash point, but there is a fairly large difference between P3 and P4. Higher temperature but also flash point time for sample P3 may affect both the higher area weight and the non-dirty finishing.

The lowest flash point temperature was reached by the Ch6 sample, which is based on polyacrylonitrile even though it has a high area weight. The polyester sample flashpoint temperature values were ranked as wool samples, while the Ch7 - flame retardant treated and Ch8 samples achieving almost identical results, but the Z10 sample treated with flame retardation lag behind the Ch7 sample.

This was probably due to the presence of a retarded polypropylene fiber, which is assigned, similar to PAN, among easily flammable polymers.

At the ignition temperatures, the situation is different, compared to the flash point temperature. With this method, the temperatures of the individual samples are more balanced. They achieved the highest values of wool-based fabrics as well as cotton (also in combination with polyester) and, surprisingly, fabrics made of polyacrylonitrile. Relatively low ignition temperatures reached the retarded samples. Between Ch7 and Ch8 the difference was only 10 ° C, sample Z10 had even the lowest value of all samples.

A different view is taken on the ignitability of the samples of individual coating fabrics when we add the appropriate flash and ignition times to the temperature values. We see that time values are greatly differentiated between individual samples. In both cases, the values of time were incomprehensibly higher by samples with retardation treatments, Ch7 and Z10.

The task of retardation is to prolong the time to ignite the material, which is important in the case of a real fire, especially when evacuating people when every second is rare in escaping from the danger zone. From the point of view of fire safety, it is important that the flash and ignition temperatures are as high as possible, but at the same time also the ignition time is as long as possible. Therefore, in terms of ignition temperature, we can assume that there is a greater risk of a possible fire by sample Ch6 polyacrylonitrile fabric that has a high ignition temperature, but this has been achieved in a very short time, which may affect the further spread of fire. This can also be stated by cotton-based samples. Literary sources confirm that the values of the flash point and igniting temperatures vary among authors. Pokojný (1986), Marková (2004) refer to a 250 °C flash point and 420 °C ignition temperature of cotton, and a polyester ignition temperature of 380 °C and flash point temperature of 460 °C. Filipi (1999), Babrauskas (1985) report a flame temperature of cotton of 360 °C and a flash point temperature of 480-570 °C. Fire Resistance (2006) reports the ignition temperature of the polyester of 485 °C and 570 °C of wool. The cause of different values may be to some extent in the fabric itself, but also in laboratory conditions.

Secondary factors, which to a certain extent affect the flammability of textiles, include physical parameters as area weight and moisture. Even with one tested fire characteristic, the area / moisture the dependence was not statistically significant for the whole sample set. Therefore, dependence was analysed by sample sets based on natural, chemical and mixtures of fibers. There were the evident differences in the individual files. As statistically significant, correlations between area weight, moisture and individual test characteristics have only been demonstrated for natural fiber-based fabric sets. However, it should be noted that the correlation was evaluated in individual sets at a small number of values, but for the natural materials, four values were sufficient to demonstrate the dependence between the individual characteristics. The results are, to a certain extent, also influenced by the fact that two natural cotton-based samples and two wool-based samples were natural materials, while the chemical and mixture fibers were more sophisticated in composition. However, even in the case of natural materials it can be stated that the thermal degradation process has a predominant influence on the chemical composition, which confirms the results of the individual characteristics - at each determination of the characteristics, the lower values of both cotton textiles as wool textiles.

An interesting partial knowledge is that in the case of natural fibers, the area weight, in comparison to moisture, has a greater influence on the following characteristics: flash point temperature, flash point time, ignition temperature, and on the other hand the greater affect has the moisture in comparison to area weight, on the ignition time.

## 5. Conclusion

In terms of their chemical nature, coating fabrics that have been the subject of research are flammable organic polymers and often contribute to the formation and spread of indoor fire due to inattention, negligence, and ignorance of people. It is therefore important to address them also from the point of view of fire protection and safety.

The method chosen cannot be used to describe or assess the fire hazard or the risk of fire of materials under specific fire conditions. However, the results of this test may be used as elements of the fire hazard or fire risk assessment, taking into account all factors relevant to the fire risk assessment in the particular case. Tests carried out under the conditions of the chosen method may be of considerable significance when comparing the relative fire initiation characteristics of the various materials in our case with different coating fabrics. The values obtained represent the lowest ambient air temperature at which ignition of the material occurs under the test conditions. The measured values allowed us to compare the textile coating materials to the susceptibility to ignition.

The paper provided original results from a set of fire characteristics such as the flash point and the ignition temperature, supplemented by the respective flash point and ignition times. The results highlighted the relatively large differences in the ignition of fabrics:

- the flash point temperature ranged from 240 ° C (cotton) to 430 ° C (Scotchard treated),
- the time to flash point was from 159 s (cotton) to 587 s (retarded PES),
- the ignition temperature was from 360 ° C (retarded fabric 50% PES / 50% PP) to 530 ° C (wool / wool),
- the ignition time was from 32 s (PAN) to 438 s (retarded PES).

The retardation treatment was evident mainly due to a significant increase in the time to the flash point and ignition temperature achievement.

Many advanced countries protect their citizens by adopting legislation prohibiting the use of easily flammable materials in upholstered furniture not only in the public sector but also in the home.

### Acknowledgments

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# Wood Fire Protection

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**Abstract**

Burning of wood has become the area of interest for many institutions and individuals. Burning of wood solutions for fire protection purpose can be defined within several separate areas. Material testing and its behaviour in terms of combustion and fire represent one of them. The second area includes the observation of the impact of wood proprieties on combustion process (moisture, density, wood structure, surface quality etc.). Third area comprises fire-retardant treatment of wood, efficiency evaluation of fire retardants and quality of fire-retardant treated material. The fourth area includes the problem of safe application of wood and wood-based materials into wooden constructions.

*Keywords*: burning, fire protection, wood, wood-based materials, wooden constructions;

## 1. Introduction

Wood has some technical characteristics predetermining it to be suitable for general use. Wood and wooden products still have their say even nowadays. However, there were some tendencies (mainly in the 70´s) to replace it with plastics or other materials. Getting to know more about its internal structure, chemical composition, physical and mechanical properties, it stimulates intensive development of its processing methods, technologies and its multi-purpose use.

Wood is processable and workable in a rather easy and economical way. It can be processed or glued in various ways and joined using no fasteners. Besides its technical and aesthetic advantages, it creates a positive psychological microclimate for man. If people are economical with it, the material is inexhaustible. Unlike other raw materials whose lifespan is several hundred years or few more decades ,wood as a raw material is renewable and thus inexhaustible (Osvald 1997).

The first and sole function of wood was to be used as fuel. It is only later when it starts to serve other purposes, e.g. building material and production material for various types of products or items of everyday consumption. Its flammability is becoming an undesirable phenomenon outnumbering its benefits as a fuel since wood can catch and spread fire.

To avoid the general statement «wood burns», we were looking for the conditions and physical parameters of environment and wood, when it ignites and burns. An important stage of the research was the evaluation of wood from the point of view of its burning behaviour by means of various tests and test methods, which assessed the materials from the fire protection perspective. The goal of the testing was not only to gain certain values, the tests themselves underwent an evaluation regarding their objectivity. Each test dealt with its specifics and specific proprieties of wood-based test specimens in order to achieve the highest evaluation objectivity possible (Osvald 1997).

Application of fire retardants represents another important set of experiments. Apart from observing its retarding effect and searching for concentration limits of the active components of the fire retardant, wood treatment technology was also evaluated (Harangozó, Tureková, Rusko 2011). With wood in growing trees, dipping and impregnation technologies, vacuum-pressure impregnation methods have been used along with

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coatings. The experiment results have confirmed that fire retardant treated wood and impregnation method have an impact on the degree of fire-retardant treatment of wood and the quality of the retarding effect. The impregnation methods even guaranteed an increased lifespan of the retardant applied in such way. It eliminated any mechanical damage of the surface of treated wood, as it might have happened if applying the retardant by coating. We were looking for new application methods and technological processes of fire-retardant treatment for wood based materials (Barbu, Réh, Irle 2014).

In the study of mechanical properties due to thermal load, we detected bimodal properties of wood for fire protection purpose. If, on the one hand, wood is a material which is relatively easy to ignite, spreads flame and burns, than, on the other hand, it shows rather positive values of fire resistance in marginal conditions.

## 2. Burning of wood and its differentiation

Research in the field of wood combustion cannot be considered as one separate discipline.  Even if the disciplines are related, we can separately characterise those referred to in fig. 1., i.e. material evaluation, test evaluation, evaluation of retarding effects and application of new knowledge into practice, wooden buildings, or buildings in general (Balog 1999, Balog Kvarčák 2014).

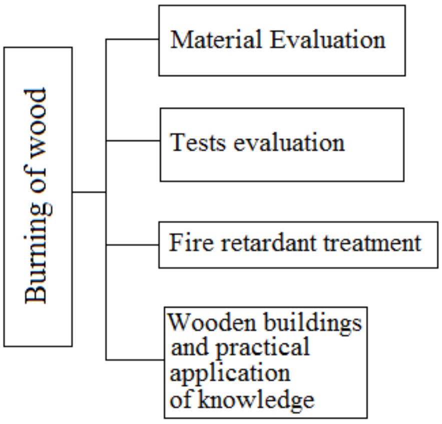


Fig. 1 Basic scheme of wood combustion process (Osvald 2017)

## 3. Material evaluation

A template (with its file name ending on .dot, Material evaluation was the first step of the process. It all starts with a statement that wood burns, and, in certain cases, it becomes standard value no. 1. Other materials are than distinguished from wood: those with a higher value - more combustible ones and those with a lower value below 1 - less combustible ones. Experts suddenly ask questions: What type of wood do we have in mind? What type of wood shall have the value of 1 - to compare it with other materials?

Tree type becomes an important factor. We find out that reactions of different types of trees to the same experimental conditions are not the same. We start to divide trees into classes and groups of flammability. If we pay attention to details, we find out that one type of tree shows large variability of results. We observe the impact of density, surface quality, geometric shape and dimensions on the test results. Research into material evaluation gives more details about the factors influencing ignition process and burning. We come up with the definition of «flameless burning» as it is a dangerous factor in terms of fire protection (Chovanec Osvald 1992, Martinka at all 2012, Požgaj et al.1997, Kačík 2012 at all, Kačíková et al.2013).

The issue of wood combustion differentiates into the study of wood in growing trees and large wood-based materials (see fig. 2). Growing wood is studied using different plants, where we look into the impact of their chemical composition on combustion process and ignition, impact of physical properties, the very structure of wood as well as various wood modifications (except for retardant treatments). Thermal modification of wood, for example, became very modern nowadays.

Besides the basic characteristics of wood described above, type of large wood-based material and its production method influence the process of ignition and burning. Size of wooden element inside a large wood-based material structure represents a limiting factor, i.e. wood fibre in a DVD as well as more compact elements of veneer in plywood. Apart from the type of the wooden element, the production technology of the large wood-based material also influences the characteristics of large wood-based materials and thus influences its burning. In general, we can assume that the main physical characteristics affecting the ignition and burning process are density and thickness of the material. Just as with growing wood, we must not forget about the possible modification of the material. Any modification must be re-tested and revised for fire protection purposes. We must not use the values with any untreated material.

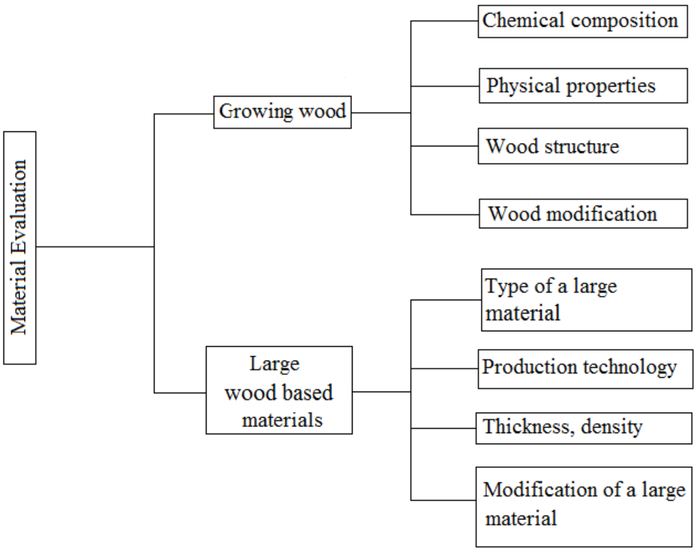


Fig. 2 Basic evaluation of wood and wood-based materials for fire protection purpose (Osvald 2017)

## 4. Wood and wood-based materials for fire protection purpose

Observation of changes has been in the centre of our attention so far. The changes caused dissimilarities in ignition and burning process of wood and wood-based materials. The second problem is the quality and objectivity of the tests carried out to observe these changes. For scientific research, these conditions can be rather easily modified and we are getting statistically confirmed values that we can consider to be credible. This would work worse in a practical application. The test methods did not take into account all specific features that wood has in the process of burning. Some tests were therefore considered to be biased. When applying the knowledge of material evaluation, size of the samples seemed to be one of the major problems (see fig. 3). As you can clearly see from the image, sample size will cause disparity in wood type evaluation. Except for moisture level perhaps, values such as specific density, quality of processing or other parameters of the samples are not prescribed, which may affect test results (White 1995, 1998, Xu et al. 2010, Zachar Mitterová 2009).

Besides the sample itself, physical parameters such as heat load, heat source (flame, radiant), length of exposure, intensity adjusted by regulators (flow rate of gas or rheostat) and operational method (direction, deviation from a plane in relation to the plane of the sample surface exposed to a source) have imposed problems during the tests. Environmental conditions, in which the test is being carried out, have been defined. It is either conditions of laboratory environment or of laboratory equipment itself. There is a significant difference between the two. If the burning process of the sample is taking place in an open space - it better simulates the conditions of a real fire; or the test is carried out in an enclosed area - it homogenises test conditions and gives better results not affected by the environment. Each method has its advantages as well as disadvantages and it depends on observers which property - in relation to wood and fire - they need to assess (Chrebet et al 2012, Martinka et al. 2014).

Evaluation criteria have been another problem of the test methods, with weight loss being an eligible as well as traditional parameter. It came in useful when evaluating the material itself or monitoring the impact of wood type on ignition and burning process, the impact of density and thickness of large wood-based materials and so on. The method is not that suitable with fire retardant treated samples. Better IT equipment, measuring, analytical and recording equipment made it possible to obtain more data about the sample and to assess, in a more comprehensive way, the test material from the point of view of its ignition and burning.

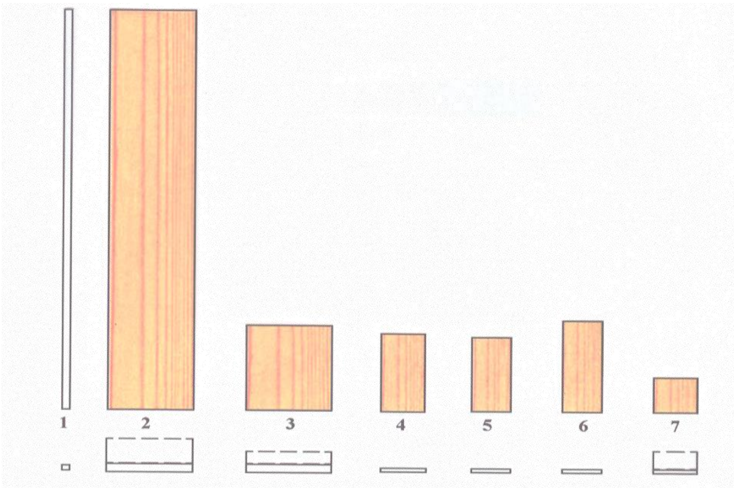


Fig. 3 Sizes of the test-bodies used in the test for fire protection purpose
1 - Truax -Harrison, 2 - DIN 4102/A2-B1, 3 - STN 73 0862, 4 - STN 73 0862/B
5, 6 - DIN 4102/B2, 7 - Conical Calorimeter (Osvald 1997)

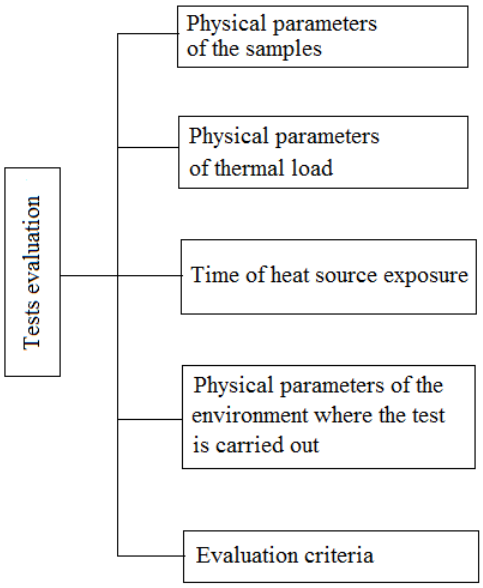


Fig. 4 Test method evaluation for objective wood/wood-based materials testing (Osvald 2017)

## 5. Fire-retardants vs. wood-based materials

Fire retardant treated wood dates back to the times of Ancient Egypt in its heyday. The second boom was recorded in the 17th century. After the emergence of new combustible materials and plastics, the term « fire-retarding treatment » revitalises and renews its importance for wood too. There were times when the application of fire retardants was repressed since people did not want more chemicals to be injected into their life. It is important, however, to know what line not to cross and when it is legitimate to exclude fire retardants from being used and thus remove the protection of wood against ignition and burning and remove its overall protection.

With growing wood, fire retardants can be applied as any wood protective substance such as fungicides, insecticides and aesthetic modifications. For wood bsed materials, it includes modification of wood, fibre, splinter, veneer, (which is economically quite a difficult process), or modification of ready-made large wood-based material (Danihelová Mitterová 2016, Mahút Horský Osvald 1983, Réh at all 1990 Réh Bučko Osvald 1991).

Fire retardant was, of course, evaluated from the point of view of its effectiveness. However, it is not the only property that was evaluated. As with any type of coating, health properties of the coating must be evaluated too. Questions related to toxicity of the fire retardant must be solved not only for the coating and its application, but also for the by-products that are created in the process of burning. Smoke density is another important factor relevant to fire retardants (Veľková, Výbohová, Bubeníková 2007).

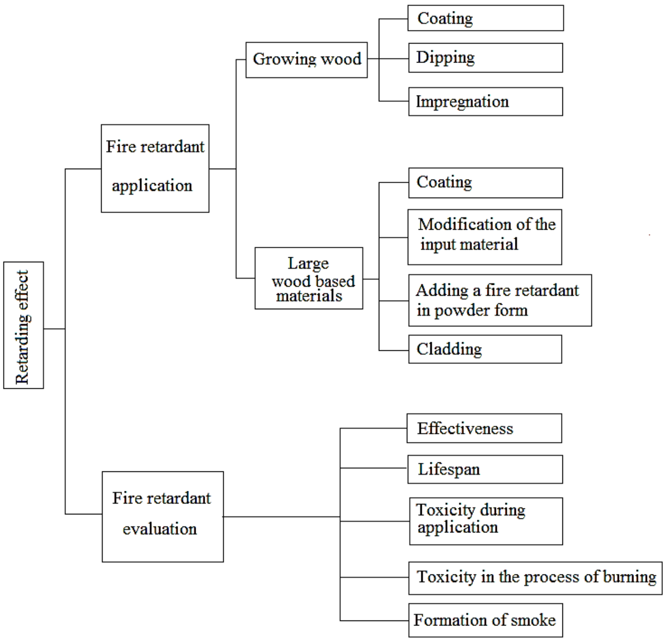


Fig. 5 Fire-retardant treatment of wood and wood-based materials (Osvald 2017)

**6. Practical application of knowledge of wood burning in wooden buildings and other constructions**

All efforts to improve fire properties of wood and wood-based materials are aimed to prevent fires in wooden buildings or wooden components inside engineering structures. However, we will never be able to completely diminish the risk of fires. This ideal condition is not real even for the buildings using non-flammable materials or with the most modern fire-fighting technologies and systems (see fig. 6).

Fig. 6 34-storey building fire, Dubai, the United Arab Emirates

The goal is to reduce the number of fires, to decrease the level of damage to property and to have as few casualties and injured people as we can. This goal can be achieved by applying modified, tested and certified materials into buildings. If the materials are used in a proper way and we abide by the conditions for structural fire protection, potential fire will not endanger people and will not cause major damage. Greater minimisation of the impacts can be achieved by using structural fire protection along with the fire protection technologies (Kuklík Kuklíková 2010, Danihelová Gergeľ, Nemec 2016, Osvald 2016).

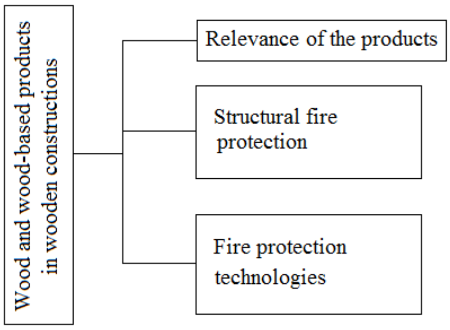


Fig. 7 Safe application of wood and wood-based materials into wooden constructions and building (Osvald 2017)

## 7. Conclusion

Efforts of scientific teams, objective evaluation of certification institutes, respecting the results in practice are a guarantee of quality wooden constructions. These constructions are safe and comply with the criteria set for fire protection. Wood as a flammable material can be incorporated into the construction without increasing the risk of fire. This way, its suitable technical characteristics - on a larger scale - will be utilized also within multi-storey buildings without increasing the risk of fire.

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# Fire plume characteristics and their application in assessment of a local fire

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**Abstract**

The paper defines local fire and its specific part (vertical section) which is the vertical smoke column called a Fire Plume. The paper presents a general description and detail of Fire Plume classification. Further, Fire Plume characteristics are described which can be divided into general and others. The general characteristics of the Fire Plume, which include geometry, temperature, flow speed and volume of smoke gases, are further detailed in relation to determining their average, minimum, maximum, axial or radial values. The discussion includes two methods for determining the said characteristics, particularly with respect to the extensive scope of methods often providing variant results. The characteristics of a Fire Plume enable a relatively detailed description of numerous parameters of a local fire and can be used in various applications for assessing the effects of a fire during the development stage.

*Keywords*: *fire development, local fire, Fire Plume, characteristics, fire safety of structures*;

## 1. Introduction

Fire is a phenomenon which has been and still is the subject of interest of safety experts.

With expanding know-how fire safety experts can disengage from the "complex perception" of fire, which is typically described by four stages of progress, i.e. initiation stage, development stage, fully developed stage and burn-out stage, and they can concentrate on researching the partial aspects of a fire.

The stage which is the subject of attention, especially in recent years, is the fire development stage, which is described by methods characterising so-called local fire. Emphasis on one of the initial stages of a fire is clearly legitimate.

The fire development stage follows on from the initiation stage and is concluded by the fully developed fire stage, when the fire parameters undergo a substantial change.

## 2. Local Fire and Fire Plume

A local fire is defined as a fire which is spread in a limited area of fire impact in the fire zone (ČSN EN 1991-1-2 [1]).

A significant aspect of the issue of a local fire is the "vertical smoke column", which is produced above its focal point. In Czech professional literature, the said smoke column is not accurately defined and it is typically generally called a "local fire" (e.g. ČSN EN 1991-1-2 [1]), even though this is not quite accurate. The vertical smoke column above the fire focal point represents a partial, though significant, part of a local fire.

Foreign professional literature sources characterise vertical smoke columns above the fire focal point with the term "Fire Plume", or "Smoke Plume" when describing its part more distant (e.g. Dinenno [2]). Definition of the Fire Plume in the fire development stage is depicted in Fig. 1

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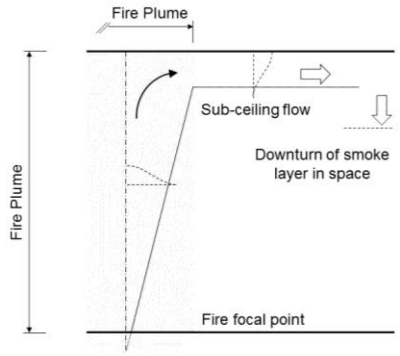


Figure 1 Schematic definition of a Fire Plume during the fire development stage

## 3. General description and classification of a Fire Plume

A Fire Plume starts to form above a developing fire from the very beginning of fire development. If it is not affected by surrounding factors it is shaped like an inverted cone.

A Fire Plume is typically divided into three zones (Dinenno [2], Hosser [3]):

- flame zone,
- transitional zone,
- smoke zone.

Flame zone is the area above the burning material's surface, which is characterised by a stable flame, increasing gas flow speed and an approximately constant temperature. In this area the Fire Plume radius is the smallest.

Transitional zone is the area which connects the flame zone with the smoke zone of the Fire Plume. The transitional zone is characterised by occasional flame and an approximately constant flow speed of burning gases. In this area the Fire Plume radius is about the same as in the flame zone.

Smoke zone is the final, often most extensive, Fire Plume zone. It is formed by a smoke column without any flames. This zone is characterised by a decreasing speed of gas flow, expanding radius, decreasing temperature, concentration of toxic gases and solid particles in the smoke.

The standard presumption is that the Fire Plume radius expands vertically at an angle of about 15 (Hosser [3], Peacock [4]).

The characteristic shape of an axially symmetrical Fire Plume is shown in Fig. 2.

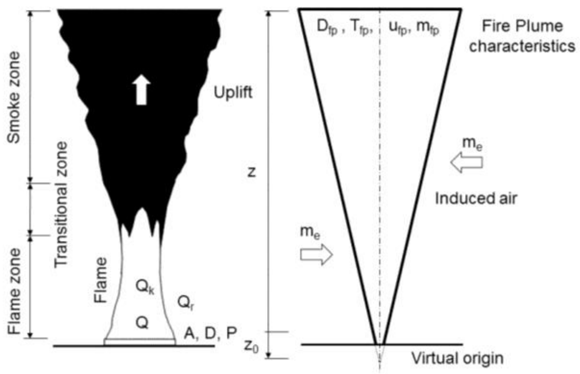


Figure 2 Characteristic shape of an axially symmetrical Fire Plume (modified from Karlsson [5], Kučera [6])

In terms of location, a Fire Plume can be classified into the following categories (Karlsson [5]):

- axially symmetrical,
- wall,
- corner,
- spilling (through window or door),
- overflowing (e.g. over balcony).

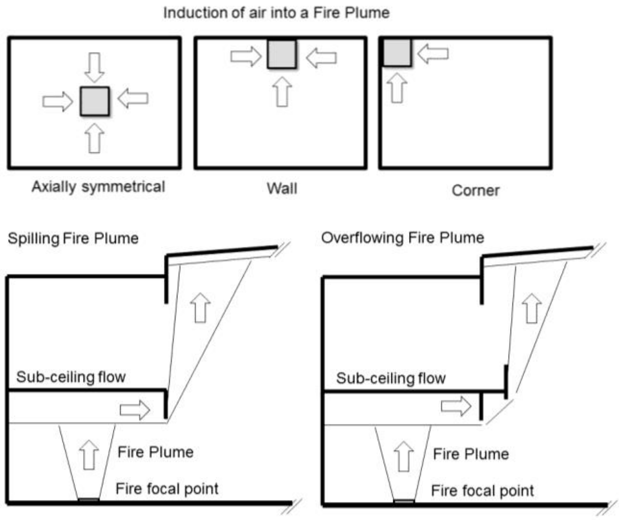


Figure 3 Classification of a Fire Plume into categories

## 4. Characteristics for describing a Fire Plume

A Fire Plume is typically described by the general characteristics which include (Dinenno [2], Hosser [3], Karlsson [5]):

- geometry,
- temperature,
- flow speed of smoke gases,
- mass (volume) quantity of gases.

Further characteristics of a Fire Plume can include gas toxicity and concentration of solid or liquid particles. Other Fire Plume characteristics are assessed sporadically.

General Fire Plume characteristics can be determined as:

- average,
- minimum,
- maximum,
- axial,
- radial.

The orientation location of average, minimum, maximum, axial and radial values of general Fire Plume characteristics is depicted in Fig. 4.

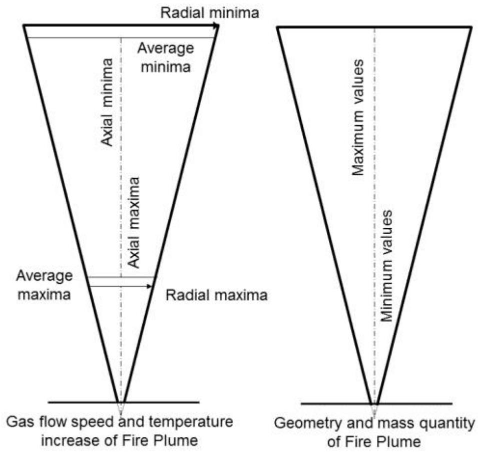


Figure 4 Orientation location of limit values of general Fire Plume characteristics

Typically, the axial and maximum values are assessed. Assessment of average values is less frequent. Radial and minimum values are assessed only in solitary cases. Classification of the most significant general characteristics is shown in Table 1.

Table 1 Classification of the most significant general Fire Plume characteristics

| **Geometry** | **Temperature** | **Flow speed** | **Smoke gases volume** |
|---|---|---|---|
| radius $b_{fp}$ | temperature $T_{fp}$ | gas flow speed $u_{fp}$ | mass quantity of smoke $m_{fp}$ |
| diameter $D_{fp}$ | axial temperature $T_{fp,osa}$ | axial flow speed of gases $u_{fp,osa}$ | mass quantity of smoke from burning material $m_f$ |
| maximum height $z_{fp,max}$ | maximum axial temperature $T_{fp,osa,max}$ | maximum axial flow speed of gases $u_{fp,osa,max}$ | mass quantity of induced air $m_e$ |
| | minimum axial temperature $T_{fp,osa,min}$ | minimum axial flow speed of gases $u_{fp,osa,min}$ | |
| | temperature at radial distance from axis $T_{fp,r}$ | flow speed of gases at radial distance from axis $u_{fp,r}$ | |
| | axial temperature under impact of layer of hot gases $T_{osa,osa,hvp}$ | | |

## 5. Discussion

The part of a local fire called the Fire Plume is a significant component of a local fire. The general characteristics of a Fire Plume are geometry, temperature, gas flow speed and smoke quantity. A local fire can be described quite accurately using the said general characteristics.

At the same time, it is possible the use general Fire Plume characteristics for assessing the effects of a fire on structures, stored materials, fire safety equipment, evacuated persons and rescue units (Kučera [7], Pokorny [8]).

With respect to safety, the application of general characteristics can be used in many operations (Turekova [9], Blecharz [10], Balážiková [11]).

In the past, numerous authors have focused on deriving methods for determining general Fire Plume characteristics, where the most significant have been Heskestad (Heskestad [12]), McCaffrey (Karlsson [5]), Thomas (Thomas [13]) and others.

It is important to mention that to determine the same characteristics of a Fire Plume there are often numerous methods producing significantly different conclusions (e.g. methods used for determining the volume of smoke in a Fire Plume). The problem of deviations has been discussed by various authors and leads to a conclusion of necessary respecting of limit conditions and the need for further research (Thomas [13]).

Current research focusing on the effect of non-standard ambient conditions on a Fire Plume and related areas is also participated in by other authors, e.g. Fang (Fang [14]) and Gao (Gao [15]), who are advancing the original know-how. Research of Fire Plume characteristics is performed for specific environments (e.g. strongly turbulent environment), which shows that the original formulae require corrections.

## 6. Conclusions

The paper emphasizes the importance of a local fire in the assessment of the effects of fires. Attention has been focused on the partial area of a local fire called the Fire Plume. Determining the characteristics of a Fire Plume yields a relatively detailed description of a local fire and thereby the general Fire Plume characteristics find broad practical application in assessing the fire safety of structures.

## Acknowledgments

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## Symbol Key

- $A$ fire area ($m^2$)
- $D$ fire diameter (m)
- $D_{fp}$ visible Fire Plume diameter (m)
- $P$ fire perimeter (m)
- $Q$ heat flux (kW)
- $Q_k$ heat flux by convection (kW)
- $Q_r$ heat flux by radiation (kW)
- $T_{fp}$ Fire Plume temperature (K)
- $m_e$ mass quantity of induced air ($kg.s^{-1}$)
- $m_{fp}$ mass quantity of smoke in Fire Plume ($kg.s^{-1}$)
- $u_{fp}$ gas flow speed in Fire Plume ($m.s^{-1}$)
- $z$ height above burning material surface (m)
- $z_0$ virtual origin (m)

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# Calculation of critical heat flux for ignition of oriented strand boards

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**Abstract**

Critical heat flux is one of the key properties characterizing the ignition of the materials. It provides quantitative data, showing the rate of energy transfer in the form of radiation required for the ignition of sample. The article deals with determination of this property for dried oriented strand boards (OSB), which is one of the widely used wood-based materials. The samples were exposed to radiations from cone heater at six heat flux values: 15 kW.m$^{-2}$, 20 kW.m$^{-2}$, 25 kW.m$^{-2}$, 30 kW.m$^{-2}$, 35 kW.m$^{-2}$, 40 kW.m$^{-2}$. Volatile flammable substances were ignited by electrical spark ignitor. Critical heat flux was calculated from measured times to ignition of samples. Five types of methods that use critical heat flux related to time to ignition in an endless scenario, and three restrictive times to ignition of sample to a specified value were used. The results of the first five methods reached an average value of 5.91 kW.m$^{-2}$. In the case of specifying the exact time restriction, the critical heat flux significantly changed over this time in range from 7.82 kW.m$^{-2}$ to 13.16 kW.m$^{-2}$.

*Keywords*: critical heat flux, burning , OSB, cone heater, ignition;

## 1. Introduction

Wood-based panels have become an important component in wood processing chain. From a materials viewpoint, wood-based panels provide a way of realizing value from materials that are not suitable for other uses, or that are residue streams from other processes. Oriented strand board (OSB) was developed as an alternative to plywood and is now used in large volumes in construction. It uses small thin flakes or strands which are oriented to provide directional properties. [1]

Most OSB is now made with strands that are 7.6 cm or longer in the surface layers. The core may be of smaller strands and may not be oriented. [2]

Wood, like other types of biomass consists of three main components: hemicellulose, cellulose and lignin. The pyrolysis of hemicellulose and cellulose occurs quickly, with the weight loss of hemicellulose mainly happened at 220–315 °C and that of cellulose at 315–400 °C. However, lignin is more difficult to decompose, as its weight loss happened in a wide temperature range (from 160 to 900 °C) and the generated solid residue is very high. [3]

Thermal degradation products of wood consist of moisture, volatiles, char and ash. Volatiles are further subdivided into gases and tars. [4] Gani and Naruse [5] described the thermal decomposition of the biomass samples in two stages. The first and second stage corresponded to devolatilization and char combustion, respectively. The first stage showed rapid mass decrease caused by cellulose decomposition. At the second stage, lignin decomposed for pyrolysis and its char burned for combustion.

OSB can be treated with fire retardants. Ayrilmis, Candan and White [6] tested physical, mechanical, and fire properties of oriented strand board with fire retardant treated veneers. As for physical properties, OSB panels with lime water ($Ca(OH)2(aq)$) showed better performance than OSB panels with untreated veneers. However, other fire retardants decreased physical properties of the panels. Lime water treatment reduced the effective heat of combustion, reduced the mass loss rate, and delayed the times for sustained ignition. It also reduced the amount of visual smoke produced.

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Ozkaya et al. [7] tested OSB treated by potassium carbonate, borax and wolmanit. According to the result of the test, potassium carbonate was determined to be the most suitable substance for improving the burning characteristics of the OSB within the existing substances, due to the fact that it had the longest ignition time and the shortest periods of burning with flames and as embers along with borax after the flames were turned off. Combination of boric acid and organic phosphate can be also used. [8]

Changes in components of wood and other materials used in the manufacture of OSB as a result of heating can also affect their other properties. For example the strength of OSB decreased as a function of temperature and exposure time. [9]

It can be shown that material properties do underlie the processes comprising the flammability of a material. These processes include [10]:

- ignition,
- burning rate per unit area,
- energy release rate (firepower),
- flame spread.

The ignitability test of wood showed the difference of ignitability depending on the way of flame exposure to specimens – exposure of the lateral side surface (edge) is more sensitive to ignition than the exposure of the main surface. [11] The pilot ignition time depends not only upon the intensity of radiation and the density of the wood, but also upon the position and possibly upon the size of the pilot flame as well. [12]

The critical heat flux is heat flux between the lowest incident heat flux to give ignition and the highest heat flux where ignition did not occur. It can be determined experimentally by exposing the samples to different incident heat fluxes and observing whether ignition occurs or not. However, it is expected that the value will be sensitive to the geometry, moisture content and orientation of the sample. All these factors would affect heat and mass transfer inside the solid. [13] The critical heat fluxes for different wood materials listed in literature are summarized in Table 1.

Table 1 Critical heat fluxes of wood and a wood-based materials

| **Sample** | **Comment** | **Critical heat flux [kW.m$^{-2}$]** | **Source** |
|---|---|---|---|
| Redwood | Along grain orientation | 15,5 | [14] |
| | Across grain orientation | 5,9 | |
| Red oak | Along grain orientation | 10,8 | |
| | Across grain orientation | 9,2 | |
| Douglas fir | Along grain orientation | 16,0 | |
| | Across grain orientation | 8,4 | |
| Maple | Along grain orientation | 13,9 | |
| | Across grain orientation | 3,8 | |
| Redwood | Vertical orientation | 12,42 | [15] |
| Southern pine | Vertical orientation | 10,68 | |
| Red oak | Vertical orientation | 10,53 | |
| Basswood | Vertical orientation | 10,00 | |
| Australian radiata pine | | 18 | [16] |
| Fire retarded plywood | Horizontal orientation | 15,5 | [17] |
| | Vertical orientation | 17,8 | |
| Plywood | Horizontal orientation | 11,6 | |
| | Vertical orientation | 13,3 | |
| Wood fiberboard | Horizontal orientation | 8,6 | |
| | Vertical orientation | 9,7 | |
| Wood fiber/cement board | Horizontal orientation | 14,6 | |
| | Vertical orientation | 18,0 | |

| Sample | Comment | Critical heat flux [kW.m$^{-2}$] | Source |
|---|---|---|---|
| Plywood | calculation | 10,5 - 11 | [18] |
| | experimental | 12 - 14 | |
| Chipboard | gas pilot flame | 6,4 | [19] |
| Chipboard melanine | gas pilot flame | 11 | |
| Fibreboard | gas pilot flame | 8,3 | |
| Hardboard | gas pilot flame | 8,1 | |
| Hardboard gloss | gas pilot flame | 12,6 | |
| Hardwood | gas pilot flame | 8,1 | |
| Plywood | gas pilot flame | 10,6 | |
| Plywood gloss | gas pilot flame | 11,4 | |
| Softwood | gas pilot flame | 13,7 | |
| Softwood intumescent | gas pilot flame | 13,0 | |

Due to the frequent use of OSB it is necessary to know their properties related to the initiation phase of fire. The critical heat flux represents one of them. It is the minimum rate of delivered energy in the form of radiation that is capable of initiating the flaming combustion of material. This paper therefore aims to determine the critical heat flux, and to compare results obtained by different methods of calculation.

## 2. Materials and methods

Commercially available OSB type 3 (structural panels for use in environments with low humidity for outdoor and indoor use) were used as samples. The thickness was 14 mm, and the samples were cut into squares with a side of 100 mm. In total, 6 samples that were dried before testing for zero humidity at 102 ° C were used. The basic raw material which they consisted of was coniferous wood mass (93.6 wt.%) with addition of small quantities of polyurethane (MDI) resin (4.7 wt.%) and paraffin (1.7 wt.%).

Each sample was exposed to an external heat flux with values of 15 kW.m$^{-2}$, 20 kW.m$^{-2}$, 25 kW.m$^{-2}$, 30 kW.m$^{-2}$, 35 kW.m$^{-2}$ and 40 kW.m$^{-2}$. The measuring apparatus was derived from the cone calorimeter complying with ISO standard 5660-1 [20]. The schematic representation is in Figure 1. The unexposed sides of the sample (2) were coated in aluminum foil and the sample was placed in the sample holder (1) in such way, that the top exposed area was 88.4 cm2. The sample holder was placed under the cone heater (4), while the orientation of the sample was horizontal. Electric spark igniter (3) was used for ignition. The unignited combustion products were collected into the hood (5) and discharged by the fan (6) outside the area of the igniter.

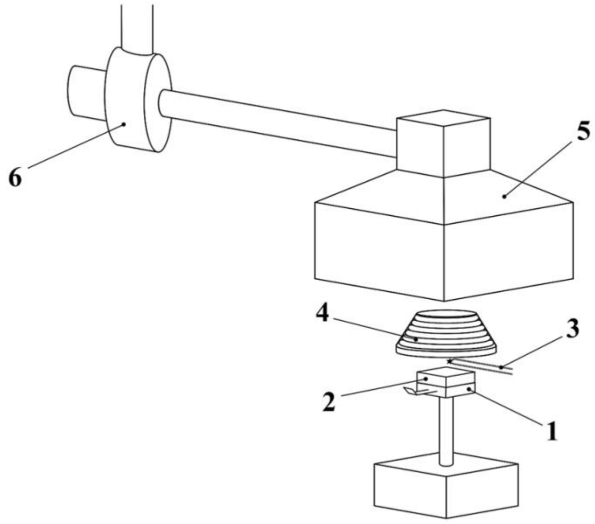


Figure 1 Test device: 1 – holder of sample, 2 – sample, 3 – spark igniter, 4 – cone heater, 5 – hood, 6 – fan

### 3. Critical heat flux calculation

If one ignores all heat losses except by conduction into the solid, the time to ignition for a thermally thick material is given by equation [21]:

$$\frac{1}{\sqrt{t_{ig}}} = \frac{2}{\sqrt{\pi k p c}.(T_p - T_0)} \cdot \dot{q} \tag{1}$$

Here $T_0$ is the initial temperature, kρc is the thermal inertia of the material, q̇" is the imposed heat flux, and $T_p$, is the surface temperature of the material at ignition.

According to the Tewarson [22] critical heat flux calculation method for thermally thick materials, the inverse of the square root of time to ignition is

expected to be a linear function of the external heat flux away from the critical heat flux value:

$$\sqrt{\frac{1}{t_{ig}}} = \frac{\dot{q}_e'' - \dot{q}_{cr}''}{TRP} \tag{2}$$

Where $t_{ig}$ is time to sample ignition, $\dot{q}_e''$ is surface density of external heat flux, $\dot{q}_{cr}''$ is critical heat flux and $TRP$ is thermal response parameter. Critical heat flux can be then determined based on the equation of heat flux dependency on reciprocal of the square root of the time to the ignition of the sample, at time $t_{ig}$ approaching infinity.

Speapoint and Quintiere [14] state, that the critical heat flux could be obtained from a linear regression through only the 'high' heat flux measurements where 'high' heat flux is an incident heat flux of around 20 kW.m$^{-2}$ or above. They describe a model in which the ratio of heat flux to the critical heat flux is between 0.758 and 0.768, so approximately 0.76. Critical heat flux can therefore be determined as follows:

$$\sqrt{\frac{1}{t_{ig}}} = \frac{\dot{q}_e'' - 0{,}76\dot{q}_i''}{TRP} \tag{3}$$

Where $\dot{q}_i''$ is intercept with the abscissa of a straight line fit thought the plot of $t_{ig}^{-0,5}$. [23]

Delichatsios described two methods of critical heat flux calculation for thermally thick materials. One allows the determination of critical heat flux from relatively high heat fluxes and the other from low heat fluxes. [24]:

$$. \dot{q}" > 2\dot{q}"'_{cr}: \frac{1}{\sqrt{t_{ig}}} = \frac{2}{\sqrt{\pi}} \frac{\dot{q}" - 0{,}64\dot{q}"_{cr}}{\sqrt{k\rho c}(T_p - T_0)} \quad (4)$$

$$\dot{q}" < 1{,}2\dot{q}"'_{cr}: \frac{1}{\sqrt{t_i}} = \frac{\pi}{\sqrt{\pi}} \frac{\dot{q}" - \dot{q}"_{cr}}{\sqrt{k\rho c}(T_p - T_0)} \quad (5)$$

Zhang Shields and Silcock [25] based on the assumption that the dependence of the critical heat flux and time to ignition can be written in general form:

$$\dot{q}''_e = \left(\frac{C}{t_{ig}}\right)^n + \dot{q}''_{cr} \quad (6)$$

Where C is a constant and n is a chosen ignition time index to give the best straight line fit.

Janssens [26] during calculations performed for a material with density of 500 kg.m$^{-3}$, emissivity of 1 and ignition temperature ranking from 250 ° C to 550 ° C determined for n depending on ignition temperature values from 0.539 to 0.561. Thus n = 0.547 still appears to be a good average and equations of the following form can be used:

$$\dot{q}''_e = \dot{q}''_{cr}\left[1 + 0{,}73\left(\frac{k\rho c}{h_{ig}^2 t_{ig}}\right)^{0{,}547}\right] \quad (7)$$

or

$$\varphi = 1 + 0.73\left(\frac{1}{t_{ig}}\right)^{0{,}547} \quad (8)$$

Where k is thermal conductivity, ρ is density, c is heat capacity, $h_{ig}$ is convection coefficient at ignition and φ is non-dimensional irradiance.

Fateh et al. [18], considered for basic relation for critical heat flux determination equation (9):

$$t_{ig} = \frac{\pi}{4} kpc \left(\frac{T_{ig} - T_0}{\dot{q}_e}\right)^2 \quad (9)$$

Furthermore, they calculated with a maximum time to ignition of 30 minutes. Critical heat flux is then considered as heat flux required for ignition of the sample in 1800 s from the initial irradiation.

Brown, Brown and Twilley [27] also based on the equation (9), and they devoted their study to the possible ignition of composite materials for naval vessels. They stated, that extrapolation to 600 s, represents the minimum external heat flux necessary for piloted ignition. Moreover, a real fire on a ship, whose radiant flux requires at least 600 s for piloted ignition of a composite material, is expected to be detected and suppressed before the composite becomes involved in the fire growth. A more practical application of the ignition times would involve determining the required irradiance to cause ignition at some other time, such as 300 s, for example.

## 4. Results and discussion

Dependencies on reciprocal of square root of the time to ignition on density of the applied external heat flux were constructed based on the equations (2) – (9). These dependencies are illustrated in figures 2, 3 and 4. High level of correlation is apparent in all cases.

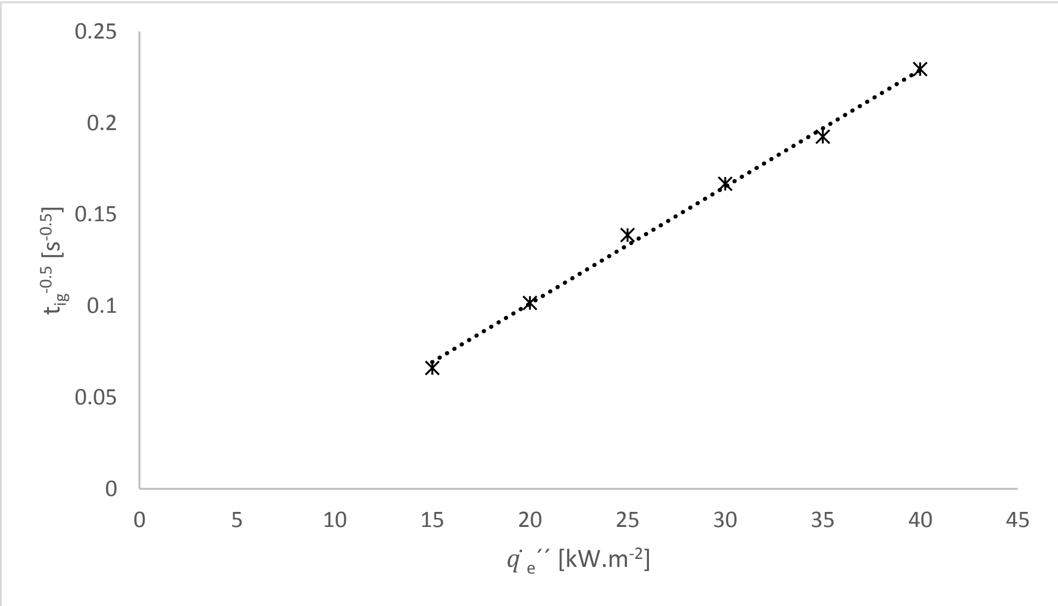


Figure 2 Time to ignition as a function of external heat flux for calculation according to Tewarson, Spearpoint and Quintiere, Delichatsios, Fateh et al. and Brown, Brown and Twilley

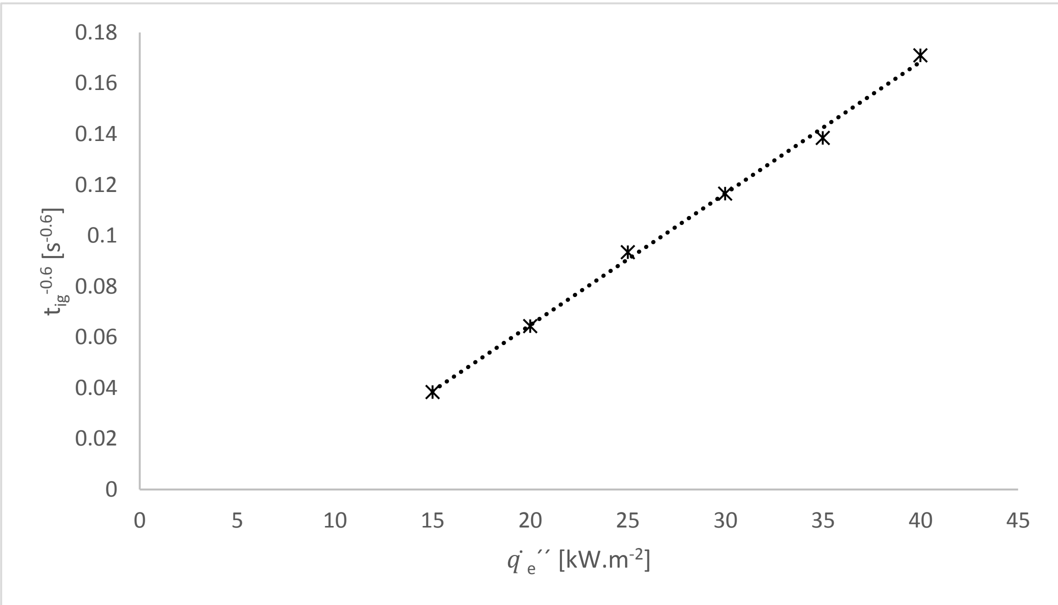


Figure 3 Time to ignition as a function of external heat flux for calculation according to Zhang, Shields and Silcock

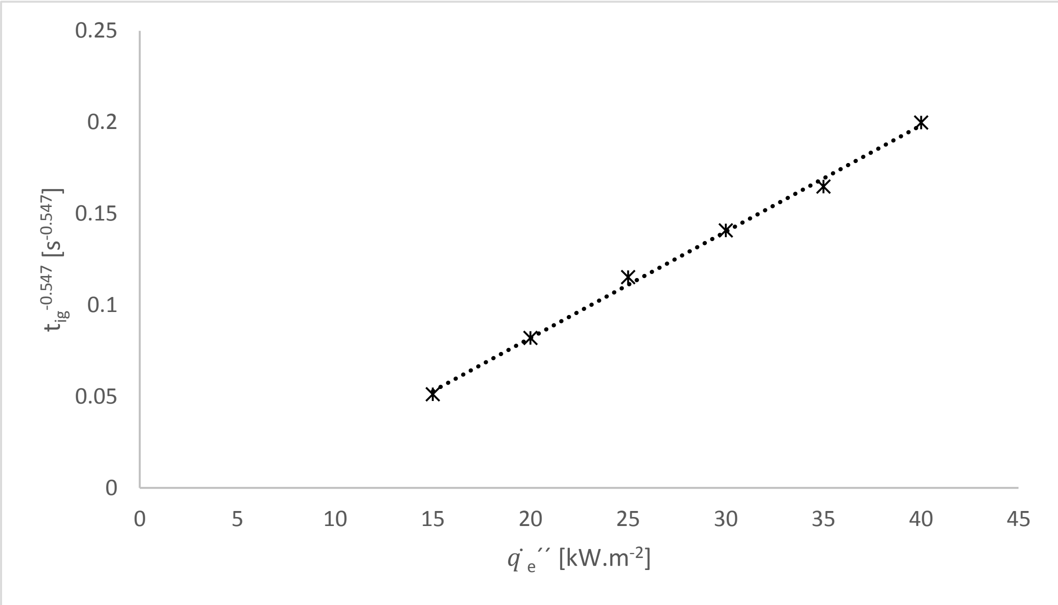


Figure 4 Time to ignition as a function of external heat flux for calculation according to Janssens

Values of critical heat fluxes were calculated from the trend lines according to different methods of calculation stated in the section about critical heat flux calculation.

The critical heat flux was between 4.14 $kW.m^{-2}$ and 13.16 $kW.m^{-2}$, depending upon the method used. Although the above variance appears too large, it is necessary to understand the individual values in relation to the assumptions on which the calculation method is based.

As mentioned above, the method according to Tewarson, Spearpoint and Quintiere, Delichatsios, Zhang Shields and Silcock, and Janssens consider with theoretical external heat flux, in other words with heat flux which would ignite the sample in an infinitely long time. Spearpoint and Quintiere and also Delichatsios also incorporate constant, which takes into account the non-linear character of the dependence in the area of low densities of heat fluxes in their calculations.

Zhang Shields and Silcock [25] eliminate the need to determine the thermal thickness of material, and under these conditions the value of n is 0.6 and the material can therefore be regarded rather as thermally thick, as thermally thin. Interesting comparison for this case is in paper in which the same material acted as thermally thin before drying but much higher critical heat flux of 16.72 $kW.m^{-2}$ was determined for this material. [28] This difference could indicate a significant influence of humidity on time to ignition of wood-based materials. It is assumed, that the evaporating water removes some of the heat from the surface and also dilute volatile flammable substance under the concentration necessary for ignition of the sample.

Calculation methods according to Fateh et al. and Brown, Brown and Twilley based on the assumption that the ignition can only occur in a certain time from the start of the heat flux irradiation. The required heat flux density steeply increases with declining value of this time.

If we compare the calculated values with the values provided for the wood material by other authors (Table 1), it appears that lower heat flux is required for ignition of OSB. It should be emphasized that the mentioned materials were not dried to zero moisture. Results of Toal Silcock and Shields [19] are virtually identical with OSB results. Although the samples were not dried, and open flame was used as igniter. Delay in ignition may be expected, if spark was used as igniter.

Comparing the square correlation coefficients, it appears that all of the calculated values have a very good informative value. The highest value is achieved using the method according Zhang Shields and Silcock, but this method is based on maximizing the correlation. The lowest square of correlation coefficient was achieved for general equations (Tewarson, Spearpoint and Quintiere, Delichatsios, Fateh et al., Brown, Brown and Twilley 1 and Brown, Brown and Twilley 2).

Table 2 The critical heat fluxes and related squares of correlation coefficients

| Calculation according | Critical heat flux [kW.m$^{-2}$] | Square of correlation coefficient |
|---|---|---|
| Tewarson | 4.14 | 0.9964 |
| Spearpoint and Quintiere | 5.45 | 0.9964 |
| Delichatsios | 6.47 | 0.9964 |
| Zhang, Shields and Silcock | 7.58 | 0.9974 |
| Janssens | 5.91 | 0.9972 |
| Fateh et al. | 7.82 | 0.9964 |
| Brown, Brown and Twilley 1 | 10.52 | 0.9964 |
| Brown, Brown and Twilley 2 | 13.16 | 0.9964 |

## 5. Conclusions

Critical heat flux represent the property of flammable materials associated with the energy required to initiate flame combustion. It can be characterized as the lowest possible rate of thermal energy delivery in the form of radiation to the material needed for its ignition.

Several authors dealt with the possibilities for its determination and different methods can be divided into two groups:

1. Methods assuming sample ignition in infinite time
2. Methods determining the maximum possible time to ignition

The samples were exposed to external heat flux from cone heater with varying densities from 15 kW.m$^{-2}$ to 40 kW.m$^{-2}$. Time to ignition of samples declined with increasing heat flux. Critical heat fluxes for absolutely dry OSB samples were calculated according different methods based on mathematical characterization of the dependence of this decline. In the cases of methods that assume sample ignition in infinite time were critical heat fluxes determined between 4.14 kW.m$^{-2}$ and 7.58 kW.m$^{-2}$. The critical heat fluxes significantly varied in the case of determination of finite time to ignition.

In areas that are not controlled, it is possible to consider the critical heat flux for OSB lower than 4 kW.m$^{-2}$ as safe. Monitored areas can contain elements which irradiate OSB with higher heat fluxes, and the maximum value must be determined depending on the method and frequency of monitoring.

## Acknowledgments

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# Safety improvement using transparent intelligent support systems for personal protective equipment

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**Abstract**

Human organs and tissues may be damaged mechanically in the workplace in case of non-compliance with the safety rules or in an emergency. The article addresses the development of hardware solutions that will improve personal protective equipment used to protect the workers' head, namely a safety helmet. In accordance with the standard rules for the free issuance of personal protective equipment, a safety helmet should be worn by all employees in the workplace. It is therefore can be used as an element of a system connected to humans to form a "human–safety helmet system" which can be considered both means of safety and an information source. Recording, monitoring, and review of this information to track down the safe values of the factors in questions, as well as the integral assessment of safety will enhance the effectiveness of human safety in the industrial environment. Once combined, a man and a safety helmet form a biotechnical system (BST) that builds an information space opening up additional methods of improving employee safety.

The paper addresses the interaction between the environment and the "safety helmet–human" biotechnical system and describes the outlook of their interaction. The paper defines the idea of "transparency" in view of system applicability for the user. The result of analytical and theoretical studies is the assessment of the long-term benefits of proposed solutions to form an integrated package ensuring the safety of employees wearing a safety helmet in different industrial environments.

*Keywords*: safety, personal protective equipment, safety helmet, biotechnical system, intelligent systems, occupational health and safety, transparency;

## 1. Introduction

Personal protective equipment (PPE) is used in the workplace when an environmental exposure may damage the employee's health. PPE is especially critical with an increased probability of a mechanical impact on vital functional body systems (Podgorski [1]), which may result in partial or complete occupational disability or adversely impact the production process in general. The probability of mechanical impacts is high in the construction, mining, and manufacturing industries, emergency response services, law enforcement authorities, armed forces, and other human activities related to increased health hazards (Coal Mine Safety Rules [2]). Sources of the mechanical impact include:

– falling from height,
– impact of moving and flying materials, parts of machines and mechanisms,
– effects of rock destruction,
– guns and fragments of a destroyed infrastructure (in armed clashes),
– road traffic accidents, etc.

In order to minimise a potential damage to human organs and tissues, such facilities use PPE to mitigate accidental or intentional impacts which may come as impulses (shocks) or change slowly (compress). One of the crucial functional body systems that requires protection against a mechanical impact is the brain and that became a prerequisite for the development of a safety helmet, PPE made of advanced high-performance and light materials capable of resisting high mechanical loads (Kovshov [3]).

Safety helmet wearing as PPE depends on the rules and regulations of a specific facility and in most cases it is included in the list of protective equipment to be worn by all employees in the workplace (Nordlof [4]). It is an important point as the safety helmet connected to humans forms a "human–safety helmet system"

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which can be considered both means of safety and an information source generated during the interaction of:

- environmental factors,
- all safety helmet properties, and
- human body factors.

Recording, monitoring, and review of this information to track down the safe values of the factors in questions, as well as the integral assessment of safety will enhance the effectiveness of activities aimed at changing (improving) the fatality and accident situation (Romanov [5]).

It should be noted that the actual implementation of this approach with regard to the equipment used is to be based on the advanced methods of building an information space and unique methods for assessing specific information [6]. This approach is inseparable from the use of a cutting-edge intelligent support system comprising:

- the set of sensors to record the parameters of factors in question,
- primary means to "compress" recorded information,
- system controls, and
- means to assess information and present its results in the format that facilitates its interpretation and decision-making..

## 2. Materials and Study Methods

A current safety helmet has a fairly ergonomic design, which will be used to accommodate intelligent support systems. However, an approach to hardware engineering and use must be based on the transparency principle in relation to an employee wearing a safety helmet as PPE. System elements must have the minimum impact on a safety helmet user by being convenient in use. The dimensions, weight, and location of any additional devices must not cause any discomfort or be visible to the user. An employee must not be involved in the maintenance of these devices. The interaction between the employee and intelligent support systems must take place in an emergency only and in the form of an easy- and convenient-to-interpret alarm.

This requirement is an important area for the improvement of methods and hardware aimed at ensuring employee workplace safety in the environment presenting increased hazards for human health. A safety helmet may be equipped with a number of additional devices and algorithms combined to form a common hardware and information space consisting of intelligent support systems built with cutting-edge hardware components.

## 3. Results and Discussion

Let us consider the interaction between different factors arising with the safety helmet and employee interface in order to implement the above safety enhancements with the use of a safety helmet. The

safety helmet is a passive safety element protecting against mechanical impacts; however in combination it becomes a part of a biotechnical system (BTS) that builds an information space opening up additional opportunities to improve employee safety methods (Figure 1).

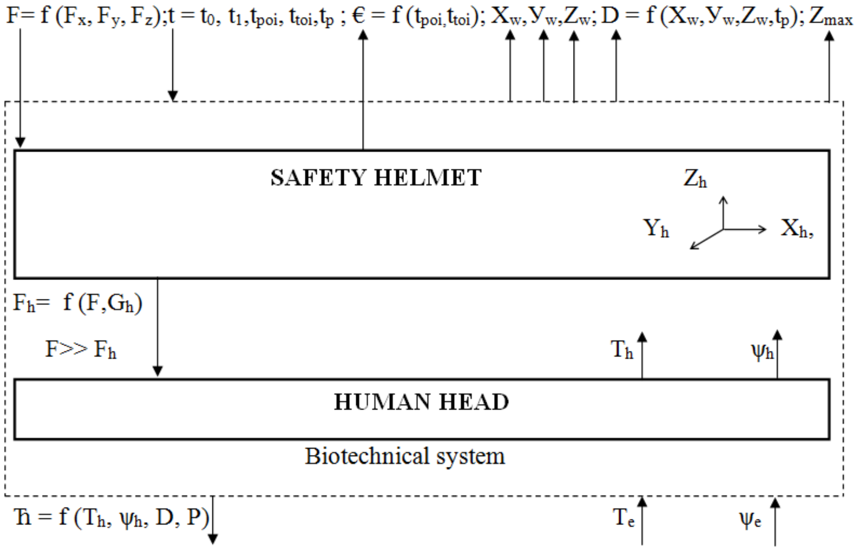

Figure 1 Interaction between the environment and the "safety helmet–human" biotechnical system

Let us first consider the way factors interact in the "environment–safety helmet–human" system. In this case, the environmental factors are the main factors that are to be mitigated through the use of a safety helmet as well as any additional factors that are to be taken into account to improve safety helmet performance. The main factor is a mechanical impact (F) which influences BTS in a 4D event space (Cartesian coordinate system for the safety helmet ($X_h$,$Y_h$,$Z_h$) and time (t)).

The following information might help: $F = f (F_x, F_y, F_z)$ – values for impact components; Fh= f(F,Gh) – values for the impact mitigated through safety helmet material properties and design ($G_h$); ($t_0$, $t_1$) – times of the start and end of the impact ($t_0$), $t_1$; £= f (F, $X_h$, $Y_h$, $Z_h$, t0, t1) – kind of safety helmet damage. The results of this information assessment may be used to improve safety helmet performance data in order to improve its safety. Furthermore, the kind of safety helmet damage and proposed time points help to investigate emergency effects.

In a number of cases, a safety helmet is obligatory in the process area [ ]. However, an unavoidable reduction of employee comfort when wearing a safety helmet may cause non-compliance with the established rules. In such conditions, it is crucial to record the astronomical time at the point when a BTS is formed (a safety helmet is put on) ($t_{poi}$) (where i=1,2,3….n means the number of time intervals of active safety helmet use) and the time when its use ends (a safety helmet is taken off) ($t_{toi}$). The review of safety helmet use time intervals (€ = f ($t_{poi}$, $t_{toi}$)) facilitates to establish control over the adequate use of head protection (stipulated by the rules and regulations in specific process areas) in the working time.

A resulting BTS may move in the process area ($X_w$,$Y_w$,$Z_w$) and is a source of information on the employee's location. This information shows the employee's motor activity time-wise ($t_p$) in different phases of a production cycle ($D = f (X_w,Y_w,Z_w,t_p)$) and plays an important role in process control, especially in case of an emergency and during search activities.

Since a safety helmet is located at the highest point of the human body ($Z_{max}$) against the ground level, any changes of this data can be used to control the vertical (horizontal) position of the body and as be additional source of information regarding the adequacy of the working condition.

A man is an active component of the BTS and is involved in metabolism and heat exchange with the environment determining the degree of comfort in the "environment–safety helmet–human" space. In this situation, it is valuable to have any information on changes in ambient temperature ($T_e$) and humidity ($\psi_e$), as well as the space between the human head ($T_h$) and the safety helmet ($\psi_h$). The follow-up of any changes in these parameters can essentially characterise the metabolic processes between the man and the environment, while coupled with heat exchange information, it can be used to assess comfort in the workplace. Furthermore, the information on temperature and humidity changes ($T_h$, $\psi_h$) combined with any parameters that characterise human motor activity (D) and body weight (P) can prompt the estimate of the metabolic cost in the work process ($\hbar = f(T_h, \psi_h, D, P)$).

A BTS design (Figure 1) includes the man as an integral organism interacting with the safety helmet and the environment when fulfilling his/her target functions. However, a safety helmet worn on the employee's head opens up additional opportunities of environmental exposure protection of the vital systems forming an integral organism and monitoring any changes in their condition due to environmental factors. It is because safety helmet components are located immediately close to such functional body systems as:

- hearing and vision,
- external respiration,
- cerebral circulation, and
- verbal system.

Additional safeguards and controls are integrated into the safety helmet and the body systems in question to form a BTS which design is shown in Figure 2.

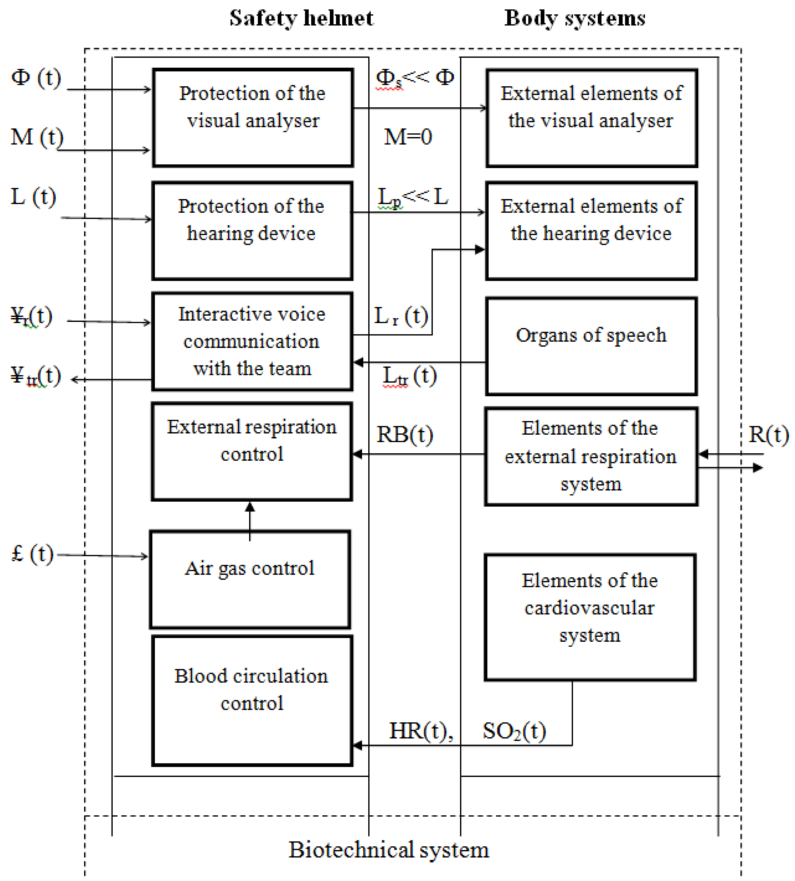


Figure 2 Interaction between the environment and the "safety helet–body system" biotechnical system

Protection of the visual analyser against mechanical damage (M(t)) and light stream exposure (Φ(t)) can be implemented with a passive element presented by a protective screen made of a high-duty acrylic material that absorbs the given spectral component (s) of the light stream (Φs<<Φ) and is a structural part of a safety helmet. A mechanical impact on the visual analyser (M=0) is until M(t) reaches a permissible value (Mmax).

Hearing protection against acoustic noise (L(t)) can be both passive ($L_p$<<L) (with special materials that absorb acoustic oscillations) and active (with special devices used to measure L(t) parameter and generate a compensatory acoustic signal). Hearing protection can be an integral part of special headphones which are a structural part of a safety helmet.

Since the human organs of speech are locate close to safety helmet structural elements, it can include an interactive voice function that transforms voice acoustic oscillations ($L_{tr}$(t)) into an information stream ($¥_{tr}$(t)), which is transmitted over the communication channel to the team and generates an acoustic voice signal ($L_r$(t)) received over the communication channel ($¥_r$(t)). Operative voice communication to the team will improve team work and actions in case of an emergency.

The human external respiration system is especially vulnerable since it is directly exposed to the environment (R(t)). Complete isolation of respiration from atmospheric gases is hard to achieve and is unreasonable in most working environments. It seems possible to evaluate a gas content and changes in the gas environment(£(t)) while monitoring main external respiration parameters (RB(t)) (e.g. respiratory rate (RB)) for early warning of impermissible gas values in the environment in two areas (technical and physiological), which will improve the efficacy of measures taken in case of an individual threat to employee health.

The information on the cardiovascular status is of significant importance as it is the source of the integral assessment of general health and the function of vital body systems. The BTS in question can be used to record the heart rate (HR(t)) and oxygen percentage in blood ($SO_2$(t)). $SO_2$(t) evaluation is efficient means of the on-line tracking of extreme human body states, while the assessment of the cardiac rhythm wave structure facilitates monitoring of employees health in the working process.

## 4. Conclusions

The BTS in question combined into a single complex enable to handle several safety issues in relation to an employee wearing a safety helmet in different industrial environments where safety helmet use is regulated by relevant rules and regulations. A specific set of safety hardware can be determined on a case-by-case basis.

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# Testing of selected types of polyurethane foams by the cone calorimeter method

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**Abstract**

Polyurethane foams (PUR foams) belong to polymeric materials whose use is relatively wide. They most frequently form filling of upholstered furniture and mattresses. If their ignition and subsequent burning occurs, the amount of toxic combustion products originated that are a common cause of death. For this reason, it is important to study these materials in terms of fire protection. In this work, we focused on four types of polyurethane foams: two standard types with different densities (N 3038, N 4050), one highly elastic type (R 4036), and a type having retardant treatment (FF 5740). Selected foam types were tested by the cone calorimeter method according to the standard ISO 5660-1:2002. Samples were exposed to the heat flux 20 kW/m2, where we obtained parameters such as the heat release rate (HRR), the total heat release, changes in the mass of the samples and the rate of the mass loss. Polyurethane foam with retardant treatment longest withstood the load of the heat flux, the value of the maximum heat release rate represented the lowest value.

*Keywords*: polyurethane foam, cone calorimeter, heat release rate, time to sample ig nition, mass loss rate;

## 1. Introduction

A relatively large number of people are injured or killed every year by fires starting by ignition of mattresses and upholstered furniture (Ahrens [1]). Fires involving upholstered furniture and mattresses can grow rapidly and result in the high heat release rate and release a large total amount of energy. The main component in most furniture and mattresses is a polyurethane foam. It is therefore important to understand the behavior of the polyurethane foam in terms of fire protection (Robson et al. [2]).

The heat release rates of characteristic components of a fire are required as a prerequisite to estimate the growth of a fire and temperature in structural fires (Kim, Lilley [3]).

The aim of this work is to watch parameters under load by heat flux of 20 kW/m$^2$: heat release rate, time to ignition of the sample, the rate of mass loss.

## 2. The experimental part

Four types of polyurethane foams were used for testing; the first letter indicates the type of polyurethane foam: N - standard, normal; R - elastomeric; FF – with retardant finish. The numbers following this letter express the density and hardness; see the Table 1 and the Figure 1. The dimensions of the specimens were 100 mm x 100 mm x 32 mm (length, width, thickness). The methodology of work was drawn up on the basis of the cone calorimeter method according to the standard ISO 5660-1:2002 [4]. The measurements were carried out in a work environment with a temperature of 22 - 23 °C and a relative humidity of

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23-24 %. The samples were exposed to the heat flux of 20 kW/m$^2$; the orientation of the sample was horizontal.

Table 1 Tested types of polyurethane (PUR) foams

| Sample | Density (kg/m$^3$) | Hardness at the relatively compression 40 % (kPa) |
|---|---|---|
| N 3038 | 30 | 3.8 |
| N 4050 | 40 | 5.0 |
| R 4036 | 40 | 3.6 |
| FF 5740 | 57 | 4.0 |


Fig. 1 Samples of the PUR foams

## 3. Results and discussion

### *3.1. Heat release rate*

Sample N 3038 was ignited at the 6th second. Sample was burning in flame by 130th second. As one can see in the Figure 2, a standard type of polyurethane foam with lower density has reached the maximum HRR during 50 s and represented a value of 393.70 kW/m$^2$.

At the curve of heat release rates (Fig. 2), it can be seen that the test sample N 4050 with higher density absorbed heat radiation from the emitter cone at the beginning of the test and the surface of the sample slowly began to generate combustion gases. At the 417-second of the test, the release of flammable substances is sufficient to form a combustible concentration, ignition initiation as well as flaming burning, that was characterized by a sharp rise in the heat release rate occurred. Burning in flames took place by the 594 s. The heat release rate reached a peak in the 455th second and was represented by a value of 326.46 kW/m$^2$.

The initiation and the subsequent burning in flames of the sample R 4036 took place at the time of 8 s; sample burning in flames lasted 162 second. As can be seen in the Fig. 2, the elastomeric foam reached the maximum HRR during 85 s represented by a value of 461.46 kW/m$^2$.

At the curve of heat release rates (Fig. 2), the longest phase of the FF 5740 sample preparation for burning can be seen up to the time of 1574 s; reflecting the retardant treatment of the sample. Burning in flames continued 1716 seconds. The maximum heat release rate was reached at the time of 1675 second and represented a value of 272.56 kW/m$^2$. The two-stage decomposition that is typical for polymeric materials is visible in the graph.

Kotresh et. al. [5] tested PUR foam samples with dimensions of 100 mm x 100 mm x 25 mm having a density of 32-33 kg/m$^3$. Under the heat flux load of 20 kW/m$^2$, sample had been ignited at the 34th second with a maximal HRR value represented by 221 kW/m$^2$, which represents a significant difference with our results when a sample of comparable density, reached the HRR peak value of 393.70 kW/m$^2$.

Robson et al. [2] tested polyurethane foams density of which he did not refer to. However, PUR foams with a substantially lower density than density of materials used for mattresses padding were a subject of the tests. The Figure 3 shows three repeat testing of polyurethane foam specimens with dimensions 100 mm x 100 mm x 25 mm (length, width, thickness) exposed to a heat flux load of 25 kW/m$^2$. The graphic display shows that the two-stage decomposition of these materials took place and the maximal heat release rate ranged from about 380 kW/m$^2$ up to about 460 kW/m$^2$.

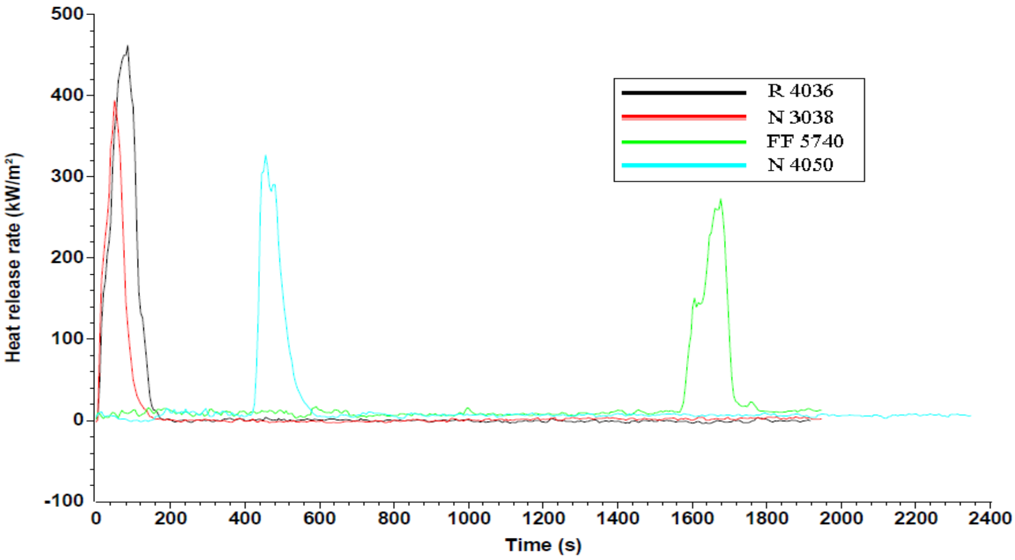


Fig. 2 Development of heat release rate

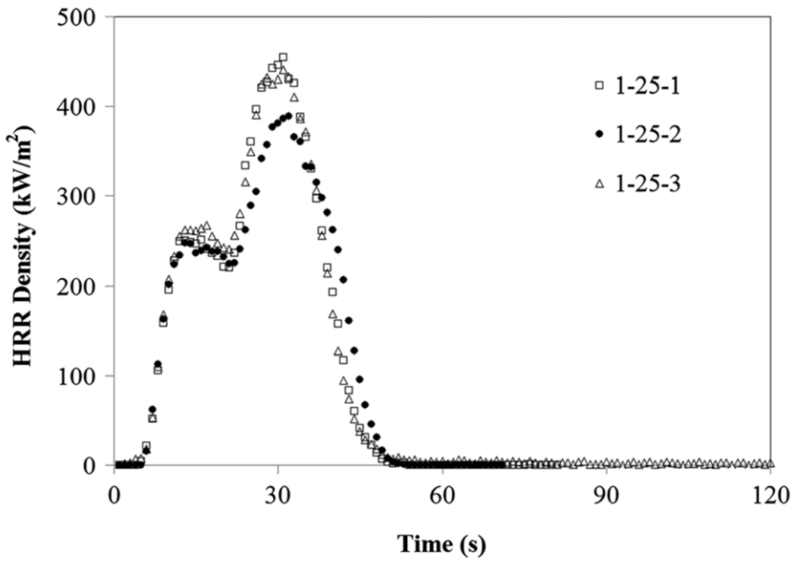


Fig. 3 Heat release rate density measurements in cone calorimeter tests (Robson et al. [2])

At the Figure 4, an example of the heat release rate typical of upholstered furniture (sofa, love-seat, single chair), the core thereof was made from polyurethane foam is shown. Curve of the heat release rate is similar to our measurements but the value of HRR in the case of Babrauskas measuring [6] is considerably higher, since in this case it was a composition of more individual materials.

The Figure 5 shows an example of the heat release rate typical for mattresses. We can see that the HRR for the mattress with retardant treatment occurs at a later time interval, in terms of saving people's lives it is important to have enough time to evacuate people. The value of HRR is higher than that of a conventional mattress.

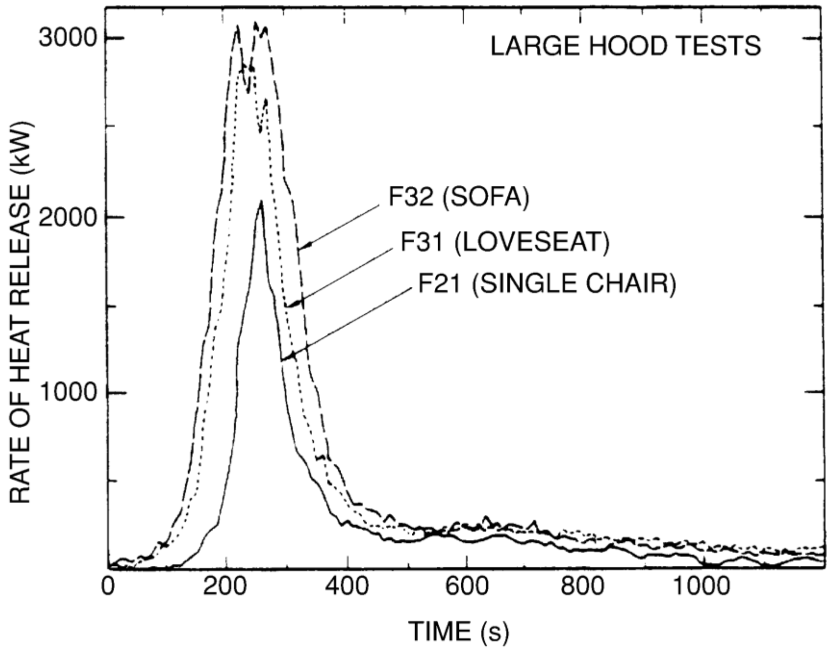

Fig. 4 Heat release rate of the upholstered furniture (Babrauskas [6])

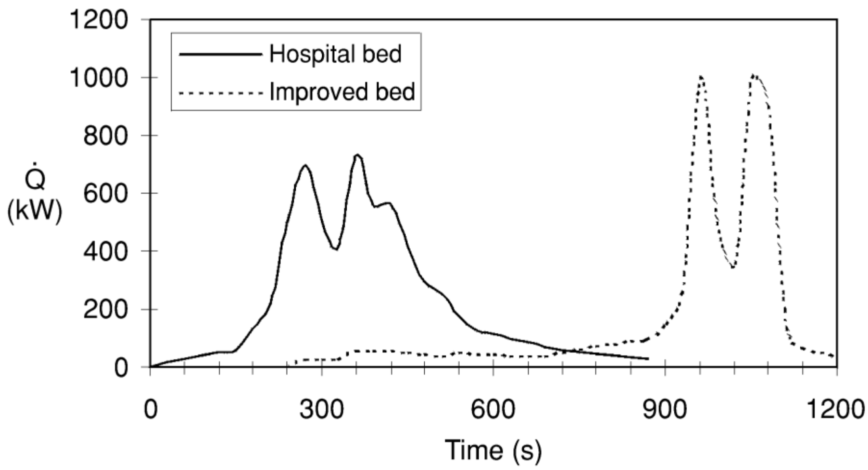

Fig. 5 Heat release rate of mattresses (Särdqvist [7])

*3.2. Total heat release*

As shown in the Figure 6, development of the total heat release took place similarly as at samples R 4036 and N 3038. The sample R 4036 reached the highest value of the total heat release among all samples tested; namely 36.81 MJ/m$^2$. The lowest value of the total heat released during sample burning in flames was recorded at the sample N 3038 with the value 22.50 MJ/m$^2$. At the sample with retardant treatment (FF 5740), remaining exothermic reactions took place after completion of flaming burning due to an external heat flux in the sample. Therefore the heat release rate did not descended to zero value and the total heat release had been growing until the end of measurement. For this reason, it could not be precisely quantified.

According Kotresh et al. [5], who tested samples of polyurethane foam with dimensions 100 mm x 100 mm x 25 mm under an exposition of the heat flux load 20 kW/m$^2$ and with the initial sample mass 8.79 grams, the value of the total heat released is 16.3 MJ/m$^2$, which is, however, lower compared to our value of 22.50 MJ/m$^2$ for the sample of N 3038 with a mass of 8.125 g.

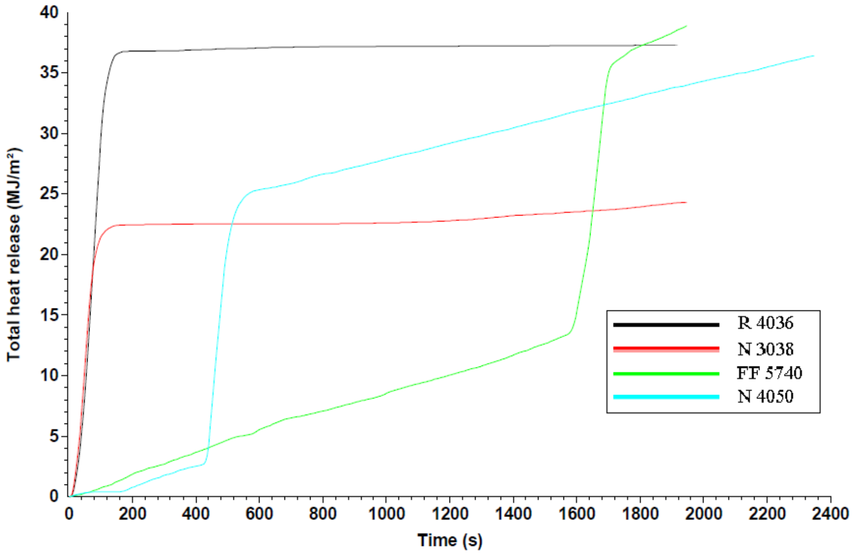


Fig. 6 Development of total heat release

*3.3. Changes in the mass of the samples and the rate of the mass loss*

Changes in the mass of the samples during testing under the heat flux load of 20 kW/m$^2$ as well as the rate of mass loss is shown graphically in the Figures 7 and 8.

The lowest average rate of mass loss represented value 0,005 g/s at the standard sample N 4050; while the highest average rate of mass loss was determined at the sample R 4036 with the value of 0.043 g/s.

The maximal rate of mass loss reached the lowest value 0.124 g/s at the sample FF 5740, while the highest value was 0.177 g/s at the sample R 4036.

At the Figure 7, the significant reduction of the sample mass after ignition of the sample is seen at the samples R 4036, N 3038. At the other hand, gradual and slow mass reduction was observed at samples N 4050 and FF 5740, until their flaming occurred and a significant reduction of mass can be seen.

The initial mass of the sample at the Kotresh et al. [5] experiment was 8.79 grams; the final mass was 1.66 grams. The average rate of mass loss represented during the measurement value of 0.023 g/s, which is comparable to the value of our measurement 0.026 g/s at the sample N 3038.

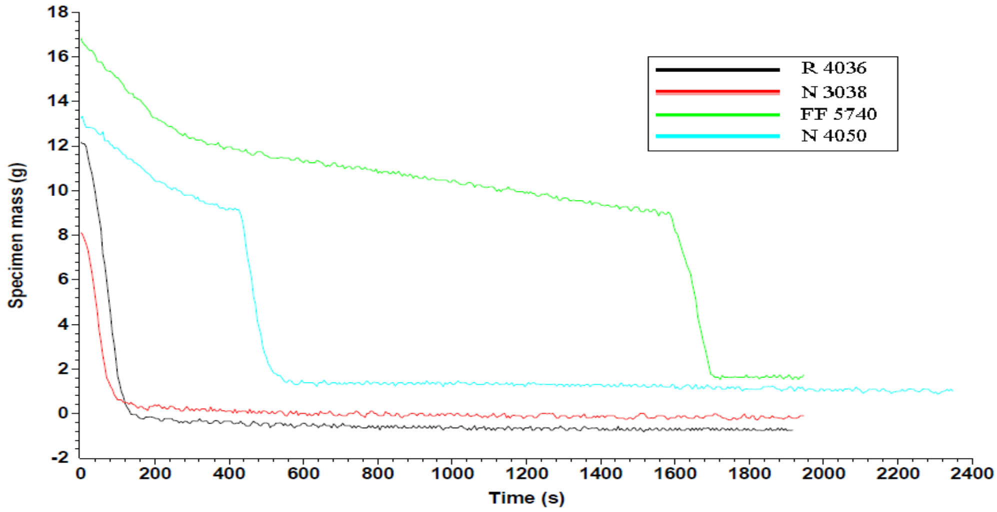


Fig.7 Development of mass of the samples

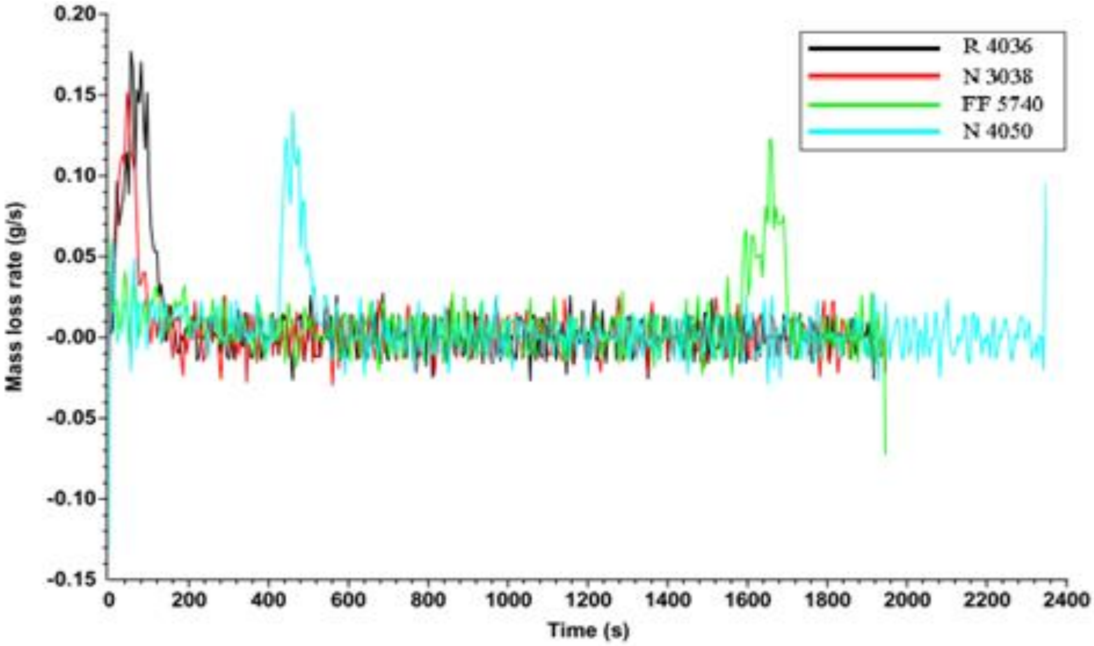


Fig. 8 The rate of mass loss

## 4. Conclusions

We decided to use a cone calorimeter for measurements, whereas the rate of heat release from the burning upholstered furniture determines the fire risk and is an important factor in fire protection issue.

In this work, we observed the behaviour of four types of polyurethane foams exposed to the heat flux of 20 kW/m$^2$, where we monitored parameters such as the heat release rate, the total heat release, changes in mass of the samples and the rate of mass loss.

The lowest value of the maximal rate of heat release was recorded at a sample with retardant coating; the value was 272.56 kW/m$^2$, while the highest value was recorded at the elastomeric sample with the value 461.46 kW/m$^2$.

At the beginning, the ignition initiation of the standard sample with lower density and the elastic polyurethane foam sample took place approximately at the same time intervals, i.e. by 10 seconds. The standard sample with higher density withstood the heat flux load until 417 seconds; while at the sample with retardant treatment the ignition initiation took place at the 1,574th second.

From the measured results, can be seen that the polyurethane foam sample with retardant treatment withstood the heat flux load for the longest time; as well as its value of the maximal heat release rate represented the lowest value, too.

### Acknowledgment

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# Impact of material composition on the fire safety of wood buildings structural elements

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**Abstract**

Suitable material composition of structural elements of wood buildings has a significant impact on the capability of the structure to withstand the effects of fire. In this paper are evaluated the results of radiant heat source loading tests of two different supporting wall structure compositions. The test results showed that using the suitable background materials, there can be achieved the greater capability of fire protection of a structure and thereby to ensure that there will be no ignition of flammable materials inside the structure for some time and thus also no overall increase in the intensity of the fire. The best results were achieved by sample with OSB board underlying the plasterboard wall finish.

*Keywords*: wooden structure, design element, material composition, background materials, fire protection capability;

## 1. Introduction

The fire safety of wood constructions is tackled according to the Decree of the MI SR no. 94/2004 Coll. [1] (the Decree) and its project standards. According to the fire reaction of the materials used, the Decree classifies the building constructions to structural elements of the types D1, D2 and D3. Wood structures are typical D2 and D3 structural elements. The main difference between them is that the D2 type cannot increase the fire intensity in the required fire resistance time, and the D3 type is capable to increase it.

Higher fire safety therefore represents the D2 structure element type, therefore the current trend is, especially in panel, column and other wood constructions, their use in designing. The design of the D2 structure type is the closure of combustible materials inside the structure with non-flammable material with the A1 or $A2s_1,d_0$ reaction class in accordance with EN 13 501-1 [2].

In practice, the plasterboard, gypsum fiber, gypsum cement or calcium silicate fire-resistant materials are used for this purpose. In these layered constructions, application of high-performance insulating materials is applied, which ensures current requirements for the energy performance of buildings [1].

These are the thermal insulation materials based on mineral wool, applied both inside the structure, most often between the supporting elements or as part of the thermal insulation systems of the external walls from the outside of the building. Correct classification of wood structures into D2 or D3 type is practically possible only on the basis of testing. In order for D2 constructions types not to increase fire resistance in the required fire resistance time, their fire protection must meet the fire resistance criterion K2, i.e. the fire protection capability according to EN 13 501-2 [3]. Class K2 may be demonstrated on the basis of a test according to EN 14 135 [4] for a time at least as long as the required fire resistance time of the structure [5]. The system of testing the structural elements of timber constructions is also applied in this paper.

## 2. Experiment

The experiment was carried out at the testing laboratory of the Department of Fire Protection of TU in Zvolen. Testing was carried out under stationary

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conditions in a closed room of a testing laboratory, using the equipment for fumes exhausting. The test samples were made as fragments of external wall with dimensions 1 x 1 m in two basic alternatives. One sample represents the sandwich construction of panel wood structure, the second one the modern single-layer log structure with mineral wool insulation.

*2.1. Material*

Sandwich Panel Construction (Sample No. 1) was tested in two alternatives. It is a structure with supporting wooden columns, insulated with mineral wool. The interior side is covered with a fire-wood on the wooden grate and on the exterior side with a thermal insulation system made from mineral wool. The first alternative of sample no. 1 has an underlying OSB board under the firewall, the second alternative is lined with FERMACELL fireproof gypsum fiberboard, which is without a backing layer (Fig. 1, Fig. 2).

**Composition of interior - exterior:**
- 12.5 mm fireproof plasterboard;
- Wood grate + mineral insulation UNIFIT 60 mm (installation gap);
- 18 mm OSB board;
- Supporting wooden frame construction + mineral insulation UNIFIT 160 mm;
- 15 mm DHF board;

Fig. 1 The first alternative of sample no. 1

Composition of interior - exterior:
- 12.5 mm FERMACELL gypsum fibreboard;
- Wood grate + mineral insulation UNIFIT 60 mm;
- Vapour barrier film;
- Supporting wooden frame construction + mineral insulation UNIFIT 160 mm;
- 12.5 mm FERMACELL gypsum fibreboard;
- 80 mm thermal insula-

Fig. 2 The second alternative of sample no. 1

Modern log construction of the external wall with thermal insulation made from mineral wool represents the sample no. 2, which was also tested in two alternatives. The first alternative has the underlying insulating plate (Entkopplung) under the internal plasterboard. The second alternative is without a base plate. The Entkopplung plate is made of polyester fibers which are resin-bonded. In the composition, the sample no. 2 was chosen experimentally, in practice it is mostly used as a cladding material. The alternative compositions of the sample no. 2 are shown on Fig. 3. .

a. b.

Fig. 3 Composition of the sample no. 2
a. First alternative, b. Second alternative

- 70 mm thick log wall made of spruce wood joined by a lamella joint,
- Reinforced paper vapour barrier,
- Wood spruce grate for placement of thermal insulation of 100 mm,
- 4 mm Entkopplung insulating plate - in case of the first alternative of the sample no. 2;
- 12 mm / 1000 x 1100 mm plasterboard, mineral plaster with a grain size of 2 mm.

*2.2. Experimental method*

A ceramic radiation panel having a maximum output of 50.5 kW / m$^2$ at a distance of 50 mm from the sample area, with an achievable radiation temperature of at most 935 ° C and a radiation area of 480 mm x 280 mm, was selected as the radiant heat source. The energy source of the radiation panel was gas propane-butane, whose constant flow was monitored by a calibrated laboratory flowmeter. The spacing of the sample location from the radiation panel was selected at 200 mm, which represents the radiant heat radiant power of 43.1 kW / m$^2$. The location of the sample and the test apparatus for carrying out the experiment is shown in Fig. 4.

Fig. 4 Sample and test equipment arrangement

*2.2.1. Position of thermocouples*

The heat transfer through the structure was monitored by measuring the temperature on individual thermocouples. The thermocouples were arranged in one plane at the center of the sample, which in case of sample 1 (panel construction) was passed through a supporting wooden column of dimensions 50 x 160 x 1050 mm

Sample no. 1 – alternative 1 (with underlying OSB board):
*T1 – on the interior surface of the gypsum board*
***T2 – on the interior surface of the OSB (bottom of the backing layer)***
*T3 – behind the OSB board (interior side of the supporting wooden column)*
*T4 – on the exterior side of the supporting wooden column*
*T5 – on the exterior side of the sample*

Sample 1 – alternative 2 (without backing layer):
*T1 – on the interior surface of the Fermacell gypsum fiberboard*
***T2 – on the interior side of the supporting wooden column (bottom of the backing layer)***
*T3 – on the exterior side of the supporting wooden column*
*T4 – on the exterior side of the sample*

*The thermocouples were very similarly arranged also in case of sample no. 2:*
*Sample no. 2 – alternative 1 (with backing board Entkopplung):*
*T1 – on the interior surface of the mineral plaster*
***T2 – between the gypsum fiberboard and backing board (bottom of the backing board)***
*T3 – behind the backing board (in front of the thermal insulation layer)*
*T4 – behind the layer of thermal insulation*
*T5 – on the exterior side of the sample*

*Sample no. 2 – alternative 2 (without backing layer):*
*T1 – on the mineral surface of mineral plaster*
***T2 – in front of the thermal insulation layer (bottom of the backing layer)***
*T3 – behind the thermal insulation layer*
*T4 – on the exterior side of the log wall*

The temperature values were recorded on each thermocouple using the Almemo device, for sample 1 at 30 second intervals and for sample no. 2 at 10 second intervals. The duration of the experiment was 60 minutes for both samples.

## 3. Results and discussion

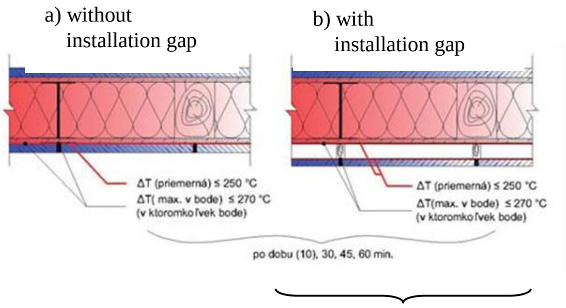
The measured results are recorded in the following tables and graphs. The basis of evaluation of the obtained results is the comparison of the temperatures measured on the bottom side of the backing layer under the fireproof layer of the samples, with the limiting temperatures determined to meet the K1 or K2 fire protection criterion according to EN 13 501-2 [3].

*3.1. Testing the fire safety properties*

K2 facing is considered to be capable of providing the prescribed protection of the cladding if, during a test according to EN 14 135 [4] at a certain time (10 min, 30 min, 60 min), the facing or parts thereof do not reverse and the following requirements are met:

a) in the case of cavity-free facing, during the test, the average temperature measured on the underside of the backing layer shall not exceed the initial temperature by more than 250 ° C and the maximum temperature measured at any point on that side shall not exceed the initial temperature by more than 270 ° C; After the test, the material must not be burnt or gritted at any point on the backing layer;

b) In the case of drywall or gypsum fiber systems, the average temperature measured at the underside of the substrate and the average temperature measured on the uncoated side of the cladding must not exceed the initial temperature by more than 250 ° C and the maximum temperature measured at any point on these sides must not exceed the initial temperature by more than 270 ° C. After the test, the material must not be burnt or grazed at any point on the backing layer and at any point on the uncoated side of the facing (Figure 5).




During the time (10), 30, 45, 60 minutes

Fig. 5 Evaluation of the fire protection capability of K2 for D2 construction element

Another condition for criterion K2 is that one of the following backing layers is used in the test:

– a particleboard (with a density of 680 ± 50 kg / $m^3$ and a thickness of 19 ± 2 mm), or
– any other specific backing layer.

In the case of criterion K1 is to meet the same requirements as for the K2 criterion but only for a specified 10 minute classification time, provided that after the test, the material must not be burnt, gritty, molten or shaken at any point on the substrate and at any point on the uncoated side of the facing. One of the following is used in the test:

– A particleboard (with a density of 680 ± 50 kg / $m^3$), or
– low density material (less than 300 kg / $m^3$ and a thickness of at least 50 mm) or any other specific backing layer.

*3.2. Results for sample no. 1*

The temperatures measured on the thermocouples of sample no. 1 are shown in tab. 1 and tab. 2 and a graphical representation of the course of these temperatures in the construction is shown in fig. 6 and fig. 7.

Tab. 1 Measured temperatures sample no. 1 - alternative 1

| **Time interval** | **T1** | **T2** | **T3** | **T4** | **T5** |
|---|---|---|---|---|---|
| **5** | 206.8 | 18.0 | 17.9 | 14.6 | 16.7 |
| **10** | 386.6 | 47.3 | 18.7 | 14.6 | 17.0 |
| **15** | 389.1 | 61.8 | 18.7 | 14.6 | 16.7 |
| **20** | 383.8 | 69.7 | 19.0 | 14.5 | 17.1 |
| **25** | 402.5 | 72.7 | 19.5 | 14.5 | 17.5 |
| **30** | **418.8** | **70.3** | **20.0** | **14.5** | **17.7** |
| **35** | 326.6 | 74.0 | 20.4 | 14.5 | 17.6 |
| **40** | 243.5 | 94.3 | 21.0 | 14.7 | 17.5 |
| **45** | 252.0 | 115.9 | 21.1 | 14.6 | 16.7 |
| **50** | 258.0 | 126.4 | 21.4 | 14.6 | 16.8 |
| **55** | 257.4 | 138.1 | 21.9 | 14.5 | 17.1 |
| **60** | 266.4 | 149.4 | 22.6 | 14.6 | 17.4 |

Tab. 2 Measured temperatures sample no. 1 - alternative 2

| **Time interval** | **T1** | **T2** | **T3** | **T4** |
|---|---|---|---|---|
| **5** | 212.3 | 15.5 | 14.6 | 19.9 |
| **10** | 347.5 | 30.2 | 14.3 | 20.0 |
| **15** | 431.6 | 68.4 | 14.8 | 20.3 |
| **20** | 451.0 | 71.9 | 14.9 | 20.3 |
| **25** | 456.8 | 72.1 | 15.2 | 20.4 |
| **30** | **482.3** | **71.8** | **14.7** | **20.6** |
| **35** | 498.7 | 71.6 | 15.2 | 21.0 |
| **40** | 493.3 | 103.8 | 14.9 | 21.0 |
| **45** | 486.8 | 189.3 | 15.7 | 21.4 |
| **50** | 480.9 | 239.1 | 15.9 | 21.5 |
| **55** | 468.1 | 283.6 | 16.5 | 21.5 |
| **60** | 456.8 | 308.2 | 17.5 | 20.9 |

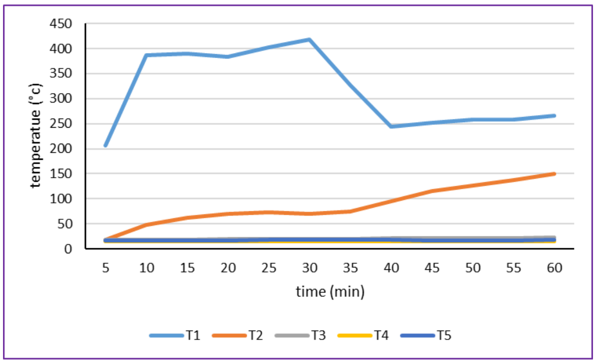



Fig. 6 Temperature progress of sample no. 1 – alternative 1

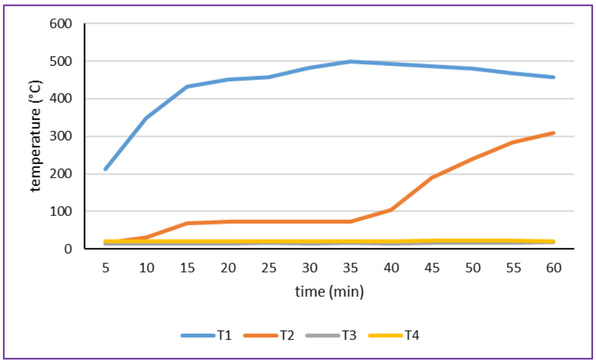



Fig. 7 Temperature progress of sample no. 1 – alternative 2

*3.2.1. Results for sample no. 1*

Sample no. 1 composition is compared with the structures in fig. 5 is referred to as "cavity facing". From the point of view of the K2 fire protection criterion, the temperature on the bottom side of the backing layer, measured on the T2 thermocouple, is important. In the case of the alternative 1 of sample no. 1, the backing layer is represented by OSB board, located behind the cavity (installation gap filled with UNIFIT 60 mm insulation). Temperatures measured on individual thermocouples are considered at 30 minutes from the start of the test, because shortly after this time, the integrity of the gypsum plasterboard was impaired. The temperature measured on the T2 thermocouple at 30 minutes was 70.3 ° C, which is consistent with the limiting temperatures to meet the K2 criterion (see Figure 5b).

The alternative 2 of sample no. 1 is also reffered to as a "cavity cladding", except that the cladding material is a FERMACELL gypsum fiberboard and the installation gap (filled with UNIFIT 60 mm thermal insulation) is followed by a supporting structure made of wooden pillars, including UNIFIT 160 mm thermal insulation. The bottom side of the backing layer therefore forms the interior of a supporting wooden column bearing a T2 thermocouple that had a temperature of 71.8 ° C at 30 minutes, i.e. a little higher than the bottom of the underlying OSB board at the alternative 1. This measured temperature also complies with the limiting temperatures to meet the K2 criterion (see Figure 5b), but since the 25-minute test was found to impair the integrity of the tile glazing panel, the K2 criterion for the classification time 30 minutes.

*3.3. Results for sample no. 2*

The measurement results are shown in tab. 3 and tab. 4. Graphical representation of the temperature of is shown in fig. 8 and fig. 9. Sample no. 2 shows, from the standpoint of assessment of the fire protection capacity, a non-cavity firewall construction (see Figure 5a)

Tab. 3 Temperatures measured by sample no. 2 – alternative 1

| **Time (min)** | **Temperature (°C)** | | | | |
|---|---|---|---|---|---|
| | **T1** | **T2** | **T3** | **T4** | **T5** |
| 0 | 20.4 | 23.6 | 23.6 | 23.3 | 24.4 |
| 4.5 | 295.3 | 50.6 | 33.6 | 24.1 | 19.4 |
| 9.5 | 349.9 | 62.1 | 42.7 | 23.5 | 17.1 |
| 14.5 | 357.1 | 69.7 | 44.7 | 20.8 | 18.2 |
| 19.5 | 365.3 | 70.8 | 42.0 | 20.7 | 17.3 |
| 24.5 | 375.2 | 67.5 | 43.1 | 20.4 | 19.2 |
| **29.5** | **374.7** | **74.3** | **41.3** | **20.2** | **16.6** |
| 34.5 | 393.1 | 103.9 | 42.0 | 21.0 | 17.6 |
| 39.5 | 397.2 | 116.5 | 40.1 | 20.1 | 15.5 |
| 44.5 | 396.2 | 127.3 | 37.4 | 20.6 | 16.1 |
| 49.5 | 402.7 | 139.3 | 34.2 | 19.9 | 16.3 |
| 54.5 | 405.3 | 149.8 | 31.0 | 20.3 | 18.2 |
| 59.5 | 411.0 | 161.3 | 22.5 | 20.3 | 16.7 |

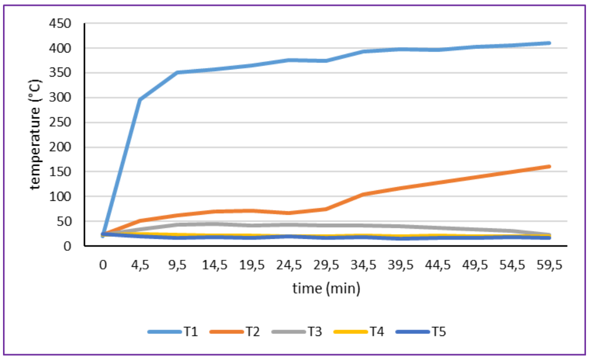



Fig. 8 Temperature progress of sample no. 2 – first alternative

Tab. 4 Temperatures measured by sample no 2 – alternative 2

| Time (min) | Temperature (°C) | | | |
|---|---|---|---|---|
| | T1 | T2 | T3 | T4 |
| 0 | 14.4 | 23.3 | 28.5 | 13.9 |
| 4.5 | 292.4 | 48.5 | 38.2 | 17.7 |
| 9.5 | 347.1 | 60.2 | 46.2 | 18.8 |
| 14.5 | 357.4 | 66.4 | 47.6 | 17.9 |
| 19.5 | 365.1 | 69.0 | 50.8 | 20.0 |
| 24.5 | 374.8 | 65.1 | 51.6 | 18.0 |
| **29.5** | **374.5** | **71.4** | **53.8** | **17.7** |
| 34.5 | 391.0 | 99.9 | 51.0 | 14.6 |
| 39.5 | 395.2 | 114.0 | 45.4 | 8.5 |
| 44.5 | 396.4 | 124.3 | 41.6 | 7.0 |
| 49.5 | 401.5 | 136.8 | 35.5 | 8.2 |
| 54.5 | 402.5 | 147.9 | 20.7 | 7.7 |
| 59.5 | 412.8 | 159.4 | 15.0 | 8.4 |

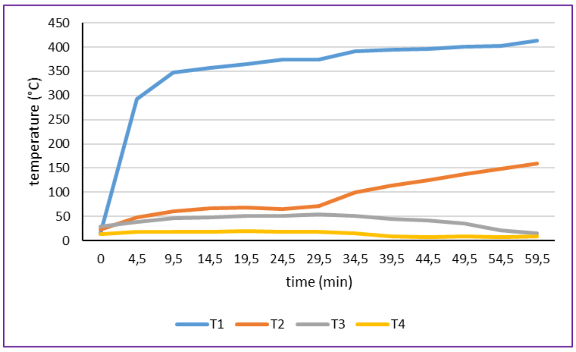



Fig. 9 Temperature progress of sample no. 2 – alternative 2

*3.3.1. Results for sample no. 2*

In the case of the alternative 1 of sample no. 2 the backing layer forms an insulating plate Entkopplung. After 30 minutes, the integrity of the plasterboard, which could not be visibly noticed due to a mineral plaster that retained its integrity throughout the test (a severe rupture of the plasterboard was heard), occurred after 30 minutes. The temperature measured on the thermocouple T2 at 30 minutes was 74.3 ° C, which is not exceeded by maximum increase in the initial temperature of 23.6 ° C by a limit temperature of 250 ° C. About 50 minutes later, steam and smoke leakage from the sample was observed. There was a more intense odour that resembled burning plastic - damage to the Entkopplung insulation board. At the place of loading, a concave part of the plaster appeared in the range of approximately 250 x 250 mm.

Difference in composition of the alternative 2 of sample no. 2 was in the absence of the insulating board Entkopplung. The slight spur of the mineral plaster was observed much earlier than in the case of alternative 1. Even in this case, the integrity of the plasterboard was impaired after 30 minutes. In 50 minutes, a more pronounced odour and smell of wood occurred due to the natural release of moisture at elevated temperature in the structure. The thermocouple T2 in front of the thermal insulation layer (bottom of the backing board) measured a temperature of 71.4 ° C at 30 minutes, i.e. somewhat lower than at the bottom of the insulating board Entkopplung in the case of alternative 1. This temperature measured did not exceed a temperature rise of 250 ° C above the initial temperature of 23.3 ° C for 30 minutes.

*3.4. Overall results*

Evaluation of the measured temperatures of sample no. 1 showed that more favourable results were achieved by the alternative 1 with the underlying OSB board under the plasterboard (Figure 10). Clearly, this is also evidenced by a steep rise in temperature in the 40-minute test on the T2 thermocouple in the case of alternative 2, after the impairing the integrity of the gypsum fiberboard (see Figure 7). This subsequently led to the ignition of the wooden grid in the installation gap and thus to further increase the fire intensity in the structure. Increased fire intensity caused the ignition of a wooden column, which showed considerable abrasion after disintegration of the sample. We assume that during the 30 minutes during which the cut-off temperatures for the K2 flame test criterion were met on both samples of sample no. 1, there was no abrasion or abrasion at any point of the substrate and at any point on the uncoated side of the facing

Fig. 10 Sample no. 1 – alternative 1 after testing

As can be seen in fig. 10, for the alternative 1 of sample no. 1, ignition and further brazing of wood grate in the installation gap under the plasterboard occurred. The OSB board behind the thermal insulation at the installation gap, however, remained intact and prevented the fire transfer to the supporting wooden column. In fig. 11 is shown sample no. 1 – alternative 2, the alternative after the end of the test, on which it is clearly visible the cross-section of the vertical support column in the center of the sample.

Fig. 11 Sample no. 1 – alternative 2 after testing

Fireproof facing of sample no. 2 would also meet the criteria for K2 classification for 30 minutes, of course provided that no blasting or abrasion would occur at any place on the substrate and at any point on the uncoated side of the cladding for 30 minutes. Both sample no. 2 alternatives have at a first view an almost identical temperature course (see figures 8 and 9). However, the Entkopplung insulation board was of importance in the design of the alternative 1 construction. Due to radiant heat, the "plate sintering" occurred during the test, creating a barrier that prevented further heat transfer to the structure. At the bottom of the test, a temperature of 74.3 ° C was measured at the bottom of the test, and only 41.3 ° C behind the plate, with partial degradation of the Entkopplung polyester plate [6] at that time.

For this reason, the classification of the fire protection capability for the alternative 1 of sample no. 2 was determined to 10 K1. Comparing the temperature on the thermocouple T3 = 41.3 ° C (alternative 1) behind the insulating plate/board (i.e. before the thermal insulation layer), with the thermocouple temperature T2 = 71.4 ° C for the alternative 2 (also in front of the thermal insulation layer), it follows that the higher temperature increase inward the construction was evident in the case of the alternative 2 of sample no. 2. In fig. 12 is shown sample no. 2 – alternative 2 after the end of the test.

Fig. 12 Sample no. 2 – alternative 1 after testing (on right degradation of Entkopplung insulation board)

In fig. 13 is sample no. 2 – alternative 2 after the end of the test. We can see the damaged gypsum board integrity and a considerable thermal insulation in the range of about 400 x 450 mm due to degradation of the vapour barrier layer deposited on the inside of the thermal insulation due to a higher temperature increase (T2 = 99.9 ° C at 35 minutes) inward of the structure.

Fig. 13 Sample no. 2 – alternative 2 after testing

## 4. Conclusions

The best result of all the samples tested was achieved by sample no. 1 – alternative 1 with the underlying OSB board. The fire protection capability of the sample was determined on the basis of measurement results of 30 K2. For the sample no. 1 – alternative 2, the K2 criterion was broken at 25 minutes, when the integrity of the gypsum fiber lining was impaired and in the next test of the firewood in the construction. For sample no. 2 – alternative 1, the fire protection capability was set to 10 K1 due to the degradation of the polyester insulating plate under the plasterboard, which was better than the alternative 2 without a backing board with an increased temperature rise in the structure and subsequent deterioration of the thermal insulation in the structure. Based on the positive results of the experiment, it can therefore be stated that wood in combination with other materials can provide positive fire performance [7].

Various material composition led to different results of the behaviour of the structure under the conditions of radiation heat loading. The results obtained show that the appropriate material solution and layout of the individual layers in the structures of the wooden constructions can already be improved in the design solution to suitably set the structure of the constructions so that they do not increase the intensity of the fire in the required time and thus prevent it from spreading to the entire structure

**Acknowledgments**

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# Preventing a dust explosion at food processing plants

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**Abstract**

Combustible dusts is composed from fine particles that can present a significant risk, especially with regard to their explosion. Under certain specific circumstances it may occur in food companies very quickly and damage, that can be caused by such explosions, mostly climb to huge amounts. A dust explosion can be catastrophic and cause employee injuries and deaths. [1] In many cases the dust explosion can cause huge destruction of the entire building. Therefore it is important to pay attention to fire-technical characteristics of combustible food dusts to protect against emergencies as a result of the explosion. To avoid an dust explosion means taking measures to prevent such situation (dust explosion prevention) or there is possible to protect people, technology and buildings in case of dust explosion by designing facilities (explosion protection). The article deals with the chosen characteristics of combustible dusts, especially with the fire-technical characteristics, as well as with an explosion protection at food processing plants.

*Keywords*: combustible dust, flammable dust, food industry, fire – technical characteristics, dust explosions, explosion protection;

## 1. Introduction

At food processing plants there is often present any kind of combustible dusts, that is mainly worked with in mills and different silos. So the most susceptible kinds of food industry to fire and explosion incidents are in the baking segment that use a lot of flour and sugar. Flour dust suspended in air is explosive, as is any mixture of a finely powdered flammable substance with air. In medieval times flour mills, candles, lamps, or other sources of fire were forbidden. Some devastating and fatal explosions have occurred at flour mills, including an explosion in 1878 at the Washburn "A" Mill in Minneapolis, the largest flour mill in the United States at the time. In the UK a series of explosions in food factories have had fatal results for both adults and children. The earliest dust explosion was recorded in Italy, in 1785. [2]

Although explosible dust cloud concentrations are not normally expected to be present within processing buildings, explosible dust clouds are regularly formed inside material handling or processing equipment when bins are being filled, powders are being transferred or dust is being collected in a dust collector. The risk caused due to the manifestation of this danger has been increased in recent decades when these dusts began to be produced industrially in huge amounts. The consequences of such events may have strong influence on the used technology but also on the health of workers. In an environment where an explosion of combustible dust is present there must be met simultaneously several conditions for physico-chemical properties and fire-technical characteristics of the dust, which are necessary for determining formation of dust explosion. Protecting the facilities and employees is paramount but the risk factors are not always obvious. Before looking at how to proactively protect the facilities it is necessary to examine how the disasters can happen. [3,4] It means it is necessary to know how the combustible dust can explode, which elements are needed to be present simultaneously at one place to cause combustible dust explosion, how the amount of combustible dust can be controled and how the ignition sources can be controled.

A summary of the explosion at a grain terminal at Blaye on the French Atlantic coast which killed 11 people in 1997 can be found in English from Ineris, the French government research institute.

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Figure 1 Consequences of dust explosion at Blaye [5]

## 2. Situation in food industry

Food factories have some specifics that make the situation more favorable compared to other industries. They have a higher level of hygiene and cleanliness in the workplace, so there is usually not used to manipulate with higher amount of dust out of the technology and thus the risk of explosive atmospheres creation relates in the vast majority only to the interior of the devices (for example, in tanks and silos of flour, sugar, cocoa and other loose (powdery) materials and in transport systems or machines for mixing raw materials. But at that same time, however, this fact conceals a big danger of underestimating of situation. Operation, which for the first view looks clean and dust-free hides considerable risks at places which are not visible. [6]

As it is possible to see at next two figures, the food industry take about 18 % within all incidents caused by combustible dust explosion. Data are revealed from an analysis of 197 incidents.

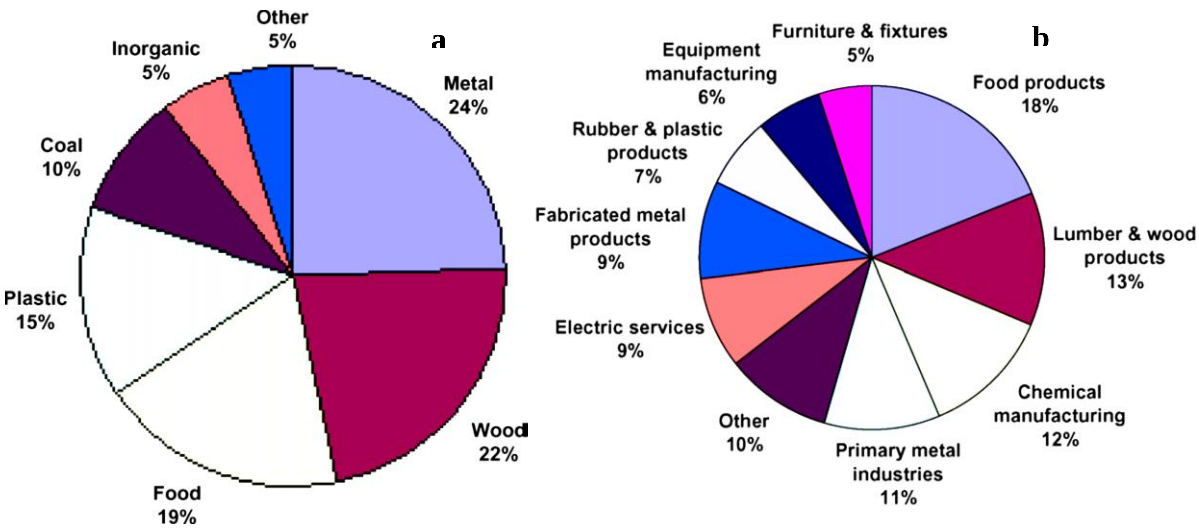


Figure 2 Type of material involved in dust incidents a) and incidents break down per industry b) [7]

*2.1. Fire – technical characteristics of food dusts*

The following elements figured at the next figure 3 are needed to be simultaneously present to occur combustible dust explosions.

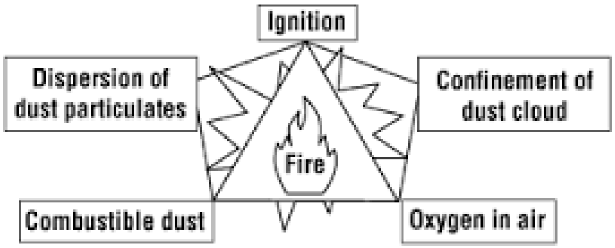


Figure 3 Pentagon of combustible dust explosion [8]

For large number of combustible dusts it can be found the fire - technical characteristics in tables or specialized technical literature. Those are lower explosion limit, maximum explosion pressure, maximum rate of pressure rise, explosion constant KSt, minimum initiation energy, combustion temperature of sedimented dust, the combustion temperature of the swirled dust, the ignition temperature of sedimented and swirled dust, limit oxygen number.

However, it should be kept in mind that the values of these characteristics have the character of intervals, so they need to be understood just as approximate guide values. Safety parameters of combustible dust always depend on a specific technology and on conditions of handling with the substance. [9] In following tables there could be seen the fire – technical characteristics of particular food flammable dusts stated in technical literature.

Table1 Fire–technical characteristics of dried milk [10, 11, 12]

| DRIED MILK | |
|---|---|
| Lower explosion limit [g/m$^3$] | 60 |
| The ignition temperature of the seated dust | 330 |
| The ignition temperature of the whirled dust | 520 |
| Maximum explosion pressure [MPa] | 0.8 |
| Explosion constant $K_{St}$ [bar.m/s] | 90 |
| Minimum ignition energy [MJ] | 35 |

Table 2 Fire–technical characteristics of cocoa [10, 11, 12]

| COCOA | |
|---|---|
| Lower explosion limit [g/m$^3$] | 65 |
| The ignition temperature of the seated dust | 200 |
| The ignition temperature of the whirled dust [°C] | 500 |
| Maximum explosion pressure [MPa] | 0,4 |
| Minimum ignition energy [MJ] | 100 |

Table 3 Fire–technical characteristics of dust sugar [10, 11, 12]

| DUST SUGAR | |
|---|---|
| Lower explosion limit [g/m$^3$] | 45 |
| The ignition temperature of the seated dust | 400 |
| The ignition temperature of the whirled dust | 370 |
| Maximum explosion pressure [MPa] | 0.7 |
| Explosion constant $K_{St}$ [bar.m/s] | 126 |
| Minimum ignition energy [MJ] | 30 |

Table 4 Fire–technical characteristics of wheat flour [10, 11, 12]

| WHEAT FLOUR | |
|---|---|
| Lower explosion limit [g/m$^3$] | 125 |
| The ignition temperature of the seated dust [°C] | 360 |
| The ignition temperature of the whirled dust [°C] | 480 |
| Maximum explosion pressure [MPa] | 0,7 |
| Explosion constant $K_{St}$ [bar.m/s] | 63 |
| Minimum ignition energy [MJ] | 40 |

### 3. Experiments and results

There are two basic methods for measuring of ignition temperature of food dust, and those are measuring in sedimented state and measuring in whirled state of dust. Our experiments shown in this article are provided according to the second method. The measuring equipment is shown in the following figure 4.

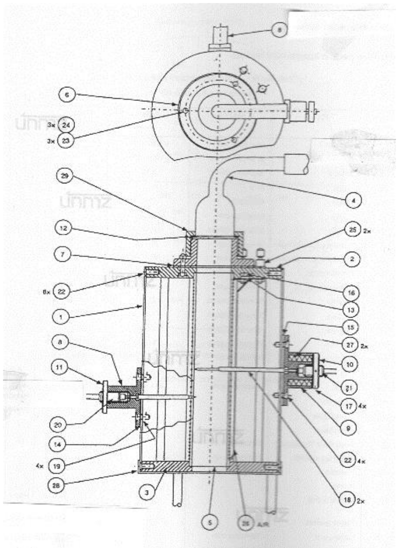

Figure 2 Equipment for measuring of ignition temperature of whirled dust*

*Legend: 1 – furnace shell, 2 – top cover, 3 – lower cover, 4 – adapter, 5 – tube, 6 – sleeve, 7 – mat, 8,9 – flange for thermocouple, 10, 11 – locknut, 12, 13, 14, 15, 24 –mat, 16 – ring, 17 – pin, 18 – sleeve, 19 – nut, 20, 21 – thermocouple, 22 – countersunk bolt, 23 – convex nut, 25 – therminal, 26 – Kanthal wire, 27 – compression spring, 28 - rack ovens, 29 – hedgings ring, 30 – dust collector [13]

The values measured by the equipment for measuring of ignition temperature of whirled dusts are shown in the next table 5. As it can be observed in comparison with the values written in technical tables and literature there are some small variations in our laboratory measurements. They can be caused, as it is mentioned above, by the particular structure of the dust, by the size of its particles, by humidity of the dust, etc.

Table 5 Fire–technical characteristics of particular food dusts measured in our laboratory

| **Minimum ignition temperature of whirled dusts [°C]** | | |
|---|---|---|
| **Dust** | **Measured value** | **Tabled value** |
| Flour | 390 | 485 |
| Dust sugar | 380 | 360 |
| Cocoa | 480 | 500 |
| Dried milk | 510 | 520 |

## 4. Conclusions

Combustible food dusts pose a serious industrial safety challenge because of their capability to explode under certain circumstances. Fire - technical characteristics of combustible dusts such as ignition temperature of dust in deposit state, ignition temperature in whirled state, minimum ignition energy, explosion constant $K_{st}$, etc. are not physical constants [14] are very helpful at solving combustible dust explosion safety but it was found that they are depending on test conditions, on structure of the dusts, on size of dust particles, on humidity and many others circumstances and conditions. Using direct value of particular fire – technical characteristics without measuring for particular dust is not the right way and the safety in the food industries and agricultural companies could not be exact. That is why every food and agricultural plant need to have measured all fire – technical characteristics of the dusts that occur in the particular company. Such way of characterization of the sample could lead to higher safety of the food industry and to protecting many lives of workers and property.

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# The formation of hazardous substances at the thermal loading of indoor polystyrene boards

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**Abstract**

The aim of the paper is to determine the formation of hazardous substances in the smoke arising at the thermal loading of indoor polystyrene boards using HeadSpace/Gas Chromatography/Mass Spectrometry (HS/GC/MS). The polystyrene samples were thermal loaded at the temperatures of 60, 80 and 100 °C in the HeadSpace sampler. We determined the mass changes and the arising gaseous products were analyzed by Gas Chromatography with Mass Spectrometry. The formation of several compounds of polystyrene degradation was achieved already at the 60 °C. The main products were styrene, α-methylstyrene, toluene, xylenes, ethylbenzene and other alkylated benzenes. With increasing temperature increases quantity of gaseous products and amount of the main products.

*Keywords*: polystyrene, thermal loading, HeadSpace, Gas Chromatography, Mass Spectrometry, styrene, alkylated benzenes;

## 1. Introduction

Polystyrene is one of the oldest used polymer materials. Since the invention of polystyrene to its industrial using came through nearly hundred years. Today styrene polymers belong among widespread used materials in different areas, mainly the building and packaging industry. Adverse utilization ways of materials request adverse properties of polystyrene especially in relation to health and fire safety. Styrene polymers have very adverse fire-technical characteristics. It is easy to ignite them, they burn quickly, combustion is attended by formation of large amount of heat and they contain a phenyl group in a side chain – for this reason reaction to heat is accompanied by release of large amount of gaseous products due the oxidative thermal degradation of native material [1, 2].

Polystyrene heating by temperatures above 80 °C causes its degradation at first, which is attended by properties changes. Cleavage of large amounts of chemical bonds takes place at higher temperatures, so the decomposition of polystyrene starts and gaseous products are formed [3, 4].

Table 1 Changes of polystyrene due the temperature acting [3, 4]

| Temperature | Process |
|---|---|
| at 85 – 90 °C | thermally stable |
| up 90 °C | softening and melting |
| at 160 °C | oxidation on the top |
| at 280 – 300 °C | decomposition of polymer |
| over 320 °C | further depolymerisation, degradation to styrene and diverse dimers (trimers) |

The aim of this work is to determine the formation of gaseous hazardous substances arising at the thermal decomposition of indoor polystyrene boards using HeadSpace/Gas Chromatography/Mass Spectrometry (HS/GC/MS).

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## 2. Material and methods

Two kinds of polystyrene have been processed in this work – expanded (EPS) and extruded (XPS) polystyrene. We used the indoor insulation boards as representatives of this material. Samples of expanded and extruded polystyrene were thermally loaded at temperatures of 60, 80 and 100 °C by using HeadSpace sampler (Agilent) for 1 hour. The arising gaseous products were injected directly to GC column and analyzed by gas chromatography-mass spectrometry (Agilent). Qualitative determination of detected compounds effects by comparison of determined mass spectra with library spectra (NIST Wiley). For quantification of some arising gaseous products (benzene, toluene, ethylbenzene, xylene and styrene) was used method of the external standard.

## 3. Results and discussion

We have thermally loaded samples of EPS and XPS and analyzed arising products. Results are described in table 2. We can classify the founded decomposition products as benzene, styrene, alkylated benzenes (toluene, xylenes, ethylbenzene and other), products of oxidation of benzene and styrene (benzaldehyde). We have testified results of other authors, who have found similar products of thermal degradation of polystyrene [2, 3, 5].

Interesting are results of comparison both of polystyrene kinds in the table 2 and figure 1.

In the figure 1 is shown the difference of mass loss between EPS and XPS. Temperatures of 60, 80 and 100 °C are low for thermal degradation and values of mass loss are under 10 % (3,82 – 4,08 % for XPS and 6,58 – 8,21 % for EPS). At the temperature 100 °C we have determined 27 compounds of expanded PS and 16 compounds of extruded PS (11/8 at 60 °C and 19/14 at 80 °C). This confirms that extruded polystyrene is thermally more stable.

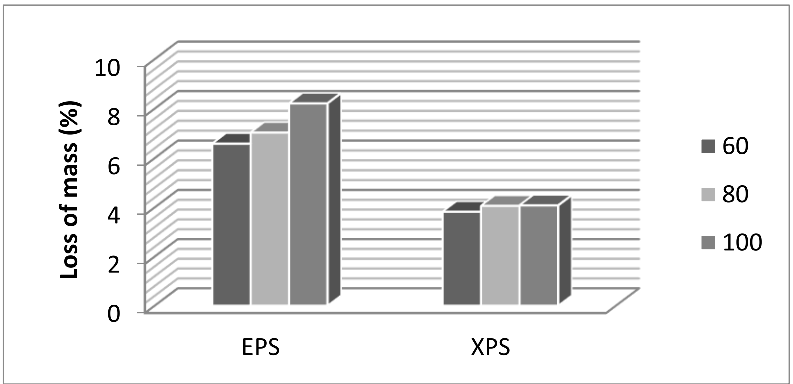


Figure 1 The determined loss of mass of polystyrene samples after thermal loading at 60, 80 and 100 °C

Table 2 The founded thermal decomposition products of polystyrene samples

| | Compound | EPS | | | XPS | | |
|---|---|---|---|---|---|---|---|
| | | 60 °C | 80 °C | 100 °C | 60 °C | 80 °C | 100 °C |
| 1. | benzene | + | + | + | | + | + |
| 2. | 1,4-dioxane | + | + | + | + | + | + |
| 3. | toluene | + | + | + | + | + | + |
| 4. | 2-octanal | | | | | + | + |
| 5. | hexanal | | | + | | | |
| 6. | ethylbenzene | + | + | + | + | + | + |
| 7. | xylene | + | + | + | | + | + |
| 8. | styrene | + | + | + | + | + | + |

| | Compound | EPS | | | XPS | | |
|---|---|---|---|---|---|---|---|
| | | 60 °C | 80 °C | 100 °C | 60 °C | 80 °C | 100 °C |
| 9. | 1-methylethylbenzene | + | + | + | + | + | + |
| 10. | 1,3,5-trimethylcyclohexane | | | + | | | |
| 11. | cyclopropylbenzene | | | + | | | |
| 12. | propylbenzene | + | + | + | + | + | + |
| 13. | 1,3,5-trimethylbenzene | + | + | + | | | + |
| 14. | benzaldehyde | | | | | + | + |
| 15. | 1-ethyl-3-methylbenzene | | + | + | | | |
| 16. | 2-propenylbenzene | | + | + | | | |
| 17. | decane | | + | + | | | |
| 18. | 1-ethyl-2-methylbenzene | | | + | | | |
| 19. | 1,2,3-trimethylbenzene | | + | + | | | |
| 20. | limonene | | | | | + | + |
| 21. | 2-ethylhexa-1-ol | | + | + | | | |
| 22. | 1-methyl-2-pyrrolidinone | | | | + | + | + |
| 23. | 1-methyl-3-propylbenzene | | | + | | | |
| 24. | 1-methylenepropylbenzene | | + | + | | | |
| 25. | acetophenone | + | + | + | | | + |
| 26. | .α-methylstyrene | + | + | + | | + | + |
| 27. | undecane | | + | + | | | |
| 28. | 1-methylethylbenzene | | | + | | | |
| 29. | naphtalene | | | + | | | |
| 30. | dodecane | | + | + | | | |
| 31. | tridecane | | | + | | | |
| 32. | 1,1'-(1,2-cyclobutanediyl)bis-, cis-, trans-benzene | | | | + | + | + |

+ the compound was detected in the sample

The largest part of analyzed products represents styrene (table 3). Gradually with the temperature increase there were analyzed the simple compounds at first – benzene, alkylated derivatives of benzene (toluene, ethylbenzene, xylene) followed by increasing amounts of styrene, α-methylstyrene, acetophenone and benzaldehyde. There were observed similar results by other authors [1, 4, 5], however they examined the samples at higher temperatures (temperatures above 400 – 500 °C) by which polystyrene burns.

Table 3 The amount of same volatile polystyrene degradation products (µg/g)

| compound | EPS | | | XPS | | |
|---|---|---|---|---|---|---|
| | 60 °C | 80 °C | 100 °C | 60 °C | 80 °C | 100 °C |
| benzene | 7.015 ±0.018 | 6.208 ±0.096 | 6.982 ±0.209 | 3.224 ±0.107 | 3.362 ±0.069 | 3.153 ±0.024 |
| toluene | 25.76 ± 0.089 | 22.94 ±0.934 | 24.89 ±0.730 | 11.67 ±0.086 | 12.63 ±0.224 | 11.79 ±0.384 |
| ethylbenzene | 8.62 ±0.015 | 18.88 ±0.598 | 41.22 ±1.269 | 3.74 ±0.030 | 6.01 ±0.111 | 8.68 ±0.247 |
| xylene | 12.63 ±0.038 | 13.33 ±0.283 | 18.04 ±0.576 | - | 6.17 ±0.128 | 5.87 ±0.204 |
| styrene | 0.79 ±0.022 | 17.37 ±0.539 | 55.57 ±1.711 | 2.33 ±0.113 | 18.48 ±0.541 | 44.98 ±1.338 |

- compound was not detected in the sample

## 4. Conclusion

In this work we have determined gaseous compounds arising by thermal decomposition of polystyrene samples (EPS and XPS) at the temperatures of 60, 80 and 100 °C. Polystyrene is thermally stable under 100 °C despite of this we have determined more than 20 volatile compounds (benzene and its derivates, styrene, α-methylstyrene, oxidation products such as benzaldehyde or acetophenone and other). This shows that the decomposition of polymer material is in progress also by influence of low temperatures for longer time (1 hour).

Importance of this research is to observe the behavior of polystyrene polymers at lower temperatures, from environmentally or fire safety point of view. Detected aromatic hydrocarbons and their oxidation products (benzene, styrene, α-methylstyrene, benzaldehyde, acetophenone) arising by thermal decomposition of EPS and XPS are suspect cocarcinogenics, tumorpromoting agents and irritant compounds.

## Acknowledgments

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# Fire research at Technical Institute of Fire Protection in Prague

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**Abstract**

In the first part of this article there you can find description of Technical Institute of Fire Protection (TIFP). TIFP is a small institute in Prague, which consists of five departments. You can also find description of main activities of these departments. In the second part of the article there is description of our research projects. Currently we deal with 5 different projects. We started 2 projects in 2016 and 3 other projects in the beginning of this year. Because we are at the beginning of the projects our results are limited. Instead of the results we want to provide some information about our institute and about its activities to create some space for possible cooperation with other institutions, which deal with the similar topics as we.

*Keywords*: research and development, fire protection, CFD modelling, ladders, CNG, traces of fire on vehicles, fire rescue vehicles;

## 1. About TIFP

TIFP is a technical facility of the General Headquarters of the Fire and Rescue Service of the Czech Republic. It was established in January 1993 and its core activities are fire testing, fire investigation and research and development in fire science.

It is located in the south of Prague, it is divided into five departments and it actually employs 32 workers including technical staff.

Core departments are Fire Investigations Department, Department of Certification, Department of Fire Equipment Testing and Research and Development Department. These are backed-up by Department of Technical and Economical support.

### 1.1. Fire Investigations Department

It works in cooperation with regional fire brigades, the General Headquarters of the Fire and Rescue Service of the Czech Republic, the Department of Forensic Technologies and Expertise, the Police of the Czech Republic and/or individuals.

Upon request Fire Investigations Department performs scene-of-fire visits, inspection of fire scenes and collection of the samples, investigation of the causes of electrically-ignited fires, determination of fire technical properties, identification of chemical substances and determination of self-ignition properties of substances and materials using physical and chemical methods, provision of the technical assistance to fire brigades in the fire chemistry area and in other fields, modelling of likely effects and hypotheses, drawing up of expert opinions and/or assessments.

It is a top-level authority for fire investigations in the Czech Republic and it works on cases with the highest damage on property or with life lost.

### 1.2. Department of Certification

TIFP is product certification body No. 3080 determined by the Czech Office for Standards, Metrology and Testing and Department of Certification is the executor of this activity. Department of Certification provides the Czech national authorisation for evaluating the conformity of fire appliances (e.g. fire hoses or

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fire hydrant systems) and other fire safety equipment (fire trucks, fire pumps etc.).

Department of Certification also participates in creation of new technical product requirements, in processing of statements to proposals of standards, regulations and documents, which hang together with fire-technical testing and certification.

*1.3. Department of Fire Equipment Testing*

Department of Certification works in cooperation with Department of Fire Equipment Testing, which is responsible for performing prescriptive assessments test of equipment for fire and rescue brigades.

Department of Fire Equipment Testing is able to perform assessment tests of equipment named bellow:

*Fire Equipment:*

– ladders,
– hydraulic extricating devices,
– fire fighting trucks (except vehicles weighing less than 2000 kg)
– fire pumps,
– equipment for rescuing people from heights (jumping cushions and sheets, escape chutes)
– air bags

*Resources of Fire Protection:*

– movable fire extinguishers,
– extinguishing agents (other than additive-free water)
– fire hoses,
– fire branchpipes and fittings,
– fire hose and hydrant systems,

*Personal Protective Resources for Firefighters:*

– protective clothing, gloves and footwear for firefighters

*1.4. R&D Department*

Research and Development Department works on research projects, some partial tasks for needs of regional fire brigades (educational trainings or full scale fire tests) and some commercial measurements for customers. Our cooperation with regional fire and rescue services includes for example monitoring of temperature in training flashover container or monitoring of temperature and pressure of flammable gas storage vessel in fire. Both for needs of Pilsen Fire and Rescue Service.

The research projects are mainly focused on a field of material fire characteristics and Computational Fluid Dynamics (CFD) fire modelling. These activities are the main research interests of our department. At this time the department works on a several projects from these areas: „Research and development of validated models of fire and evacuation and their practical application in fire safety of buildings“, „Accidental release of CNG from passenger vehicles“, „Study of traces of fire spread and flammability of vehicle components for fire rescue service of the Czech Republic“.

R&D Department also works on project based on needs of the General Headquarters of the Fire and Rescue Service of the Czech Republic. These two projects are „Safety improvement of extension ladders for firefighters“ and „Color markage of fire rescue vehicles“).

We are equipped with material and fire labs, used not only for projects presented above, but also for commercial measurements based on customer needs or needs of our Fire Investigations Department. Both material and fire labs are equipped with modern unique apparatuses such as high pressure differential scanning calorimeter (see fig.1), 2017 FTT cone calorimeter, high pressure autoclave (see fig.2) and many others. We are open to offer these resources for the interscience cooperation.

Fig.1 High pressure differential scanning calorimeter


Fig.2 High pressure autoclave

## 2. Ongoing research projects

### *2.1. „Research and development of validated models of fire and evacuation and their practical application in fire safety of buildings”*

The project deals with using of performance based design (PBD) in area of building fire safety design, which is an alternative to normally used prescriptive methods of fire safety design. Use of PBD can be beneficial in a way of decreasing cost but not decreasing the safety level. Some fire safety engineers have already started using these methods but the guidelines and requirements are not set.

Overall scope of the project is to provide guidelines for fire safety engineers as well as for assesing authorities so the PBD will be an alternative for prescriptive design and assesing authorities will be able to make judgement if design (PBD) is correct.

It is divided into four work packages. Each package deals with several branch of fire safety design. This project is cooperation of 4 institutions. Czech Technical University in Prague, Brno University of Technology, Technical University of Ostrava and Technical Institute of Fire protection. TIFP works on two work packages. TIFP is responsible for measuring and preparing comprehensive database of fire-technical properties of various materials used in buildings as well as preparing a guide for the right usage of input parameters for numerical models.

Another area, where TIFP cooperates with Technical University of Ostrava, is preparing a guideline for correct using of computer fire models for design of fire safety equipment of buildings. For example smoke ventilation systems, regular and residential sprinklers, fire detection systems and other.

Next areas of the project where TIFP is not involved is preparing similar guidelines for using fire models for design of fire resistivity of structures and for EVAC studies.

The project started at January 2016 and it lasts until 2019. During the first year of the project we defined the best model situations for using CFD fire models and the matrix of possible usage of fire models. Next steps will be a comparison of defined model situations with real-life fire designs and preparation of the examples.

For purposes of database, some tests of several composite materials were done on the cone calorimeter. The tests were carried out for wood-plastic and wood-metal composites mainly for indoor usage in buildings. The wood-plastic composites were measured for two irradiance levels 35 kW.m-2 and 50 kW.m-2. These data will be used as a first input for online public database. It was found that data for the wood-metal composites cannot be easily used as an input for fire models or even calculations and needs further testing and choosing the right test setting.

Next work on this part of the project is measuring more materials and add some next test methods than cone calorimeter.

### *2.2. „Accidental release of CNG from passenger vehicles”*

The aim of the project is to study the accidental release of CNG from the pressure vessels in the passenger cars, its dispersion from the source and combustion in the enclosure.

This phenomenon is getting more and more importance nowadays. Because of economical and ecological reasons alternative fuels like CNG are widely used. However problem with such vehicles in underground parking lots is not yet legislatively resolved in Czech Republic resulting in need of improving the guidelines for design of these parking lots.

The release of the CNG from the pressure vessel through the safety valve is firstly studied experimentally. Output of the experimental study is used as an input to the Computational Fluid Dynamics model. CFD is used to predict the dispersion of the gas from the release source and its combustion in enclosures.

The project started on January 2017 and it lasts until 2019. To this time some first experiments were done. For different initial pressures (from nominative 200 bars to 50 bars) the mass loss rate and decrease of pressure in a vessel was studied. Also CNG release was studied by high speed camera. See fig,3. These experiments gave the first ideas about speeds and shape of the release of gas. Obtained data are now being studied and next experiments with the assuming the geometry of a car are being prepared.

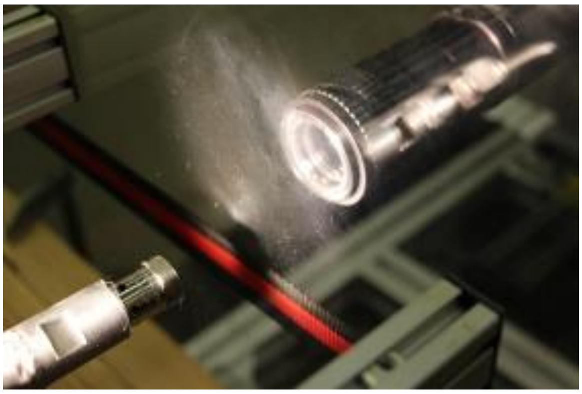

Fig. 3 Study of CNG release by high speed camera

On this project TIFP cooperates with the University of Chemistry and Technology, Prague.

### *2.3. „Study of traces of fire spread and flammability of vehicle components for fire rescue service of the Czech Republic”*

Study of traces of fire spread on metal parts of the bodyworks of vehicles according to a kind of metal finishing of bodyworks. The aim is to define each character of the traces. The result of it is to create a methodology for determination of a case of fire. The second part of the research is to determine fire technical characteristics of materials used in vehicles. The result of this part will be a database useful for both fire technical expertise and purposes of numerical modeling.

This projects is a result of long term study of fire traces on metal parts found on scene of fire visits of Fire Investigations Department. As the pre-experiments for the project, fire tests of four passenger cars were carried out. Each car was ignited in a different way. During the test spreading of fire was studied. After the test the final traces on body-parts were studied. These tests led to first information how to read the traces and the aim of this project is to continue in this topic and to create some general methodology how to read these traces. The first conclusions of the pre-experiments were published on 2016 Inteflam resulting into cooperation with Fire and Rescue Service of Singapore. At the beginning of the project fire investigators from Singapore provided some more data for testing the conclusions of the pre-experiments and for preparing the methodology.

The project started on January 2017 and it lasts until 2019. The experiments for creating the methodology or for the preparing the study guide is still being prepared.

### *2.4. „Safety improvement of extension ladders for firefighters”*

The projects is aimed to improve safety of extension fire ladders in several ways. Firstly material properties are studied by the destruction tests of fire ladders. Obtained data will then be used for validating the finite element method (FEM) models. Afterwards, validated FEM models will be used to see behavior of fire ladder under extreme conditions which can occur during safety operations such as overloading of the ladder, extreme angles or lengths or some other situations. These findings will then be used for improvement of testing procedures as well as tactical guidelines for fire rescue personnel. Other part of the project is aimed to study ladder behavior under extreme heat condition which can occur during fire intervention. The last part of the project deals with process or criteria for decommissioning ladder.

The project started in 2016 and it lasts until 2020. On this project TIPF cooperates with the University of Chemistry and Technology in Prague, Czech Technical University in Prague.

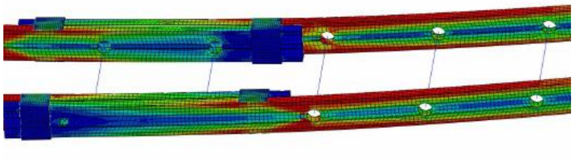

Fig. 4 FEM Analysis of standart test procedure
(courtesy of Czech Technical University in Prague)

*2.5. „Color markage of rescue fire rescue vehicles"*

This project is based on the direct need of the General Headquarters of Fire and Rescue Service of the Czech Republic. The color markage is not uniform for all the regional Fire and Rescue services as well as the codes and requirements on the fire trucks and vehicles are not clear enough. It results into several problems such as different color markage on fire trucks from different regions or different hue even between trucks and vehicles at the same unit, not uniform service life of the color markage from different suppliers or different price of different color markage.

The aim of the project is to find the best color solution with respecting safety of fire and rescue personel, civil people and drivers, economical aspect and service life of the truck.

After a solution will be find, requirements and test procedures for the manufactures will be set. Project started at February 2017 and it lasts untill January 2018. Besides TIFP is project solved by Transport Research Centre in Brno and SYNPO a.s. from Pardubice.

# Evaluation of fire behaviour of lining material under different irradiance heat flux using the cone calorimetry

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**Abstract**

Bench scale tests by Cone calorimeter were conducted to evaluate the fire behaviour of a vinyl based lining material with and without anti-corrosion painting. The samples were tested with two irradiance heat flux, $35kW/m^2$ and $50kW/m^2$. Östman/Tsantaridis' empirical linear regression model and Hansen/Hovde's multiple discriminant function analysis (MDA) were used in the predicting flashover time and classifying the lining material from the results of $50kW/m^2$ tests.

*Keywords*: fire behaviour, lining material, cone calorimetry, flashover prediction;

## 1. Introduction

Vinyl products can be found in just about every home or business, in hundreds of different applications. The durable and low maintenance quality of vinyl makes it a popular material in Siding, roofing, fencing, decking, railing, piping, flooring, wall-coverings household electrical applications, automotive and electrical applications.

Fire retardance and heat performance of vinyl products draw great attention in application. Although most vinyl products are manufactured to be safe from normal fire hazards, fire behavior is still a great concern in its special use.

Many studies have shown that the initiation and development of accidental fires are complex matters. Fire behaviour is a measure of how easily a substance will burn through fire or combustion. This is an important property to consider when a substance is used for construction, flooring or lining. Various countries have their own code in defining fire behaviour of materials [1].Only those meet the code could be used as building materials or aircraft and marine applications. The degree of fire behaviour depends largely upon the chemical composition of the subject material. A number of factors must be taken into account in assessing the contribution of any one material to a fire situation; especially it is used in room lining for cabin in aircraft and marine applications. In

a detailed assessment of the overall fire-performance of a material many factors must be taken into account. These factors are ignitability, flammability, heat release, spread of flame, smoke emission, toxic gas emissions, and corrosion hazard. When the lining material is used in restricted room space, its fire behavior leading to flashover should be considered as a key reference for fire protection design.

Large scale fire test in ISO room is a good method to classify lining material according to its flashover time. But it is costly to perform. Bench scale cone test could also be involved in quantifying the degree of fire behavior [1]. Ignitability, flammability, heat release and smoke emission can be evaluated[2]. Researchers have tried to find rational model to relate cone test data to ISO room classification. Kokkala and et al. developed classification indexes by applying dimensional analysis and fire growth modelling to the ISO Room Fire Test [3] based on the test results in the Cone Calorimeter at 50kW/m2 irradiance. The indexes can be used to group materials based on their predicted time to flashover. Östman and Tsantaridis[4] presented a very simple empirical linear regression model for prediction of time to flashover in the room corner test based on cone calorimeter results from tests at

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50kW/m2. Hansen and Hovde [5] evaluated the application of multiple discriminant function analysis (MDA) also on cone test data to predict the FO-category in the room corner test, which made up for the deficiency of Östman/Tsantaridis' model performing poorer for time to flashover above 10 min. We verified Östman/Tsantaridis' and Hansen/Hovde's models on GRP fire behaviour by cone and ISO room tests[6] in previous research. Present studies also use these models in evaluation and classification the fire behaviour of lining materials. This will be helpful in fire investigation and improving the research on anti-fire performance of these materials.

## 2. Test procedure and results

The tests were performed with the cone calorimeter in State Key Laboratory of Fire Safety Science, China. This cone system is designed based on "the oxygen consumption Method", and meet all existing standards including ISO5660 and ASTM E1354.

12 sample of the vinyl lining materials were tested in the horizontal orientation. 6 of them without anti-corrosion painting of average density 1152kg/m$^3$, which were labelled as F-1-35 to F-3-35 under 35kW/m2 irradiance heat flux and F-4-50 to F-6-50 under 50kW/m$^2$ irradiance. The others are 6 samples with anti-corrosion painting of average density 1173kg/m$^3$, which were labelled as S-1-35 to S-3-35 under 35kW/m$^2$ irradiance heat flux and S-4-50 to S-6-50 under 50kW/m$^2$ irradiance. All the samples were 100mm×100mm and 2mm thick, and were bonded to the same size steel plate with epoxy resin. The sample was put on a sample plate with the edge and bottom was covered by aluminium foil to avoid edge effect. The effective test surface area is 0.008836m$^2$. The nominal exhaust system flow rate for all tests was 0.24m$^3$/s. Samples were conditioned in a condition case with certain temperature and humidity before test.

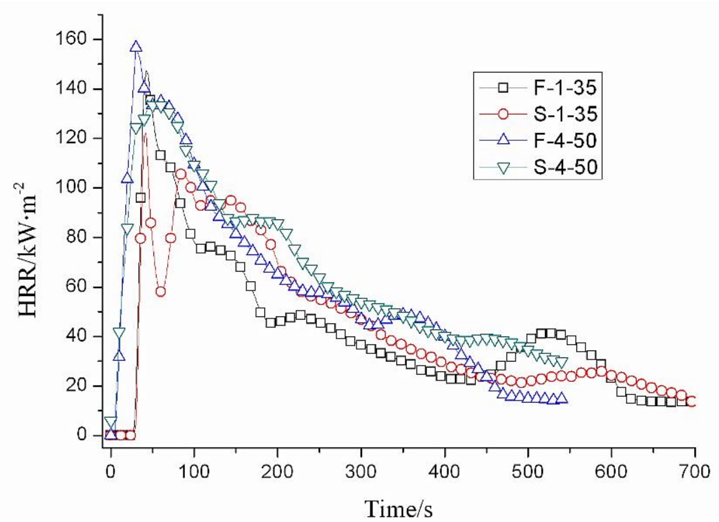


Fig. 1 Typical HRR in cone tests

Fig.1 show a summary of heat release rate (HRR) curves for both materials under two irradiance heat flux. Because test data showed a high level of repeatability among samples tested at the same irradiance; for simplicity, only one test of one material under each irradiance is represented. Only S-1-35 to S-3-35, which were with anti-corrosion painting and tested under 35kW/m$^2$, have the multiple peaks shown in their HRR curves. For the 35kw/m$^2$ irradiance, F-1-35 curve decreases monotonically after only one sharp peak. S-1-35 has two peaks and the curve decrease shortly after the first peak. The decrease does not last a long time, which is shorter than 20 seconds, then increases to the second peak. The trough between to peaks is assumed to be caused by charring of the painting which delays the surface pyrolysis of the lining material.

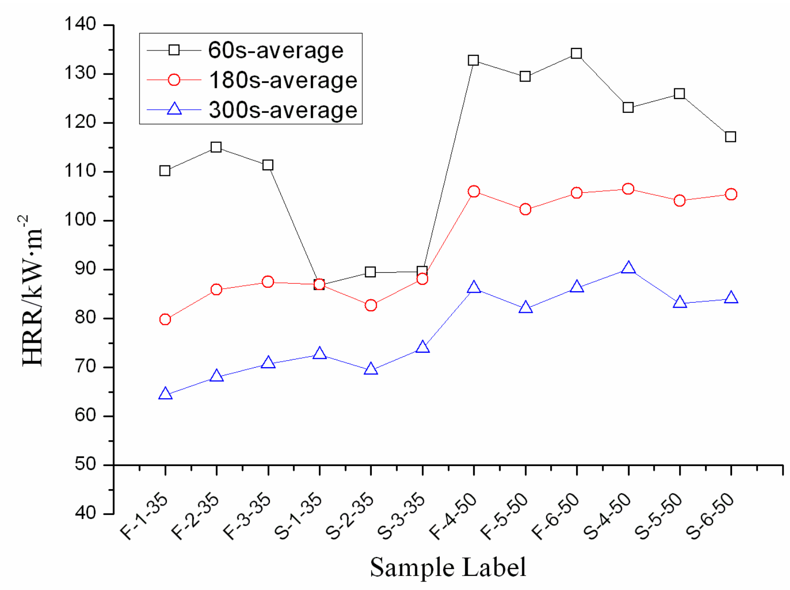


Fig. 2 Average of HRR in cone tests

Fig.2 illustrates the 60, 180 and 300 second average HRR of all 12 samples. Due to late ignition and a deep trough after first peak, the 60s average and 180s average of S-1-35 to S-3-35 are almost the same.

### 3. Discussion and conclusion

Kokkala and et al. developed classification indexes by applying dimensional analysis and fire growth modelling to the ISO room fire test [3] based on the test results in the Cone Calorimeter at 50kW/m2 irradiance. The indexes can be used to group materials based on their predicted time to flashover.

Östman and Tsantaridis [4] presented a very simple empirical linear regression model for prediction of time to flashover in the room corner test. The model is based on empirical data, and was found to predict time to flashover with good accuracy for several products. Cone calorimeter results from tests at 50kW/m2 are used as input data to this model, which also requires information about mean density of the tested product. The regression model is expressed in the following equation

.

$$t_{FO} = 0.07\frac{t_{ig}^{0.25}\rho^{1.7}}{THR_{300}^{1.3}} + 60 \tag{1}$$

where $t_{FO}$ is the time to flashover in the room corner test, $t_{ig}$ is the time to ignition in the cone calorimeter at $50kW/m^2$, $THR_{300}$ is the total heat release during 300s after ignition at 50kW/m2 and ρ is the mean density. $THR_{300}$, $t_{ig}$ and calculated $t_{FO}$ are all listed in Table 1 and Table 2 for both samples. For both of the samples with and without painting, the ignition times under $50kW/m^2$ are 10 seconds shorter than those under $35kW/m^2$.

Table 1 The first specimens' parameters and results of Cone calorimeter tests

| | F-1-35 | F-2-35 | F-3-35 | F-4-50 | F-5-50 | F-6-50 |
|---|---|---|---|---|---|---|
| Irradiance (kW/m$^2$) | 35 | 35 | 35 | 50 | 50 | 50 |
| Ignition time (s) | 29 | 31 | 31 | 19 | 17 | 19 |
| Maximum HRR (kW/m$^2$) | 153.6 | 165.3 | 164.1 | 165.3 | 160.5 | 161.9 |
| Time of max. HRR (s) | 39 | 39 | 41 | 29 | 26 | 25 |
| Average EHC (MJ/kg) | 3.4 | 3.7 | 3.3 | 8.9 | 8.5 | 9.5 |
| THR300 (MJ/m$^2$) | 29.6 | 33.9 | 32.2 | 35.2 | 36.5 | 38.7 |
| ln(FIGRAcc) | - | - | - | 1.74 | 1.82 | 1.87 |
| $t_{fo\ (}$s) | - | - | - | 288.4 | 271.9 | 261.9 |

Table 2 The second specimens' parameters and results of Cone calorimeter tests

| | S-1-35 | S-2-35 | S-3-35 | S-4-50 | S-5-50 | S-6-50 |
|---|---|---|---|---|---|---|
| Irradiance (kW/m$^2$) | 35 | 35 | 35 | 50 | 50 | 50 |
| Ignition time (s) | 35 | 35 | 32 | 17 | 19 | 16 |
| Maximum HRR (kW/m$^2$) | 119.8 | 124.1 | 121.3 | 138.3 | 156.9 | 155.7 |
| Time of max. HRR (s) | 41 | 40 | 41 | 47 | 57 | 58 |
| Average EHC (MJ/kg) | 3.6 | 3.1 | 3.7 | 8.9 | 8.5 | 8.6 |
| THR300 (MJ/m$^2$) | 32.6 | 32.1 | 35.7 | 39.5 | 37.9 | 37.1 |
| ln(FIGRAcc) | - | - | - | 1.08 | 1.01 | 0.99 |
| $t_{fo\ (}$s) | - | - | - | 257.2 | 274.0 | 270.7 |

Determining surface material belongs to which FO-categories can help to predict the time to flashover. The FO-categories grouping is based on ISO room tests. The ISO room corner test is used for classification of surface materials. A propane burner placed in a corner exposes the test material to a heat release rate of 100 kW for 10 min and then 300 kW for the next 10 min. The test is terminated if flashover has been reached; otherwise the total testing time is 20 min. A set of separation criteria for grouping products according to the time to flashover (tFO) based on above ISO room test. These criteria divide the tested products into four groups, the so-called FO-categories [5] 1 to 4.

Surface material belongs to which category is determined by application of the following set of rules:

- FO-category 1: products not reaching flashover during 1200 seconds of testing time
- FO-category 2: 600 seconds $\leq t_{FO}$ <1200 seconds
- FO-category 3: 120 seconds $\leq t_{FO}$<600 seconds
- FO-category 4: $t_{FO}$ <120 seconds

With above method, the calculated $t_{fo}$ of the test material is from 257.2s to 288.4s, thus the material could be classified to FO-category 3.

Surface material can be determined to belong to which FO-category based on statistical information from cone calorimeter[5], which is called multivariate statistical method. This method may find links among different variables that are recorded in cone calorimeter tests, such as time to ignition, smoke gas concentrations, heat release rate, specimen mass loss, optical smoke density, density and thickness of samples.

Hansen and Hovde [5] evaluated the application of multiple discriminant function analysis (MDA) to deal with cone calorimeter data, which could be used to predict the FO-category in the room corner test with satisfactory accuracy. MDA is a multivariate statistical method used to classify cases into groups. The groups are determined based on a categorical dependent variable. By using Fisher's linear discriminant function for classification of cases, the result of this analysis is a set of four linear functions, one for each of the four FO-categories. A new case will be assigned to the FO-category for which the classification function obtains the highest value. Three out of about 20 variables, which give information concerning smoke production, production of CO, HRR, time to ignition, time to extinction etc., were found to be able to distinguish between the four FO-categories were. The selected parameters were:

- $z_1=\rho_{mean}$ ($kg/m^3$)=mean density
- $z_2=THR_{300}$ ($MJ/m^2$)=total heat release during 300 seconds after apparent time to ignition.
- $z_3=\ln(FIGRA_{cc})$ where $FIGRA_{cc}$ is the maximum value of the ratio between HRR and time when HRR was measured.

Anne Steen Hansen [5] gave the four classification functions that are expressed as follows:

$F_{FO1} = 0.01789z_1 - 0.06057z_2 + 0.971z_3 - 7.910$

$F_{FO2} = 0.01492z_1 + 0.03354z_2 + 1.877z_3 - 7.418$

$F_{FO3} = 0.008589z_1 + 0.409z_2 + 2.721z_3 - 13.406$

$F_{FO4} = 0.0000256z_1 + 0.347z_2 + 3.621z_3 - 9.215$

Ln ($FIGRA_{cc}$) are listed in Table 1 and Table 2. Substitute these data into above equation, and the results are listed in Table 3.

Table 3 Calculation results of MDA for F-4-50 to F-6-50 and S-4-50 to S-6-50

| | **F-4-50** | **F-5-50** | **F-6-50** | **S-4-50** | **S-5-50** | **S-6-50** |
|---|---|---|---|---|---|---|
| $F_{FO1}$ | 12.2568 | 12.2557 | 12.1710 | 12.0889 | 12.1179 | 12.1469 |
| $F_{FO2}$ | 14.2164 | 14.4102 | 14.5778 | 13.7336 | 13.5485 | 13.4841 |
| $F_{FO3}$ | **15.6199** | **16.3692** | **17.4051** | **15.9349** | **15.0900** | **14.7084** |
| $F_{FO4}$ | 9.3294 | 10.0702 | 11.0147 | 8.4327 | 7.6241 | 7.2740 |

For the six samples, all FFO3 give the largest value of all the four Fisher's liner discriminate functions. Thus, the vinyl lining material can be determined as a member of FO-category 3, which would reach flashover in ISO room from 120 to 600 seconds. The calculated results from Östman/Tsantaridis' empirical linear regression model and Hansen/Hovde's multiple discriminant function analysis (MDA) are the same in predicting flashover time and classifying the lining. These models should be used together in the same procedure to evaluate fire behaviour of materials and verify each other, and that would be helpful to improve the reliability of prediction.

## Acknowledgments

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# Section B – Fire-Fighting Equipment and Fire Tactics

# Emergency response and safety fire fighter in relation to technologies used in electric vehicles

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**Abstract**

Paper refers to technology in the context of electric vehicles. A substantial part of the article focuses on the challenges which comes this new technology for the firefighter unit in case of an emergency. In the present article describes the fire-fighting activities and responds to a variety of security issues. The use of renewable energy in vehicles creates hazards which require new fire policies and procedures.

*Keywords*: electric vehicles, fire brigades, rescue operation, incident;

## 1. Introduction

An emergency incident involving a motor vehicle is not an uncommon occurrence for the fire service. It would not be unusual for a particular fire department to respond to a motor vehicle crash or fire during any given day. This is based on the large number of motor vehicles, of all types, that exist today on public roadways in the Europe.

## 2. Assessing the current state of development of electric cars

The popularity of alternative fuel vehicles in recent years, the upward trend based on the effort to maximize fuel efficiency and minimize unnecessary waste environment. Today, there are millions of these vehicles across the road and this number continues to grow. Figure 1 shows the trend for the use of vehicles in 1995 - 2016. The alternative fuel vehicles as vehicles powered by other than traditional combustion engines, oil-based and uses the alternative fuel source. Namely Energy Policy Act of 1992 (Introduced by Philip R. Sharp - representative in Congress from 1975 to 1994), defines alternative fuels as one of the following options:

- Biodiesel (B100);
- Natural gas and liquid fuels domestically produced natural gas;
- Propane (LPG);
- Electricity; is H;
- a mixture of 85% or more of methanol,
- denatured ethanol and other alcohols with gasoline or other fuels;
- Methanol, ethanol denatured,
- Coal-derived, domestic production of liquid fuels;Fuel (other than alcohol) derived from biological materials; [1]

New registrations of electric cars (including both battery electric and plug-in hybrids) increased by 70% between 2014 and 2015, with over 550 000 vehicles being sold worldwide in 2015.

The United States was overtaken by China as the largest market for electric cars in 2015, with over 200 000 new registrations (Figure 1). Taken together, these two markets accounted for more than half of the global new electric car registrations in 2015. The market share of electric cars in 2015 was close to 1% for China and 0.7% for the United States. New registrations of electric cars declined in the United States between 2014 and 2015, while they experienced a three-fold growth in China. In 2015, 90% of car sales took place in eight main electric car markets: China, the United States, the Netherlands, Norway, the United Kingdom, Japan, Germany and France. All of these

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markets except Japan and the United States experienced sustained growth between 2014 and 2015. Sales more than doubled in the Netherlands, where the market share of electric cars reached close to 10% (Figure 1), the highest in the European Union and the second-highest globally, after Norway (23%). The 2015 year-on-year sales growth for electric cars also exceeded 75% in France, Germany, Korea, Norway, Sweden, the United Kingdom and India. [2]

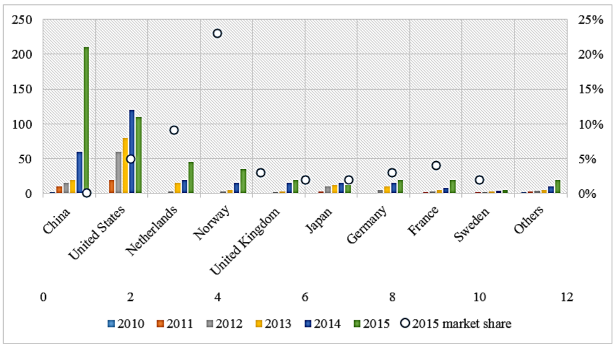


Figure 1 Electric cars sales and market share in a selection of coutries and regions, 2015 [2]

The Paris Declaration on Electro-Mobility and Climate Change and Call to Action, developed in the framework of the Lima-Paris Action Agenda and announced at COP21, calls for the global deployment of 100 million electric cars by 2030 (UNFCCC, 2015b). The 2DS of the IEA ETP 2016 sets a deployment target for electric cars exceeding the goal of the Paris Declaration: 140 million (10% of the total stock of passenger light-duty vehicles [PLDVs]) by 2030, and nearly 900 million (40% of the PLDV stock) by 2050. This translates to sales targets close to 20% by 2030 and 40% by 2040, with accelerated deployment in member economies of the Organisation for Economic Co-operation and Development (OECD) and rapidly developing emerging economies (IEA, 2016a, 2016b). [2]

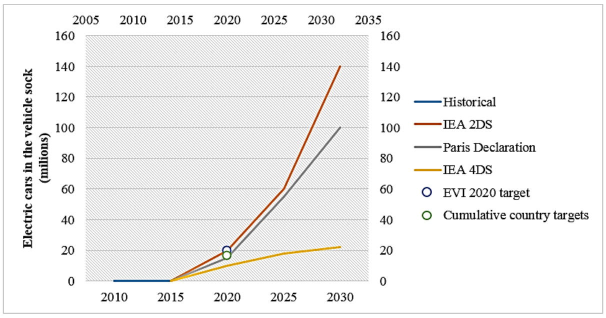


Figure 2 Deployment scenarios for the stock of electric cars to 2030 [2]

Meeting the 2030 target of the IEA 2DS implies that the global stock of electric cars should maintain annual growth rates above 25% by 2025 and in the range of 7% to 10% between 2030 and 2050. Meeting the targets of the Paris Declaration requires stock growth rates a factor 0.1 lower than those needed for the IEA 2DS until 2030. [2]

## 3. The golden hour philosophy for rescuing people

The golden hour philosophy, which was introduced by Dr. R. Adams Cowley in 1961, recognises that casualties will have a much poorer chance of survival if they are not delivered to definitive care within one hour from the time of the accident. (Definitive care being a hospital operating table 1.) The golden hour includes the time taken for call-out, travel to the incident, extrication and transport to hospital. This timescale does not allow for a lengthy extrication time at the accident scene if lives are to be saved and healthy recoveries promoted. For the majority of road traffic accidents the time taken for extrication should not exceed 15 minutes. This figure is realistic and can be met if crews are adequately trained and work as a team at the scene. [3]

The Fire Service has no control over most of the actions shown in the table, the time taken for extrication is really the only one where the Brigade can have an influence. For this reason, it is essential that the extrication is carried out as efficiently as possible. [3]

Tab. 1 Schedule,, Golden Hour "[4]

| Cumulative Time | Action | Time Taken |
|---|---|---|
| 0 min | Accident Occurs | 0 min |
| 5 min | Call to Emergence Services | 5 min |
| **15 min** | **Turnout travel to incident** | **10 min** |
| 30 min | Extrication | 15 min |
| 35 min | Package and transfer to Ambulance | 5 min |
| 60 min | Transport to Hospital | 25 min |

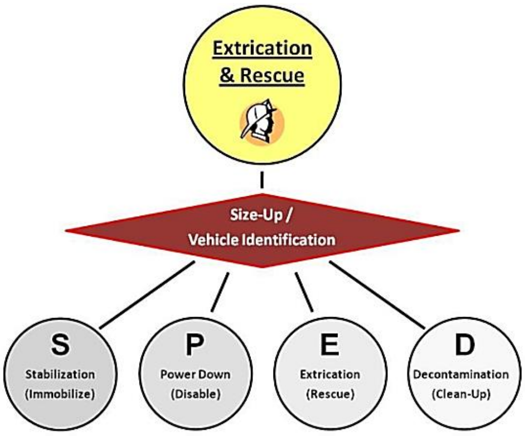


Figure 3 Example of Approach to Extrication & Rescue [5]

### *3.1. Extrication of trapped victims from a damaged motor*

Extrication of trapped victims from a damaged motor vehicle is among the most significantly challenging tasks faced by fire fighters during an emergency event. Often the victims are in dire need of medical treatment and rapid intervention is essential, and meanwhile the risks of the situation may be further complicated with a cadre of additional challenges such as vehicle fire, downed power lines, or an external hazardous materials exposure. Preparation and training for vehicle extrication is paramount to achieving an efficient operation that takes reasonable precautions for the emergency responders and victims alike. While every event involving extrication and rescue is unique, certain approaches used by the fire service provide clear direction to emergency personnel on how to handle the event. [4,5,6]

A team-based approach proposed by Wimer is based on coordinating resources into four subunits that focus on the following: stabilization team; power-down team; extrication team; and the decontamination team.146 Each of these resource units has specific duties and responsibilities, and they interact and support each other using defined brother/sister relationships. This concept is illustrated in Figure 3, Example of Approach to Extrication & Rescue.[4,5,6,7]

### *3.2. Emergency scenarios in relation to electric vehicles*

The primary emergency scenarios that could be expected by the fire service responding to an emergency involving an Electric Vehicle or Hybrid Electric Vehicle (EV or HEV) are illustrated in Figure 4, Key Emergency Scenarios for EVs and HEVs. This figure considers the four basic possibilities of: (1) Extrication/Rescue; (2) Fire; (3) Water Submersion; and (4) Other Scenarios.

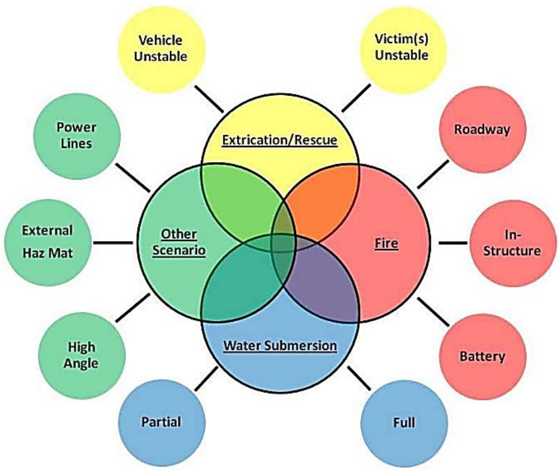


Figure 4 Key Emergency Scenarios for Motor Vehicles

The most probable emergency event involving motor vehicles is a motor vehicle accident (MVA). This could be either a collision with another vehicle, with a stationary object (e.g., telephone pole), a collision between multiple vehicles, or any combination of these. Often an MVA will include victims with injuries requiring prompt medical attention. In some situations the victims may be trapped and require extrication. Vehicle rescue and extrication is a specialized function performed by the fire service, and it is a task in which an EV or HEV may present additional hazards to the emergency responders (i.e., electrical shock) when they are cutting and removing portions of the damaged vehicle. Another possible emergency incident for responding fire fighters is a vehicle fire. This may be the result of an MVA, or it may be a fire occurring independent of any collision or crash, as in the case of a parked vehicle. A factor of paramount concern to firefighters is if the burning vehicle is in an open area with no exposures (i.e., roadway or highway), or if it is within or near a structure with serious exposure concerns (e.g., within a residential garage). Another issue of importance for EVs or HEVs as compared to a conventional motor vehicle, is if the high voltage battery sustains direct fire and heat damage and how this fire is controlled and mitigated. [4,5,6,7]

Other emergency scenarios include the vehicle being partially or fully submerged in water, with or without entrapment. Other scenarios include additional challenging special hazards that could occur with any motor vehicle, such as the vehicle draped by downed power lines, an external hazardous materials incident exposing the vehicle, or a high angle rescue such as on the edge of a bridge or cliff. These special situations can be especially problematic when they occur with entrapment and require extrication.

Figure 5 A lithium -ion battery pack incorporated into an electric vehicle

**4. Risks arising from the operation of electric vehicles for fire departments in the event of intervention activities**

In terms of vehicle extrication, perhaps the most significant difference between a conventional vehicle and an EV or HEV is the high voltage electrical system. EVs and HEVs typically include high voltage batteries, and the presence of high voltage components creates a possible electrocution hazard (between 36 and 600 volts of electricity) to emergency personnel, especially before they realize the vehicle is a hybrid model. [2, 3, 4]

The cabling for these high voltage systems were voluntarily colored bright orange by auto manufacturers for easy and consistent identification.

In certain recent models blue and yellow color coded cables have appeared that also present a dangerous shock hazard, despite not being specifically considered as high voltage. Further, the high voltage cabling in vehicle designs is often shielded in protective conduit channels making it hard to visually locate. While the high voltage in electric and hybrid electric vehicles understandably raises concerns among fire fighters that demand a higher degree of caution, it also leads to certain misconceptions that deserve to be addressed. For example, electrocution is not a realistic hazard from simply touching the exterior of a crashed EV or HEV. [2, 3, 4].

Figure 5 A lithium -ion battery pack incorporated into an electric vehicle

This should be no different than a conventional motor vehicle, since the high voltage system is fully isolated from the vehicle chassis/body. However, the one obvious exception for an exterior electrocution hazard, and which would apply with any vehicle, is a crash situation involving an exterior electrical power source such as when downed power lines are draped over the crashed vehicle. [2, 3, 4]

In these vehicles, particularly in road accidents in the field of fire brigades in intervention, there will always be unexpected moments of their threat. These moments due to the new technology will be additional training of fire brigades and educational measures. [2, 3, 4]

One of the biggest emergencies in road transport, where the electric car collision with stationary object has become in Indianapolis, US. The car was travelling at high speed and the driver lost control and plowed into a tree. Lithium ion batteries burn very hot and the impact disintegrated the motor and debris exploded over 130 meter.

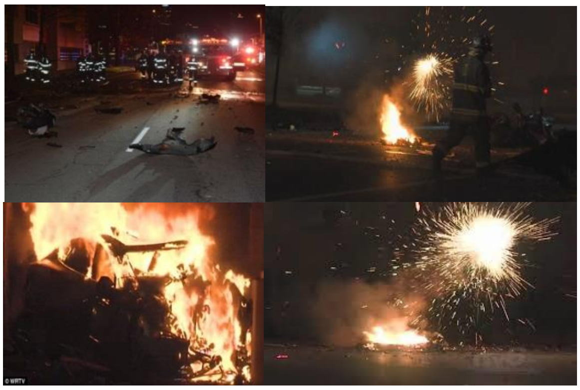

Figure 6 Battery cells explode after Tesla crash [10]

To extinguish that type of fire with those batteries involved, it's necessary to apply copious amounts of water.

National Fire Protection Association set up a body needed to know about the safety of electric vehicles:

- High-strength steels are used in most models of electronic vehicles. Identification of the location of the steel is important as to the knowledge in the correct use of the instruments, arising in response to the incident.
- Access to vehicles IBA edge, not from behind or from the front - start the vehicle,
- If it is determined that the vehicle has a remote ignition key, it must move away from the vehicle (approximately 15 m);
- in case of fire vehicles to observe a safe distance.
- In case of fire and hitting the HV battery HV system or parts of your vehicle to burn rather because for some types of vehicles, not recommended to extinguish the vehicle (eg. BMW, Mercedes).
- The correct procedure for identifying suitable points, which are subject to shearing.
- Electric vehicles emit very little sound. Therefore, the need to ensure that the vehicle is properly switched off.
- Stay at a safe distance from the vehicle when it is on fire.
- Never touch, cut, or open any orange or cable components protected orange shields.
- New challenges for charging stations and other infrastructure, which is connected to an electric vehicle.
- When any new technology is a very important training. [5, 6, 8, 9]

The points represent the so-called universal measure for fire service for the execution of rescue works in a car accident hybrid / electric car. Since the idea of security cars with electronic drive is united and guided by each automaker is not alone, there is a space for understanding the key elements of the technology.

## 5. Conclusions

Finally, the article can be stated that vehicles with electric drive are in terms of intervention activities different fire brigades danger than it is with conventional drives cars. It is now much more interested in using vehicles with alternative energy sources than in the past and forecast the future point to their expansion. Therefore it suggests some measures for the intervention of firefighters crashed. It is also necessary to vehicles were equipped with at least one piece of contactless flow meter and dielectric footrest when working with hybrid vehicles. When working with hybrid cars should be added wrecking electrically insulated tools.


### Acknowledgments

Acknowledgments should be inserted at the end of the paper, before the references, not as a footnote to the title. Use an unnumbered section heading for the Acknowledgments, similar to the References heading.


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# Use of high-capacity pump for fire-fighting

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**Abstract**

The article talks about using a high-capacity pump Hytrans to transport water to large fires. It states fire statistic in Slovakia and defines when is appropriate to use the system Hytrans. It describes details of the system Hytrans, its basic parts, and the principle of activity and performance parameters. It concludes whether to use the system for extinguishing large fires and other emergencies.

*Keywords*: high-capacity pump, large fires, Hytrans pump, water transfer;

## 1. Introduction

Fires annually cause great material damage to our property, endanger the lives and health of people. The success of intervention at the time of the fireis determined by sufficiency of extinguishing agent of lack thereof. The most common water sources are fire trucks which are used by firemen to perform action. The amount of water is sufficient for most fires, but for large-scale fires and fires with high intensity burning, large extinguishing is necessary. If there is no suitable water source on the site of the fire, it is necessary to provide transport of the extinguishing agent to the fire site. The paper introduces the possibilities of using a high capacity pumps, its performance and comparison with other ways of transportation of extinguishing agent.

## 2. Statistic of fires in Slovakia

Number of fires in Slovakia has an irregular course, moving around 10,000 fires annually. Number of fires is partly affected by the weather situation during a given year, prevention and many other factors. The figure 1 Shows the development of the number of fires for the period 2002-2016.

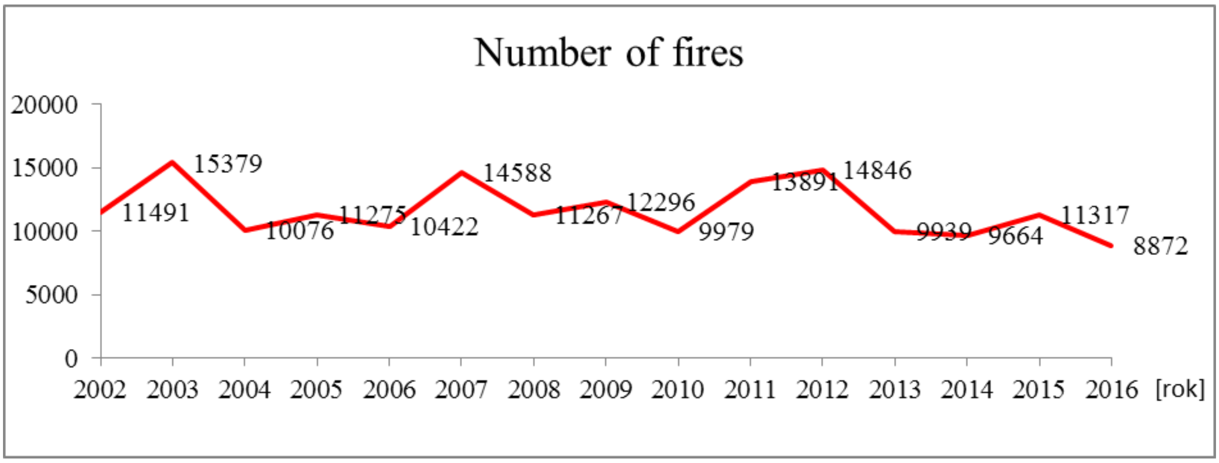


Fig. 1 The development of the number of fires in the period 2002-2016 (MV SR, 2017)

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Most of the fires are managed to be disposed in the second phase of burning or there are smaller scale fires and the amount of extinguishing agent imported in fire truck is sufficient.

About 10 % of fires are large fires when it is necessary to supply appropriate transfer of water to the fire site. Shuttle transfer of water is the most used approach because of its simple organisation and plenitude of fire tankers. However, this way is ineffective when there is a need for a large flow or long-term water supply.

**3. High-capacity pump Hytrans**

It is a unique container system used to pump large amount of water from big depth and to long distance.

Water can be pumped up to 60 m of depth and transferred to the distance of hundreds of metres or kilometres. The amount of water transferred is 3500 l/min by the system configuration. Device if fully automaticaly managed and has only minimal demand on attendant. Similarily so, the preparation of device to employ and and the deployment of the whole hoseline is a matter of several tens of minutes (Hytrans, 2016).


Fig. 2 System Hytrans a loading of container HydroSub 150 (author)

System Hytrans consists of:

– container for draining water and water transfer to large distance,
– container for large water extraction,
– two containers of fire hose,
– two bearing frames for containers,
– trailer.

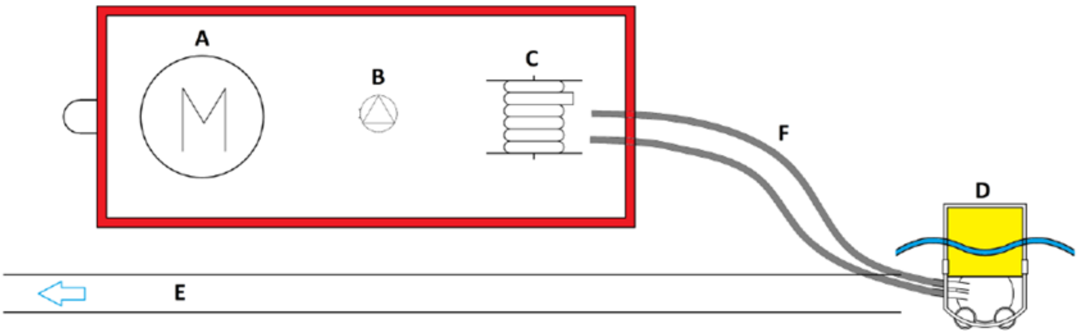


Fig. 3 Principle of water transport used by system Hytrans (Pyronova, 2016)

A – engine, B – hydraulic pump, C – reel for hydraulic hoses, D – submersiblepump, E – large diameter hoses, F – hydraulichoses.

Basic parts of large water transfer system:

– *Submersible pump* pushes the water into large diameter hose. Submersible pump is hydraulically driven mobile pump, which allows quick access to all open source waters. Thanks to 60 m of hydraulic hoses from main pump, submersible pump can draw water from the depth of 60 m.
– *Main pump HFS HydroSub 150* – Deutz TCD 6 engine with horsepower 160 kW at 1900 rpm is placed in the main pump and serves to drive the hydraulic pump. The hydraulic pump is an axial piston pump with a capacity of 110 ccm, which forms the pressure of 35 MPa. The pump is also equipped with a drum with 2 pressure 60 m long hoses, working pressure of the main hose is 35 MPa and return hose is 6.5 MPa. The basic parts are in figure 3.
– *Large diameter hoses* – 6" diameter (150 mm) are stored in separate containers. Thanks to large diameter it is possible to minimize friction loss of pressure. This allows transferring large amount of water to long distances. The total length of hoses is 2000 m and they are ended with Storz couplings.
– *Implemented and repacking of hoses* – Hose is directly placed from container by reeling out up to vehicle speed of 20 km/h. Container is equipped by reeling unit HRU 200 for hose reverse gathering. The result is a possibility of quick hose deployment to large distance with only 2 members' crew.

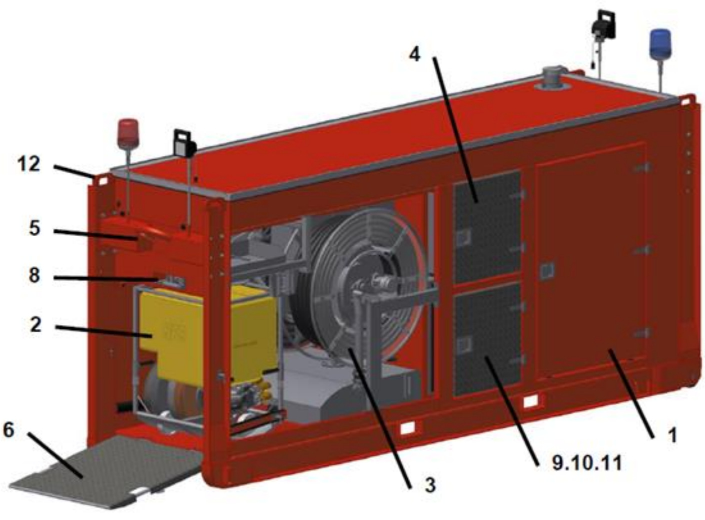


Fig. 4 Description of base parts of HFS HydroSub 150 (Pyronova, 2016)

*1 – engine, 2 – submersible pump, 3 – reel drums for hoses to hydraulic oil, 4 – control panel, 5 – hooking rod, 6 – ramp, 7 – reel, 8 – instruction for reel rope, 9 – power supply, 10 – stage pocket, 11 – main system switch, 12 – eyebolts*

**4. Deploying of Hytrans system**

Apart from long distance water transfer,Hytrans system can work in different work modes. In the body of submersible floating pump it is possible to change pump impeller and according to the type of impeller (blades inclination), the pump can work in these modes:

– Standard, in this mode the pumps'rated flow is 2500 l/min at 1.2MPa (3000 l/min at 1,1 MPa). This mode is used for water transfer to long distance.
– High-flow (large flow), rated flow reaches from 4500 l/min at pressure 0,8MPaup to8000 l/min at pressure 0.25 MPa. This mode is designed specifically for water drainage.

- Flood Module, it can deliver up to 40 000 l / min at 0.2 MPa because of parallel coupling of 3 floating pumps.

This article is focused on using the high-capacity pump to firefighting, thus the standard mode, when pump reaches the pressure of 1,2MPa.

Deployment of high-capacity water transfer system HYTRANS consists of this operations:

- Driving out time: 10 min
- Range time: it depends on the distance of the place of incident
- Setting up the system – removal of containers, preparation of the aggregate, placing of the pump to water level (approx. 20 min).
- Laying hoseline– it depends on the length of hoseline and terrain accessibility, the maximum speed of laying specified by a manufacturer is 20 km/h. (approx. 10-20 min).

There is one system for every region of Slovakia, table 1 lists firefighters units, where this system is dislocated.

Tab. 1 Area dislocation of Hytrans system

| Region | Location |
|---|---|
| Region of Bratislava | HaZÚ hl.m. SR Bratislavy |
| Region of Trnava | OR HaZZ in Galanta |
| Region of Nitra | OR HaZZ in Nové Zámky |
| Region of Trenčín | OR HaZZ in Prievidza |
| Region of Banská Bystrica | OR HaZZ in Zvolen |
| Region of Žilina | ZB HaZZ in Žilina |
| Region of Košice | OR HaZZ in Košice |
| Region of Prešov | ZB HaZZ in Humenné |

In the case of driving out the container is loaded onto automobile loaders Mercedes Benz Arocs 3336 and second container is joined to a vehicle on trailer.

*4.1. Performance parameters*

The pump is used in standard drawing mode 3000 l/min at 1,2MPa. The flow can be rised up to 4000 l/min, when it comes to the reduction of operating pressure and increase pressure loss in the hose line, and results in reducing the maximum distance transport of water. In it is a flow reduction when you can deliver water at an even greater distance. It is necessary to calculate an altitude difference of terrain, water level axis and the axis of the end of the hose. Due to the relief of our country it would be a decisive condition for water transfer. The relationship between terrain elevation and distance from the water source to the fire location is shown in the graph of figure 5 (Hytrans, 2016).

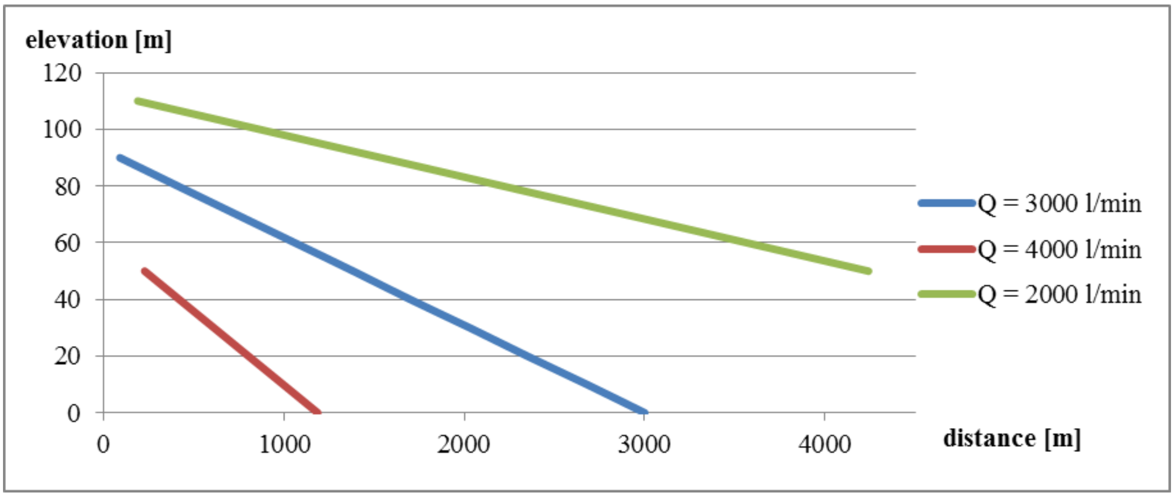


Fig. 5 The relationship of transfer distance and elevation for different flow of the pump Hytrans (author)

Pumps´ parameters are not affected by suction line, because this pump floats above the water level. To shuttle water transfer and long distance water transfer from machine to machine it is necessary to deploy great number of technical equipment and firefighters.

Forces and means needed to water realisation using in different ways are compared in table 2.

Parameters for the given table are: terrain elevation 30 m, water transfer distance 2000 m, rated flow 3000 l/min, end hoseline pressure 0.2 MPa.

Tab. 2 The comparison of different ways of water transfer at specified parameters

| | Number of pumps/automobiles | Number of firefighters |
|---|---|---|
| Hytrans HydroSub 150 | 1 pump | 3 firefighters |
| Shuttle water transfer CAS 30 | 6 vehicles | 12 firefighters |
| Series connection CAS 30 | 10 pumps | 20 firefighters |

## 5. Application of Hytrans system

The pump is able to draw salt water, chemically polluted water, mud and debris. It can operate in shallow water without the risk of pump failure due to cavitation. Pumps systems can be connected in series and water can be transfered to unlimited distance. The application of the system is mainly in industry.

Options of application:

– Water transfer for firefighting large fires (high-capacity firefighting using monitors).
– Water transfer for creating pump site (using fire-flex)
– Water transfer in long lasting fires.
– Create temporary (mobile) network to water supply (earthquakes, storms, floods).
– It can create a supply of drinking water from nature source in connection with water cleaning system.
– Temporary network for a supply of drinking water from drinking water source.
– Pumping water to long distance (channel, floods).
– Emergency delivery of cooling water into a power plant.
– Transport of polluted liquids.

The high-capacity pump is effective in large and long-term fires, when there is a need for supply great amount of water at a rate of 3000 l/min at the pressure of 1,2MPa. Thanks to hoses with diameter of 150 mm, the water can be transferred to distance up to 3000 m, however it is affected by altitude elevation which can shorten this distance. 2000 metres of hoses make part of the pump system. In the case of 10 m elevation we can transfer 4000 l/min of the water to the distance of 1000 m. On the other hand if we lower the flow to 2000 l/min, we can transfer the water to the terrain with elevation of 83 m to the distance 2000 metres.

### 6. Conclusions

High-capacity pump can transport large amount of water to the long distance. It is mostly used in large and long-term fires, in nature or in industry. It also enables emergency supply of water for cooling reactors in nuclear power plants or creation of a network for drinking water.

Compared to the shuttle water transfer it can lessen the demand up to 6 times less forces and means at the maximal parameters of Hytrans pump. There is also a reduction of the number of vehicles to transport water, which can often have a failure. Compared to the long-distance water transfer with pumps connected in series we can save as much as 10 times forces and means, however such transport demands correct pressure conditions in the hose line, otherwise there is a possibility of damage to the hoses and the failure of the entire transport. Hytrans pump needs longer starting time for commencing the transport of water. There is one such pump system in each region of Slovakia. It is necessary to count with the time of arrival at the event location, the deployment at the water source, placing the hose line. Usage of this pump allows to change tactic of intervention and thanks to the large water supply and elimination of necessary equipment and firefighters, it allows to speed up the localization and liquidation of fire.

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# Distance of water resources and their impact on long-distance water transport for extinguishing forest fires

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**Abstract**

The article deals with the problem of water resources in relation to the long-distance transport of water for extinguishing forest fires. Possibilities of particular ways of water transport using existing transportation and capacity possibilities of firefighting machinery and equipment in Slovakia is discussed by the case study.

*Keywords*: long-distance transport of water, forest fire, water;

## 1. Introduction

Questions on the perception of safety among Continuous supply of extinguishing substance belongs among essential conditions of successful localization and suppression of fire. Without this condition, neither extinguishing ones of the most difficult fires, which include forest fires can be done. In contrary of industrial fires, where characteristics of a burning set are known in advance as well as required manpower with their training and extinguishing equipment is carried out in relation of specific most complicated scenario of possible adverse event, forest fires is characterized by a lot of unknown variables. Properly defining of these parameters is up to the intervention commander decision. One such variable are the water sources and transport of the water to extinguish forest fire.

Based on experience with forest fires extinguishing in Slovakia, one can see that the decisive factor concerning to the time of suppressing of forest fires is a site of the fire and its distance from the water sources. Both these variables impinge on the fundamental issue – that is accessibility. It depends directly on the density of forest road network. Recommended standards in terms of the forest road network are 15 m/hectare in a flat terrain; 22.5 m/hectare in a hilly one; and 27.5 m/hectare in mountain conditions, respectively, are based on the needs of optimal forest management, which could include also fire protection (Sačkov, 2012)

But when analysing density of forest road network in details, especially in mountain conditions, the reality does not exceed neither 50 % of the recommended value. This situation is caused by categorizing these areas into the third up to the fifth degree of nature and landscape protection as well as by insufficient financial resources for maintenance of existing roads. The worst status is in the 1L category of transport forest roads; yield thereof was only 3.17 % of the whole road network in 1988 (Dvorščák). No significant change of that parameter took place even after 18 years.

In generally, it can be said that neither the quality nor the density of the forest road network in Slovakia is sufficient and it reaches approximately only 30-50 % of density in some developed European countries. The length of forest roads in 2005 was 37 thousand kilometres with the average density oh 18.5 m/hectare. The percentage of the 1L category roads that allows all-year operation is only 17 %; that of the 2L category roads that allows at least season operation is 40 %. The rest represents roads of lower categories that are not passable for the firefighting machinery. Except this, the actual distribution of forest roads is irregular while the density thereof in mountain forests is insufficient (Moravčík, Schwartz, 2009).

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According the data form the Green Report 2015, the above mentioned situation still remains. The percentage of the own property 1L category roads reached only 17.35 % and with the use of the other property ones 1L category roads reached nearly 24 %. Detailed data are referred to in the Table 1.

Table 1 Accessing of forests by a transport network (The Green Report, 2015)

| Road types | | Year 2014 | |
|---|---|---|---|
| | | Length (km) | Density (m.hectare$^{-1}$) |
| Own property roads | 1L category main removal forest roads (with paved carriageway) | 6 516 | 3.3 |
| | 2L category removal forest roads (locally paved) | 15 051 | 7.7 |
| | 3L category earth back roads & TPCs | 16 039 | 8.3 |
| | *Total* | 37 606 | 19.3 |
| Other property roads – removal roads 1L | | 3 212 | 1.6 |
| Total (own property and other property roads) | | 40 818 | 20.9 |

Source: [Statistical summary of the Ministry of Agriculture of the Slovak Republic: Forest (MoA SR) 5-01; Specific survey of the National Fores Centre - NLC]

Explanatory notes:

1L – main removal forest road equipped with the paved carriageway allowing all-year use;

2L – removal forest road without the carriageway with local paving by gravel aggregates allowing seasonal use;

3L – earth forest road constructed within parameters of removal forest road allowing also wood removing in suitable geological and climatological conditions;

TCP – permanent approach earth back road with maximal longitudinal slope up to 20 %.

As regards fire protection, the ideal status is when each forest cover is accessible. The use of forest road network for firefighting machinery has, however, other philosophy than that for machinery used for removal and approaching of wood. From the forest management standpoint, the priority is to use forest road for transport of empty machinery; i.e. non-loaded machinery into the forest and loaded one from the forest. The sequence is opposite in the firefighting practice. The loaded machinery, full fire engine provides transport of extinguishing agent in the vicinity of the fire site. The empty fire engine leaves the fire site and runs to the filling site for loading an extinguishing agent – water.

Thereby, the forest road network provides basic vertical and horizontal availability of firefighting equipment with regard to the slope availability and use of lateral stability of various categories of fire-fighting vehicles.

Under sufficiently securing of access into forest, the water supply from water sources can be ideally used on the intervention site. But even with the lack of water resources on the intervention site, the forest road network can be used for some type of the long-distance water transport and deployment of forces and equipment to the place of intervention, eventually to its close vicinity.

When the access into a forest is not available, the transport capacity decreases as regards tank fire engines (hereinafter only „CAS“) from 9 000 litres (vehicles T 815 – 7 CAS 30, T 815 CAS 32 reused, or IVECO TRAKKER CAS 30) down to 2 000 litres in case o aircraft water delivery (e.g. Oto bag) or down to 10-15 litres in case of firefighters‘ back (GENFOVAK bag). When the long-distance water supply is carried out by the hose line, the decrease is from the maximal flow rate 3000 l.min$^{-1}$ (using fire pumps CAS 30) down to 1200 – 1500 l.min$^{-1}$ (for fire pumps PS 12, PS 15) even down to

200 ÷ 400 l.min$^{-1}$ with use of the pond system.

An illustrative example of using existing firefighting machinery in relation to the access into forests in Slovakia is shown in Figures 1 and 2.

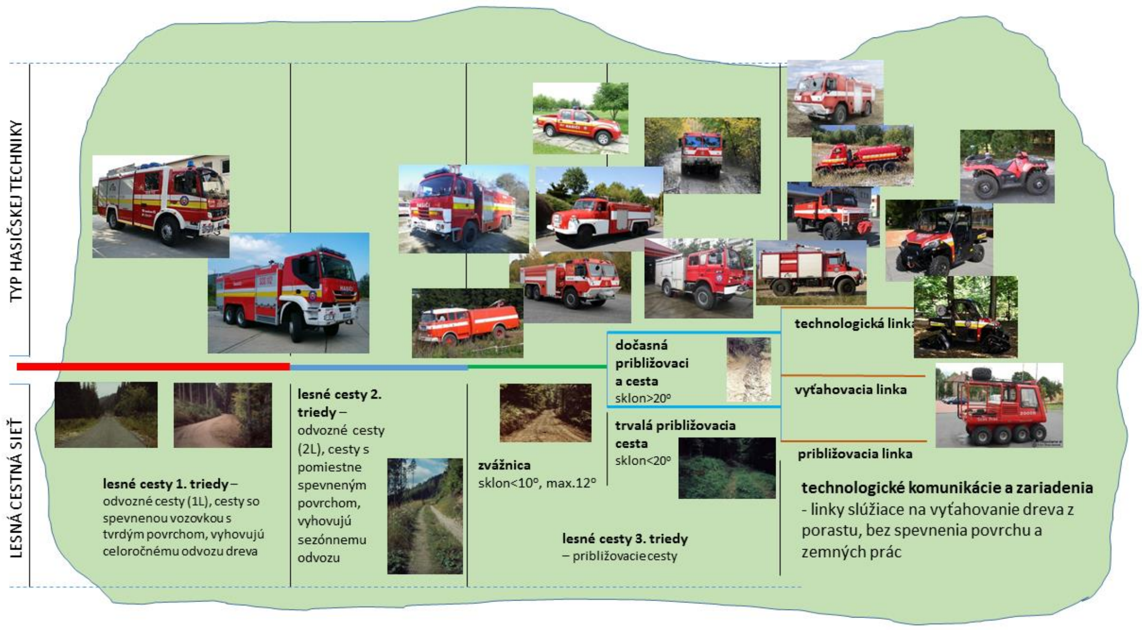


Fig. 1 Firefighting machinery and accessible forest covers with use of the forest road network

Legend:

| | |
|---|---|
| typ hasičskej techniky | Type of the firefighting machinery |
| lesná cestná sieť | Forest road network |
| lesné cesty 1. triedy – odvozné cesty 1L, cesty so spevnenou vozovkou s tvrdým povrchom, vyhovujú celoročnému odvozu dreva | 1st class forest roads – 1L category removal forest roads equipped with the paved carriageway with solid surface; allowing all-year wood removal |
| lesné cesty 2. triedy – odvozné cesty 2L, cesty s pomiestne spevneným povrchom, vyhovujú sezónnemu odvozu | 2nd class forest roads – 2L category removal forest roads equipped with locally paved surface; allowing seasonal wood removal |
| lesné cesty 3. triedy – približovacie cesty | 3rd class forest roads – moving closer roads |
| zvážnica – sklon < 10°; max 12° | Forest logging road – slope < 10°; max. 12° |
| dočasná približovacia cesta - sklon > 20° | Temporary moving closer road – *slope* > 20° |
| trvalá približovacia cesta - sklon < 20° | Permanent moving closer road – *slope* < 20° |
| technologické komunikácie a zariadenia – linky slúžiace na vyťahovanie dreva z porastu, bez spevnenia povrchu a zemných prác | Technological road and equipment – lines serving for hauling wood from the stand cover, without paved surface and earthworks |
| technologická linka | Technological line |
| vyťahovacia linka | Hailing line |
| približovacia linka | Moving closer line |


Fig. 2 Firefighting machinery and accessible forest covers without use of the forest road network (bumpiness and passability of terrain)

Legend:

| | |
|---|---|
| typ hasičskej techniky | Type of the firefighting machinery |
| lesná cestná sieť | Forest road network |
| lesné cesty 1. triedy – odvozné cesty 1L, cesty so spevnenou vozovkou s tvrdým povrchom, vyhovujú celoročnému odvozu dreva | 1st class forest roads – 1L category removal forest roads equipped with the paved carriageway with solid surface; allowing all-year wood removal |
| lesné cesty 2. triedy – odvozné cesty 2L, cesty s pomiestne spevneným povrchom, vyhovujú sezónnemu odvozu | 2nd class forest roads – 2L category removal forest roads equipped with locally paved surface; allowing seasonal wood removal |
| lesné cesty 3. triedy – približovacie cesty | 3rd class forest roads – moving closer roads |
| zvážnica – sklon < 10°; max 12° | Forest logging road – slope < 10°; max. 12° |
| dočasná približovacia cesta - sklon > 20° | Temporary moving closer road – *slope* > 20° |
| trvalá približovacia cesta - sklon < 20° | Permanent moving closer road – *slope* < 20° |
| technologické komunikácie a zariadenia – linky slúžiace na vyťahovanie dreva z porastu, bez spevnenia povrchu a zemných prác | Technological road and equipment – lines serving for hauling wood from the stand cover, without paved surface and earthworks |
| technologická linka | Technological line |
| vyťahovacia linka | Hailing line |
| približovacia linka | Moving closer line |

However, any further increase of transport capacity requires not only enormous increase of time to fulfil this task but also requirements for increase of manpower and machinery and equipment.

From the Fig. 2, one can see that for increase of passability of firefighting machinery in the forest terrain, the forest machinery can be used. The example is the use of forest road machinery for increase of fire engine machinery on the MB UNIMOG chassis. But this solution, however, is on the limits of this machinery with the risk of its damage or destroying.

One of the way how to increase performance characteristics of firefighting machinery intended for transport of extinguishing medium is to use chassis of the light duty trucks with the 4x4 drive (e.g. (Nissan Navara, Land Rover), which are in the property of the Fire and Rescue Corps or those belonging to forest machinery themselves (e.g. forest road machinery or removal truck units). Use thereof can be arranged by construction of special superstructures or by use of uniaxial vehicle trailers with tank superstructure. Besides the water transport, these superstructures can be used for transport of equipment and other technical tools required for intervention activity. The possibility to transport thereof by the helicopter suspension is the bonus.

The example of such trailer shown in the Figure 3 designed and constructed themselves by the members of the Voluntary Firefighting Corps (DHZ) of the Valaská village (the Brezno region). The trailer is used for the four-wheel quad vehicle POLARIS. Built-in pump allows not only filling the superstructure but also supplies firefighting line "D“ for fire extinguishing.

Fig. 3 Themselves made trailer for the quad vehicle POLARIS (photo DHZ Valaská)

The research activity at the technical University in Zvolen deals with the issue of increasing the performance of existing firefighting machinery. One of the goals of the project „Development of an auxiliary device and its technological employment to increase the efficiency of extinguishing forest fires (APVV-14-0468)“ is a development of the firefighting superstructure for chassis Nissan Navara and Land Rover.

*1.1. Effect of the water source distance on the water transport for forest fire extinguishing*

In general, water supply for forest fires extinguishing is provided:

- with tank fire engines (CAS),
- from water sources on the fire site (natural water sources or artificial ones).

The optimal length of hose line for creating offensive firefighting streams from the tank fire engine or from firefighting pump in case of water source varies within the range 80 -100 metres. If water supply driven in the CAS tank engine and water sources nearby the fire site are not sufficient in terms of capacity or there are no water sources in the fire site vicinity, the long-distance water transport from distant water sources is carried out. This kind of water transport can be organized in following ways:

- water transport by hose line; usually with use of several firefighting pumps;
- shuttle water transport with use of tank fire engines or other cistern vehicles;
- combined water transport using both above mentioned ways.

As regards difficulty even impracticableness of building hose line in distances greater than 500 m (in terms of material and manpower) in case of long-distance water transport, there is an assumption of priority use of shuttle water transport. Success of such way of water supply is influenced, besides the perimeter or area of the forest fire and fire site, particularly by:

A. Water source

- Distance of the water source;
- Capacity of the water source;
- Accessibility of the water source.

B. Forest road network

- Carrying capacity of the road;
- Road width and road profile;
- Transverse and longitudinal slope;
- Carrying capacity of bridges and crossings.

C. Firefighting machinery

- Number of tank fire engines;
- Volume of a tank;
- Average speed rate during transport;
- Intensity of fire extinguishing water delivery;
- Skill of the personnel.

**2. Methodology of the work**

Calculation of the required number of tank fire engines follows from the essential equation (Hanuška, 1996):

$$N_c = \frac{t_1 + t_2 + t_3}{t_4} + [2 \div 3], ks \qquad (1)$$

where:

$N_c$ – number of tank fire engines - CAS (pcs),
$t_1$ – time needed for tank filling with water (min),
$t_2$ – time of CAS drive from water source to fire site (min),
$t_3$ – time of CAS drive from fire site to water source (min),
$t_4$ – time of emptying of the tank (min).

For securing water transport, a reserve is created; 2 reserve CASs for calculated CAS number up to 10 CASs; 3 reserve CASs for calculated CAS number more than 10. The reserve minimalizes engine failure or accident risk or for unforeseen difficulties on roads.

Particular periods of time are calculated as follows:

$$t_1 = \frac{V_c}{Q_1}, min \qquad (2)$$

where:

$V_c$ – volume of the water tank (l),
$Q_1$ – amount of water delivered by the filling pump (min);

$$t_2 = \frac{60.\,l_1}{v_1}, \text{min} \qquad t_3 = \frac{60.\,l_2}{v_2}, \text{min} \qquad (3)$$

where:

$l_1$ – distance from the water source to the fire site (km),
$l_2$ – distance from the fire site to the water source (km),
$v_1$ – average speed rate of the full CAS from the filling site to the fire site (km.h-1),
$v_2$ – average speed rate of the empty CAS from the fire site to the filling site (km.h$^{-1}$).

Note: Specified distances and speed rates may not be the same. As regards speed rates, the CAS after filling runs generally with lower average speed rate than an empty one. Especially, when driving uphill and in difficult terrain. Also, the distance may not be the same. Forest road may have only one lane and on that section may not be the place for sidestep or rotation of CASs. For this reason, the route of empty CASs can be voted in another road that due to CASs higher speed may be even longer. Therefore, neither final time t2 may can be equal to the time t3. Moreover, the average time for the actual CAS delivery time to the filling place and to the emptying site is included in that time.

$$t_4 = \frac{V_c}{Q_2}, \text{min} \qquad (4)$$

where

$V_c$ – volume of the water tank (l),
$Q_2$ – amount of water taken out from the tank ($l.min^{-1}$). It represents sum of flow rates of firefighting branchpipes used for fire extinguishing of total intensity of continuous water delivery to the fire site.

One of the essential conditions is that $t1 \leq t4$.

In the case that tanks with different volumes are used, their substitute is calculated in terms of the greatest volume tank used in the shuttle water delivery according to the equation (5)

$$N_B = \frac{(N_C - N_A).V_A}{V_B}, ks \qquad (5)$$

where

$N_B$ – number of CASs which will substitute missing CASs (pcs),
$N_C$ – calculated number of CASs having the greatest volume applied for the shuttle water transport (pcs),
$N_A$ – number of available CASs having the greatest volume (pcs),
$V_A$ – volume of the greatest tank (l),
$V_B$ – volume of the tank that will substitute missing machinery (l).

For this article purpose, a model example was processed that is a part of discussion.

## 3. Results and discussion

*Model example*

Intensity of extinguishing agent supply for forest fire represents $I_o$ = 9.2 $l.m^{-1}.min^{-1}$ when extinguishing takes place at the fire site perimeter or $I_p$=1.8 $l.m^{-2}.min^{-1}$ at the fire site area, respectively, when linear fire spread rate is $v_l$ = 1.3 $m.min^{-1}$. When assuming that fire suppression is led on the fire front having length 200 meters, it is necessary to deliver approximately water amount $Q_2$ = 2000 $l.min^{-1}$ into area of intervening activities. The water source is located 2 kilometres from the fire site and for the water transport are used tank fire engines CAS 30 T815-7 6x6.1 having tank volume of 9 000 litres. Applying the equation (1) and assuming the declared pump performance 3000 $l.min^{-1}$, speed rate of full CASs 40 $km.h^{-1}$ and empty CASs 50 $km.h^{-1}$ ; and calculation of particular times according the equations (2), (3), and (4), this task can be provided with four CASs; 2 tanks from this amount are reserved ones.

The effect of distance on the fire engines when remaining the same distance for drive the full and empty tank vehicles is shown in the table 2.

Table 2 Calculation of the dependence of number of CAS 30 T 815 – 7 6x6.1 fire engines on the distance of the water source from the fire site in case of shuttle water transport delivering ($Q_2$ = 2000 $l.min^{-1}$) according to the model example

| Distance (km) | Number of fire engines (T 815 – 7 CAS 30 6x6) | | |
|---|---|---|---|
| | calculated* | rounded | total with the reserve |
| 1 | 1.26 | 2 | 4 |
| 2 | 1.86 | 2 | 4 |
| 3 | 2.46 | 3 | 5 |
| 4 | 3.08 | 3-4 | 5-6 |
| 5 | 3.66 | 4 | 6 |
| 6 | 4.26 | 5 | 7 |
| 7 | 4.86 | 5 | 7 |
| 8 | 5.46 | 6 | 8 |
| 9 | 6.06 | 6-7 | 8-9 |
| 10 | 6.66 | 7 | 9 |

* Number of fire engines calculation is always rounded to the next following engine. In case of marginal values in the table (3.08 or 6.06, respectively), the incident commander decides which variant he chooses. The final effect is reached only after starting and debugging the shuttle transport.

Other usable tank fire engines for this way of water supply can be CAS 30 IVECO Trakker trucks with the same tank volume as well as CAS 32 T 815 trucks with the original tank volume 8 200 litres (after overhaul with 9 000 litres volume) or CAS 32 T 148 trucks, which despite the tank volume 6 000 litres or 6 600 litres, respectively, is classified among great-volume tanks.

Should other types of tank fire engines with a lower tank volume be used for the shuttle water transport, there would cause not only increase of number thereof but also of demands on personnel (driver – machine operator). This situation can occur because of re-evaluation of the forest road status, terrain load capacity, etc.

Calculations for fire engines having tank volumes 4000 and 2000 litres, respectively, were processed for comparison. Within the category of fire engines having 4000-litre volume tank, belong forest special trucks CAS 30 T 815 – 7 4x4.1, forest specials constructed on the chassis Renault Camiva 4x4 or Mercedes Benz Unimog U5000 4x4. Also fire truck CAS 25 Š 706 RTHP with 3500-litre tank can be included into this group. Within the category of fire engines having 2000-litre volume tank, belong tank vehicles on the chassis Praga V3S a Mercedes Benz Unimog. Results recalculated according to the equation (1) are referred in the Table 3.

Table 3 Recalculation of different volume tanks for long-distance water transport

| Distance (km) | Number of tanks calculated / rounded / **with the reserve** | | |
|---|---|---|---|
| | Volume 9000 l | Volume 4000 l | Volume 2000 l |
| 1 | 1.26 / 2 / **4** | 2.05 / 2-3 / **5** | 3.37 / 4 / **6** |
| 2 | 1.85 / 2 / **4** | 3.4 / 4 / **6** | 6.05 / 6-7 / **8** |
| 3 | 2.46 / 3 / **5** | 4.75 / 5 / **7** | 8.77 / 9 / **11** |
| 4 | 3.08 / 3-4 / **5** | 6.1 / 6-7 / **8** | 11.47 / 12 / **15** |
| 5 | 3.66 / 4 / **6** | 7.45 / 8 / **10** | 14.17 / 15 / **18** |
| 6 | 4.26 / 5 / **7** | 9.1 / 9-10 / **11** | 17.4 / 18 / **21** |
| 7 | 4.86 / 5 / **7** | 10.15 / 11 / **13** | 19.54 / 20 / **23** |
| 8 | 5.46 / 6 / **8** | 11.5 / 12 / **15** | 22.27 / 23 / **26** |
| 9 | 6.06 / 6-7 / **8** | 12.85 / 13 / **16** | 24,97 / 25 / **28** |
| 10 | 6.66 / 7 / **9** | 14.2 / 15 / **18** | 27.67 / 28 / **31** |

Based on theoretical calculation, distances of water source as well as quality of forest road network have an influence not only on number of tank fire engines used for extinguishing water transport but also on amount of transported water. For example, when water is transported from 4-kilometre distance under conditions referred to the model example, even 15 tank fire engines are required for water transport only. To this number, yet 1 tank fire truck shall be added for creating an offensive hose line and machinery for tank filling. From this numbers, also numbers of qualified personnel, minimally drivers and machinery operators, are derived. Despite this fact, forest special trucks have their justification in areas where the forest road network absents and terrain load capacity allows their use.

Alternative solution, long-distance transport of water by hose line at such a distance, encounters great demands for securing material means and equipment. For achieving the required flow rate Q2, there would be necessary to build minimally three type Bg hose lines where requirement on hoses would result from the distance. For example, to build transport hose line within the 1 km distance, 50 hoses would be required and adequate number of firefighting pumps. This hose amount does not include hoses for building offensive hose deployment from the last fire pump to the fire site. Further not negligible fact is time required for building such hose line as well as requirements concerning personal securing this task. This is further reason supporting building sufficient number of suitable water sources connected with forest road network.

From this standpoint, shortening time of extinguishing agent transport in terms of forest fire development (fire perimeter and fire area) depends on four basic factors:
water source + forest road network + fire-fighting machinery + personnel = > efficiency of intervention.

It is difficult and very often even impossible to secure symbiosis of all these factors. This results from the fact that it is no known in advance where the forest fire origins. Thus it is up to the Incident Commander how he can utilize information support relating to all these factors influencing not only successfulness and efficiency of intervention activity but also quality of mentioned information support.

One criterion of the information support is up-to-dateness information in relation to technical equipment. Nowadays, Regional Headquarters of the Fire and Rescue Corps, Rescue Brigades of the Fire and Rescue Corps and the Slovak Water Management Company (Slovenský vodohospodársky podnik, š. p.) are equipped with new machinery within the Project "Active Anti-Flood Measures". Theoretical use of assembly of the water pumping container and water transport for long distances HFS HydroSub HS 150 (hereinafter only "HCP") and a container containing fire hoses allows transport of 3000 $l.min^{-1}$ of extinguishing agent flow rate to the distance 2 km via "A" type fire hoses. Emplacement of this equipment on one chassis and use of automatic hose deployment decreases demands on personnel and other material and technical equipment as well as requirements concerning replenishment of fuel.

The advantage of this system is a possibility of serial or parallel connection of particular modules within the region and thus increasing the transport distance or transported volume of extinguishing agent at long-distance water transport process (Pyronova, 2016).


Fig. 4 Components of the HCP HydroSub HS 150 during training

Comparing results from the table 2 with HCP possibilities, saving of 3 up to 7 CAS fire engines depending on their volume capacity occurs at the transport of 3000 l.min$^{-1}$ flow rate and saving of technical equipment represents minimally 100 pieces of “B” type hoses per one hose line at the transport capacity 800 l.min$^{-1}$. This amount shall be multiplied by the required amount for securing transport flow rate of 3000 l.min-1.

Similar way of the transport of fire extinguishing agent can be carried out by use of machinery of the Armed Forces of the Slovak Republic (system PDP – 150) but in this case rigid pipes are used. However, this system requires higher demands on personnel providing transport (OS SR, 2016).

## 4. Conclusions

Despite possibilities presented in the discussion part, issue of accessibility forest covers as well as water sources capacity, whether volume or flow rate one, remains one of the current problems concerning protection forest against fires that should be calculated not only in case of existing forest stands but also at creating new covers that are planted in areas destroyed by wind disasters or large extent forest fires. Despite technical and personal capacities of firefighting units that in current time reaches their historical maximum, the forest accessibility and water sources have the highest priority that finally determines the final fire site area after forest fire suppression.

## Acknowledgments

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[8]

# Assessment of economic life of firefighting and rescue appliances based on chassis MAN TGM in the South Moravian region

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**Abstract**

This paper is focused on the evaluation of economic data obtained from operational records of fire-fighting equipment with a focus on Firefighting and Rescue Appliance type of vehicles, especially on exit vehicles based on the chassis MAN TGM, during the period 2010 - 2015. These vehicles were operated by professional units of the Fire and Rescue Service of the South Moravian Region. The paper's aim is to specify the optimum lifetime of the fire-fighting vehicles by the marginal analysis of fire-fighting vehicles' economical operation. Theoretic calculations of the optimum lifetime have been processed with implementing both the method of exponential trends, and Brown method. The residual value of vehicles has been calculated both according to the current Czech tax law, and to the Expert Standard Valuation of motor vehicles in force in the Czech Republic.

*Keywords*: acquisition value; costs; depreciation; residual value; economic life;

## 1. Introduction

This paper follows on previous publications of the author focused on the functional reliability assessment of Firefighting and Rescue Appliances in general (Monoši, 2016) and in detail on vehicles based on the chassis MAN TGM type 13.240 4x4 BL (Jánošík, 2014a; Jánošík, 2014b; Jánošík, 2015). Further, the paper draws on results of theoretical economic lifetime calculations of vehicles based on the chassis Mercedes-Benz Atego deployed in the Moravian Silesian Region (Jánošík and Jánošíková, 2016), and on results of similar calculations for vehicles based on the chassis Renault Midlum in Zlin Region. Those results were sent to be published in the journal Communications – Scientific Letters of the University of Zilina.

Presented results of alternative economic lifetime calculations of referred appliances are based on the vehicles purchase price 5 mil. CZK. Vehicles were acquired between 2007 and 2009 under a special program in the budget of the Ministry of the Interior "Periodic renewal of basic fire-fighting equipment at units included to the blanket coverage". This program was conducted in the years 2007 to 2011.

When evaluating the operation of monitored vehicles, provided primary data (Ježek, 2016) for the years 2010 to 2015 from the Information System II IKIS were exported to Excel file format.

## 2. Characteristics of referred fire fighting vehicles

Essential identification, operational and economic characteristics of the monitored equipment for the period 2010 to 2015 are given in Tab. 1.

Essential tactical-technical parameters of referred vehicles MAN TGM 13.240 4x4 BL are: the engine power 176 kW at a rpm 2300, the total weight 17500 kg, dimensions (length/width/height) 120/2505/3300 mm, the drive to all four half-axles, the pump flow 1500 l/min, water tank capacity 2200 liters, foam compound tank capacity135 liters. Further details of these

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vehicles can be traced for example in the source (Jánošík, 2015; Monoši et. al., 2013).

Tab. 1 Essential characteristics of referred vehicles during years 2010 to 2015

| Vehicle dislocation | Registration mark | Date of commissioning | Fire-fighting appliances manufacturer | Mileage [km] | Machine work at the site [hour] | Amount of fuel [litr] | Repair costs [CZK] |
|---|---|---|---|---|---|---|---|
| Hustopece | 6B8 9984 | 01/01/2009 | SPS Slatiňany | 39 866 | 923 | 13 502 | 296 144 |
| Hodonin | 5B2 6375 | 01/01/2007 | THT Polička | 35 318 | 681 | 11 987 | 208 460 |
| Veseli na Morave | 6B8 9987 | 01/01/2009 | SPS Slatiňany | 34 981 | 844 | 13 017 | 392 444 |
| Kyjov | 4B6 6194 | 01/01/2008 | THT Polička | 42 075 | 740 | 14 711 | 199 354 |
| Blansko | 5B2 6374 | 01/01/2007 | THT Polička | 23 847 | 522 | 8 729 | 192 118 |
| Slavkov | 4B6 6260 | 01/01/2008 | THT Polička | 31 096 | 793 | 11 459 | 719 887 |
| Znojmo | 6B8 9982 | 01/01/2009 | SPS Slatiňany | 15 467 | 309 | 6 404 | 80 525 |
| Moravsky Krumlov | 5B2 6376 | 01/01/2007 | THT Polička | 23 995 | 667 | 8 937 | 94 722 |
| Hrusovany nad Jevisovkou | 6B8 9983 | 01/01/2009 | SPS Slatiňany | 21 216 | 567 | 7 555 | 240 996 |
| Lisen | 4B6 6196 | 01/01/2008 | THT Polička | 55 027 | 1 136 | 18 007 | 313 408 |
| Rosice | 4B6 6231 | 01/01/2008 | THT Polička | 58 878 | 1 458 | 22 079 | 537 776 |
| Tisnov | 6B8 8318 | 01/01/2009 | SPS Slatiňany | 30 911 | 589 | 12 436 | 273 823 |

## 3. Materials and methods

Service life is the ability of the technical system to perform desired functions in order to achieve the ultimate state (ČSN IEC, 1993). Economic life of the vehicle can be generally characterized as reaching the limit state when further operation is economically unsustainable (Stodola, 2002).

The economic efficiency of the investment is calculated to assess the economic life of the technical system in the business environment. This procedure would be relatively difficult to apply for the evaluation of firefighting appliances. The methodology of these calculations is based on the input data extremely difficult to define in the sphere of public service. Expected annual returns and/or annual operating costs in dealing with accidental incidents are representatives of these data. Revenues are primarily represented by preserved properties during the liquidation of accidents. Property owners and insurance companies usually have different views on the amount of damages. Forensic expert opinion and/or the court proceedings decide in these disputes thereafter. The total amount of investment, bank loans, the tax rate for the calculation of investment income taxes and annual depreciation might be examples of detectable data. Further reason for the impossibility of using this calculation method is the requirement of the initial setting of the technical system's lifetime. The approximate lifetime can be only theoretically assumed from the Machinery Service Order (Instructed, 2006), where there are shown approximate lifetime of fire-fighting appliances.

Therefore, the calculation of the monitored vehicles' economic life was performed by use of two simple and generally known methods, both the exponential trends method, and the Brown method (Daněk and Široký, 1999; Holub and Vintr, 2002). Calculations according to both methods were performed for 5-year operation time period. The residual value of appliances, which is one of data used for calculations, was variously calculated according to the Act No. 586/1992 Coll. on Income Taxes (Act, 1992), and according to the Expert Standard No. I/2005 - Valuation of motor vehicles (Standard, 2005).

*3.1. Exponential trend method*

Theoretical foundations of the method were published in 1963 (Brown, 1963). The principle is displayed graphically in Fig. 1.

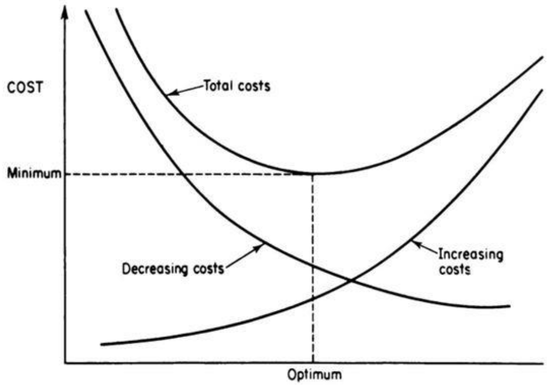


Fig. 1 Fundamentals of operation research

The exponential trend method is based on the theoretical assumption that the value of the technical system in time Np(t) has the shape of downward sloping exponential curve (Daněk and Široký, 1999). The curve is defined by the equation:

$$N_p(t) = C \cdot e^{-\alpha \cdot t} \quad (1)$$

In equation (1) the constant C [CZK] represents the value of the vehicle at the zero year (in our case 2010, which is calculated according to the Expert standard), α [-] is the coefficient of depreciation percentage exponent and t [year] is the time. Similarly, we can define by using an upward sloping exponential curve the trend of costs for maintenance and repairs Nu(t) according to the equation:

$$N_u(t) = A \cdot e^{\beta \cdot t} \quad (2)$$

In equation (2) A constant [CZK] represents the amplitude of maintenance costs in zero year (in this case 2010), β [-] is the exponent coefficient. Other variables are explained above. The total value of firefighting appliances Nc(t) is a sum of equations (1) a (2):

$$\mathrm{N_c(t)} = C \cdot e^{-\alpha \cdot t} + A \cdot e^{\beta \cdot t} \quad (3)$$

Further, we can count the local extreme of the function (3) by derivation. The local extreme ($N_c(t)$ minimum in this case) represents the optimal time $T_{opt}$ for replacing the appliance:

$$\mathrm{T_{opt}} = \frac{1}{\alpha + \beta} \cdot \ln\left(\frac{\alpha \cdot C}{\beta \cdot A}\right) \quad (4)$$

After reaching the minimum point the function Nc(t) rises, due to declining price of the firefighting vehicle Nc(t) and increasing maintenance and repair costs Nu(t). The constants A, C and exponent coefficients α, β are obtained after processing the input of economic data, building charts and drawing related exponential curve from these charts by using appropriate software, e.g. MS Excel.

*3.2. Brown method*

This method was first published over 55 years ago in the journal Railway Age, in Brown's paper "What's the Life of a Diesel?" The method was used for the preliminary determination lifetime of rail vehicles (Daněk and Široký, 1999). The optimum lifetime $T_{opt}$ is given by:

$$T_{opt} = \sqrt{\frac{2 \cdot H_0}{B}} \quad (5)$$

Here, $H_0$ is the vehicles' acquisition value given as a percentage = 100 % and $B$ is the linear incremental trend coefficient of the maintenance and repair costs. This coefficient is obtained likewise from the charts using linear regression of data. Application of this method is connected with some weaknesses, as discussed below in the results.

*3.3. Vehicle's residual value calculations*

Calculations of the vehicle's residual value according to the Act on Income Tax (Act, 1992) consider the depreciation period of 5 years in Article 30 within motor vehicles for special purposes, according to the classification in Appendix No. 1 of the Act. Depreciation percentages are fixed for the first year at the level of 11 % and for the next four years they are changed to 22.25 %. Calculating the relative technical value of the vehicle PTHS in any year of operation is carried out in a percentage of the purchase price, in accordance with the Expert Standard (Standard, 2005), by the equation (6):

$$\mathrm{PTHS} = \frac{THSN \cdot (100 - ZA) \cdot (100 \pm TS) \cdot PDS}{10^6}$$

Initial technical value of the group THSN = 100 %, technical condition changes TS = 0.0 % and the relative group proportion value PDS = 100 % were applied in the equation, in the case of maintained and operational firefighting appliances. Basic amortization ZA [%] was the only variable in the equation (6). ZA is calculated as the arithmetic average in the following equation:

$$\text{ZA} = \frac{ZAD + ZAP}{2} \tag{7}$$

ZAD parameter is the basic percent reduction during the operation defined in Annex No. 1.4 of the Expert standard (Standard, 2005) and ranges from 20 % in the first year of operation to 90 % in the tenth and following year of operation. ZAP parameter [%] determines the percentage of the basic reduction for the mileage (see ibid.). The value of ZAP parameter is 0.3 % per each 1000 km for trucks over 16 tons mainly used in difficult operational conditions.

## 4. Results

Overall results of calculations are stated in the following tables and graph exemplifications of which are evident constants and coefficients exponents values used for the calculations in equations (4) and (5).

The difference of calculated results of the vehicle's residual value was set in Figs. 2 and 3, as demonstrated on the case of the vehicle registration number 6B8 9984, deployed at the fire station Hustopeče. Examples of input data and partial and final results of calculations for this vehicle are shown in Tabs. 2 and 3.

It is evident that the Expert Standard is more suitable for both longer amortization time, and mileage consideration. These factors can significantly affect the vehicle wearing. Expert Standard gives even higher residual value of the particular vehicle in the final outcome. Residual value calculated for this year according to the Expert Standard as the vehicle's starting price was used for calculation of vehicle's residual value according to the Act on Income Tax from 2010 onwards.

Tab. 2 The residual value according to the Act on Income Tax

| Year | | Residual value [CZK] | Depreciation percentages [%] | Depreciation value [CZK] |
|---|---|---|---|---|
| 2010 | 0 | 4 215 710 | 11.00 | 463 728 |
| 2011 | 1 | 3 751 982 | 22.25 | 937 995 |
| 2012 | 2 | 2 813 986 | 22.25 | 937 995 |
| 2013 | 3 | 1 875 991 | 22.25 | 937 995 |
| 2014 | 4 | 937 995 | 22.25 | 937 995 |

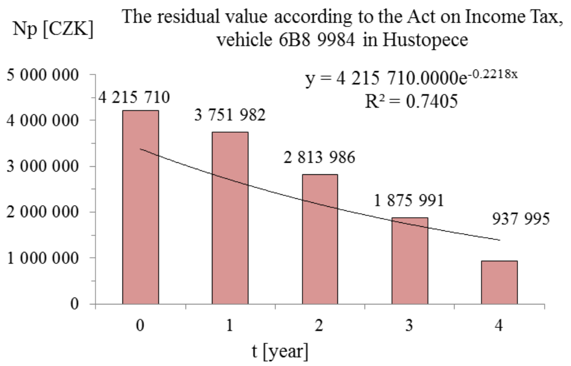


Fig. 2 The residual value according to the Act on Income Tax

Tab. 3 The residual value according to the forensic Expert Standard

| Year | | Residual value [CZK] | ZAD [%] | Mileage [km] | ZAP [%] | ZA [%] | PTHS [%] |
|---|---|---|---|---|---|---|---|
| 2010 | 0 | 4 215 710 | 30 | 4 572 | 1.37 | 15.69 | 84.31 |
| 2011 | 1 | 3 958 315 | 40 | 5 558 | 1.67 | 20.83 | 79.17 |
| 2012 | 2 | 3 699 953 | 50 | 6 673 | 2.00 | 26.00 | 74.00 |
| 2013 | 3 | 3 450 988 | 60 | 6 535 | 1.96 | 30.98 | 69.02 |
| 2014 | 4 | 3 190 653 | 70 | 7 913 | 2.37 | 36.19 | 63.81 |
| 2015 | 5 | 3 060 388 | 75 | 8 615 | 2.58 | 38.79 | 61.21 |

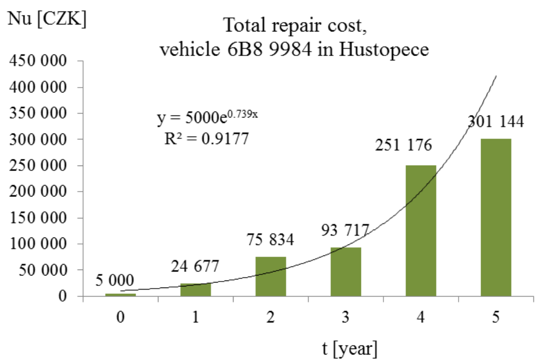


Fig. 3 Total repair costs according to the exponential trends method

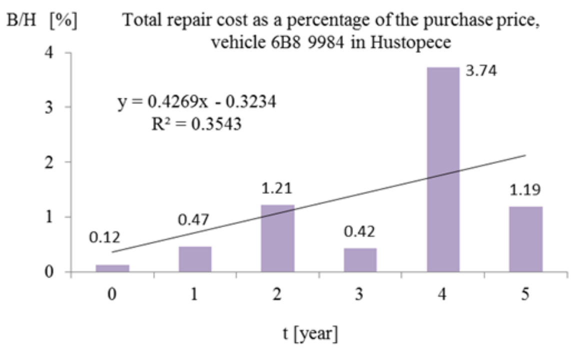


Fig. 4 Repair costs according to the Brown method

Tab. 4 Maintenance and repair costs according to the

| Year | | Maintenance and repair costs [CZK] | Maintenance and repair cost in [%] of the purchase price |
|---|---|---|---|
| 2 010 | 0 | 5 000 | 0.12 |
| 2 011 | 1 | 19 677 | 0.47 |
| 2 012 | 2 | 51 157 | 1.21 |
| 2 013 | 3 | 17 883 | 0.42 |
| 2 014 | 4 | 157 459 | 3.74 |
| 2 015 | 5 | 49 968 | 1.19 |

Results of the recovery time when depreciating according to the Act on Income Tax are shown in Tab. 5 (Act, 1992). Tab. 6 presents alternative results of calculations while using the depreciation according to the Expert Standard (Standard, 2005). Both results are counted when applying the method of exponential trends. As written above next to Figs. 2 and 3, the influence of valuation methods is reflected in the final size of the recovery time. Considerable maintenance and repair costs are another factor affecting the recovery time for these vehicles.

Tab. 5 Recovery time in accordance with the Act on Income Tax

| | | Maintenance and repairs cost ratio $N_u(t)$ | | | Residual value of firefighting appliances in time $N_p(t)$ coefficients | | | $T_{opt}$ [year] |
|---|---|---|---|---|---|---|---|---|
| Vehicle dislocation | Registration mark | $A$ [CZK] | $\beta$ [-] | Correlation coefficient $R$ | $C$ [CZK] | $\alpha$ [-] | Correlation coefficient $R$ | |
| Hustopece | 6B8 9984 | 5 000 | 0.7390 | 0.96 | 4 215 710 | 0.2218 | 0.8605 | 5.8 |
| Hodonin | 5B2 6375 | 4 626 | 0.7818 | 0.76 | 3 717 488 | 0.2218 | 0.8605 | 5.4 |
| Veseli na Morave | 6B8 9987 | 21 240 | 0.5694 | 0.90 | 4 223 900 | 0.2218 | 0.8605 | 5.5 |
| Kyjov | 4B6 6194 | 23 394 | 0.4056 | 0.94 | 3 961 953 | 0.2218 | 0.8605 | 7.2 |
| Blansko | 5B2 6374 | 11 799 | 0.4974 | 0.91 | 3 676 140 | 0.2218 | 0.8605 | 6.9 |
| Slavkov | 4B6 6260 | 26 888 | 0.6006 | 0.94 | 3 974 485 | 0.2218 | 0.8605 | 4.9 |
| Znojmo | 6B8 9982 | 792 | 0.9524 | 0.74 | 4 238 840 | 0.2218 | 0.8605 | 6.1 |
| Moravsky Krumlov | 5B2 6376 | 11 066 | 0.3734 | 0.90 | 3 726 960 | 0.2218 | 0.8605 | 8.9 |
| Hrusovany nad Jevisovkou | 6B8 9983 | 24 000 | 0.4771 | 0.88 | 4 223 660 | 0.2218 | 0.8605 | 6.3 |
| Lisen | 4B6 6196 | 29 444 | 0.4433 | 0.88 | 3 945 815 | 0.2218 | 0.8605 | 6.3 |
| Rosice | 4B6 6231 | 54 381 | 0.4469 | 0.79 | 3 933 387 | 0.2218 | 0.8605 | 5.4 |
| Tisnov | 6B8 8318 | 105 963 | 0.1492 | 0.97 | 4 226 381 | 0.2218 | 0.8605 | 11.0 |

Tab. 6 Recovery time in accordance with the Expert Standard

| | | Maintenance and repairs cost ratio $N_u(t)$ | | | Residual value of firefighting appliances in time $N_p(t)$ coefficients | | | $T_{opt}$ [year] |
|---|---|---|---|---|---|---|---|---|
| Vehicle dislocation | Registration mark | $A$ [CZK] | $\beta$ [-] | Correlation coefficient $R$ | $C$ [CZK] | $\alpha$ [-] | Correlation coefficient $R$ | |
| Hustopece | 6B8 9984 | 5 000 | 0.739 | 0.96 | 4 215 710 | 0.0509 | 0.9643 | 5.1 |
| Hodonin | 5B2 6375 | 4 626 | 0.7818 | 0.76 | 3 717 488 | 0.0456 | 0.9740 | 4.7 |
| Veseli na Morave | 6B8 9987 | 21 240 | 0.5694 | 0.90 | 4 223 900 | 0.0509 | 0.9646 | 4.6 |
| Kyjov | 4B6 6194 | 23 394 | 0.4056 | 0.94 | 3 961 953 | 0.0493 | 0.9704 | 6.6 |
| Blansko | 5B2 6374 | 11 799 | 0.4974 | 0.91 | 3 676 140 | 0.0526 | 0.9740 | 6.4 |
| Slavkov | 4B6 6260 | 26 888 | 0.6006 | 0.94 | 3 974 485 | 0.0493 | 0.9696 | 3.8 |
| Znojmo | 6B8 9982 | 792 | 0.9524 | 0.74 | 4 238 840 | 0.0501 | 0.9614 | 5.6 |
| Moravsky Krumlov | 5B2 6376 | 11 066 | 0.3734 | 0.90 | 3 726 960 | 0.0451 | 0.9748 | 8.9 |
| Hrusovany nad Jevisovkou | 6B8 9983 | 24 000 | 0.4771 | 0.88 | 4 223 660 | 0.0495 | 0.9624 | 5.5 |
| Lisen | 4B6 6196 | 29 444 | 0.4433 | 0.88 | 3 945 815 | 0.0494 | 0.9716 | 5.5 |
| Rosice | 4B6 6231 | 54 381 | 0.4469 | 0.79 | 3 933 387 | 0.0490 | 0.9703 | 4.2 |
| Tisnov | 6B8 8318 | 105 963 | 0.1492 | 0.97 | 4 226 381 | 0.0507 | 0.9644 | 13.0 |

Results acquired by the Brown method with using linear trends are shown in *Tab. 7*. The results confirmed previous conclusions which we have reached in the calculations for vehicles Mercedes-Benz Atego (Jánošík and Jánošíková, 2016) and Renault Midlum.

The Brown method application is inappropriate for fire equipment. Calculation results are completely out of reality. Correlation coefficients of each regression curve are very low. The optimal economic life calculations by the equation *(5)* for negative values of constant $B$ cannot be accomplished thereafter.

Tab. 7 Recovery time in accordance with the Brown method

| Vehicle dislocation | Registration mark | $B$ [-] | Correlation coefficient $R$ | $T_{opt}$ [year] |
|---|---|---|---|---|
| Hustopece | 6B8 9984 | 0.4269 | 0.60 | 22 |
| Hodonin | 5B2 6375 | -0.0626 | 0.11 | |
| Veseli na Morave | 6B8 9987 | 0.0237 | 0.04 | 92 |
| Kyjov | 4B6 6194 | -0.0416 | 0.14 | |
| Blansko | 5B2 6374 | 0.1031 | 0.40 | 44 |
| Slavkov | 4B6 6260 | 0.4674 | 0.20 | 21 |
| Znojmo | 6B8 9982 | 0.0034 | 0.03 | 243 |
| Moravsky Krumlov | 5B2 6376 | 0.0381 | 0.16 | 72 |
| Hrusovany nad Jevisovkou | 6B8 9983 | -0.0522 | 0.09 | |
| Lisen | 4B6 6196 | 0.0398 | 0.11 | 71 |
| Rosice | 4B6 6231 | -0.2140 | 0.20 | |
| Tisnov | 6B8 8318 | -0.1869 | 0.45 | |

## 5. Discussion

Using this method has its disadvantages, which come from the premise of linear increasing costs. This premise almost never comes true in case of firefighting appliances. The method was formulated for rail vehicles, which have high initial costs, and the expected optimum life is considerably longer than 10 years. For example, rail kit CityElefant type 471/071/971 costs CZK 217 million within the lifetime of 30 years or rail kit RegioSprinter BR 654 costs CZK 47 million within the lifetime of 25 years.

Application of this method assumes steady and in time rising repair costs. Two-percent annual increase of maintenance and repair costs in relation to the purchase price is assumed for reaching the optimal economic life over 10 years. It represents CZK 100 000 per year for observed vehicles. Two vehicles of the group did not reach this level of costs even during six-year operation (see Tab. 1). The annual average of maintenance and repair costs was only CZK 49 300 per vehicle in the whole group of vehicles. Thus, to assess the lifetime of less costly firefighting equipment (in comparison to the rail vehicles) by the Brown method the results are not those we expected.

## 6. Conclusions

Calculations results show that we can theoretically expect the optimum lifetime close to 8 years operation since the beginning of assessment (i.e. since 2010) of firefighting vehicles based on the chassis MAN TGM. Graphical distribution of calculated values presented in Tabs. 6 and 7 is shown in Fig. 6.

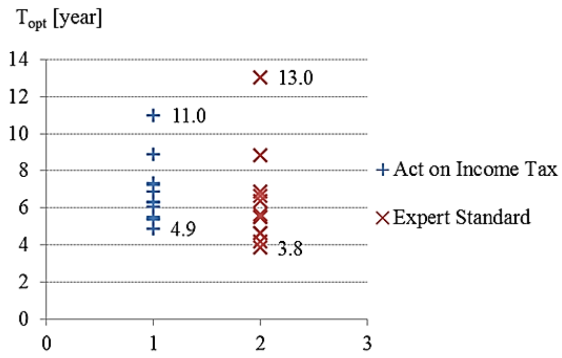


Fig. 6 Summary results

The unavailability of costs for the first years of vehicles' operation since the acquisition of appliances to the end of 2009 caused the inaccuracy of presented calculations, as mentioned in the introduction. Aggregate averaged results of calculations split by the fire appliances, the vehicle's age and evaluation method are given in Tab. 9.

Tab. 9 Summary results

| Fire-fighting appliances manufacturer | SPS Slatinany | THT Policka | |
|---|---|---|---|
| Age of the Vehicles [year] | 7 | 8 | 9 |
| | $T_{opt}$ [year] | | |
| Act on Income Tax | 6.9 | 5.9 | 7.1 |
| Expert Standard | 6.8 | 5.0 | 6.6 |
| average | 6.9 | 5.5 | 6.8 |

This lifetime depends on the current operational load. Further, upgrading of 5 vehicles increased the maintenance and repair costs and made distorted economic assessment of vehicles' operation.

The firefighting vehicle lifetime can be prolonged by relocating trucks from the group of emergency vehicles to reserves that are in lower service load. The next recommendation is using the Expert Standard for more accurate and more realistic residual vehicle value determination than using the Act on Income Tax, in spite of the fact that longer lifetime of some vehicles was the result of calculations in accordance to the Act. Confirmation of the Brown method unsuitability for these calculations on the third group of vehicles is the last major finding.

## Acknowledgments

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# Commitment to Training in New South Wales Rural Fire Service, Australia: Exercise Northern 16

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**Abstract**

In the paper there is briefly introduced the history of the Rural Fire Service in New South Wales and the Department of Bush Fire Services, fire statistics, fire-fighting safety principles used in the New South Wales Rural Fire Service, training courses provided as well as the personal rewards awarded.

*Keywords*: Australia, bush fire, fire-fighting, NSWRFS, training;

## 1. History of the Rural Fire Service in New South Wales

The New South Wales Rural Fire Service (NSW RFS), with over 80,000 members, is the world's largest volunteer fire-fighting organisation. It has responsibility for responding to all fires and other emergency-related incidents (motor vehicle incidents, for example) occurring in 99% of the 800,630 square kilometres that geographically comprise the land mass of the State of New South Wales. This also represents over 10% of the Australian continent.

Like many large police and emergency service organisations today, the NSW RFS had humble beginnings. For example, reference to controlling fires was first mentioned in NSW legislation in the 1867 Municipalities Act, which identified the legally constituted Municipalities. Section 153 of this Act read inter alia that: "The Council of any Municipality may from time to time make by-laws for preventing and extinguishing fires." The NSW Fire Brigades was established by the NSW State Government through the 1884 Fire Brigades Act (No 3) with responsibility for fire prevention and control vested in therein. In 1896, the first volunteer bush fire brigade was established in Berrigan and was formally recorded in November 1900.

As the 20th Century began, two further Acts of the NSW Parliament, the 1901 Careless Use of Fires Act (revised in 1906, 1912, and 1930) and the 1906 Local Government Act were passed to ensure that volunteer brigades could be formed through local councils.

The early 1980s saw some of the worst bush fire seasons since the 1950s. In the 1980-81 season, eight people tragically died and over 887,000ha were scorched. The following year, a pine plantation worth $12 million was destroyed in Southern NSW. This fire was so hot that it burnt 24,000ha in just two and a half hours. Lightning strikes on Christmas Day in 1984 ignited more than 100 fires in grassed areas of Western NSW. Half a million hectares were burnt as a result. That year 6,000 fires raged; four people lost their lives, and a total of $40 million of losses was recorded. The decade closed as it had begun, with major fires burning in the eastern part of the State.

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**2. Department of Bush Fire Services**

In 1985, Philip (Phil) Koperberg, then Chairman of the Bush Fire Council was appointed Executive Officer of the Bush Fires Branch. Whilst in this role, Mr Koperberg lead the response to the bushfires that occurred during the 1993-94 fire season, which, at the time, was the most protracted and largest fire-fighting effort in Australian history. Over 18,300 volunteer fire-fighters were deployed at over 800 fires throughout NSW. Notwithstanding their efforts though, four lives and 206 houses were lost. Following the subsequent Coronial Inquiry, the NSW Government introduced legislation for a single Rural Fire Service in 1997, the Rural Fires Act 1997 No 65, which was proclaimed 1 September 1997. Philip Koperberg AO AFSM BEM, was appointed as the first Commissioner of the NSW Rural Fire Service.

In October 2007 Shane Fitzsimmons AFSM succeeded Phil Koperberg to become the second (and current) Commissioner of the NSW RFS. The year also boasted a remarkable number of members participating in a new online communication channel with 10,600 members registered users of the "MyRFS" volunteer website. Mr Koperberg continued to be involved with emergency management and recently completed 5 years as Chair of the NSW State Emergency Management Committee (SEMC).

The Rural Fires Act 1997 established the Rural Fire Service, and defined it's organisational structure which included rural fire districts that are constituted around local government boundaries. The Act also strengthened the operating capabilities of the Service, and laid the groundwork to simplify how the NSW RFS was to be managed. It redefined the world's largest fire service and built on a century of experience in protecting some of the most fire-prone areas on earth.

In August 2002, the Rural Fires and Environmental Assessment Legislation Amendment Act 2002 amended both the Environmental Planning and Assessment Act 1979 and the Rural Fires Act 1997 to provide an even stronger and more streamlined system for building developments in bush fire prone areas.

Today, the NSW RFS is the combat agency for bush, grass, and structure fires along with other incidents in rural fire districts. It is also the lead agency for coordination of bush firefighting and prevention throughout the State.

**3. Statistics for year ended 30 June 2016**

For the year ending June 2016, the NSW RFS recorded a membership of approximately 80,000 volunteers in over 2100 rural fire brigades across the State. These volunteers were equipped, supported and trained and operationally managed across the State through 50 Fire Control Centres (FCCs). The RFS operates over 5,300 vehicles as follows:

- 3,783 tankers
- 65 pumpers
- 1,296 transport and command vehicles
- 59 bulk water carriers
- 81 catering vehicles
- 40 specialist communications vehicles.

In the last financial year, 2,000 qualified trainers delivered 314,680 hours of training at local centres. The Service also completed hazard reductions which protected 118,021 properties and 2,773 community education programs were conducted across the State. In partnership with community and through the professionalism of its members, the NSW RFS continues to grow and to improve - while always promoting the ethos of volunteering.

Additionally, over 900 staff members are employed to manage the day-to-day operations of the Service at District Fire Control Centres, Regional Offices, Customer Service Centres, Operational and Mitigation Support Service bases across the State, and the Service's Headquarters at Lidcombe.

During the year, the RFS attended over 16,000 incidents as follows:

- Bush and grass fires 7,686
- Structural Fires 1,166
- Motor vehicle fires 1,808
- Motor vehicle incidents (crashes), 4,562
- Assistance to other agencies 1,085
- Together 16,307.

**4. Safety in Fire-Fighting**

Safety in the NSW RFS is paramount and predominates all the Service's activities. Too many lives have been lost fighting fires over the years in NSW – 69 in total since 1954. Sadly, despite the increasing strong emphasis on safety, the perilous dangers experienced by fire-fighters in-the-field and the unpredictability of

Mother Nature, 14 volunteer fire-fighters still lost their lives since the year 2000 .

The NSW RFS recognises the contribution and sacrifice of those members who have lost their lives in the line of duty, while helping to protect others in need and their property. The names of those volunteers are inscribed on the Volunteer Memorial Honour Roll at Mrs Macquarie's Chair in Sydney. A service is held at this Memorial each October and NSW RFS members, family, friends and members of the community are welcome to attend. We sincerely hope that no further names are inscribed on this memorial.

Although fighting fires and protecting the community from emergencies is the most visible aspect of the NSW RFS, as the leading agency for bush fire management and mitigation in NSW, the Service has many other functions and responsibilities that support the provision of those services.

The NSW RFS employs a range of people with a variety of skills and varying backgrounds. Essentially, the work carried out at Regional and District levels includes:

- Membership (Brigade management, Learning and Development, OHS&R, staffing etc.);
- Operations (response, hazard management, mitigation planning, community engagement etc.);
- Infrastructure (brigade stations, fleet, communications, IT etc.) Management.

Corporate areas include positions in the areas relating to environmental planning and assessment, development control, corporate planning, research, finance, information technology, volunteer support, human resources, engineering and executive services, just to name a few.

## 5. Commitment to training in Region North

In 2016, Exercise Northern 16 was held over three days from Friday 18th to Sunday 20th March with the Glen Innes Showgrounds being the main staging point where vehicle were parked and participating members slept, ate and received briefing / debriefings. Members travelled to Glen Innes on the Friday, attended the scenarios throughout Saturday and on Sunday morning, and returned to their home brigades on Sunday afternoon.

Scenarios change from year to year based on assessed needs throughout the region. The scenarios that participants were exposed to during Exercise Northern 16 were:

- Fire Overrun;
- Motor Vehicle Crash (colloquially referred to as an 'MVAs', however, they are rarely 'Accidents');
- Water pumping;
- Back-to-Basics;
- Vehicle Maintenance & Engineering;
- Structure Fire;
- Counter-Terrorism (Conducted by members of the NSW Police Force);
- First Aid;
- Aviation incident (both fixed and rotary wing aircraft);
- Liquid Petroleum Gas (LPG) fire.

**Fire Overrun**: One of the most dangerous events that can occur during fire-fighting is being overrun by fire. Today, the construction of fire-fighting appliances includes the ability of the appliance to provide a level of protection for fire-fighters caught in such circumstances. Appliances have water-sprayers to protect the vehicle, and drop-down reflectorised curtains to protect against radiant heat. These supplement the wearing of full personal protective equipment (clothing) including fire-hoods and the use of fire-blankets so that the fire-fighter is completely covered whilst inside the vehicle. This one-hour scenario provided members with information about the importance of being prepared for such an event, including some strategies for avoiding being caught in such situations in the first place, and the opportunity to practice what to do in the event of a fire over-run.

**Motor Vehicle Crash (MVA)**: Increased vehicular movements on roads and highways make MVAs an all-too-frequent occurrence. Responding to MVAs (and rail and aviation incidents), whether they involve fire or not, can be a psychologically traumatising event, especially for volunteers. This scenario at the Exercise, even though staged, provided a high level of realism, thus allowing members, particularly those who may have not previously attended an MVA, to experience how they might react to a real-life situation. As volunteer, they are not required to attend an incident if they fell uncomfortable doing so. The scenario involved a three-vehicle crash with multiple simulated casualties, including an entrapment, a serious injury and a third patient wandering aimlessly in the vicinity of the crash. It was also simulated that one of the vehicles had caught fire. Being exposed to this type of activity in the exercise situation allows members to make better decisions about their own well-being in real-life circumstances.

**Water pumping**: Without water, fire-fighters are little more then by-standers. Water pumping occurs for a variety of reasons, including: refilling appliances from static water supplies (creeks, dams, swimming pools etc.), a temporary water source established near such a source where appliances might not be able to otherwise access without getting bogged, and transferring water from one appliance to another (i.e. in relay). This two-hour scenario involved drafting, foam application and how to identify and solve problems associated with pumping.

**Back-to-Basics**: No matter how well people are trained, irrespective of what type of activity it is, it never hurts to go back and revisit the basics. Fire-fighting is no different. Fire-fighters, like anyone, can forget, or variations to the correct process can creep into how they go about something. In order to improve and enhance interoperability, all fire-fighters must do things the same way and to the same standard, i.e. in accordance with Standard Operating Procedures. This helps improve the effectiveness of not only fire-fighting operations, but also safety for individual fire-fighters and their colleagues performing fire-fighting activities beside them. Additionally, this one-hour scenario reinforced the use of the Incident, Threats, Actions, Support, and Command and Control (ITASC) approach when performing briefings along with the importance of ensuring the accuracy of information being transferred from the fire-ground to Incident Management Teams (IMTs) and/or the public.

**Vehicle Maintenance & Engineering**: Basic maintenance of vehicles and equipment allocated to Rural Fire Brigades, is the responsibility of the Brigade members, especially vehicle drivers, thus members need to know what needs to be checked and how conduct those checks, not only on the various types of vehicles but also the equipment (e.g. pumps and chainsaws, etc.). It is necessary to know the correct location and procedures and lifting (tilting) truck cabins, accessing dip-sticks and air-filters etc. Incorrectly accessing, removing and/or replacing these could result in damage to the vehicle thus rendering inoperable for fire-fighting purposes and incurring costly repairs. Members attending this scenario were provided with practical skills for maintaining appliances and pumps, and viewing the latest prototypes of appliances and PPE improvements.

**Structure Fire**: Although the name Rural Fire Service has it's origins in bush fire-fighting, the RFS is responsible for responding to all types of fire and emergency-related incidents that occur outside populated urban areas where Fire and Rescue New South Wales are the primary response agency. This includes, in some instances, urban areas on the outskirts of Sydney and other major population centres. In rural areas the RFS responds to fires in houses, farm sheds, caravans and any other structure if might be affected by fire. In some areas, RFS members are also trained in the use of Compressed Air Breathing Apparatus (CABA) equipment so as to be able to perform fire-fighting and/or rescue in structures that are alight. Topics covered in this scenario included positioning of appliances, hose-work and Crew Leader responsibilities. The demonstration of hose work in this scenario, utilising actual fire in a caravan to simulate a structure fire, was particularly useful for members as it included a technique for conservatively and effectively applying water onto a fire inside a structure.

**Counter-Terrorism**: This scenario was conducted by members of the New South Wales Police Force's Anti-Terrorism & Security Group. It comprised the provision of information on the history of extremism and global terrorism, and some of the signs to look for when responding to and fighting fires that might occur particularly in remote areas, especially if they are without any reasonable indication as to how they started. The importance of this type of instruction cannot be overstated. Extremists frequently travel to remote areas to practice or perfect whatever it is they plan to cause and create death, devastation and fear into the community, and RFS members are generally the first on-scene, or the only agency to respond. The ability to recognise suspicious, or possible terrorist-related situations, not only could save their life, or the life of a colleague, it could also provide the statutory investigative authorities with valuable information and evidence.

**First Aid**: Heart attack and cardiac-related conditions is one of the biggest causes of death amongst fire-fighters during fire-fighting operations. Knowing the signs of these types of conditions, and how to provide first aid to those suffering them, could well be a life-saver. This includes how to use an Automatic External Defibrillator (AED) that is carried on many of the RFS's vehicles, and how to perform cardiopulmonary resuscitation (CPR). Snakebites are also possible when conducting fire-fighting operations in the forests and open spaces. Participants were also shown the most recently approved method of bandaging a snakebite victim during this two-hour scenario which was conducted by Paramedics from the Ambulance Service of New South Wales.

**Aviation incident**: Actual fire was utilised during this scenario which included both fixed and rotary wing aircraft and casualties (dummies) in the vicinity of the aircraft. Positioning of appliances and angle of approach are particularly relevant when responding to this type of incident. Fire-fighters need to be cognisant of the possibility of aviation fuel exploding, and the presence of metals, alloys and composite-fibre materials that are sometimes used in aircraft construction and might be hazardous to humans, along with tensioned cables and other hazards. Members were required to safely approach the scene, suppress the fire, and extract the victim during this one-hour scenario whilst also being cognisant of the need to preserve the scene for transport safety investigators.

**Liquid Petroleum Gas (LPG) Fire**: This scenario also used actual fire and required crews to use a three-man fog attack to suppress a gas fire in a barbecue. The intensity of the explosion of a pressure can filled with gas was also demonstrated during this one-hour scenario.

## 6. Awards and Rewards

**In addition to the personal rewards that each** member received individually by way of improved knowledge and skills from attending and participating in the Exercise, it is important to also have some formal rewards. During the debriefing, at lunchtime on the Sunday, the annual exercise awards were announced. The recipients of these awards, along with the prizes and sponsors, are listed hereunder.

- "The Alan Brinkworth Perpetual Award" for Outstanding Crew: Prize - $500 from Gilbert & Roach Isuzu: Gladfield Maryvale Brigade, Queensland Fire and Emergency Services (QFES)
- Best Strike Team Leader: Prize – Mini I-Pad from RFSA valued at $1,000: Ken Barker, Northern Tablelands
- Best Crew Leader. Prize - Mini I-Pad from RFSA valued at $1,000: Nathan Greaves, The Hills (Region East)
- Committee Encouragement Award. Prize - $500 from Gilbert & Roach Isuzu: Dianne Fellows & the Catering Crew, support members from various Districts from throughout the Region
- Committee Encouragement Award. Prize - RFSA Voucher for $500: Brayfield Dury Liverpool Range Zone
- Outstanding Support Person. Prize - RFSA voucher for $250: Alan Minty, Namoi Gwydir RFB
- Outstanding Crew Member. Prize - RFSA voucher for $250: Steph Greacen, Mid-North Coast District
- Best presented Appliance. Prize - RFSA Voucher for $500: Crows Nest Brigade, QFES
- Best presented appliances – Runners up. Prize - Grease gun & truck wash kits from Gilbert & Roach Isuzu:
    - North Shore1, Mid Coast
    - Hattonvale, QFES
    - Woodenbong 1, Northern Rivers
    - Southampton 1, Clarence Valley

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Captain Laurie Sherwood, Karangi Rural Fire Brigade, NSW Rural Fire Service, Karangi (near Coffs Harbour).

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# The analysis of the causes of accidents and technical support of the intervention activities in traffic accidents

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**Abstract**

The issue of traffic accidents is a serious social problem in all spheres of human activity. The members of the Fire and Rescue Service of the Ministry of Interior of the Slovak Republic (HaZZ MV SR) are involved in resolving them in terms of saving persons and property. The article deals in the first part with the legislation and factors affecting the operation of fire-fighting units of HaZZ MV SR. It also deals with analysis of the causes of accidents on the roads. An emphasis is laid on the analysis of intervention activity of units of HaZZ MV SR and on the forecast for the year 2020. In the next part of the article, technical support of intervention of fire fighters in road accidents is designed.

*Keywords*: traffic accidents, accident statistics, fire-fighters, extrication technology, intervention;

## 1. Introduction

An issue of traffic accidents is a serious social problem in all spheres of human activity and therefore requires a comprehensive and rational approach. The first car accident with fatal consequences for the driver was on a London street back in 1898. A merchant, while driving downhill, passed the permitted speed limit of thirty kilometres an hour and after a brake failure the car crashed into a tree. [1]

The authors of the article focused only on certain aspects related to the traffic accident rate on roads and on technical support of intervention activities.

## 2. Traffic accidents and their causes

Traffic accidents are a daily occurrence in our roads, so it requires close attention to all traffic participants and also the preparedness of each unit of the integrated rescue system (the "IRS). In the event of an incident, coordinated cooperation of IRS units, the Operations Centre and the other parties involved in intervention activities is necessary, the Operations Centre and the other parties involved in intervention activities.

By the term of law traffic accident is an event in traffic which becomes directly related to traffic vehicles and where [2]:

- A person is killed or injured (any injuries),
- On road (motorways, roads, local or utility roads) are damaged or charitable bodies (eg. road signs, electricity pylons etc.)
- A leakage of dangerous materials (hazardous for humans and the environment) occurs ,
- The damage higher than one and half of more damage under the Criminal Code occurs on some of the participating vehicles including the transported objects or other property.

Traffic accidents can be divided according to various criteria. In the Slovak Republic ("SR") The Police separate traffic accidents, for example by:

- the nature of the injury (fatal, heavy and light);
- alcohol use (up to 0.48 mg / l and more than 0.48 mg / l),
- participant (driver, motorcyclist, cyclist and pedestrian, citizen and non-citizen),
- provinces and police districts,
- time (day or night),

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– visibility (decreased and non-decreased)
– the type of communication (highway, expressway, road I., II., III. classes, and other);
– sex (man or woman), etc.

Every year, the statistics of traffic accident point to the major problems in the use of traffic vehicles. Overview of road accidents and their consequences for the years 2002-2015 is shown in table number 2.

Tab. 1 Review of basic statistical indicators of traffic accidents for the years 2002 to 2015 [3]

| **Year** | **Count of TA** | **Consequences of traffic accidents** | | |
|---|---|---|---|---|
| | | **Death** | **Severely injured** | **Slightly injured** |
| 2002 | 57 060 | 610 | 2 213 | 8 050 |
| 2003 | 60 304 | 645 | 2 163 | 9 158 |
| 2004 | 61 233 | 603 | 2 157 | 9 033 |
| 2005 | 59 991 | 560 | 1 974 | 8 516 |
| 2006 | 62 040 | 579 | 2 032 | 8 660 |
| 2007 | 61 071 | 627 | 2 036 | 9 274 |
| 2008 | 59 008 | 558 | 1 806 | 9 234 |
| 2009 | 25 989 | 347 | 1 408 | 7 126 |
| 2010 | 21 611 | 345 | 1 207 | 6 943 |
| 2011 | 15 001 | 324 | 1 168 | 5 889 |
| 2012 | 13 945 | 296 | 1 122 | 5 316 |
| 2013 | 13 586 | 223 | 1 086 | 5 225 |
| 2014 | 13 307 | 259 | 1 098 | 5 519 |
| 2015 | 13 547 | 274 | 1 121 | 5 628 |

Table 1 shows that in past years The rate of accidents on the roads of the Slovak Republic significantly decreased, although in 2015 274 people was killed on the roads, which is 15 people more than in 2014. Table number 3 shows ten major causes of fatal traffic accidents and accidents that happened in 2015.

Tab. 3 Major causes of traffic accidents in 2015 [3]

| **Fatal traffic accidents** | | **Traffic accidents** |
|---|---|---|
| 1. | Breach of duties of drivers (Failure to take care to driving, talking on the phone, etc.). | Breach of duties of drivers (Failure to take care to driving, talking on the phone, etc.). |
| 2. | Inadequate driving speed | Inadequate driving speed |
| 3. | Wrong way of driving | Wrong way of turn and reverse |
| 4. | Breach of assessments of pedestrian | Wrong drive through crossing |
| 5. | Wrong drive through crossing | Breach of duties of traffic participant |
| 6. | Wrong way of outrun | Violate of the distance between vehicles |
| 7. | Breach of duties of traffic participant | Wrong way of driving |
| 8. | Wrong way of turn and reverse | Breach of assessments of pedestrian |
| 9. | Incorrect behaviour at rail crossing | Wrong way of turn |
| 10. | Wrong drive in driving lane | Wrong way of outrun |

## 3. Technical support of rescue services in traffic accidents

One of the conditions of rescue and subsequent evacuation of trapped persons from vehicles in traffic accidents is the use of appropriate technical means of Fire and rescue services.

These technical means may include automobiles of fire and rescue services and breakdown equipment. Automobiles are divided into different types on the basis of the construction and assumed designation (Tab. 4) [4].

Tab. 4 Types of automobiles of fire and rescue services [4].

| Type | The possibility of using the automobile |
|---|---|
| 1 | Complex interventions in road accidents, technical interventions and fires |
| 2 | Complex interventions in road accidents |
| 3 | Elemental breakdown and rescue works in traffic accidents |
| 4 | Severe breakdown and rescue works in traffic accidents |
| 5 | Disposal of leaks of hazardous substances in road accidents, |
| 6 | Early intervention and command of intervention. |

The most significant and most frequently used vehicle is the type AHZS 1B – MB Atego 1529 4x4 AF vehicle (Figure 2). Besides other functions, this vehicle is also intended as the initial vehicle of fire and rescue service of type 1B in traffic accidents.

Its equipment allows, among other things:

- recovery and rescuing people in the crash of vehicles on roads,
- lighting the place of the accident (intervention)
- lifting of the crashed vehicle outside the road and make the communication passable,
- fire intervention with water or foam. The vehicle is equipped with a tank of 3000 litres of water, 250 l foamer and powerful combination Centrifugal pump.


Fig. 5 AHZS 1B - Mercedes Benz Atego 1529 AF 4x4 [5].

For basic activities, while intervening in traffic accidents, the firefighters use special equipment designed for rescuing people from crashed vehicles. This equipment is an integral part of furnishing of firefighting units. It can be divided into:

- hydraulic extrication equipment,
- pneumatic lifting and sealing bags,
- manual extrication tools,
- other equipment and tools.

The most important hydraulic extrication equipment products include:

- *Hydraulic cutters* that firefighters used to cut the pillars, roof reinforcements, door hinges, cutting solid material or steel ropes (Fig. 6). Shear force on the hydraulic cylinder tool and on working pressure which is in the range of 35-72 MPa. Shear force is greatest at the pin of the hydraulic shears. Cutting springs and hardened steel is prohibited.depends

Fig. 6 Hydraulic rescue cutters [6]

- *Hydraulic expansion spreaders* (Fig. 7) are used for opening the door by spreading or pushing the parts of the vehicle (the door). The expansion force of the working part may reach 6-20 tons.

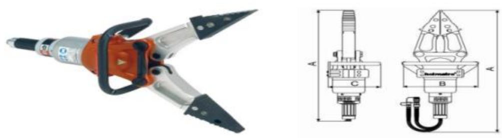

Fig. 7 Hydraulic expansion spreaders [6]

- *Hydraulic ram* (Fig. 8), which is used as an expansion device where the length of the spreaders jaw opening is insufficient.

Fig. 8 Hydraulic space ram [6]

Recovery tools have a decisive influence on giving the first aid to wedged persons in vehicles. Especially in the recent time period, the demands on the performance parameters of hydraulic rescue tools when recovering people in traffic accidents in connection with the Railroad traffic are rising.

Statistics of fire-fighting units' intervention activities was monitored for 14 years, which showed that a number of technical interventions grows and the number of interventions in traffic accidents Decreases very slightly. Table No. 4 and 5 [7].

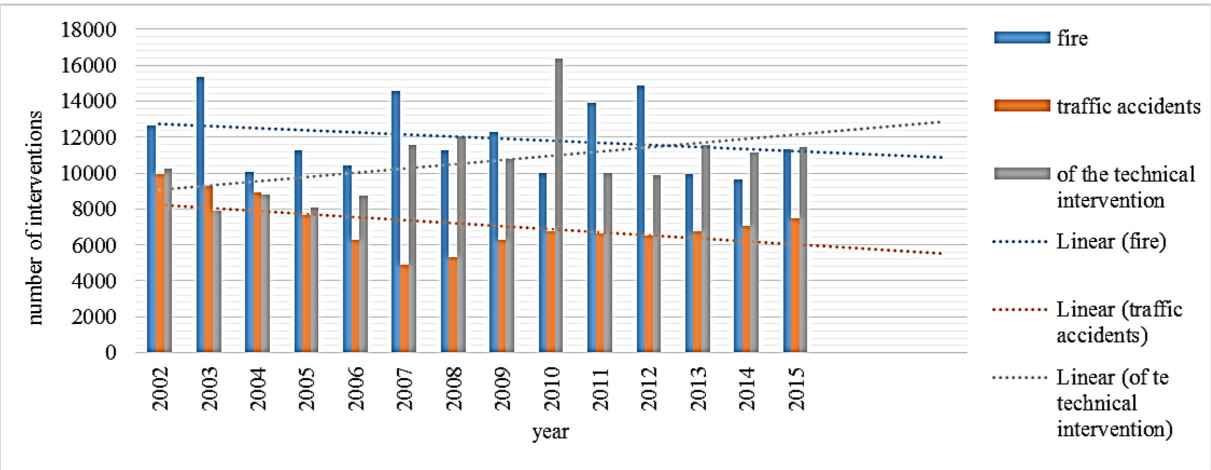


Fig. 9 Intervention activities of Fire and rescue services in 2002 – 2015 and prognosis to 2020

Tab. 5 Intervention activities of Fire and rescue services in 2015 [7]

| Intervention activities | Number of intervention |
|---|---|
| Fires | 11 317 |
| Technics intervention | 10 509 |
| Hazardous substances | 920 |
| Traffic accidents | 7 466 |
| False alarm | 618 |
| Exercise | 1 176 |

From the statistics of the intervention activities, it is clear that the majority of them were technical interventions, and it was about one third more than fire interventions. Two thirds of technical interventions was traffic accidents, which means that preparedness of emergency services to these types of interventions is important and it is necessary to set focus towards education and training.

## 4. Factors affecting intervention activities

A number of factors can impact an execution of intervention, the most important of which may be classified as legislation, type of a crashed car, freight, an area in which the intervention is carried out, available technical equipment of Fire and Rescue Service, etc.

The most significant legislation can be listed as follows: The order of the Ministry of Interior nr. 162/2006 of Codex about properties, specific operating conditions and regular security controls of firefighting technics and material means to protect against fire [8].

Tactical and methodical procedures of intervention. Methodical sheet no. 90. Topic: Actions of Fire and Rescue Services - traffic accidents on roads, which defines traffic accidents and types of accidents in terms of Fire and Rescue (differently from the Legal definition), and assigns rescue operations tasks and procedures in a traffic accident. [9]

Traffic accident is defined as an event in traffic, during which an injury, death or property damage occurs as the direct result of traffic motor or non-motor vehicles [9].

Types of traffic accidents [9]

- *Simple car accident* - an accident in which one person was Slightly injured or One person was injured severely Or if one person was killed,
- *Mass Traffic accident* - an accident in which five people were Slightly injured or Three people were injured severely, there was at least two people killed, or there was five or more vehicles,
- *Traffic accidents with dangerous substances* - traffic accident of vehicle carrying a dangerous substance, with the risk of leakage of the substance into the environment with the consequent of threat to the population.

Factors resulting from traffic accidents which complicate fighting activities:

- the condition of crashed cars:
  - type of vehicle,
  - sharp edges,
  - leakage of dangerous substances (hereinafter „DS"),
  - battery disconnected,
  - difficult access to crashed vehicle,
- the place of the accident:
  - heavy traffic,
  - enclosed terrain,
  - inaccessible terrain,
  - broken glass,
  - long distance from water sources ,
  - the presence of DS,
  - unpredictable behavior of accident participants, as well as bystanders.
- traffic accidents participants:
  - numbers of rescued and evacuated people,
  - type of injury of people of different age,
  - position of stranded driver and any passengers in the vehicle,
  - various distorted and incomplete human remains of different ages,
  - unpredictable behaviour towards intervening firefighters,
- transported cargo:
  - the type and amount with an emphasis to SD,
  - method of fixation or loading,
  - the need for reloading the cargo to another vehicle
- others:
  - lack of information,
  - lack of appropriate forces , principally technical means,
  - threat from transported animals, etc.

Road accidents in which Extrication equipment is used, SD leaks are disposed of or there is a need to haul vehicles from depth or heights Fall into the technical interventions category. Traffic accident at which the vehicle caught fire falls into category of fire interventions caused by traffic accidents with cause of a traffic accident.

## 5. Conclusions

Firefighting units are ready to intervene and help those in need in traffic accidents. The statistics of traffics accidents constantly gives us information about its development, and although there is a reduction in the number of traffic accidents, the numbers are overall alarming. The individual factors of intervention activity depend on the particular situation, of Firefighters training and intervention units' facility. In recent years there is a growth in the number of accidents at railroad crossing where there are many vulnerable people, and therefore it is necessary to pay special attention to the training of firefighters and to equipment with technical means to facilitate an intervention in different conditions.

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# Section C – Crisis Management and Crisis Situations Coping

# Process of organizations renewal damaged way interaction of extraordinary events in consideration of increase in security population

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**Abstract**

Paper is geared on arbitration the present state organizations renewal way interaction damaged extraordinary events in the Slovak Republic. Extraordinary event occurring on homestays lands innumerable a lot of. From several statistic sources results, that in the Slovakia be featured causes damages way interaction flood. Additional often reasons damages be able to spring flood, wash under roads, slump. Boundary unique reasons belong earthquakes, snowy avalanches, terrorist attacks, industry accident damage, accident damage nuclear energy furnished and last but not least this be able to too military conflicts. Flood to our lands come into being mainly in the following extreme collision, vehement crease of temperature by the high supply snow in the trot round, storm rainfall collision by the storms, but also following strong crease of temperature by the frozen water - course. Individual these hazards can they endanger substantially attributes, environment, but also life and health nation. Processes organizations renewal damaged way interaction is safeguards depression the material loss on lands and life settings and of course too increase in safety population in the infliction of areas of extraordinary event. In the introduction article are described ground activities renewal the land interaction during extraordinary event. All needs information is draw from Methodical direction on realization furnished economic mobilization. Paper further approaches single stage renewal damaged way interaction. In fine is characterized analysis by the organizations renewal damaged way interaction concerning increase in safety population on lands Slovakia's republic. Entireties process of are trained - in in brief patterns of, who particular point from this patterns of are dismantled to detail. She divided by is on two stage, who be also detailed specify. Examination too difficult of the process to loll against several individual areas of such as too by over predicamental planning and predicamental managing in Slovakia, who are dismantled in last two portions of hereof article.

*Keywords*: defective way interaction, special events, flood, safety of population, economic mobilization, Slovak Republic, organizations renewal, risks, crisis planning, crisis managing;

## 1. Introduction

Today's time with brings different special events, those ravages induce large damages of way interaction on lands Slovakia's republic. Be talking above all about flood, who what - once more frequently come into being to our lands. In the article are simplification described the main activities renewal the land interaction during extraordinary event, subsequently stage renewal the damaged way interaction and in conclusion article are dismantled analysis by the organizations renewal the damaged way interaction concerning increase in safety population on lands Slovakia's republic. All necessary information is draw from required documentation operating organizations renewal the damaged way interaction but also through the medium counsel with specialized worker the specialisation transport – department road districts of Trencin autonomous region.

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**2. Main activities renewal the land interaction during extraordinary event**

In this part of article to survey on individual rules operating maintenance and renewal the land interaction during extraordinary event. We elaborated proposition of renewal the land interaction in detail. A part of maintenance land interaction we elaborated only widely. Individual these rules result from methodical direction on realization furnished economic mobilization – organization planning motoring safety, concrete is concerned of the fifth a part of – maintenance and renewal land interaction, building - up substitute way bridged. [1]

In the realm of ordinary and building maintenance in the terms critical things performative mainly these single activities:

- safety continual negotiability roads,
- strain - hardness and modification border stone,
- dressing cracks and chinks, filling road hole, levelling strip mine lake roads,
- alleviation of obstacles way traffic,
- alleviation of obstacles prohibitive outflow waters in the ditches and sluice,
- jury application or renewal damaged the bridge little span in 3m,
- execution of a project motoring marks and his renewal,
- determination and marking circumvention. [1]

Cleaning roads from surface interaction remove objection substance and impurities, who aggravate safety of running, but also hygienic and protection life settings. In the terms critical things is cleaning mainly geared on the disposal:

- deposits earth (e.g. loam, mud) et alias cloth on roadway (e.g. stones, branch, bushes), who oneself can they bearing flood deposit on way interaction (Fig. 1),
- remains crash cars and its cost filling, who escaped accident injury,
- the material, who in transit fell from car, remains inert the material after winter maintenance. [1]

Fig. 1 Drift obstacles on way interaction [2]

Polluting the material by kind and arrays of removes:

- bestrew sorptive the material and sweep (mechanic or by hand),
- recapitulating (by hand or through the medium ploughshare, or by other mechanization yard furnished),
- sanitary wallpapers flush and below.

At need polluting the material will load and removal on designated place (dump dangerous waste, communal waste and below.). By the flood, who are on lands Slovakia's republic frequently exist maintenance on land interaction understand above all disposal various deposits earth, stones, branch, trees and in like manner, who flood deposit on the way interaction. Removal individual the material and deposits, who are on way interaction influence flood find safeguards at the hand of motoring and mechanization yard haemostats of propriety Slovak road districts. [1]

*2.1. Period renewal the damaged way interaction*

Renewal roads in the condition crisis things and after crisis things be the introduction of upset or destructions roads or object and devices, who they are her a part of, into service able the condition namely by either on reduced or primal operation parameters. Depending of time concluded on renewal, area destruction, powers and haemostats, that are in concrete area available and availability renewing the material, renewal performs in the of three stage:

- 1st period – short - time renewal on transit cars at speeds of min. 20 $km.h^{-1}$,
- 2nd period – temporary renewal on transit cars at speeds of max. 40 $km.h^{-1}$,
- 3rd period – entire renewal in interim. [1]

In applying the provision individual tasks general focus present renewal:

- earth carnality,
- little artificial buildings (sluice, walls of, draining device and below.),
- little highway bridge, with waste ready prefabricated element,
- highway bridge, with waste of engineering documentation and the material substitute way leap fronts,
- highway bridge, female former temporary bridge, after manipulated skeleton assistance scheme and with waste the material standby supply or mobilization reserves. [1]

Short - time renewal is generally realizing renewal an earth carnality convenient the material, generally is concerned loam, stone, macadam, who from aspects directional and level ratios, but also carrying capacity provide for required basis of position roads with the gravel covered. Gravels cover must be thoroughly rammed. On infilling cavity at top portions of gravel cover oneself utilizes hardening mortar totalled mix sand, loam or clay. [1]

Temporal renewal way interaction (Fig. 2) is realizes on base skeleton assistance scheme, who in the terms crisis things will draw up competent person id Est authorized projector or authorized civil engineer on base demand Transport Ministry, building - up and regional development, let us say VUC. [1]

Fig. 2 Temporal renewal way interaction

By the temporal renewal is how pavement utilizes recoated aggregates of stones, cement mortar or

blockhouse panel inflict upon especially trim gravel - sand layer. In the event of a great area destructions roads and objects on them oneself is renewal be resolving built underground slip road. By the building slip road be needed:

- trace route slip road,
- modify convention and exit on steady way interaction,
- modify (plane) terrain and remove barriers on route slip road in the width min. 5m,
- strengthen way interaction rammed her surface blinding measures or saved blockhouse panels.

Pro activity renewing units by the renewal land interaction is utilizes traffic engineering, means of mechanisation, tools and aids, with who disposes subject economic mobilization in the state of safety. Completion failure techniques and personnel be on the terms crises things realized through propriety district authorities form matter - of - fact filling, resp. working incident. In the period after over crises things, require provide for total renewal land interaction. [1]

## 3. Analysis by the organization renewal damaged way interaction concerning increase in safety population on lands of the Slovak Republic

All procedure relative organizations renewal the way interaction damaged extraordinary events is too complex and demanding operation. Examination of such difficult of the process is attachment for several individual areas of such as too by over crises planning and crises managing on lands Slovakia republic. Process individual step by the renewal we are draw in organizational patterns of (Fig. 3) and subsequently also in progressive step.

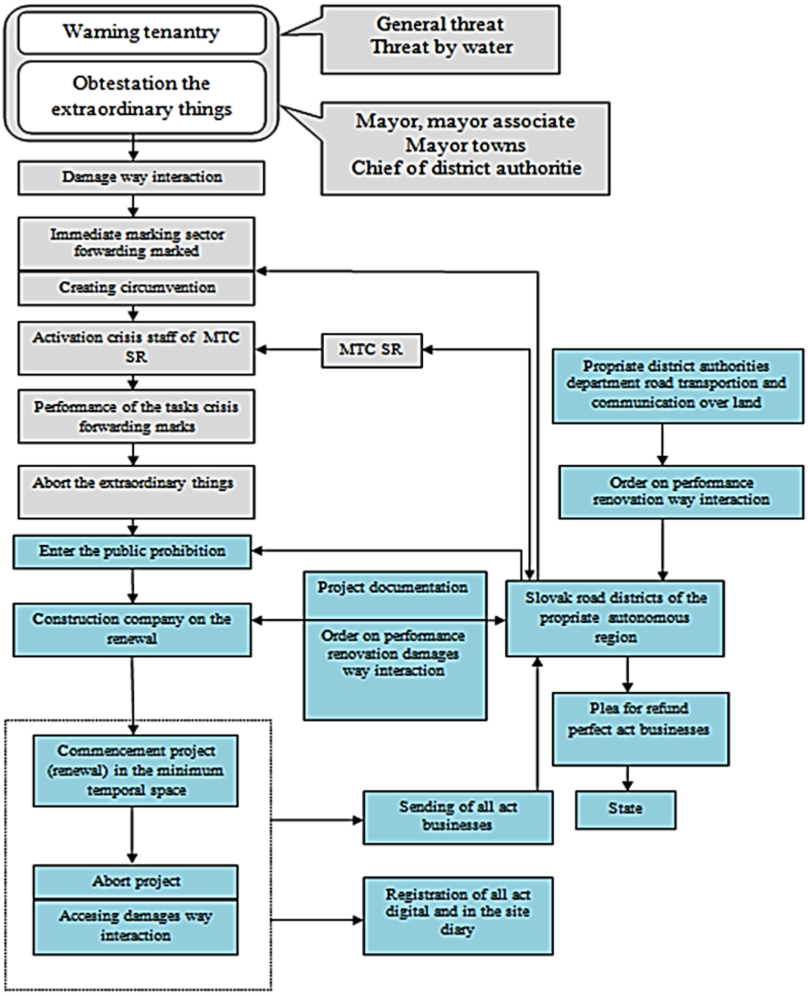


Fig. 3 Diagram organizations of renewal damaged way interaction

In general maybe renewal way interaction damaged extraordinary events break up into two terms (Fig. 4).

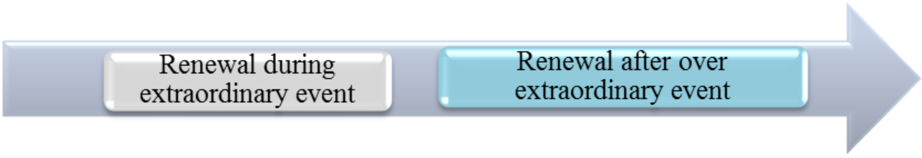


Fig. 4 Terms renewal

Organization diagram depicts compendium renewal damaged way interaction II. and III. classes on lands Slovakia's republic. Blue colour in the diagram depicts period after over extraordinary events and grey ointment colour depicts period during extraordinary events. Subsequently we are organization planning renewal specify too in gradual steps:

1. Warning tenant - is performs the warning signal and this by either common threat or threat by water.
2. Attestation extraordinary things - (e.g. degree flow activities) extraordinary situation testify mayor, or mayor in the village, town; chief district authorities in the territorial district and chief district authorities in the residence region on lands region. anger appropriate water - course designs proclamation and appeal degrees' flow activities.
3. Damage way interaction - area destructions be able to various, depend this of accidental character extraordinary events.
4. Marking sector forwarding marked, creating circumvention - Slovak road districts appropriate region it safeguards, where special event come into being.
5. Activation crisis staff of MTC SR - coordinates activity chosen terminal economic mobilization in the process of solution crisis event.
6. Performance of the tasks crisis forwarding safety during extraordinary things.
7. Abort extraordinary things - end threat or end ction results extraordinary events is testifying two - minute constant tone sirens without having rep (signal – extremity threat).
8. Import public order - safeguards appropriate Slovak road districts through divided public acquisition. Is concerned enter order on performance building work (renewal damaged way interaction).
9. Firm on safety renewal damaged way interaction - renewal performs firm, which he won selection procedure by the sponsor embargo on renewal damages way interaction. All acts businesses must be considered to be chronicled not only does digital but also single acts must be presented in site diary. All these acts are transported on appropriate region (owner roads II. and III.) and the he asks state by over refund building work.
10. Opening project in the minimal temporal space.
11. Financing public order - financing individual tasks on renewal damaged way interaction oneself generally receives by either from state budget SR or from sources European union.
12. Release damages way interaction - start to be after over building work appropriate businesses, which exercised renewal damages way interaction. [3]

### *3.1. Renewal way interaction during solution extraordinary events s*

Renewal way interaction is binding preferentially on crisis state. The crisis state induces special events levels III. and IV, is able to concern natural catastrophe, such as flood, warfare or war. Function transport and way interaction is in a certain territory or on lands impaired. Renewal working way interaction and transport is not to be possibly without having onset special powers and haemostats for example subject economic mobilization. [4]

High level in the management transport introduces MTC SR. Government department performs quite a number of activities, between who belongs too regulation activities directly submissions organs, specialist state news on sector transport, between who belongs too construction, working and maintenance and renewal land interaction. Government department guards too arrangements to solve individual questions on sector transport, including the furnished safety during solution crises state. Bottom-of-the-line model crises managing on sector transport be possible co - ordinate single stage:

- prevention creation crises event,
- crises planning in the forwarding secure,
- response to crises event in the transport,
- solution crises event in the transport,
- **renewal transport process and forwarding infrastructure after over crises state:**

- performance renewal forwarding infrastructure after stage,
- renewal working and forwarding infrastructure in asking qualities, melds and area outside the crisis. [4]

In solution the crises event in the transport input transporter, organizations performing message, maintenance and working forwarding infrastructure, but also different external subjects. During solution crises event oneself performs restraint on damaged way interaction, cut - down performance. or performance individual mode transport. Crises cartage short hedging performs during crises situation and come under furnished economic mobilization. Boundary responsibilities organizations crises motoring safety belongs too maintenance and renewal land interaction. [4]

### *3.2. Renewal way interaction after over extraordinary events*

Renewal damaged way interaction is after over predicamental phenomenon performs generally after integrated stage. Primary objective aim of these stage is first place full sail re - issue working too at the expense of constraints performance and wholes qualities transfer of the process. Individual cartage building and devices re-established with waste provisional construction such as alternate way leapfrog they are gradually builder how always building.

Realization renewal damaged way interaction be very complicated and difficult process. After over crises state is renewal fully in the competence individual executive elements transport system too with external building firms. Sections and trade unions department transport watching the course renewal. During course renewal oneself declare null and void crises measures in the department, crises staff for is no active. Transport will be performing only with waste ordinary cost limited. [4].

## 4. Conclusions

Topics our article was she organization planning renewal way interaction damaged extraordinary events. Renewal way interaction damaged extraordinary events is wide theme with the its specification macro from look categories reinsertion land interaction, predicts crises state, area damages way interaction, disposition and haemostats, public acquisition, financing, levels of recovery management and various of other factors. Primary objective aim this article has been described theoretic apparatus solution renewal way interaction damaged extraordinary events on lands Slovakia's republic. Complex processing solution proposition would its area high overrode demands area hereof article, because we are in the proposition in compose only main information about this topic. Process renewal damaged way interaction after over crises event is lengthy and difficult process of, whom we had present bigger focus concerning temporal, cartage, substantially, organizational safety and last but not least too on safeness population.

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# Security of the Slovak Republic and issues of protected interests: Security and criminal law research topics

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**Abstract**

To protect a certain interest in an effective way, we have to study and research the subject, its surroundings and the relationships among them. With this, we can also contribute to the fulfilment of one of the functions of the state, which is undoubtedly also the provision of the security of the state as well as the security of citizens. The security of the state is estimated as a term in relation to a large entity and the safety of a citizen is understood as a relationship of an individual, e.g. the protection of the life and health of the individual as well as of his/her property, rights and interests.

*Keywords*: security, law, protection, protected interests, research;

## 1. Introduction

According to the security and law aspects, it is necessary to emphasize the complexity of our research and the professional preparation of the staff primarily for the courses and disciplines which are focused on the issue of security and law agenda, security management, crisis management, on the public administration and on the field of defence, protection and rescue, on the area of economic mobilisation as well as on the issue of civilian temporary planning, emergency planning, the protection of citizens, fire protection of people and property, the protection of classified information, personal security, copyright, trade secret, and the media community etc. The work with talented students, especially during their research for their PhD degree, who shall be the followers of our universities is a guarantee of further development and formation of newly forming groups and subgroups of the Department of Science and Technology of the Slovak Republic, maybe the "security disciplines", also integrating the key departments for the research of the provision of protected interests of the state and citizens as well.

## 2. Identification of problem

The scientific-research work and also the professional preparation of specific selected security and law community is realised within the framework of the security and law research and education (education, training, and practice) in the following way: by the means of studies and education, by the means of scientific research and by the means of the performance of security and law practice.

In line with the OECD organization – The Organization of Economic Cooperation and Development (Organization for Economic Cooperation and Development in Europe) we can identify the security sector in the country as a system of the following components:

- "the key safety actors"
- the safety management of the state
- the institutions as a subgroups of the Department of Home Affairs and Justice,
- and private security organizations. [1] OECD

The selected employees of particular components of the security sector in the states create a targeted group for graduate students of the security and law study fields. The main aim of this professional training

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of the staff therefore requires a systematic transfer of the information gathered from the security and law discipline research into the security and law education and practice.

*2.1. Issue of protected interests*

Synthetic understanding of the security disciplines is a profoundly explored discourse and in many aspects, it leads to a professional discussion regarding the interdisciplinarity, logical-structural relations of professional, technical, legal and social subjects especially within the issue of protected interests.

This investigation has suddenly faced a number of challenges, particularly those of epistemological and systemic nature:

- the problem of the subject and content of security sciences;
- difficulties considering the definition of the main directions of the security disciplines construction;
- the relationship between dominant and subsidiary disciplines,
- methodological issues and determination,
- the possibilities and reality
- subjectivist risks, etc. [2]

According to professor Porada, the contributions of particular social science disciplines to the security disciplines create the following relationship for example: Legal sciences, criminalistics and criminology are the base of the security disciplines, belonging to the set of social sciences. A crucial role is played by criminal law and administrative law with its impact on the theory of security, methodologies and methods of its activity. The criminology is not a part of the security discipline, but according to a concept assessed, it forms the base for addressing various security situations, it contributes to the definition of the subject of the security discipline and fulfils certain methodological features for emerging professional security partial theories, e.g. operatively searching activity etc. The process of constitution of the security discipline also doesn't expect mechanical application of the criminology knowledge. The position of criminology in relation to security can be described by means of a theoretical-methodological and by means of an instrumental connection and mainly by means of the application of criminological knowledge in security activities. [3]

Scientific knowledge and characteristics of security risks, security threats, crisis situations and corresponding specification of measures and tasks in the field of security is perceived as the basis for the protection of people and property within the framework of crisis management in public administration.

The classification of these tasks, the structure, power and resources for the crisis management corresponds with two qualitatively different states of the society; the state of society in a peacetime, contrary to the situation at the time of a state of war threat, or at war.

This approach corresponds to the traditional division of the state security for an internal and external dimension, more precisely in the time of building and development of the necessary skills:

The building and development of defence competences

The building and development of the protection competences

The building and development of rescue competences.

The basis for a systematic approach within the "security disciplines" is the protected interests of the state. Based on the national security definition in the Constitutional Act No. 227/2002 of the Body of Laws, the following protected interests may be identified: the provision of sovereignty, territorial integrity and intangibility of borders; the protection of human lives and health; the protection of property; the protection of fundamental human rights and freedoms, the protection of the economic interests and environment. [4]

Protected interests of the state represent a strategic subject of the "security disciplines" investigating the reality through unique research areas characterised by selected subjects of the research and the application of relevant theoretical and methodological approaches for study in this field.

The 2005 Security Strategy of the Slovak republic defined the essential bases of the Slovak security policy realisation and security interests aiming at guaranteeing a required and historically possible level of security of citizens and the country.

The security interests of the Slovak Republic are based on the principle of guaranteeing the security of citizens in line with international legal norms and the constitution, and they are also based on basic civil and democratic values. The Slovak Republic respects and protects the values of liberty, peace, democracy, legal state, lawfulness and justice, plurality, prosperity, solidarity and respect for human rights and freedoms.

The Slovak security interests result from the following values:

- the guarantee of the security and protection of essential human rights and freedoms of citizens;
- the guarantee of the territorial integrity, sovereignty, intangibility of borders, political independence and identity;
- democratic state system, lawfulness and market economy;
- economical, social, environmental and cultural development of the society;
- transatlantic strategic partnership, co-guarantee of the security of the allies;
- the effectiveness of the international organisations a member of which Slovakia is, the support of the expansion of NATO and EU;
- the development of good partner relations and forms of co-operation with the countries we share common interests with;
- the support of the spread of freedom and democracy, the compliance of human rights, lawfulness, international order, peace and stability in the world. [5]

The Slovak Republic, as a NATO and EU member focuses on fulfilling its commitments and on an effective utilisation of the collective defence. The Slovakia's membership in these organisations changed its security position in a significant way and it has been creating qualitatively new assumptions regarding the realisation of its security interests. Slovakia became an integral part of the Euro-Atlantic security communion, it gained contractually established security guarantees and it became a co-guarantor of the security of the allies. The essential goal of the defensive policy of Slovakia is realised from the Euro-Atlantic position. Slovakia committed to fulfil the commitments resulting from the membership in NATO and EU within the range of a defensive policy, to increase the level of applicability and operational readiness of the armed forces. [6].

## 3. Application of specific methodological approaches to the issue of protected interests

**The philosophical approach** to the issue of protection of persons and property is considered as scientific realism that respects the objective reality when examining the questions related to the security in a complex way, in all dimensions.

**The methodology of resolving the issue of protected interests** within the range of assuring the protected interests results from a **system approach and synergistic effect towards the security and law questions in both the all-society and the individual dimension**.

*The safety of citizens – the protection of their persons, properties and other protected interests must be ensured in all safety dimensions*.

Beyond the scope of the general methodology of sciences, the methodology of police and military disciplines and beyond the scope of the potential of the methodology of legal and practical disciplines, we aim at utilising the following **specific methodological approaches** in order to examine the questions related to the protection of citizens, ensuring their safety or property or a particular protected interest in a complex way [7]:

- the original **Sector Safety Concept of the so-called Copenhagen School** (COPRI – Copenhagen Peace and Research Institut),
- **The OSN Human Safety Concept** (UNDP – The United Nations Development Programme)
- and the forming **safety risk management theory**.

Due to objective reasons it is not necessary to mention that the **state**, being the safety guarantee, is the crucial **referential object according to the Copenhagen school. However, our primary referential object is an individual (a person, a citizen), or a property, or a concrete protected interest**. We respect the fact that the state shall not be considered as safe unless the citizen (an individual) is not safe and vice versa. In a same way, the security environment of the international communion shall not be considered as positive unless their members or their protected interest are "endangered" and vice versa. We can assume that by means of studying and by means of scientific work in the area of protection of persons and property, we usually investigate the safety-legal and technological aspects of the citizen's safety, the property protection or a concrete protected interest.

**4. Research topics focused on the issue of protected interests**

By means of the scientific work of teachers and doctoral students and persons we can contribute to the solution of the following scientific problems, or, more precisely, to the research and development (development and innovation projects) topics:

In the military-police security sector
- the protection of people, property, the protection of the population and the provision of other protected interests in crisis situations caused by the use or the threat of the use of the force,
- the international activities to protect people, property and the provision of the protected interests in conflicts in the fight against terrorism and extremism etc.,
- the police and its activities as a research object,
- the potential intelligence of a democratic state to protect people, property and the protection of security interests,
- the private security and the paramilitary organisations protecting people and property at home and abroad etc.

In the political security sector and the public administration sector
- the reform of the security sector to provide the safety of citizens,
- the security management of each state in terms of the fulfilment of the basic functions of the state to provide the security, protection, defence and rescue of the citizens, property and the provision of protected interests,
- the management of the security systems
- the security-related aspects of protection of persons, property and the provision of protected interests within the law of the Slovak Republic,
- the protection of persons, property and the provision of protected interests in crisis situations caused by non-military threats,
- the crisis scenario elaboration methodology and their verification using simulation technology,
- the decision to support elements for crisis management etc.

In the societal security sector
- the management and the development of the security education,
- the security-related aspects of human rights and freedoms,
- the protection against intolerance, discrimination and extremism to maintain an individual level of security for citizens,
- the fight against human trafficking,
- the trends in the migration policy and the impact of the migration on the maintenance of the required individual and local level of the security of citizens,
- the security-related aspects of the civil and social conflicts,
- the disruption and the prevention of privacy, i.e. the protection of individuals with the regard to the processing of personal data
- selected topics of violation and prevention of the protection of classified information,
- selected topics of violation and prevention of the protection of intellectual property,
- the problems of formation of the sociology security: the security solutions to social problems.

In the economic security sector:
- the protection of the economic interests of personal and legal entities and the protection of the economic interests of the state,
- the crime and economic crime,
- the prevention of the economic crime, the insurance fraud and tax evasion investigation, the breach of commercial confidentiality etc.,
- the legal aspects of security, crime and its prevention in traffic, transport and logistics processes.

The technogenic security sector:
- the safety and human factors in engineering and technological processes,
- the critical infrastructure protection,
- the protection of information, cyberspace, the cybercrime,

– the security of the challenges of science and technology for the individual level of security – security of citizens, protected rights and interests, and the protection of the public.

## 5. Conclusions

International security and law research and development projects as well as institutional projects in the scientific disciplines [8] focused on the protected interests have enabled to connect the potential of the security and law community to improve the theoretical work, performance of its activities and the fulfilment of its commitment. Except for the traditional security sectors according to the Copenhagen School (military, political, economic, societal and environmental sector), we partially contribute to the investigation of newly forming security sectors, such as the energetic sector or information sector, "new protected interests in these sectors". Selected results of the security research are also presented in our common publications.

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# Mental health aspects of crisis management with real examples

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**Abstract**

Mental health can contribute to all stages of crisis or disaster management, specifically pertaining to vulnerability towards disasters during the prevention stage. This article shows the aspects of the Brazilian social structure, which make it vulnerable to the climatic events that affect the country. It endows itself with a sociological concept of disaster, which is defined by a disruptive event of social structure. In addition, it presents the structure of civil protection and mental health as part of management. The paper presents the natural disaster in the Mountainous region of Rio de Janeiro in 2011 together with the mental health work accomplished. Important aspects of mental health and good governance practices are pointed out in order to contribute to current strategies and assist in building effective plans. It is concluded that not only mental health professionals should invest in research and development of good governance practices, but organizations should include, in their structure, the findings and potentialities of mental health to deal with disasters and comply with the plan for more resilient societies. Plans like these should include the adequate preparation of the professionals who will work in-depth diagnostic assessment of the situation and consistent with the culture, just as the development of strategies for empowerment and creation of networks with the community.

*Keywords*: mental health, natural disasters, good governance, community-base, protection;

## 1. Introduction

This paper seeks to reflect on aspects of good governance in the area of mental health, corresponding to disaster management by natural phenomena. In order to do so, it addresses information on the activities of civil protection and mental health work in the disaster that occurred in Brazil, especially the case in the upland areas region of Rio de Janeiro in 2011. This came to be considered the country's worst disaster in terms of deaths, 918 in total, and drove the government to form of prevention plans.

The management of mental health in natural phenomena is not a new field in countries that frequently deal with the disaster, in Brazil, still maintains the dialogue with the civil protection about its action and intervention being able to be carried out in 3 steps (prevention, preparation and response). But, in the state councils of the profession, especially in psychology, there are still debates about the psychologist's best practices in this field.

Brazil is not a country with many major disasters, but its socioeconomic structure affects thousands of people, who sometimes do not have the necessary conditions, for example housing, the access to health and the education. These people are living in unsuitable places for housing that are the most vulnerable to the climatic events that affect the country. For the design of mental health interventions, it is important to measure the effects that catastrophes, whether direct or indirect, have on human mental health, and this will depend on the relationship between factors such as vulnerability, personality and type of disaster. Professionals should bear in mind that the concept of trauma is not the only operator in the face of mental health interventions, and that a major focus has now been given to community-based strategies, that is; important community characteristics should be considered. Disaster management plans should address the complexity of the social structure as well as the perception of risk by the population. The latter being essentially an activity related to the prevention phase. Humanitarian and volunteer professionals should be trained and assisted

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from the look of mental health. Thus, the present article addresses the good governance practices associated with mental health performance in the field of emergencies and disasters and the following question is asked to formulate this work: What would be the components of good governance practices corresponding to the intervention plans mental health?

Large scale fire events belong also to disaster management and they can require mental health support too. In many cases mainly in developing countries building industry does not keep rules and fires can cause massive destruction of concrete structure (Balazs [1]) (Lubloy [2]) even if there are some new methods to keep structures at higher fire resistance (Beda [3]) (Lubloy [4]). Habitants lost their homes for long time and it can generate also mental health problem.

To that end, we sought to analyze, through the experiences reported in published articles and intervention plans formed by international organizations, such as the Pan American Health Organization, the IASC guide on mental health and psychosocial support in emergencies and disasters published by the Standing Committee Interagencial, the recommendations plan developed for intervention in the event of emergencies and disasters carried out by the Argentine health team and the guide on Mental Health in emergencies and disasters proposed by the Ministry of Social Protection of Colombia.

## 2. Aspects of the Brazilian social structure and its relationship with disasters

In Brazil we can find approximately 206 million inhabitants, full of natural resources and endowed with an extensive territorial dimension that leaves its landscape as one of the most diverse of the planet. It also has a wide cultural diversity becoming a country of contrasts and antagonisms. According to the UNESCO "Brazilian society is made up of different ethnic-racial groups that characterize it, in cultural terms, as one of the richest in the world. However, its history is marked by inequalities and discriminations, specifically against blacks and indigenous people, thus preventing their full economic, political and social development." (Unesco [5])

There is a concentration of the low-income population in places that do not always present the necessary conditions for living, one of the ways in which the characteristics of social inequalities in Brazil are seen. An important process of urban transition and transformation of population redistribution is characterized as incomplete because it was not accompanied by the necessary investment in terms of infrastructure and public services in cities. (Carmo [6])

When we related it to the disasters, these populations, are the main victims, framed as vulnerable groups facing the climatic events that affect the country. (Carmo [6])

In this regard of the concept of disaster, especially elaborated by authors of contemporary sociology, like Perry and Quarantelli, define it as "a social phenomenon or, more precisely, an event of disruptive character of the structure or social system.” (Perry [7]) Yet, "disasters do not completely destroy existing social systems, but are capable of maintaining continuous processes of social indifference" (Valencio [8]). In the case of Brazil, Civil Defence in its planning structure does not consider social complexity and only classifies vulnerable groups. (Corrêa [9])

Understanding these complexities of the Brazilian social structure requires flexibility and commitment from the agencies, according to Valencio et. al. (Corrêa, [9]) "The more vulnerable the social situation of the group, the less expert knowledge is accessed because it seems distant, difficult to apply, clearly insufficient, useless and dispensable." In addition, and in a complementary way, the way groups perceive and signify disaster as well as their own risk situation, will influence the process of rehabilitation and reconstruction; this understanding on the part of the different authors can contribute to a better interaction between the Civil Defence and the community. (Corrêa, [9])

### *2.1. The Brazilian disaster management structure: Mental health area*

Brazil presents a different reality in relation to catastrophes, when it is compared to the countries of North America and Asia, which often deal with phenomena like hurricanes earthquakes, and tornadoes. Due to this reality on these continents, countries are forced to make sound programs for the different stages of disaster response. (Paranhos & Werlang [10]) But, according to the Annual Disaster Statistical Review, a survey was published by the Catholic University of Louvain (France) As a result Brazil ranks 8th place in the list of countries with the largest number of natural disasters, the same prominent position in the number of deaths as a result. (Miguel [11])

In a survey conducted between 1991 and 2010, there were 31,909 natural disasters in Brazil with a total of 3,404 deaths.

Table 1 Natural Disaster Registry in Brazil, 1991-2010. Source: (UFSC-CEPED [12])

| **Types of Disasters** | **Number of event** | **Affected** | **Death** | **Morbidity (sick and minor and severe injuries)** | **Directly exposed (displaced / homeless / evicted)** |
|---|---|---|---|---|---|
| Hydrological | 10.444 | 38,836,257 | 1,567 | 309,529 | 4,176,851 |
| Climatological | 18.450 | 49,868,081 | 273 | 167,582 | 1,554,450 |
| Meteorological | 2.290 | 4,120,439 | 161 | 4,917 | 276,847 |
| Geological | 725 | 3,544,059 | 1,403 | 5,530 | 173,259 |
| Total | 31.909 | 96,368,836 | 3,404 | 487,558 | 6,181,407 |

"Of the total number of events, 57.8% were climatological, with drought and drought predominating. These events were the most affected by the population in Brazil, with almost 50 million people affected and corresponding to more than half of the total. Hydrological events, mainly floods, correspond to 32.7% of the total, with almost 39 million affected. In terms of direct impacts on the population, it is the hydrological events that present the greatest direct exposure, number of mortality and morbidity. In terms of lethality, geophysical or geological affairs are the most outstanding, with an average of 2 deaths per event, representing, on average, 13 times more chances of death than in the cases of hydrological events, which the largest total number of deaths. " (Freitas [13])

The National Civil Defence System (SINDEC), the body responsible for dealing with disasters, has the objective of planning, articulating and coordinating civil protection actions in Brazil, defined as "a set of preventive, relief, assistance and recovery aimed at avoiding disasters and minimizing their impact on the population and restoring social normality "(BRAZIL, 2010). For the Civil Protection disaster is "the result of adverse, natural or man-made adverse events on a vulnerable ecosystem, causing human, material or environmental damage and consequent economic and social damage" In Brazil, disaster risk management began to be structured as a result of the catastrophe in the Mountainous Region of Rio de Janeiro (2011). For this purpose, a national center for monitoring and warning of natural disasters was made. However, disaster management already existed in the 1960s. The heavy rainy days caused floods and landslides in the southeastern region of Brazil, resulting in material and environmental impacts, leading to deaths. (CEMADEN [14])

Table 2 Psychologist's performance in Civil protection. Source: Framework elaborated by the author referring to the event "Talking with the Civil protection ", given by Colonel Alexandre Lucas, 2012

| Stages | Psychologist Activity |
|---|---|
| **Prevention** | - Community mobilization<br>- Risk Mapping<br>- Awareness |
| **Preparedness** | - Specific training<br>- Organization, alert and alarm<br>- Advisory of scale<br>- Mobilization<br>- Joint Surveys |
| **Response** | - Next to the affected ones: absorption of the impacts of demands, accompaniment of shelters and support to the mourning<br>- Together with managers and agents: intelligence activities monitoring of stress level, support for mourning, volunteer management and general advice. |

Disaster management is done through 3 steps: Before, during and after the event. In the pre-disaster period, risk minimization is achieved through the construction of structural works, as well as the involvement of the community in environmental education. During the disaster phase, the actions are directed to the relief, evaluation of the damages and the assistance to the people affected, in order to remove them from the situation of danger. In the post-disaster phase, the work is focused on the recovery and reconstruction of the scenario reached. At this stage, victim support should be focused on minimizing material and psychological damage. (Tominaga [15]).

The involvement of mental health with civil protection happens at all stages of action, according to the municipal coordinator of Civil Protection at an event promoted by the Psychology Council of Minas Gerais in February 2012. For Colonel Alexandre Lucas, psychology must act this way:

Despite of the possibilities of psychologists acting in this context to be broad and multidisciplinary, many challenges are still clashed in relation to the lack of knowledge of the potentialities of psychology in the face of civil protection; "The difficulty of professional interaction and practical engagement of professionals in the various phases of civil protection; the personal and institutional vanities and the political and ideological use of the theme." (Lucas [16])

### *2.2. Case - Mountainous region of Rio De Janeiro / 2011 and the intervention of mental health*

Heavy rains occurred in the Mountainous region of Rio de Janeiro at dawn on January 12, 2011, resulting in floods and landslides in seven municipalities. The hugest impacts were seen in the municipalities of Teresópolis, Petrópolis and Nova Friburgo. The disaster attacked about 32 000 inhabitants of the region, resulted 918 deaths 8,795 homeless and 22,604 evacuees. This was the worst disaster in the history of the country, because of the number of deaths. Rural and urban areas were affected, with some isolated regions, as well as public services, buildings and housing were destroyed by landslides. (CEPED/UFSC, [12])

Slips, floods and heavy rains are not new in the this region of Rio de Janeiro. The Table 3 shows the municipalities, which have dealt with these events for decades.

In the Mountainous Region, the lack of urban planning and construction in areas of risk (river banks and slopes) contributes to increase socio-environmental vulnerability, constituting a chronic problem that affects the poorest in a more intense way. (CEPED/UFSC [12])

Regarding that many of the families lived and are still living in areas considered at risk, an important point should be given to their perception of risk, a fundamental factor for understanding disasters. According to Bindé and Carneiro (Gomes [17]), "Risk is perceived as a social construct, which is shaped by the characteristics of the individual's emotional-cognitive system and its social reality, including specific values and social interests. Thus, risk refers to the possibility of unwanted side effects in the case of technological disasters and the possible consequences of natural disasters.

Table 3 Histories of floods and landslides in the Mountainous Region of RJ. Source: Freitas C.M et al., 2012

| Year | Events and Consequences | Affected municipalities |
|---|---|---|
| **1987** | Sliding with 282 deaths | Petrópolis e Teresópolis |
| **1988** | Floods with 277 deaths and | Friburgo, Petrópolis e Teresópolis |
| **2000** | Floods with 5 deaths | Friburgo, Petrópolis e Teresópolis |
| **2001** | Heavy rains with 48 deaths | Petrópolis |
| **2003** | Heavy rains with 33 deaths | Petrópolis |
| **2007** | Heavy rains with 23 deaths | Friburgo, Sumidouro, Petrópolis e |
| **2008** | Heavy rains with 10 deaths | Petrópolis |

In a study carried out in another Brazilian state, Piauí, where 79 municipalities were affected by floods, and that directly or indirectly reached 1,155,289 people in 2009. This study shows the lack of awareness of the risk, which makes it difficult to prepared for catastrophes and hence, increases vulnerability of populations. They report that "because it is a repeated experience, it is perceived that "flood victims tend to blunt their emotions, creating defense mechanisms that distance them from the inevitable suffering of losses' " (Gomes [17])

Another situation that the study points to is the lack of information from the poorest communities on the role of assistance and public power in the face of disasters.

Considering the Mountainous Region of Rio de Janeiro, is the mental health strategy in response to the disaster in one of the cities, Nova Friburgo, initially referred to the knowledge of the Municipal Health Contingency Plan and the National Contingency Plan in the first 72 hours after the disaster. They report that the plans emphasized "the measure of targeting 'are for people who are victims of trauma and stress', but they did not refer to the preparation of local teams for mental health care in a disaster situation." (Weintraub[18])

This work is also highlighted the important emphasis that mental health gives to the concept of trauma and thus, guides its interventions, either individually or in groups, often leaving aside the most social and community concepts. In this way, (Weintraub [18]) affirm that "the psychologist's performance in the context of disasters transits between the fine line between the normality of the pain reaction loss and the crisis, and the pathology, often used as the only mechanism to legitimize the disaster."

## 3. Mental health and good governance in disasters: Important elements for intervention

Mental health, as part of disaster management, aims to reduce the impact of stressful events on all actors involved, as well as restore balance and avoiding the re-victimization of those affected. (Ministerio de Salud de la Nación,[19]) It is important for a management due to good aspects of governance, especially on mental health, that initially the teams become aware of the elements that make up the plans and that they are based on the psychosocial dynamics of populations in which it is intended to intervene, as well as the integral care of the agents, stimulation, capacity building and community empowerment.

Lack of knowledge, planning and structuring of plans can result in improvised action by teams, provoking equal or even greater problems than those the community faces. The Ministerio de La Salud states that "most international protocols agree that if it is not univocal what to do in an emergency situation, it is always better not to intervene than to do it badly or improvised." ((Ministerio de Salud de la Nación,[19])

Although mental health in disasters is not a current theme, the focus has been shifting in the last decade. More emphasis has been placed on the issue of psychological resilience, adaptive behavior in the face of new post-disaster scenarios, and community-based interventions. The challenge is to help affected people and facilitate the recovery process of a functional community with a focus on strengthening their strengths. (Act Alliance, [20]) The action should be broad and beyond the event, not focusing solely on the traumatic issue. (Ministério de Salud de la Nación, [19])

The plans based on a Community approach consider the aspects of "vulnerability and risk, human rights, ethnic, linguistic, cultural and gender equity."(Pan American Health Organization, [21]) It is important to accent that the first actions should be directed to the needs of the population, such as "with food, water, shelter, a minimum of physical and emotional comfort - although not performed by psychologists, these are also mental health actions." (Noal [22])

Actions should be in accordance with contingency plans in order to maintain an organized, articulated and effective response. In short, all the work must be collaborative and orchestrated with the objective of reducing the risk of suffering, contributing to the prevention and control of the diversity of social problems among the population, especially those most affected. For the Pan American Health Organization (2012), the aim is "to prevent, treat and rehabilitate mental disorders that occur as a direct or indirect consequence of the disaster; provide psychosocial support and assistance to members of response teams; ensure psychosocial performance." Pan American Health Organization,[21])

Based on the experiences reported and the reading of the plans, such as the Pan American Health Organization, the IASC guide on mental health and psychosocial support in emergencies and disasters published by the Permanent Interagency Committee. The recommendations plan developed for intervention in the face of the situation Emergency and disasters carried out by the Argentine health team and the guide on Mental Health in emergencies and disasters proposed by the Ministry of Social Protection of Colombia. Elements are considered importance for a community-based intervention that can be case of the Mountainous Region of Rio de Janeiro. The table 4 below shows the elements considered essential to the above plans, covering the different stages (prevention, response and recovery) in the face of disasters..

Table 4 Important elements for good governance in disaster-related mental health according to community-based models. Source: Author

| Community Based Models | Prevention | Response | Recovery |
|---|---|---|---|
| **Guideline IASC about Mental Health (2007)** | - to develop protection and safety strategies;<br>- Create awareness among organizations<br>- Provide social support activities | - Establish intersectoral coordination mechanisms in mental health<br>- Diagnosis of the mental health and psychosocial support;<br>- Facilitate the conditions for the community<br>- Provide access for people with health problems. | - Develop sustainable coordination structures,<br>- Strengthen community participation in the validation and dissemination of information;<br>- Encourage the ability of the community and government |
| **Pan American Health Organization for the Caribbean (2012)** | -Team training,<br>- Health education<br>- pre-disaster planning;<br>- recording information system<br>-monitoring activity | - Analysis of the mental health situation;<br>-Psychological first aid;<br>- Advise the authorities<br>- Carry out joint activities;<br>- Encourage to participate in the planning and implementation of actions. | - Specialized care for cases with complex mental disorders. |
| **Guide to Mental Health Care in Emergencies and Disasters-Colombia (2011)** | - Establish relationships<br>- Train the professionals in psychological first aid;<br>- Prepare education and information for risk communication; | - Perform psychological first aid;<br>- Distribute educational information - Provide technical assistance;<br>- Put into practice the elements of basic security. | -Monitor the new needs of special populations;<br>- Carry out interventions<br>- Foster and improve the capacity of social support networks;<br>- Anticipate and plan to cope with the memories of the trauma. |
| **Recommendations Plan developed for emergency interventions- Argentina (2015)** | -Preventive protection;<br>-Identify competent staff;<br>- Training | - Contain emotionally;<br>- Information and Guidance;<br>- Situational diagnostic evaluation;<br>- Psychological First Aid. | - Creation of the mental health action plan;<br>- Creation networks;<br>-Community organization<br>- Follow-up of specific cases. |

In the prevention period, emphasis is placed on the training of professionals, as well as on community involvement in preventive actions. The essential aim is "to prevent to avoid further damage to the impact of the disaster; mitigate to minimize the impact and alert to notify the presence of a hazard." (Ministerio de la Salud de la Nación, [23]) Mental health professionals need to be "community educated by their leaders and cultural agents in the following areas. Community structure and functioning, family structure and gender roles, priorities, strengths and weaknesses of the community and past experiences with disasters." (Pan American Health Organization, 2012, p.52) Community support and education in relation to risk perception is the best form of mitigation, which is the preparation of the community for coping with the possibility of a phenomenon occurring. (Albuquerque [24])

As for the response phase, in the event of catastrophes, "an increase in intense emotional reactions is expected, however, the vast majority of manifestations are normal, but the low coverage of the health areas does not allow a rapid identification, specifical of those who need specialized support." (Ministerio de la Salud de la Nación, 2015, p.12) According to the literature, rapid psychological attention to those affected can prevent more serious disorders, such as Post Traumatic Stress. In the view of this, we can identify the importance of a situational assessment, as well as a screening phase that covers the specific cases that will require specialized care. As per to the plans, Psychological First Aid is the technique most used as an initial intervention. This can and should be performed by any professional who contacts the affected. Also communities can be trained to provide such support in the face of any emergency or disaster.

In care programs in crisis situations, in order to promote timely interventions, professionals working in organizations within the community are excellent channels of accessibility. (Ministerio de la Protección Social, 2011) The recovery phase in mental health is aimed at monitoring specific cases, developing the structures and monitoring and strengthening the community structure.

## 4. Conclusions

Psychic illness in emergencies and disasters is only one of the factors to be considered, however, the effort itself must be given to health promotion. Despite of the wide possibility of mental health work in the different stages that make up the management of disasters, it is still incipient in practical and technical terms, in addition to being exclusively focused on the response phase with the affected ones with approaches directed to the trauma. However, the response potentials go further, the strategies created by mental health professionals in coordination with all agents can contribute, to a large extent, to alleviate the suffering of the population as well as favour the return to its functionality.

Coordinated mental health interventions can also provide effective dialogue between the community and civil protection agents. This can be done through capacities, strategies and mediations, with the aim of working in a network aimed at empowering the community. The community-based model for the demands that Brazilian society presents, considering the diversity and specific characteristics, is the most appropriate because it respects cultural diversity and proposes dialogue with the community. In this way, the plans must include the adequate preparation of the professionals who will work as well as a detailed situational diagnostic evaluation that is consistent with the culture.

It is concluded that not only mental health professionals should invest in research and the development of good governance practices, but also organizations should include in their structures the findings and potentialities of mental health, especially elements that value the communities aspects to deal with disasters and comply with the plan of more resilient societies.

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# Disaster risk reduction (DRR) interventions implementation challenges and successes: A discussion on Zimbabwe, South Africa and India

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**Abstract**

Zimbabwe, South Africa and India are developing countries. The first two countries are located in the southern part of Africa and India is in Asia. All nations embraced disaster risk reduction (DRR) as their new disaster risk management (DRM) approach although that was being implemented differently in specific countries. They were also experiencing almost similar hazards with dissimilar extremities and disaster outcomes. Methods: An in-depth and extensive review of relevant literature was carried out. After that, findings were validated through discussions and circulation of results to appropriate authoritative citizens of relevant countries for comments which were subsequently incorporated to this paper. Results: The study revealed that Zimbabwe, South Africa and India were at different DRR implementation levels. Their approaches were customised to suit specific country's prevailing political, economic and administrative systems that resultantly, their DRR challenges and successes also varied. Hence, significant lessons can be drawn from the discussion.

*Keywords*: disaster risk reduction (DRR) interventions, disaster risk management (DRM) frameworks, fail-safe communication, Zimbabwe, South Africa, India;

## 1. Introduction

The three countries discussed were selected for study mainly because of their congruencies and heterogeneities. Basically they were experiencing similar hazards, different vulnerabilities and possessed varied disaster experiences. South Africa and India legislatively adopted the Hyogo and Sendai framework provisions in their systems. Zimbabwe had not yet transformed its relevant legislation but its disaster management practice reflected DRR attributes. Notwithstanding the noticeable DRR achievements, the three countries were also facing challenges. In that respect, a discussion of the countries' background, DRM frameworks and practices, ensue. If we want to make researches in these countries, we have to know about their background. The Table 1 shows the most important information in connection with the three countries. (Zimbabwe, South Africa, India) We can check the total population, the disaster incidences and the associated data.

The data below reveals that all countries considered above had more flood disaster frequencies than other natural disasters from 1990 to 2014. (Douben [1]) (Murwira [2]) referring to flood disasters, postulated that 65% particularly in Zimbabwe due to long incessant precipitation while 15% were a result of torrential rains and 10%, caused by tropical cyclones. In addition, Zimbabwe had a higher percentage of deaths and economic losses induced by the same hazard compared to South Africa and India. Although India recorded the least deaths attributed to floods during the period under review, South Africa had the lowest percentage of flood induced economic losses. That data supports (Picard's [3]) research findings. Picard comparatively ranked a sample of many countries in line with level of DRR implementation. Particularly using the criteria of best enacted national DRM laws. The research saw India and South Africa being classified

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in the second most prestigious place. While Japan, Algeria and US were ranked among the best. That therefore shows that Zimbabwe and many other countries can learn from South Africa and India's systems. Unfortunately with regards to data, Du Plessis argues that it is more advisable to use cumulative probability distributions if data is meant to inform policy decisions than total mean damages presented above. It can further be strongly argued that that data might have underestimated disaster losses witnessed in remoter areas by virtue of difficulties often encountered in trying to accurately capture and quantify rural disaster losses in addition to other reasons. That claim holds water considering that many people in Africa and Asia were still part of poor communities living in areas with limited access to basic services. (Du Pleiss [4])

Table 1 Disaster data summary per country: Zimbabwe, South Africa and India. Source: Author

| | **Zimbabwe** | **South Africa** | **India** |
|---|---|---|---|
| Total country population as of 2014 | 14,148,648 | 52,981,991 | 1,252,139, 596 |
| **1990-2014 mean incidences/annum** | | | |
| Floods | 57.9% | 37.9% | 53.5% |
| Droughts | 31.6% | Insignif. | Insignif. |
| Landslides | Insignif. | Insignif. | 8.5% |
| Storms | 10.5% | 33.3% | 22.7% |
| Wildlife induced disasters | Insignif. | 13.6% | Insignif. |
| Extreme temperatures | Insignif. | Insignif. | 10% |
| Earthquakes | Insignif. | 6.1% | Insignif. |
| Other disasters | Insignif. | 9.1% | 5.3% |
| **1990–2014 mean mortality/annum** | | | |
| Floods | 97% | 55.9% | 31% |
| Storms | 2.3% | 17.9% | 16.7% |
| Earthquakes | Insignif. | Insignif. | 41.7% |
| Wildlife induced | Insignif. | 13.6% | Insignif. |
| **1990–2014 economic losses/annum** | | | |
| Floods | 85.3% | 30.4% | 66.3% |
| Storms | Insignif. | 20.8% | 23.1% |
| Droughts | 14.4% | 33.4% | Insignif. |
| Wildlife induced | Insignif. | 14.7% | Insignif. |
| Earthquakes | Insignif. | Insignif. | 7.1% |

## 2. Disaster risk management (DRM) legal framework in Zimbabwe

Zimbabwe's DRM was being regulated under the Civil Protection Act of 1996. (Civil Protection of Act Chapter 10:16 [6]) But current practice in the country was positively transitioning away from that legal framework. In 2011, Zimbabwe drafted its first DRM bill although that bill had not superseded the 1996 Civil Protection Act yet in-spite of its practical limitations relative to modern DRR. The main objective of the Civil Protection Act of 1996 hereby henceforth referred to as the Act, forms part of current DRM hindrances in Zimbabwe. In fact, its main purpose was to create the Civil Protection Unit (CPU) and a disaster fund (Government of Zimbabwe [7])

A weakness of the Act was its age. It was last revised in 1996. Yet many changes in the field were ushered in from around the year 2000. Confirming De Soto's (De Soto [8; 2001:111]) claim that some developing countries had antiquated legal systems whose doctrines and formulas now had little relevance to real world developments. Relatively, the Zimbabwe Civil Protection Unit (CPU) was still a small department under the Ministry of Local Government, Public Works and National Housing in line with the Act. That department was under command of the director of civil protection. Hierarchically reporting to a permanent secretary who ultimately had direct access to the government minister. Due to noticeable challenges of that structure, the DRM bill contained provisions which should amend the anomaly.

The Zimbabwe CPU was supposed to enjoy advantages emanating from proximity to local government institutions since it was under the Ministry of Local Government, Public Works and National Housing. There were existing structures which had to enable easy linkages between CPU and all administrative tiers of government down to the grassroots level in addition to other relevant departments in the same ministry. Those included the department of national housing and public works that was responsible for town and regional planning and public infrastructure development. In fact, such merits are more realisable where interdepartmental DRR integration and cooperation were nurtured in ministry's culture. However contrarily, Madzudzo advised that legal frameworks were existing in Zimbabwe, but law enforcement always lacked. In fact spatial settlement planning laws, building standards and building codes were there but they were not fully observed in both rural and urban areas. Conforming to Douben's (2006:18) claim that lack of law enforcement was common in many developing countries. DRR integration and cooperation in government was also noted as minimum And Cloete & De Coning validated the view stating that most countries in Africa were still stuck in the silo mode of disaster governance though Elliott reinforced the claim by noting that the silo approach to DRM was actually common in many other countries world over. (Elliot [9; 1998:28])

*2.1. Composition and operation of the National Civil Protection Committee (NCPC)*

Section 4 of the Civil Protection Act provided for establishment of the National Civil Protection Committee (NCPC) for disaster planning purposes. However, the committee membership was purely skewed towards 'top-heavy' securocrats and politicians though Red Cross Society (RCS) and the fire brigade formed part of it. In addition, its role was more inclined to emergency management than DRR. The Civil Protection Act further gave the Minister of Local Government, Public Works and National Housing powers to appoint three other members with experience to form part of that committee. Unfortunately the law did not provide guarantees against nepotism which can influence appointment of committee members especially in societies where jobs can be scarce. Mostly, that is also probable when extra benefits are attached to the task like in this case. Besides that, the committee was provided to be made up of people in executive jobs with possibility of making it difficult to form a quorum. Likewise, the decision making environment had the possibility to additionally suffocate contestations and thought diversity due to uniformity of committee members' background and interests. In instances where decisions were to be made through circulation of written proposals for voting as alluded in the Act, that had imaginable negative impacts on individual members' decision autonomy. Lastly, all subcommittee decisions had to be reviewed by the NCPC before implementation and there are merits as well as demerits to that.

Fortunately in practice, there was already a variance between the actual NCPC membership composition provided for in the Civil Protection Act and the National Planning Committee (NPC) proposed in the bill. Also, practically the NCPC was now already more inclusive although that was also not yet embodied into law. Resembling how the sense of the bill was already influencing DRR practice on the ground. Nonetheless, the Act and the bill did not set mandatory meeting timeframes for the NCPC and the intended NPC. That was left to respective committees' discretion. With negative probability that meetings would only be held when the nation was likely faced with foreseeable dangers. Against modern DRM practice that contextually supersedes emergency management. However, practically NCPC meetings were being held on a monthly basis in line with international recommendations (The World Bank, [10;9]). On a more positive note, NCPC was now consisting of members with various backgrounds. Nonetheless, members' attendance to the forum had been inconsistent. The Director of Civil Protection (DCP) rarely attended the meetings against The World Bank's (2011:9) recommendation too. Which reflected the challenge in appointing senior government officials in these committees as stipulated by the Act. Total number of attendees to the two NCPC monthly meetings whose minutes where accessed by the researcher in 2015 was 22 and 47 respectively (CPU [11]), (CPU [12]). And propitiously, membership was drawn from NGOs, government departments, municipalities, universities and intergovernmental agencies in line with DRR principles and practices.

It should be noted that members' attendance in meetings was voluntary. As a result, members could lack persistent motivation to be part of the meetings. More-so, there were no more sitting allowances despite their provision in the Act and junior officers with limited decision making powers were major attendants of those meetings. Grassroots people were physically not represented on platform unless it can be agreed that NGOs were those communities' de facto representatives. Without making changes, the bill retained powers provided in Act for committee members to request for a committee meeting outside ordinary sitting days. Those requested meetings had to be held after giving seven (7) days' notice and within thirty days from the day of giving notice if the request was granted. The researcher postulates that, that could give the committee extra room to delay important decisions especially in the face of impending disaster. Even though Section 9 of the bill intended to create the National Disaster Risk Management Platform (NDMP) to close that gap.

### *2.2. Staff conduct, contracts and state liability in disasters*

The National Civil Protection Act moreover made provision for establishment of civil protection plans and training of people for civil protection purposes at various community levels in the country. Also through the same laws, the government was encouraging the spirit of volunteerism among citizens. By accepting liability for volunteers and officers negatively exposed to danger in conducting disaster related duties especially during emergencies. In another administratively progressive way, volunteers and officers were bound by employment contracts. To give the state (employer) thirty days' notice before voluntarily terminating the contract. Which is important for disaster planning reasons. Positively, the Act moreover limited powers of civil protection officers. They were legally prosecutable whenever they violated citizens' natural and property rights during discharge of duties. That is ordinarily imperative for example, when citizens' private property is infringed to settle flood disaster victims without a clear plan for compensation. Nevertheless, further analysis of the Act regrettably revealed that government property appeared mainly protected compared to private property especially under Section 23(10). Although government indicated priority to compensate private persons for any losses incurred in the course of assisting disaster victims. Those provisions had to motivate citizens develop the spirit of altruism. Yet conversely if not managed well, lack or inadequacy of that compensation can foster cement resentment and uncooperative tendencies among citizens (Honhold [13]). Hence, due care had to be taken to ensure the facility was always effective. To ensure that those who always helped in disasters got their dues. In that mind, it was also positive that the government of Zimbabwe further committed in its laws, to help bury dead disaster victims, assist deceased's families quickly acquire death certificates. Thereby sharing the burden of loss and in a way encourage communities to report disaster related deaths to government authorities.

### *2.3. Powers of the president, minister and Civil Protection Unit staff*

In Zimbabwe, powers to declare a state of disaster were wholly vested in the state president who was legally permitted to notify the national parliament later. Especially in case of sudden onset disasters. Which meant powers of parliament were limited as far as disasters were concerned. The problem with that approach is, the president had to personally choose to declare the disaster situation as a state of emergency or not. With the disadvantage that despite apparent need, as long as that would conflict his/her other interests his decision prevailed. In addition, a study of Section 38(i) of the Civil Protection Act further revealed a perforation. The Minister of Local Government, Public Works and National Housing was mandated to transfer powers or duties from local civil protection officers and relocate it to other persons in the prevailing context. The new duty bearers were required to be serving employees of government. With the exception of those serving in the security sector. Because their deployment was given to be strictly regulated by their relevant senior officers. It can be argued that whereas these civil servants were deployable it might not be easy in every case especially where involved line ministers may hold different persuasions. Where that could prevail, that means requested civil servants may not be released on time and those taking new responsibility may not be privy to basic DRR principles. Having new personnel taking over may further de-motivate initial staff who might be more appraised in terms of local culture, politics and other factors essential for DRR success. Hence, deployment of such staff can consequentially lead to conflict, delayed recovery and other unexpected challenges. When a person in authority like a government minister, confers power on an individual without enough explanation to concerned parties. The act can be negatively construed as undisputable and dictatorial. To the extent that community stakeholders sympathising with the former may fell undermined and opt to ostracise new appointees using different means. And, suppression of such reactions may not be easy without violating rights of the same.

Though the minister's initial decision was meant to benefit that community.

However, the bill addressed the issue by diluting powers currently given to the minister by the Act. For example, Section 4 of the bill had divested his/her powers in line with distribution of stockpiled or donated resources. That is important where quick technical decisions had to be made relative to what would be most practicable on the ground though provisions of the same bill can still be regarded as insufficient. Mainly, the bill made provision for the decision process to be a departmental function. Without vertically and horizontally expanding the responsible department that was recurrently lacking own budget and decision making autonomy. That is why the researcher can argue that the ordinary definition of a disaster given in the bill was also inadequate. The definition should be broader enough. Beyond a mere event. Because disasters are results of a process. Whereby communities initially try to cope with the hazard using own resources until their efforts fail.

### *2.4. Role of the media in disasters*

The media was included in the bill and that was a further development from the Act which is naturally silent about that subject. The problem with the bill was that media was only included at provincial level in the whole bill and not at national platforms. Though it is common knowledge that most media houses in Zimbabwe were headquartered in major cities. Where national disaster management platforms resided also. In a normal set-up, media relations have to start at the centre and then cascade to peripheries. Although in this case, it was evident that co-option of media houses in the bill was an afterthought. Media as a word or subject only appeared once in the whole bill. Suggesting that seriousness in involving media in disasters was minimal. Although positively, the bill expressly proposed inclusion of disaster education in the country's main education curricula.

### *2.5. DRR administration in provinces and districts and disaster resources management*

The researcher rejects the idea that provincial administrators had to be default government DRR coordinators in provinces given in the bill. (G.O.Z [37]) The view held by the researcher was that DRR coordinators had to be dedicated officers in charge of DRR issues. And, that role had to include working with various development partners in the appropriate development levels. As a full-time job instead of a part-time or after normal work duty. The office has to be involved in national development programmes and projects at its administrative level to ensure DRR effectiveness. However, more progressively, the bill provided for decentralisation of disaster functions down to Zimbabwe's four government administrative tiers. But, the relationship in existence between central and local government structures should be reassessed and synchronised when it comes to the proposed DRR resourcing in country. To ensure that any mechanism adoptable remains practicable and sustainable within the national context to avoid system overload on citizens.

Nations should guard against overburdening citizens especially due to double taxation. That can happen when same taxes are collected at the centre as well as in local governments. Therefore, introduction of disaster fees should not create that effect on citizens but in fact, a multi-stakeholder trust fund can reduce disaster aid fragmentation (Geatani, [10]). What saddens in the bill was that its main inclination at local government level was still obliquely towards the fire hazard while DRM fund was strictly limited to preparedness, response and early recovery. Without consideration of the fact that such activities alone, were only fragments of real DRR practice. Therefore, it could be concluded that that bill is not yet best to be considered Zimbabwe's DRM law. If it is passed without significant adjustments noted, it would stifle new thinking than opening minds to broader DRR perspectives. Another clause the researcher had reservations on in the bill, states that mobilised financial resources not used within a specific period of five years had to be returned to the general fund. In actual fact, that leaves a lot more to be desired. When financial resources are returned to the general fund, then what would follow? Would that improve DRR while retired in the general fund and for how long should the resources be retained? Without getting befitting answers to the questions, the bill should be further re-thought through and its sense moved away from mere emergency management to DRR which is broader and now more preferable.

In summing-up, DRR initiatives proposed in the bill were further uneasy to attain at local level in Zimbabwe except if the devolution principle envisaged in the national constitution is first realised. Most local government strata could not singly fund DRR. They were already overwhelmed with service delivery issues and had limited space for extra revenue generation that, they mainly needed more government financial support. Moving on, the bill was spot on in setting up stringent measures to wad-off disaster resources leakage in the supply chain and mechanisms to improve easy passage of relief resources, services, personnel and equipment to any intended community in the country. In addition, aid trade, unnecessary embargoes and disaster resources diversionary tendencies were also proposed to be criminalised through the bill. However, the challenge that should be significantly tackled remains the implementation and enforceability of those provisions especially where the government itself had 'dirty hands' in that regard.

Zimbabwe's DRM policy, legislation and practice reflects a huge gap compared to the international DRR strategy which is the main template (SADC, [14]). Even where laws and policies were in place, Zimbabwe often lacked consistent policy resourcing and law enforcement necessary for effective policy operationalization (Madzudzo, 2015:8 &10). To the extent that whereas DRR was already being integrated for example through the climate change policy among others, it was not yet integrated in other sectors like in the health sector strategy (SADC, 2013:51). In-spite of those weaknesses, Zimbabwe was becoming more DRR conscious as reflected in the discussed DRM draft bill and that actually shows good progress. (Picard [3])

## 3. Disaster risk management (DRM) in South Africa

South Africa has already made giant steps in implementing DRR in its legal and other institutional frameworks. Reflecting a higher level embrace of the DRR concept including climate change related issues (RSA [16]). The country enacted the Disaster Management Act (No. 57 of 2002) and then developed the National Disaster Management Framework (NDMF) of 2005 to guide the implementation process. In the same respects, South Africa Disaster Management Act was further amended in 2015 (RSA, 2015). It is important to note that the Act and framework possessed characteristics of the nation's constitutional and political systems belief. South Africa adopted an interdependent and interrelated DRR governance structure in central government, metropolitan provinces, districts and local municipalities. (Humby [17]) And, it was advantageous that the country's government system further spanned to the grassroots levels. There also existed the Intergovernmental Relations Framework Act Evolution and Practice (No. 13 of 2005) that was meant to reduce role duplication in government, coordinate government efforts, save government costs and reduce responsibility disputes between government departments since DRR can be a whole-of-government business.

### *3.1. Purpose of the Act*

The Act spelt-out general legal responsibilities and powers of various DRR bodies and stakeholders. While the NDMF laid out specific expected actions, outcomes and likely challenges which were expected to be faced during the process of implementing provisions of the Act. The framework generally further shows a high DRR implementation ambition. That had to be realised gradually through a tri-phased plan. The stance could be regarded as rational actually. Mainly because DRR implementation can be expensive and strenuous if governments determine to drastically have it wholly achieved within a short time. Where that route is followed, major DRR assets and infrastructural investments may end become white elephants in the longer term, if the implementation process gets financially burdensome along the way before completing the desired investment process. This study revealed that South Africa's DRM laws and administrative structures were more developed compared to those in Zimbabwe. In fact, South Africa clearly tailor made its DRR laws and guidelines. The laws and guidelines specifically included roles and responsibilities of stakeholders at various administrative levels in the country. Further, the framework promoted disaster funding and consistent procedures for risk assessments. For example, each department of government responsible for DRR was mandated to conduct risk assessments and develop disaster management plans in that regard within its functional area. In addition, the departments were required to make provisions for administering early warning communications and risk awareness and establish stakeholder engagement platforms in a socially inclusive manner (RSA [18]). Issues related to gender and needs of special groups, monitoring and evaluation of operations and DRR implementation progress reporting were also well articulated in the Act. (The main purpose of the South Africa Disaster Management Act (RSA [19]) as amended, was noted as, to further integrate and coordinate disaster prevention, risk reduction, mitigation, preparedness, response, recovery and rehabilitation.

### *3.2. DRR institutions, administrative structures, deliberative platforms and funding*

The National Disaster Management Centre (NDMC) which was established to coordinate DRM activities in South Africa was being led by the director general and it was located in the department of cooperative governance. It can impress to note that the director general's position was hierarchically reporting directly to the responsible minister of government (Long Term Adaptation Scenarios (LTAS [20]), and (RSA, [21]). The department also had powers to monitor related stakeholders to ensure they complied with the national DRR laws. Further, the department was legally empowered to initiate and facilitate access to DRR funding, facilitate stakeholder interaction, information sharing and learning; nationally, regionally and internationally. In that view, South Africa through the Act, undertook to assist fellow Southern Africa region states whenever need for disaster related support was found necessary.

The Act further had other legal provisions mandating the state to assist South Africa's local governments whenever they were failing to contain disasters alone or with collaborators. In that respect a DRM contingency fund was being administered by the NDMC. That was supposed to be accessible by government organisations in the lower tiers too. Hence, the Act required that every cost attributed to disasters at every government level in the country, had to be officially reported and documented to help future DRM planning, budgeting and efficiency evaluations (RSA [21]). However, it was found to be unfortunate that some local authorities in South Africa naturally lacked basic budgets specifically for disaster mitigation in their areas (LTAS [20]). Where that persists, may also depict that the local authorities were mainly using incremental planning and budgeting that usually maintains the status quo in terms of traditionally funded areas without any new radical shifts in consideration of new challenges and developments. Where incremental planning and budgeting are used as a policy approach, they normally left little room for accommodating new expenditure initiatives too. However, if those provisions to embrace new innovations are not made at every level, it should be noted that governments were also usually unable to wholly fund DRR or compensate disaster victims to full recovery in case of a disaster. Especially since it was traditionally common knowledge that most state departments naturally functioned without adequately funded budgets.

For example, R30.76 million was released for Ndlambe, Sundays River Valley, Kouga and Koukamma for restoring specific infrastructural projects only after the October 2012 floods in Cacadu District in Eastern Cape, out of the total budget requirement of around R500 million that was needed to ensure the victims attained full recovery after the disaster. (Lingen [22]) Of course that compensatory support which was extended to the vulnerable communities by government was much in terms of money value but at the same time, that further exposed limitations of government when it comes to DRR funding. Governments need support from other partners such as NGOs and the business community. The difficulty to fully compensate disaster victims was not witnessed in South Africa alone. Turkey used to offer a 20 year interest free loan to citizens after disasters specifically for reconstruction purposes. But even there, it became infeasible after the catastrophic earthquake of 1999. That, in 2000, Turkey government abolished that legal provision and subsequently stopped the loan facility for disaster recovery. A position that leads the researcher to ask the questions: Who is responsible for community DRR; is it the state or the vulnerable communities themselves and if both, what should be the level of each party's contribution? In that regard, the researcher's opinion is that the state should create economic conditions which guarantees citizens the ability to individually protect themselves than to depend to the greatest extend, on an external authority/being such as the central government alone.

The Act in addition provided for establishment of administrative and deliberative DRM forums in the country. These included inter-ministerial disaster management committees (IDMC), the national disaster management centre (NDMC), provincial disaster management centres (PDMCs) and municipal disaster management centres (MDMCs). Advisory forums had to be established also at national, provincial and municipal levels and that was given to include traditional leadership as part of the membership. Such legal provisions prove that disaster management in South Africa was more than mere emergency management. Further, it was a task evidently financially and politically supported because generally there was very good legislation and implementing institutions in the country. The only problem is that DRR implementation was proved to be realistically a different story. A research conducted revealed that some DRR administration levels had not yet established deliberative platforms noted above. Therefore, stakeholders could not give DRR input in-spite of existence of legal provisions for that. As a result, effective DRR planning was being seriously hampered by lack of baseline data that is usually needed for making correct evaluations and strategic decisions. Also, in instances where the platforms existed; formalities, procedures and other unreasonable delays were negatively affecting functionality of the platforms (LTAS [20]) Lastly, there is always room that other people can misuse such platforms for personal gains if not safe guarded in advance (Intergovernmental Relations Act (RSA [18]).

The major challenges in South Africa's DRR endeavour were lack of well-articulated DRR roles and responsibilities among personnel in some local municipalities as well as general non-appointment (inaction) or appointment of junior officers to be the DRR focal persons for government departments and for participation in deliberative forums. As a result, certain decisions were being delayed in instances where junior officers in those forums needed to consult with their seniors before arriving at a decision. That wasted time unnecessarily, delayed other subsequent processes and negatively affected the need for quick adaptation to changing community needs and circumstances .Further, some fire departments in municipalities were getting more burdened and involved in disasters outside area of speciality mainly because such institutions had not transformed towards DRM activities beyond traditional fire management. Though the Act required all tiers of government to increase their DRR capacities through training, education, research and overall disaster classification and zonation throughout the country (LTAS [20]).

### *3.3. DRR implementation challenges in South Africa*

DRR implementation challenges noted in South Africa were many despite presence of key legislation and administrative structures. For example since 2005, significant DRR funding was disproportionately targeting post-disaster initiatives while specific DRR funding in most local government institutions generally lacked. Where the fund existed, it was mostly reserved for relief and recovery. In addition, resources located in the NDMC generally remained uneasily accessible by lower level government institutions. Due to stringent minimum requirements to be fulfilled before the fund could be released. Also, there was lack of knowledge in some local governments, about those minimum requirements while the ability to meet those requirements generally lacked and therefore, there was not hope for ever receiving the funds in some instances. The other problem was in the formulation of national DRR policies and programmes. Consultancies were contracted for the tasks and surely, absolutely best theoretical documents were being developed but they were proving difficult to implement at local levels since most of their views were rarely considered during policy and programmes formulation phases (LTAS [20]). Therefore, since DRR is a cross-cutting and whole of community endeavour, the same approach should be employed when developing relevant national development policies and plans (Picard [3]). On the other hand, the role of the Intergovernmental Relations Framework Act stated above was constrained because its powers were subordinate other Acts of Parliament except by-laws (RSA [18]). So, South Africa should make the Intergovernmental Relations Framework Act Evolution and Practice more binding to ensure stronger DRR coordination within and between departments. The challenges which prevailed in Zimbabwe and South Africa validates the claim by Raubenheimer that many countries were interested in DRR but some were backing-down on implementing provisions which had to promote full realisation of the concept locally.

## 4. Disaster risk management (DRM) in India

According to Picard (2014:17), India was a lower middle-income feudal union of 28 states and seven (7) territories. Under a parliamentary government system (NIDM [23]) The Disaster Management Act of the country was enacted in 2005 (Government of India (G.O.I. [24]). While the National Disaster Management Policy (NDMP) was approved by the union cabinet in the year 2009 (G.O.I. [25]). What was specifically peculiar in the Act was that it provided a comprehensive definition of disaster management that was fully in line with the Hyogo and Sendai framework definition. The definition included issues related to disaster prevention, mitigation, capacity building, response, risk assessment, evacuation, rescue and relief, rehabilitation and reconstruction just as the South Africa Disaster Management Amendment Act did (Government of India (G.O.I [24]). Which reveals that India had a very progressive DRR framework too. In terms of pre-disaster risk assessments included in legal frameworks, Alexander viewed that as an important precursor to the identification of disaster zone escape routes and best means of communicating early warnings in addition to other benefits derivable from that. (Alexander [26])

### *4.1. Disaster risk management institutions in India*

There were three DRM governance levels in India. Namely, the National Disaster Management Authority (NDMA), State Disaster Management Authorities (SDMA) and District Disaster Management Authorities (DDMA) (G.O.I. [25]). DRM was administratively located in the Ministry of Home Affairs - Disaster Management (DM) Division. But, the Ministry of Panchayat Raj and Rural Development had the responsibility to train Panchayat Raj, representatives of local bodies and integrating disaster resilience principles in national development projects (NIDM [23]). The NDMA that was mainly responsible for DRM coordination was constituted in the year 2006 (NDMA [28]). Comprised of the National Disaster Management Committee (NDMC), a full-time secretary, five joint secretaries and a financial advisor; assistant financial advisors, joint advisors and directors, assistant advisors, undersecretaries, support staff and consultants (G.O.I. [27]). Chapter II of India’s Disaster Management Act (DMA) stipulated that the NDMA had to under leadership of the prime-minister. By virtue of that post, he/she was qualified chairperson and ex-officio member of the National Disaster Management Committee (NDMC) (G.O.I [25]). The committee was made up of ten members. They included the mentioned chairperson who also possessed discretionary powers to select and appoint other committee members to collectively oversee functions of the NDMA. Unfortunately, the Act prescribed that the committee had to meet as and when it felt necessary. With the effect that where a sense of discipline and responsibility lacked, the committee can convene when faced with imminent hazard threats only. Contrary to DRR principles but emergency management. Though it was commendable in India that the government legally pledged human and technical resources support to the committee to ensure success in carrying-out the committee mandate and NDMA functions. And in that mind, it can be held true that as long as support staff and committee members were selected professionally, the NDMA was guaranteed to possess requisite technical guidance and support towards successful achievement of the national objective in that regard.

In addition, involvement of the prime-minister in the DRM body presents support to the view that India’s government was fully committed to DRR implementation. Having people in authority in such platforms is a euphorically a pledge of political leadership support in as far as NDMA’s plans and recommendations are concerned, in higher national decision making levels. Unfortunately, some Indian citizens felt that the Act had not provided the standard criteria for appointing the committee’s office bearers in addition to regulation of their tenure of office, age limits and skills-set requirements. As a result, the NDMA was not viewed as fully credible, transparent, objective and adequately representative of all states as an institution (G.O.I [27]). Such exposition left the researcher assuming that some existing applicable office bearers were already lacking relevant skills and professional requirements to meet desired task demands.

Also, NDMA in India lacked full autonomy for policy implementation and enforcement because it was mostly performing an advisory role to the system. In addition, India's NDMA structure was obliquely 'top heavy' in terms of political power of membership and professionals with a track record of work experience yet, with less effective grassroots participatory approaches (G.O.I [27]). Another peculiar issue about India in terms of professionals was that, it had the requisite disaster management experts among its citizenry that it was actually deploying some of its staff members to help in other countries faced with disasters. In that respect, during the Himalayan earthquake in April 2015, India was recognised for coordinating rescue, relief and giving technical guidance and support to in Nepal (NDMA [28]). Hence, it was evident that India's DRM system was stronger, effective and more reliable when compared to the Zimbabwe.

More eye-catching in the Indian approach was how the National Disaster Management policy (NDMP) was crafted. It contained a hazard map important to DRR agencies and that in itself shows that India was carrying out comprehensive hazard assessments. In addition, the DRM Act and policy were presented in a very simple and easily comprehensible language. That was also imperative because DRR involves whole communities and those communities may always vary in terms of literacy levels. Also, the policy clearly illustrates that India had adopted a multi-hazard approach that harnessed and promoted use of new technologies and adaptation of a culture of safety that is key for DRR success (G.O.I [25]). The policy vision can also remind the reader that DRR can be implemented as a step by step progressive endeavour. Though, like South Africa, India was experiencing related implementation challenges due to limited DRR financing (Picard [3]). Authority structures at national level of the DRM system were replicated at state level. In that regard, State Disaster Management Authorities (SDMA) were administratively operating under the Chief Minister of State's command. The same automatically was provided to be chairperson and ex-officio member of the State Disaster Management Committee (SDMC). Also, the chairperson and ex-officio member of the State Executive Committee (SEC) had to be the Chief Executive Officer of the SDMA. While the Lieutenant Governor or Administrator had to chair the authority in union territories although that was different in Delhi. There, the Chief Minister of State was vice chairperson. Another unique aspect in India was that its disaster legislation empowered existing DRM executive committees to monitor building standards and development plans in their various jurisdictions as a DRR strategy.

More-so, either the Collector, District Magistrate or Deputy Commissioner had to be the chair and ex-officio member of the disaster management committee at district level. In addition, an elected representative of the local authority had to further co-chair the committee too. Which meant those two were sharing authority in terms of delegating duties and convening meetings whenever they found it necessary (G.O.I [18]). The committee's responsibility was given as, to coordinate national, state and district plans and policies as well as monitoring and evaluating partners' activities to guarantee efficient and effective DRR interventions at that level. That level was required to rope-in grassroots as well as voluntary and non-governmental organisations. Co-opting use indigenous knowledge systems too, in developing response plans and procedures (G.O.I., [25]). Unfortunately India was experiencing same problems which were prevailing in some parts of South Africa. District authorities in India also lacked specifically dedicated personnel and therefore they were not conducting mock drills to test DRR plans' efficiency in advance in some lower levels. In fact, it was given that some lower tiers' operations were mostly focussing on response and relief than mitigation and other DRR activities. Also, district committee meetings were mainly being held twice per year pre-cyclone season only. While DRM plans were always developed though they were sometimes never implemented (NDMA [28]).

### *4.2. Disaster insurance and observance of standard DRR guidelines*

India's Disaster Management Policy (G.O.I., 2009:14) had it that government had to assist disaster victims quickly restore their lost assets and livelihoods. The support was meant to facilitate repayment of outstanding loans and to acquire new loans on agreed terms for the same purpose. Unfortunately, the plan was grossly underfunded that a housing restoration programme that launched after Cyclone Hudhud failed to achieve the desired objectives on time (NDMA, 2015:36). In fact, that is why more private and cooperative micro-credit and insurance organisations should be supported to grow as an alternative to government funding in all countries. As those can be very useful in quickly restoring human health, small scale assets, livestock and crops. However, it can be argued that realistically, disasters can destroy whole communities including those local insurance investors except where investments are held offshore but that should not discourage the idea. (Mechler [29]) Though due to those fears, initiatives to co-opt smaller indigenous investors may not be easy to develop. Since small scale investors can shun high risk investments. But, failure to facilitate establishment of such facilities can also translate to bigger government resource burden towards community relief, recovery and reconstruction after disasters. Continuing the discussion above, India was making it compulsory for companies to be insured as a mitigation strategy. Though unfortunately, it was discovered that some public companies were not insured, against the law. For example, Steel Authority of India incurred huge uncompensated losses during Cyclone Hudhud induced disaster (NDMA [28]). Of course the Minister of State for Home Affairs stated that government was providing enough money for DRR to the NDMA, the claim was solely based on a weak criteria that, NDMA had completed targeted mitigation projects (F.India [30]). However, the major problem arises when governments fail to implement requisite policy provisions in their own institutions like what transpired in the case of Steel Authority of India. Such behaviours can create policy resistance by the private sector if perceived as deliberately unfair selective application of laws by government. The Act further compelled India to develop standard guidelines for relief work. From shelter to hygienic food and food preparation facilities, drinking and bathing water, medical provisions and other facilities relevant to special groups in disasters. With special consideration to building hazard resistance, resilience and sustainable livelihoods. One of the most problems is building fires. Fires can cause special stress to building materials and reduces drastically its weight holder's capability (Balazs [31]). Even if there are rules also in India to keep the quality concrete structure of buildings in many cases not enough strong to resist against fire stress however there are many initiatives to raise its resistance (Beda [32]) (Lubloy [33]). Further respecting cultural diversity and interventions cost-efficiency as outlined by the Sphere Project and other related standards (NDMA [28] (G.O.I [25] Sphere Project, (IASC [33]). Domestic and wild animals' shelter, food, general safety and security, were also to be included in India's disaster plans (G.O.I. [25] which was also in line with the Livestock Emergency Guidelines and Standards (LEGS) (Practical Action [35]). Those provisions are important because domestic and wild animals are people's direct and indirect livelihoods source. Humans depend on them for food, draught power and tourism gains among others. Positively during Cyclone Phailini in East India, Odisha and Andhra Pradesh states managed to evacuate more than 30 000 animals to safe areas (Harriman [36]). Which shows that the country could be ahead of Zimbabwe and South Africa in that regard. In addition to the successes mentioned, India was also emphasising restoring livelihoods of artisans, children and women headed households. Farmers and other marginalised sections of its community. Through development of more roads, facilitating provision of housing, safe water and sanitation, credit facilities as well as more accessible and efficient agriculture supply chain technologies noted as critical in building resilient communities (G.O.I. [25]).

### *4.3. Preparedness, emergency operations and involvement of the security sector in disasters*

The National Disaster Task Force (NDTF) was initiated to tackle disasters requiring special knowledge and skills while other responsible government ministries continued to retain responsibility for dealing with certain hazards in their traditional line of specialisation. This taskforce had battalions throughout the country (G.O.I. [25]) to carry-out response and recovery functions under direction of the NDMA. Precisely, during Cyclone Hudhud in Pradesh and Odisha, forty-two teams were deployed immediately to threatened states after receiving the first early warning. Though unfortunately, the NDTF response personnel had no requisite tools and equipment for the task. They anticipated that tools would be supplied by the host authority and that approach was viewed to have caused unnecessary resource constraints on receiving state district administration (NDMA [28]). Such a mishap can be attributed to poor DRM coordination that could have been existent between involved administrations before and during the disaster. But spectacularly, that team of men and women that was led by the Director General of Civil Defense and the National Disaster Response Force (NDRF) possessed a very high level of skills relative to natural and high technology induced calamities. They were also had a special budget for disaster mitigation that, they integrated mitigation whenever they seized the opportunity even during the disaster response process (G.O.I [25]). Like the South African central government to its provinces, India had delegated primary responsibility for disaster management to states. From prevention, mitigation, early warning, planning, integration and funding with necessary support extended from national purse as stated before (G.O.I [25]). Probably that is why the NDRF did not bring tools and equipment to Pradesh and Odisha states. Such decentralisation of DRM was also a practice in Australia. There, local agencies were equally responsible for providing equipment, warning, labour and leadership in local disasters (Flood Plain Management Working Group [5]). Though it can be strongly argued that delegated responsibilities should always be followed by accessible requisite resources and effective centre periphery communication. What practically happened in Pradesh and Odisha confirms that local authorities as always, are usually underfunded, understaffed and stretched thin by other social responsibilities at that level that they may not be able to successfully handle bigger disasters without external equipment, manpower and other support resources especially in developing countries. (Flanagan [37])

The DRM Act further set the priority that emergency operation centres (EOCs), medical preparedness as well as mock drills and simulations had to exist in all administrative levels nationally Thence, India adopted use of mobile surgical teams and Ministry of Railways' accident medical relief vans stationed in every 100km radius across the country (G.O.I [25]). Which was a positive move towards DRM efficiency. Because during Cyclone Hudhud, the Ministry of Railways quickly fixed damaged railway electric lines and the transport service was restored without external support Even though it was noted that some trains were damaged mainly because they were not resistant to stormy weather. The efficiency is commendable and can be attributed to the presence of sound standard operation procedures (SOPs) and incident command systems (ICS) in India's DRM institutions (NDMA [28]). Another admirable practice in India was that the army were deployed to a disaster area only when the situation got beyond the coping capacity of state governments and the NDMA (G.O.I [25]). Four columns of the Indian Army and four ships of the Nervy were just on standby for a rescue mission during Cyclone Hudhud (NDMA [28]). Which means India had a DRM system that was mainly civilian managed like in South Africa. In many countries, armies successively remained the major disaster response and rescue force. Though the practice was in other instances followed by reports of human rights violations. That is why India fits as a perfect example of best DRR practice for developing countries. That country's Standardised Response System (SRS) further laid good ground for stakeholders to share a common understanding of disaster operations. A milestone that can be achieved by the creation and development of flexible organisational structures, specialised training, clear chain of command, constant rehearsals and shared disaster coordination models (NIDM [23]) although it should be noted that these good systems were mainly common in particular states in the country.

### *4.4. Human rights, social justice, reconstruction and restoration*

The Act spelt-out punishable offenses under Chapter XI. These offenses included corrupt tendencies in handling DRR resources. Spread of false disaster information to cause fear, despondency and any form of harm on citizens and negligence of DRM related duty by government officers (Das [38]). However, it can be supported that rumour control is always necessary because it helps avoid unnecessary curiosity and panic among citizens. Failure to control such untoward behaviours can actually pointlessly harm certain groups of people. Therefore, it was positive that the Act set stiff penalties to those offenders. The penalty was given to be a period extending one year imprisonment and/or fine in that category, for both natural and juristic persons. Furthermore, the DRM laws allowed aggrieved persons to procedurally approach courts when they felt laws were also selectively applied by disaster stakeholders on vulnerable groups. Lastly, relevant government officers were bound by law to accept deployment for duty into zones where their skills were mostly on demand. At any given time and of course, within precincts of prevailing administrative laws and justice.

A dispute resolution mechanism was also provided by the law through the Act. To cater for people who would feel exploited in disasters and therefore, deserving compensation. The aim of that was to reduce opportunity for conflict within and between communities in disasters. In the same mind, the Act authorised responsible DRM authorities to appropriately regulate and guide fellow disaster related stakeholders. So that they remained accountable in their actions, transparent and efficient in handling necessary resources (G.O.I [25)] In fact to achieve that, the responsible authority had to ensure availability of a viable and well-coordinated NGO network (G.O.I [24)] NDMA was also accountable to Parliament and had been submitting a comprehensive overall report of the country's activities in that respect. Reconstruction and recovery work in India was always meant to be a participatory process, quality conscious and set to be completed within the first two to three years after the disaster. In ending, psycho-social support and temporary shelters among other provisions, had be afforded to victims early enough in the interim while permanent recovery and reconstruction solutions were being developed. (G.O.I [25)]

## 5. Conclusions

In conclusion Zimbabwe, South Africa and India attained different levels of DRR implementation progress. Zimbabwe was transitioning in practice towards DRR although legally it was still guided by the Civil Protection Act of 1996. South Africa was ahead of Zimbabwe in terms of laws, institutions and funding provisions for DRR but India appeared to have the best DRM framework compared to the other two nations although India's level of DRM practice did not reflect implementation homogeneity in the federation. On the other hand, development of DRM frameworks in the countries under consideration differed and that was partly attributed to the number of past disasters experienced in the countries. Since disaster frequencies can represent the internal governments have, to invest against the most recurrent hazards. It is further noteworthy that national DRR structures were mainly modelled in line with the national government system they existed. Also, it became clear that DRR was mainly a gradual and continuous process of implementing, reviewing, learning and improving relevant policies, programmes and plans. However, the countries studied had to do more to incorporate grassroots communities in DRM processes to ensure whole community cooperation, increased success and sustainability of interventions although the study basically provided many important DRM lessons.

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# Crisis management based on GIS – Case study

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**Abstract**

In the paper we introduce the particular GIS environment and tolls to be used together with recently developed methodologies to support the decision process of crises managers at local level. We applied those tools and methodologies for the area of Banska Bystrica district, Slovakia. The analyses are focusing risk and risk components assessment, in particular the susceptibility and vulnerability to flood and wildland fire. Based on the results obtained as well as consultancies with experts in the field of disaster or crises managers, fire-fighters, those methodologies are fully applicable in the current practice of crisis management, civil protection as well as operative management and coordination of emergency responders of Integrated Rescue system of the Slovak Republic. The only limitations are represented by the low level of knowledge and experience of the crises managers to work in the GIS environment and to use its tools and functions properly as well as the lack of extended GIS environments to provide the spatial analyses in them. In presence the provided GIS environments like CIPREGIS and GIS in CoordCom uses mostly the visualisation function of GIS.

*Keywords*: decision support, GIS, emergency, modelling;troduction

## 1. Introduction

Crisis management is defined in the terminological dictionary of crisis management (Šimák et al. 2006) as a summary of the activities of competent institutions, applied for the analysis of security/safety risks and threats, for risk monitoring, for prevention of crisis situations and for planning, organizing, implementing and controlling the activities intended to create conditions for crisis situations coping, as well as an interdisciplinary science that deals with the management as the purposeful human activity. While its mission it is to create a methodology of management with an emphasis on achieving the effectiveness of this action, in relation to the objective pursued, i.e. persons and property protection against the effects of the crisis (prevention) and during the crisis situation.

At the same time, it is also a type of activity or set of activities that allows the managers to achieve the specified objectives. It has a coordinating nature, unites and directs people of different professions.

Finally, the crisis management is a control action of people who perform management functions in a specific area, different from the normal administrative and production environment.

The main tasks of crisis management include (Šimák 2001):

- Implementing the preventive measures, prevention of crisis phenomena,
- Creation of conditions for the management of crisis phenomena, an adequate response to the crisis,
- Readiness for action at all levels (management and crisis management executive branch must immediately respond to the identified crisis phenomena).

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The objectives of the crisis management are (Šimák 2001):

- To assess potential risks and analyse the conditions of crisis phenomena,
- To describe the anticipated development and course of the crisis:
  - to develop variants of the crisis (to assess the strengths and weaknesses of the crisis),
  - to analyse of options from a system perspective and in terms of participation of the various parties in the crisis (to assess the effect of negative effects of the crisis),
- To take appropriate solutions that would be used in case of crisis,
- To get the crisis under control and minimize losses.

For the purpose of assessing the potential risks and the conditions of crisis phenomena occurrence, as well as an analysis of the development and progress of emergencies, crises respectively, there is advised to use an existing information and geographical information systems (GIS) as well as existing math (decision-making) models and methodologies, i.e. spatial decision support tools. Application of geoinformation technologies allows seeing the problem spatially.

In the field of crisis management, GIS brings great application opportunities in particular in the risk assessment process. They create also a part of alert or warning systems that publish information about dangers for the entire continents. In addition, the GIS is also used as an environment for creating and visualizing the input data or output data from modelling and simulation of emergencies such as fires, floods, hazardous substance releases, and radiation threat (Majlingová, Boguská, Monoši 2012)..

## 2. Decision support tools to be implemented in the risk management process

Risk management is a logical and systematic method of determining the context of any operation or process, identifying, analysing, evaluating, reducing and ongoing monitoring the risks, which allows minimize losses and maximize opportunities (Šimák 2006).

In the world, the issue of risk management and analysis of its individual components is dedicated to a number of experts. Most of these professionals are associated together under the United Nations University – the Institute of Environmental and Human Security (UNU-EHS). Its main objective is to improve human security applying approaches based on knowledge and experience and leading to the mitigation of vulnerability and environmental risks. UNU - EHS highlights the aspect of risk and vulnerability, public safety, as well as the effects of complex environmental threats and maintaining the continuous development.

In terms of the risk assessment process, the work focuses mainly on the possibility of assessment of individual components of risk, i.e. susceptibility, exposure, vulnerability, applying the GIS tools and systems for modelling and simulation.

Identifying and updating the hazards in terms of natural disasters, accidents, catastrophes and terrorist attacks, in Slovakia, is performed at the level of district offices, at the offices of crisis management, in the framework of development and annual updating of the document called "Analysis of the district territory according to possible emergencies" (the "Analysis of the district territory....". This is being developed based on the categorization of the territory of the Slovak Republic according to the Government of the Slovak Republic No. 25/1997 Coll., on the categorization of the Slovak Republic territory.

The „Analysis of the territory", in the Act of the National Council of the Slovak Republic No. 42/1994 Coll. on civil protection as amended, is defined as an assessment of potential threats (hazards), with respect to the source of the hazard. It is developed in the form of a series of documents. The structure, content and range of analysis and development and updating terms are determined in the 13/XXVI/12 Instructions of general director of Crisis Management Section of the Ministry of Interior of the Slovak Republic for the development of the document "Analysis of the area according to possible emergencies".

In the Analysis are described the possible emergencies as well as the potential harms to the people and damages to the property, in particular based on the extent of the affected area known from previous emergencies, but almost completely without any application of modelling and simulation tools.

The decision-making is the most important part of governance at all levels and in all areas. It is necessary in the strategic, tactical and operational management.

In general, it is necessary to distinguish between the concepts of management and decision making. Management is broader activity that includes implementing the decisions and control of their execution. The aim of management is to achieve the desired state that is ensured by the known change of the current system status. The problem of management is therefore the difference between the current and desired state of a system, resources available (personal, material, financial, technical), procedures and limits to achieve it. A manager must not only take a decision, but also to ensure its implementation in practice by the resources available and by keeping all the requirements specified on its implementation. Decision-making is one of the stages that take place in the course of management activities (Tucek, Koreň, Majlingová 2013).

For decision support is important the data existence. Implementation of geographical information systems in the 60s of the 20th century opened the possibility for spatial decision support.

Currently there are several programme environments (software) that allow to visualize, process and analyse spatial relationships among objects and their properties and this way provide necessary support for the decision maker, the operator of emergency hotline case of the management and removing the emergency consequences or incident commander, or crisis manager, at all. One of those environments is also the ArcGIS environment, but also the spatial extension of the HEC-RAS hydrodynamic model, i.e. the HEC-GeoRAS extension for ArcGIS.

In this paper we introduce the methodological approaches and results of analyses focusing the three types of emergencies – flood, wildland fire.

## 3. Experimental area and methodology

### *3.1. Experimental area*

The territory of the district of Banská Bystrica is an experimental area for the analysis and testing of the decision models built to assess the susceptibility of the district to the occurrence of a fire in the natural environment and the flood. In order to assess the vulnerability of the area to the a fire in the natural environment and to verify the suitability of the FARSITE program to be implemented in the crisis management practice, but in particular the management of rescue services at the site of intervention, the area affected by forest fires in 2011 was selected as the experimental territory. It is located in the cadastral area of the Staré Hory village. For the purposes of vulnerability to flood assessment and verification of the suitability of the HEC-RAS hydrodynamic model into the practice of crises management, the territory of Banská Bystrica was chosen.

### *3.2. Susceptibility assessment*

Susceptibility is a part of one of the components of risk – exposure. Under the exposure can be understood the number of communities and the environment or other elements of the existing systems existing in the assessed area that could potentially be damaged or destroyed by a negative factor of natural or technical nature. Susceptibility is then expressed as the "weak" points of those systems, which can directly cause an emergency or encourage its progress under certain circumstances (conditions). In the process of assessing the susceptibility of a territory is therefore necessary to identify the hazards arising from the nature of an area or type of industry which is operated there.

Among the most common natural disaster in Slovakia belong floods (caused by torrential rainfall or ice floods), wildland fires, wind storms, landslides.

#### *3.2.1. Susceptibility to flood*

In terms of susceptibility of the territory to floods should be considered not only the type of flood (caused by torrential collision, ice drifts, etc.), but also the environment for which the analysis is performed (natural or urban environment). In accordance to the type and nature of the environment and spatial scale of analysis differs also the methodology used for assessment, see methodology published by Majlingová, Galla (2015) suitable to applied for district, regional or national level and methodology published by Majlingová, Závacká, Kliment (2012) to be applied in an analysis provided for local level.

*3.2.2. Susceptibility to wildland fire*

For susceptibility to wildland fire the methodology published by Majlingova (2015) was applied. This is based on multi-criterial analysis (MCDA method application) using the spatial decision support systems (NetWeaver and EMDS). For data pre-processing the ArcGIS environment was used. In the NetWeaver environment was built an independent hierarchical network to automate the procedure of forest fire risk, susceptibility to fire respectively, assessment. The assessment process was carried out in EMDS (Ecosystem Management Decision Support) system, a spatial decision support system which was used in the form of extension to ArcGIS environment, which the visualization of assessment results was provided in. The analysis was based on mutual assessment of two basic groups of factors: natural and social. The associated susceptibility to forest fire was assessed. The group of natural factors consisted from the following subgroups: factors of forest fuel (consisting of factor of fuel model and factor of fuel height), geographical factors (landform factor, slope and aspect factor), and forest stand factors (tree species composition factor, stand age factor and health condition factor). The social factors are represented by factors of the distance from nearest road, nearest settlement, identified forest fruit picking areas, management activities performed in forest during the 10 years period and identified tourist localities and structures. To particular factors were assigned intervals and intervals of fuzzy values, as well as their weights, which they entered the evaluation process with.

*3.3. Vulnerability assessment*

Vulnerability of systems, infrastructure or any object at risk, is composed of numerous components. The severity that presents is determined by the impact of the emergency. It indicates potential damage and is a variable that can be used for predicting. It has a predictive quality: hypothetically represents a method of conceptualization, which may lead to the identification of the population at risk and the individual hazards. Assessing the vulnerability means finding answers to the question of what happens when one of the agents affected some of the objects at risk (e.g. community).

The vulnerability can often be measured only indirectly and retrospectively. The dimension that is normally used for this indirect measure is the harm or damage.

What is commonly seen as a result of the disaster is not the vulnerability itself, but the damage. Vulnerability of objects and elements at risk is reflected in the relationship between the force of hazard applied and the extent of the damage.

For purposes of assessing the vulnerability it is appropriate to use special tools designed for modelling and simulation of crisis phenomena. These are often available as OpenSource software. To work with it does not require the purchase of licenses.

One of such systems is also the hydrodynamic model HEC-RAS, which was used for modelling the 100-years and 500-years flood on the area of Banska Bystrica town. The methodology of its application has been published for the first time by Majlingová, Galla (2015).

For modelling the extent of wildland, respectively forest, fire in Stare Hory locality, FARSITE programme environment was applied. In addition to the fire site extent (area, perimeter) provides also information on the intensity of the fire, flame height, rate of fire spread, etc., at the same time. It also allows incorporate the information on the ongoing intervention (ground or aerial) into the modelling, in the form of so called barriers.

## 4. Results

*4.1. Results of susceptibility to wildland fire assessment of Banska Bystrica district natural environment*

First we introduce the results of analysis focusing the associated susceptibility to wildland fire (figure 1), which was calculated as a sum of fuel, natural, stand and social factors groups fuzzy values  Raster representing the spatial distribution of this sum was repeatedly subjected to fuzzification process. Consequently, those new fuzzy values were extracted for the particular centroids of polygons representing the individual forest stands in the experimental area.

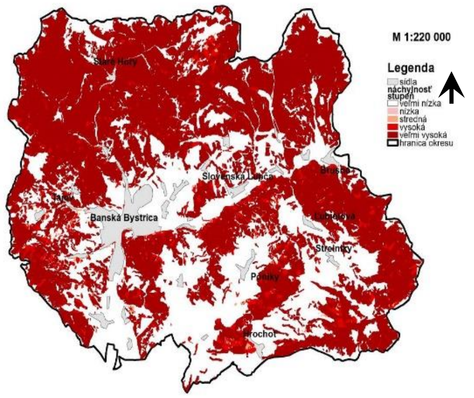


Figure 1 Results of asociated susceptibility to wildland fire in the area of the Banska Bystrica district

Overview of results related to associated susceptibility of the Banska Bystrica district natural environment to wildland fire is introduced in Table 1.

Table 2 Results of asociated susceptibility to wildland fire in the area of the Banska Bystrica district

| Category | Degree of risk | Area (ha) | Represent. (%) |
|---|---|---|---|
| 0 | no | 54 | 0.122 |
| 1 | very low | 0.99 | 0.002 |
| 2 | low | 682.75 | 1.537 |
| 3 | medium | 26 991.76 | 60.762 |
| 4 | high | 16 793.81 | 37.805 |
| 5 | very high | 6.28 | 0.014 |
| Total | | 44 421.79 | 100.00 |

The results of the analysis of the associated vulnerability to wildland fire showed that up to 60% of the area of the district falls into the medium degree of susceptibility to wildland fire and 38% of the area even to a high degree of susceptibility (Figure 1 and Table 1). The higher degree of susceptibility is caused mainly by fuel factors and geographical factors.

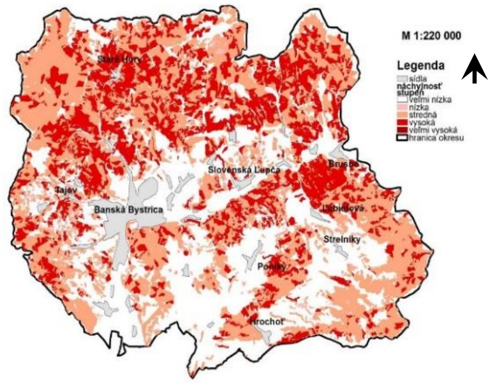


Figure 2 Results of susceptibility to wildland fire in the area of the Banska Bystrica district in terms of geographical factors

Table 2 presents the results of the analysis of the susceptibility of susceptibility of the Banska Bystrica district natural environment to wildland fire in terms of geographical factors, i.e. terrain conditions..

Table 2 Results of susceptibility to wildland fire in the area of the Banska Bystrica district – geographical factors

| Category | Degree of risk | Area (ha) | Represent. (%) |
|---|---|---|---|
| 1 | very low | 5.90 | 0.01 |
| 2 | low | 27.49 | 0.06 |
| 3 | medium | 273.52 | 0.62 |
| 4 | high | 2 530.30 | 5.70 |
| 5 | very high | 41 584.58 | 93.61 |
| Total | | 44 421.79 | 100.00 |

From the analysis results shown in Figure 2 and Table 2 is evident that more than 93% of the area is situated in very high degree of susceptibility to wildland fire. The reason for this phenomenon is the most pronounced value of the susceptibility of the territory caused by the factor of the shape of the terrain, its subdivision.

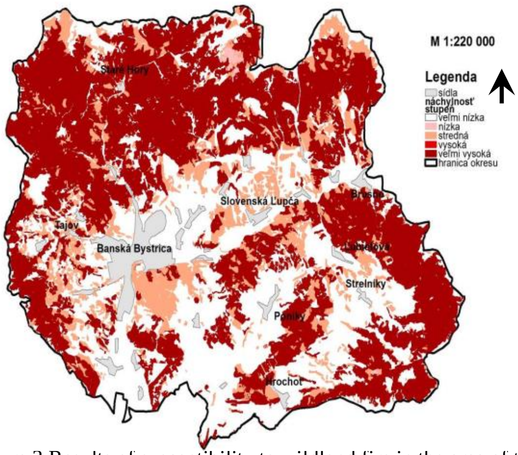


Figure 3 Results of susceptibility to wildland fire in the area of the Banska Bystrica district in terms of forest fuel fators

The analysis results are introduced also in table 3.

Table 3 Results of susceptibility to wildland fire in the area of the Banska Bystrica district – forest fuel factors

| Category | Degree of risk | Area | Represent. |
|---|---|---|---|
| | | (ha) | (%) |
| 1 | very low | 0.62 | 0.001 |
| 2 | low | 162.72 | 0.366 |
| 3 | medium | 9 348 | 21.044 |
| 4 | high | 0.00 | 0.000 |
| 5 | very high | 34 903.45 | 78.573 |
| Total | | 44 421.79 | 100.00 |

As already mentioned, the factors of surface forest fuel have also had a significant impact on the associated susceptibility of the area of the Banská Bystrica district. As can be seen from the results (Figure 3 and Table 3), up to 78% of Banská Bystrica's territory falls into a very high degree of susceptibility to wildland fire, due to the composition of surface forest fuel and its height. These are mixed and species-rich forest stands that create a very suitable environment for the growth of many plant species and herbs that are fuel for the surface type of a forest fire. It should be noted here that these factors are also highly dependent on the relative humidity of the fuel.

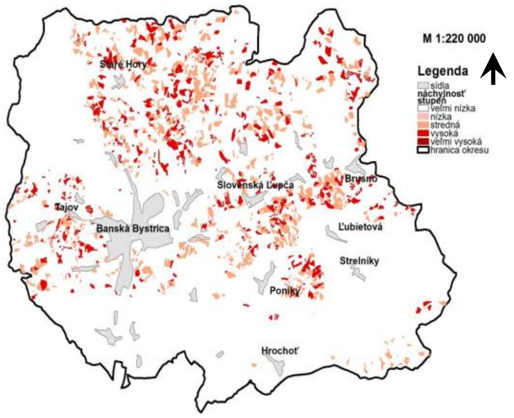


Figure 4 Results of susceptibility to wildland fire in the area of the Banska Bystrica district in terms of stand factors

The analysis results are introduced in table 4.

Table 4 Results of susceptibility to wildland fire in the area of the Banska Bystrica district – stand factors

| Category | Degree of risk | Area | Represent. |
|---|---|---|---|
| | | (ha) | (%) |
| *0* | no | 38 341.87 | 86.31 |
| 1 | very low | 0.00 | 0.00 |
| 2 | low | 0.00 | 0.00 |
| 3 | medium | 3 682.02 | 8.29 |
| 4 | high | 2 397.90 | 5.40 |
| 5 | very high | 0.00 | 0.00 |
| Total | | 44 421,79 | 100.00 |

From the point of view of stand conditions, it is evident from the results shown in Figure 4 and Table 4 that almost the entire area is situated in the lowest degree of susceptibility to wildland fire, where the occurrence of a fire is very unlikely. This is due to the tree species composition of the forests, which is premixed and the age of the stands in particular. A higher degree of susceptibility occurs especially in the stands which have been affected by wind disaster disturbance during the last 10 years and subsequently by the reproduction of bark beetle.

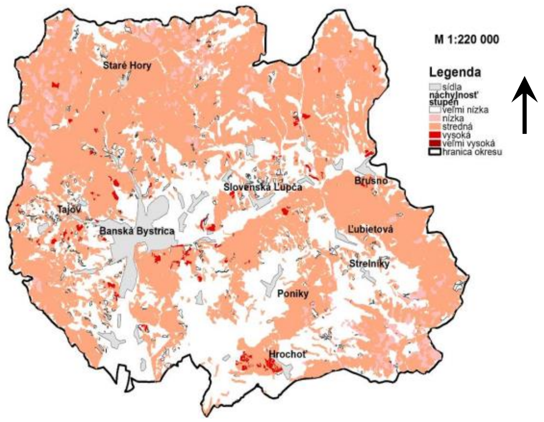


Figure 5 Results of susceptibility to wildland fire in the area of the Banska Bystrica district in terms of social factors

Table 5 Results of susceptibility to wildland fire in the area of the Banska Bystrica district – social factors

| Category | Degree of risk | Area | Represent. |
|---|---|---|---|
| | | (ha) | (%) |
| 1 | very low | 1315.53 | 2.96 |
| 2 | low | 2937.15 | 6.61 |
| 3 | medium | 39641.46 | 89.24 |
| 4 | high | 527.65 | 1.19 |
| 5 | very high | 0.00 | 0.00 |
| Total | | 44421.79 | 100.00 |

From the point of view of the results of the analysis of social factors (5) it can be stated that most of the areabof the Banská Bystrica district falls in the medium degree of susceptibility to fire (89%). The highest values of susceptibility were observed in the factors distance from the nearest road and picking the forest fruits, where the sites with the occurrence of blueberries, raspberries, cranberries were identified, based on the polygonal vector layer of forest types and their analysis from available phytosociological literature (Križová 1995).

### *4.2. Results of susceptibility to flood assessment of Banska Bystrica district natural environment*

The basic spatial unit for which a susceptibility category was identified in the afforested river basin district was the unitary spatial division of the forest (JPRL) at the division level (DC), the partial area (CP) and the breeding group (PS). Altogether, X breeds, which fall under the territory of the Banská Bystrica district, were assessed. For the remaining area of the district, excluding forest stands, we have chosen as the base unit for determining the polygonal-prone category, determined by the type of landscape cover (non-forest land)..

that three of the five categories for the susceptibilty of the area to the flood are represented by three degrees (Table 6), category 2 - low susceptibility of the territory to the flood, category 3 - medium susceptibility to flood and category 4 - high susceptibility to floods. Spatial distribution of the various categories of susceptibility of the area to the flood is evident from Figure 6 and Table 6.

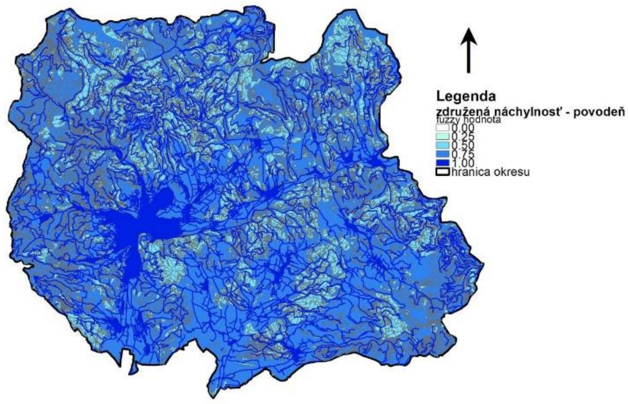


Figure 6 Results of asociated susceptibility to flood in the area of the Banska Bystrica district

Table 6 Results of asociated susceptibility to flood in the area of the Banska Bystrica district

| Cat. | Degree of risk | Area (ha) | Relat. share (%) |
|---|---|---|---|
| 1 | very low | 0.00 | 0.00 |
| 2 | low | 42.61 | 0.05 |
| 3 | medium | 24 893.12 | 30.77 |
| 4 | high | 55 958.50 | 69.18 |
| 5 | very high | 0.00 | 0.00 |

The area of category 2 (low flood susceptibility) occupies an area of 42.61 ha (0.05%). Category 3 (medium susceptibility) occupies an area of 24,893.12 ha (30.77%). The most represented category on the area of the district, with an extent of 55,958.50 ha (almost 70%), is category 4 - high flood susceptibility. In this category, 55% (19,479.91 ha) of belongs to forest stands and the remaining 45% (36,478.59ha) of land other than forest cover.

The dominance of Category 4 is due to the nature of the geomorphologic consitions of the area under consideration (predominant category 4), which are characterized by terrain slope (Figure 7) in particular, which consequently affects the distribution of soil types in the area and also increases the representation of the soils with a higher susceptibility category (Figure 8). An important factor in this case is also the factor re-presenting the drainage potential, which is relatively high for the territory. The above factors are, in our opinion, among the dominant and determining susceptibility of the area to the flood, and unfortunately belong to a group of factors that can not be affected or changed in any way, too.

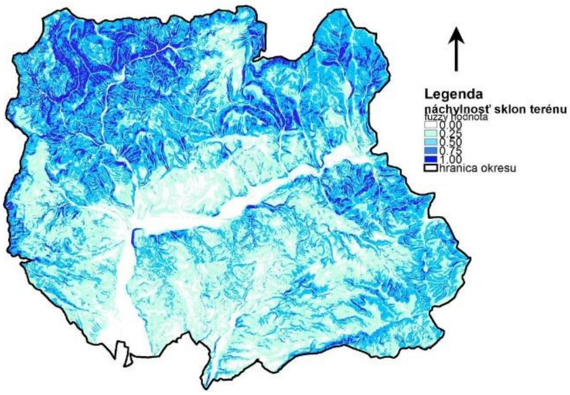


Figure 7 Results of asociated susceptibility to flood in the area of the Banska Bystrica district in terms od terrain slope

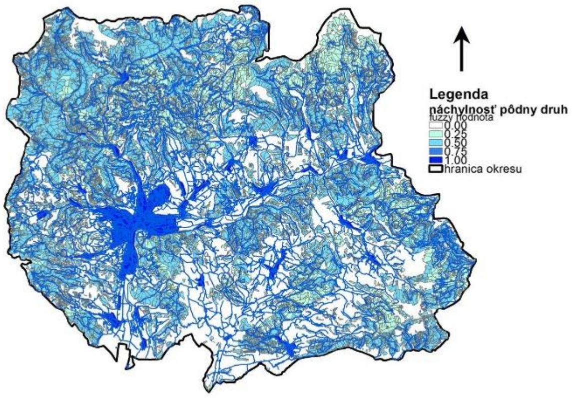


Figure 8 Results of asociated susceptibility to flood in the area of the Banska Bystrica district in terms of soil type

The second group of factors represent the other factors (forest type group - figure 9, degrees of ecological stability, non-forest landscape), which could be influenced by the appropriate measures within the integrated river basin management, so we could, but only to a certain extent , to dampen the negative influence of a "group of non-variables" on the overall assessment of the susceptibility of the area to the flood.

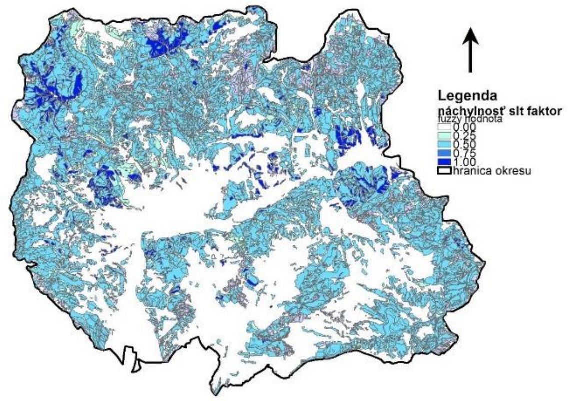


Figure 9 Results of asociated susceptibility to flood in the area of the Banska Bystrica district in terms of forest type group

*4.3. Results of vulnerability to forest fire assessment for the cadaster territory of Stare Hory village*

The modeled fire was announced to the Regional Operational Center of the IRS in Banská Bystrica on April 10th, 2011 at 14.25 h. According to the Fire Damage Report, the fire was localized only on April 12th, 2014 at 16.30, i.e. after 50 hours of fire. The area of the fire site was set to 43.88 hectares at that time and the fire perimeter to 3.63 km (see Figure 10).

On the basis of the fire modelling results provided in FARSITE environment, the extent of the fire site at 16.30 h was calculated to 44.6 ha (area counted in the horizontal direction), 51.3 ha (the topography of the terrain was considered) respectively, and its perimeter to 3.9 km, respectively 4.2 km (considered with topography of the terrain). On the basis of these data, the accuracy of FARSITE fire site area calculation was set to 98.2%. For the purpose of comparison, the area calculated in the horizontal direction was used, as these are derived from the 2D data representations in the Intervention Report.

This is a relatively high accuracy of modelling when considering the comparison of real fire extent with the modelled one.

However, the accuracy of the simulation must be verified with regard to the shape of the fire site visually.

It is necessary to mention the fact that we did not have the information on real fire area necessary for the visual evaluation of the modeling accuracy, because none of the requested data providers (regional Directorate of Fire and Resciu Service in Banska Bystrica, Forests SR S.E. in Banska Bystrica) have such a layer. We only managed to get a map of the forest stands affected by the fire, but they were not damaged throughout the entire area, but only partially.

As can be seen from Figure 10, even in the case of the modeling of a fire in which we have implemented data on ground and aerial fire-fighting by creating so-called barriers through which the fire did not pass through in the modeling process, the fire damaged all the above mentioned stands. but not all of them destroyed completely.

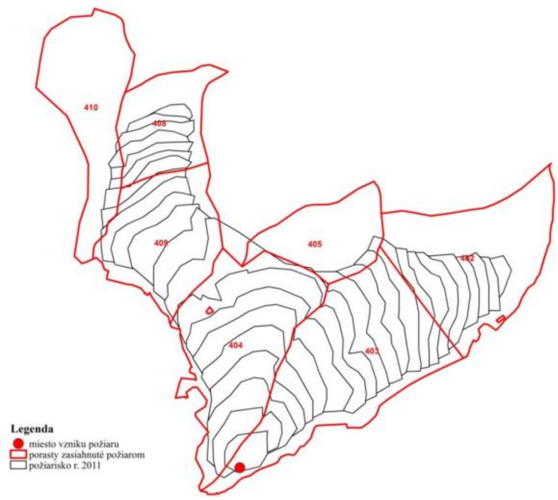


Figure 10 Resulting fire site area obtained by modeling from FARSITE compared to the area fire affected stands

### *4.4. Results of vulnerability assessment of Banska Bystrica town to flood*

To simulate the course of Hron river and assesment of flooded area extent the HEC-RAS hydrodynamic model was applied. A 1D mathematical model was developed for the entire wate rbody of river Hron running through the cadastral area of Banská Bystrica (up to Radvan). Flood flow rates Q100 and Q500 were calculated. In the calculations of the proposed flood levels and subsequent assessment of the state of flood protection of the section under consideration, the flow rates from the Slovak Hydrometeorological Institutes were used as well as the flow data obtained from the technical documentation of the Slovak Watermanagement Enterprise, S.E.

The calculations also took into account the inflows of water courses flowing into the river Hron near and directly in the town of Banská Bystrica, The inflow of Bystrička stream and the Hron river.

In addition, there are introduced the results obtained by processing the results from the HEC-RAS environment in ArcGIS environment applying the tools of this environment and the tools of its extension HEC-GeoRAS.

The data from HEC-RAS model were further processed in ArcGIS environment. The graphical out puts are showed in figure 11 and 12.

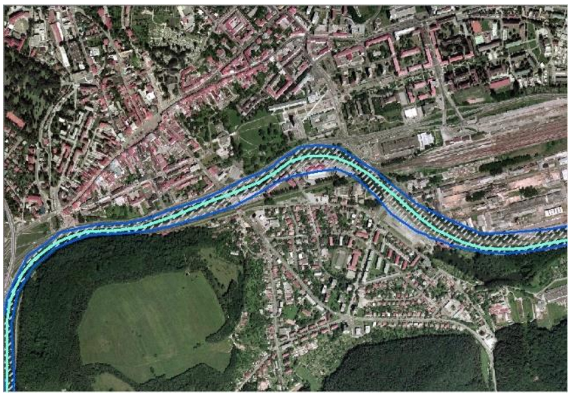

Figure 11 View of the 100-yers flood (Q100) affected area

Figure 12 View of the 500-years flood (Q500) affected area

In view of the threat to the population caused by floods caused by Q100 (Figure 11) and Q500 (Figure 12), it is necessary to evacuate the inhabitants located in the buildings and facilities of former Smrečina enterprise, a railway line near the Main Railway Station in Banská Bystrica and the ice-hockey stadium. From a threat point of view, it is necessary to close or, at the time of the flood, to evacuate the Štefánikovo and Štadlerovo nábřežie as well as the E66, E77 (lanes in the direction of Banska Bystrica) in the section from the Main Railway Station to the bridge at the railway station in Radvan.

Another threat in terms of the possible domino effect occurrence is also the lower part of the analyzed section of the Hron River in Kráľová, especially with regard to the potential leakage of harmful substances from Detox's company, which deals with the collection and disposal of several types of dangerous substances.

## 5. Conclusion

The problem of the occurrence of emergencies arising from ongoing climate change is currently one of the frequently discussed issues. The effort of the whole society to adapt to these changes as well as efforts to mitigate ongoing climate change is gaining momentum. Frequently used term in relation to this issue is adaptation in terms of adapting to changing climate conditions by mitigating the effects of climate change or adapting to it.

This adaptation is only possible by preparing for an increasingly frequent occurrence of these emergencies in the future. To be prepared to remove and mitigate the effects of such events is only possible through a functioning and effective risk management system - from knowledge of the threats, localization in area, knowledge of their potential impacts and planning and subsequent implementation of preventative measures as well as measures relating to the protection of the population, the planning of forces and necessary necessary for its coping.

In view of the occurrence of emergencies such as natural disasters - wildland fires and floods, it is therefore important to locate their potential occurrence, which should be based on a combination of data on the susceptibility of the area to their occurrence in terms of established factors and their critical values, and on the current weather situation. For this purpose, it is necessary to build fire and flood warning systems, especially at national level.

Awareness of the current danger, associated with monitoring a threatened territory gives the premise of timely announcing of this emergency and its subsequent timely removing.

Knowing the terrain/territory, in which an emergency occurred and in which the rescue services carry out its activity related to the emergency coping and rescue operations providing, is one of the key preconditions for timely and effective intervention as well as their own safety.

Building a suitable, up-to-date and available database is one of the pre-requisites for optimizing the decision-making process of crisis managers, as well as for supporting the management and coordination of rescue services themselves under the conditions they may encounter during the fighting and removing a particular emergency.

## Acknowledgement

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# Unmanned Aerial Vehicle (UAV) application in developing countries: a life-saving technology supporting crisis management

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**Abstract**

Mitigating disaster impacts, responding to emergencies or carrying out post-disaster assessments are critical in both research and practice. However, remote rural areas, absence of or damaged infrastructure and hazardous post-disaster situations pose a challenge to such operations. This paper, therefore, explores the use of drones in developing countries. Methods: This paper focuses on civilian applications of unmanned aerial vehicles (UAVs) in developing countries. Literature study of different materials as well as personal experience in similar environments resulted in the compilation of this work. Results: UAVs come in many shapes and sizes and are useful both in developed and developing countries. They have been used to obtain imagery for disaster risk assessment and response. They also have been used in wildlife protection, delivery of medical samples to remote areas, mapping disaster risk, helping displaced persons and conflict emergency surveillance. UAVs provide an effective, fast and less expensive solution to save more lives and the environment in developing countries.

*Keywords*: unmanned aerial vehicle, drone, applications, developing countries, surveillance;

## 1. Introduction

Initially developed for government and military requirements unmanned aerial vehicles (UAVs) are strongly associated with military applications. (Fahstrom & Gleason [1]) Nevertheless, they are soon becoming a household name in civilian operations. They are among the most powerful and promising topical technologies that could transform disaster response and relief operations. Many scholars render them as a 'game-changer' for disaster risk reduction in the three phases like prior, during and after disaster. They capture useful and timely information for timely and effective response as well as search and rescue for victims and deliver disaster relief (Htet [2])

UAVs, also known as drones, are aircraft that do not have a human operator aboard. (Restas [3]) (Bhattacharjee [4]) (Sandbrook [5]) (Limnaios [6]) (OCHA [7]) According to the Department of Defense Dictionary of Military and Associated Terms (2001:494 [8]), an unmanned aerial vehicle is "a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload." "Unmanned" infers complete absence of a pilot on the aircraft. This means that UAVs can be operated remotely or completely autonomously. (Limnaios [6]) Simply put, it is an aircraft that operates without a human operator on board. (Sandbrook [5]) (Wagner [9]) Various names are used for UAV such as drones, robot plane and remotely piloted aircraft system, with 'drone' as the most popular name. The name 'unmanned aerial vehicles' however, seems to be one of the more popular one with many experts. (Restas [3]) (Bhattacharjee [4]) (Sandbrook [5]) In this study the terms 'UAVs' and 'drones' will be used interchangeably.

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## 2. Historical perspective on UAVs

to when drones were first used. Kilani traces their use back to 1849 during the attack of Venice by Austria using unmanned balloons filled with explosives. Wagner also dates it back to the 19th century for aerial-military reconnaissance photos which were taken in the Spanish-American war. Limnaios et al. and Khan however, record Ancient Greece as the starting point of UAVs. It is claimed that in 425BC Tarentum of South Italy, built the first-ever UAV which was in the form of a wooden mechanical pigeon, (see Figure1). This UAV flew only once, for 200 metres. A lot of machines were made between then and the 19th Century, leading to the current UAV designs. (Limnaios [6]) (Wagner [9]) (Kilani [10]) (Khan [11])

In 1916 America produced the first 'modern' UAV through the work of Lawrence and Sperry. It was called the 'aviation torpedo' and it flew over a distance of 30 miles .Some scholars, however, state that drones were first developed and used for military purposes by the United States of America in the 1950s. (Webb [12]) This corroborates Limnaios et al. (2012) who state that the Ryan Model 147 series aircraft developed then can bear the current definition of unmanned aerial system. (Limnaios [6]) The 1960s and 1970s witnessed its use by the USA for reconnaissance missions over China, Vietnam and other countries. Since then the USA and Israel have been developing smaller and cheaper UAVs. While the use of drones in military operations is almost common knowledge to most people, the 21st century has come with their increasing involvement in civilian applications. This might have come about as a result of them being miniaturised and the significant price reduction that ensued. (Sandbrook [5]).

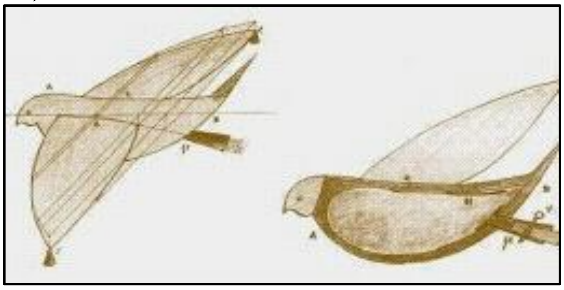

Figure 7 Archytas' Pigeon Source: [11]

### *2.1. Technical summary of UAVs*

There are many types and sizes of UAVs with different weights, configurations and capabilities. United Nations Office for the Coordination of Humanitarian Affairs (OCHA) states that even though most UAVs are remotely controlled, some fly autonomously following pre-set coordinated or patterns. Fahlstrom and Gleason (2012) state that in recent years the range in size has increased tremendously with the smallest UAV being as small as an insect and some larger than a usual light manned aircraft. (Fahlstrom [1]) The smaller the UAV is the more portable it is, such that it can be carried, launched or operated with much ease. The miniaturisation of UAVs also has brought about the positive outcome of significant price. (Sandbrook [5]) On the other hand, the bigger UAVs are also necessary for the provision of long endurance and the coverage of larger area. The Predator 7, for instance, is not included in Table 1 because they were not considered appropriate for UN missions. It is at the larger end, and can fly for 40 hours to an altitude of up to 25 000 fee. (OCHA [7]) The larger UAVs are also more stable than the smaller ones, especially in windy situations. Moreover, they allow for a larger arrangement of payloads, especially for surveillance or search and rescue purposes. (Mc Farland [13]) However, the small UAVs are more capable to produce higher resolution imagery because imaging devices are now lighter than before. (Dorn [14])

## 3. Applications

Both the developed and developing worlds face challenging situations where they need to effectively address emergencies and the devastating socio-economic, infrastructural and environmental impacts they cause while keeping costs down. Defining uses for which UAVs are applicable is not an easy task. The possibilities for UAV applications are many. Although UAVs were developed primarily for military and government requirements, they have found their way into the civilian arena; creating two main categories of applications which are the military and civilian. Furthermore, these usually overlap in the field of reconnaissance and surveillance. (Fahlstrom [1]) When equipped with sensing devices, UAVs provide a plethora of opportunities in disaster or emergency situations. OCHA (2014) states that UAVs are mostly used to provide high-altitude photogrammetric imagery and video feed which can be broadcasted live to the responders or decision makers. They allow for more accurate rapid synopsis of the situation and provide close to real-time information. Some of the prevalent civilian applications of UAVs today include monitoring crowds, following suspects at night, emergency and disaster monitoring and response, search and rescue, wildlife protection, border patrol, delivery of medical supplies, weather observation, police surveillance, fire-fighting monitoring and management, mineral exploration, advertising, precision agriculture. (Bhattacharjee [4]) (Sandbrook [5]) (Wagner [9])

**4. Developed countries**

Developed countries make many researches on different threatening. Taking building fires as an example there are researches to show the effect of fire stress on concrete structure (Balazs [15]) and also initiatives to keep its resistant much higher (Lubloy [16]). Drones have been successfully used in many emergency situations in the developed world such as Hurricane Katrina in 2005 which caused extensive destruction on the Mississippi Gulf Coast. National Science Foundation reports that, with their speed portability and access, two UAVs investigated the communities that were damaged by the storm. (NSF [17]) They searched for survivors and took videos to help responders know which areas to either focus their attention on or avoid. Streets blocked by collapsed houses or fallen trees could not stop the UAVs to capture details of the presenting situation; even from as far as 1000 feet. UAVs were also used when Japan suffered successive disasters of earthquake, tsunamis and the Fukushima Daiichi nuclear power plant melt down in March 2011. (Adams [18]) With the damaged nuclear facility that was emitting radiation it became dangerous for humans to access the area. The US RQ-4 Global Hawk

(see Figure 2 [19]) came to the rescue and undertook 20 missions in two months. During that time it photographed thousands of images that were shared with the Government of Japan and aid organisations. [20] UAVs are patrolling the difficult terrain of USA border with Mexico and Canada; equipped with infrared and high resolution cameras. This reduces the risk for border agents and increases coverage and precision. They are involved in search and rescue for missing persons, monitoring forest fires and monitoring traffic accidents, among other applications (Finn [21]) (Carr [22])

*4.1. The developing countries*

The mention of UAVs or drones invokes images of death and destruction in many people's minds. However, the past couple decades have witnessed this technology being used to protect and save lives as well as the infrastructure and environment; in Africa and other parts of the world. Several departments of the United Nations such as the United Nations Department of Peace Keeping Operations, United Nations Refugee Agency (UNHCR) have employed this technology to respond to emergencies, save lives and bring peace sooner. (UNHCR [23]) UAVs have been used in countries like the Philippines, Haiti, Democratic Republic of Congo (DRC), Niger, Burkina Faso, Uganda, South Sudan, Burkina Faso, Nigeria, Rwanda, Chad, Central Africa Republic and South Africa. (OCHA[13]) (UNHCR [23]) (Kasaija [24]) (Karlsrud [19]) In these developing countries drone technology has proved to have peaceful applications and a multitude of opportunities still lie unexplored.

Figure 2 Aerial View of Shelters of Displaced People, Niger (Source: [19])

### *4.2. UNHCR drones helping displaced people in Africa*

The paradox of technology: created to deploy bombs and kill on target, drone technology is now being employed to help refugees in Africa. In countries like Nigeria, Burkina Faso, Niger, South Sudan and Uganda UAVs have been used to assess the needs of displaced persons, map huge populations and assess environmental damage caused by massive displacements. (UNHCR [23])

The imagery produced by the use of UAVs (see Figure 3 [25]) provided UNHCR officials and its partners with improved situational awareness that helped them meet the health, physical, socio-economic and education needs of the refugees and at less cost than if they used manned aircraft. (Aduloju [26])

Figure 3 Drone carrying medical Supplies.
(Source: [25])

## 5. Wildlife protection

Norton Rose Fullbright records that with one rhino being killed every 7.2 hours; South Africa's largest rhino population in the world was under threat of being extinct. (Fullbright [27]) With a large and difficult landscape it has been a challenge to monitor the rhinos every day for 24 hours.

Moreover, the long distances the rhino travel added to the challenge of any effort to prevent further loss of the rhino. To protect the remaining rhino population South Africa's UDS together with Kruger National Park equipped UAVs with both visible and infrared cameras which searched for poachers' heat signs. (Vision System [28]) On a positive note, Norton Rose Fullbright reports that the use of UAVs in the anti-poaching campaign resulted in a significant reduction in the poaching cases. In some areas unofficial figures showed that the poaching had currently abated.

However, poaching incidents started to rise when UDS left, showing that the use of UAVs were effective in deterring poachers. Kerr reports that Kenya is also using UAVs to improve its fight against the poaching of rhinos and elephants. (Kerr [29]) (Fullbright [27])

## 6. Delivery of medical supplies

Technology has become relevant in Rwanda by addressing the country's challenges of the majority of the 11 million people who are poor and live remote areas that are difficult to reach. The roads are washed making it difficult to access the remote parts of the country. With the use of UAVs approximately 150 deliveries of blood was expected to be made to 21 facilities every day. Where it used to take four hours to make an emergency delivery the drone will carry out those deliveries in 15 minutes. This will significantly save a lot of lives as postpartum haemorrhaging was the major cause of death for pregnant women in the country. The launching of UAVs to transport medical supplies in Muhanga district was expected to expand to cover the rest of the country by early 2017. (Aljazeera, [30]) In South Africa, Professor Barry Mendelow from Witswatesrand University carried out 300 fully audited drone flights in transportation of medical samples, such as blood, snakebite serum or rabies and sputum, from remote areas to laboratories in the urban area up to a maximum of 100km. The drone used in Barry Mendelow's study was called e-Juba (ijuba is Zulu name for pigeon). Figure 3 shows a drone carrying medical supplies. Where it used to take six weeks to get a tuberculosis diagnosis, with UAVs it could be done in a single day.

Moreover, none of the cargo was lost during those trial flights and the cost proved to be less than when using road transport. (NICD [31]) (Borgen Project [32]) For instance, the DNA samples of sputum are lightweight, take very little space and are not target for potential thieves. The Borgen Project (2016) argues that drones may revolutionise healthcare in South Africa On another note, Smedley (2015) reports that the Aerial Robotics Laboratory at Imperial College London was setting up African drone networks to deliver blood supplies to rural health clinics which could see more drone activity in developing countries. (Smedley [33])

## 7. Current use of UAVs in conflict emergency surveillance

The United Nations, humanitarian organizations and police have started using UAVs for aerial surveillance which yields such information tasks as real time information as well as for search and rescue. Surveillance drones do not have the ability to stop conflict. The information gathered through them, however, can contribute to the protection of human rights, save lives and help bring peace sooner. According to the OCHA, Karlsrud and Kakaes the UN has used drones for the protection of human rights in (OCHA [7]) (Karlsrud [19]) (Kakaes [25])

- 2006 – MONUC; in Democratic Republic of Congo (DRC)
- 2006-2009 – to monitor Sudanese border with Chad, during invasion from Darfur
- 2007 – MINUSTASH; the peacekeeping force in Haiti
- 2009 – MINURCAT; eastern Chad and north-eastern Central Republic,
- 2013 – MONUSCO; in DRC,
- 2015 – Timbuktu; Ornen, Svalan and Korpen were deployed by Swedish peacekeepers

According to Kasaija (2014) the 'MONUSCO drones'made a mark in the history of aerial surveillance and UN peacekeeping and their use may be expanded to other countries such as Sudan and South Sudan. The two major priorities under MONUSCO were the protection of civilians and the consolidation of peace in DRC. MONUSCO was mandated to employ all necessary means and UAVs became one of the major instruments used. In spite of lingering challenges concerning the use of drones especially with regards to regulation, they significantly contributed to the ending of the rebellion of the M23 group in eastern DRC. In these operations, such as in Haiti and Chad and several others, the application of drones proved beneficial in monitoring the movement of opposition forces and protecting civilians. (Kasaija [24]) (Kakaes [25])

## 8. Challenges to effective use of UAVs

### *8.1. Regulation*

One of the major obstacles to deploying UAVs in the national airspace is the absence of an appropriate legal framework that regulates their use. This applies to many countries including South Africa. For instance, Mendelow, (2015) argues that there is need for a legislative framework that empowers the South African Civil Aviation Authority to legitimize cargo carrying drones. He further argues that the developed world civil aviation authorities have imposed tough laws on drones in order to reduce the danger of accidents. Due to the absence of necessary regulation the use of UAVs, after the Super Typhoon Haiyan in the Philippines, was cleared by a special agreement with the Mayor of Tacloban. (Htet [2]) (OCHA [7]) (Kerr [29]) (Mendelow [34])

### *8.2. Privacy*

The concern with regards to privacy is still a subject of debate. (Htet [2]) (Carr [22]) Longeley (2016 [35]) refers to a poll conducted by the American Government Accountability Office (GAO) where 42 % 0f 1 708 randomly selected adults indicated that they were concerned about their privacy in relation to the use of UAVs and 15% indicated otherwise. The concerns about privacy seem to be ubiquitous. After the South African mayor of the city of Cape Town announced plans to use drones to monitor copper cable theft that is costing a lot of money every year, the human rights and legal activist organisations raised concerns about privacy. The argument is that the public should be protected from the infringement of their individual privacy as a result of technological advancement. UAVs have the ability to penetrate private establishments without prior warning or warrant. (Fullbright [27])

### *8.3. Safety/ security*

With over 50 organisations developing and producing UAV designs, safety concerns have increased. The concerns are that these UAVs will interfere with the usual commercial and general flying aircraft. Furthermore, there is apprehension that they could also interfere or even cause danger to the people and property on the ground, especially in the event of a drone crash over a populated area The American Government Accountability Office (GAO) stated the following as the aspects of safety concerns as a result of using UAVs: (Carr [22]) (Longley [35])

– UAVs are incapable of recognizing other flying objects
– There are weaknesses in the command and control of UAV operations such as hacking, cyber terrorism or jamming of GPS
– No operational and technological standards in place to guide their safety
– No regulatory framework to speed up their integration into the national airspace

With the increasing need for UAVs in developing countries, Civil Aviation Authorities have a lot of work to do to alleviate these challenges.

## 9. Benefits of using drones in the developing countries

Just as the use of UAVs has revolutionised the military, the same is happening with civilian applications. They are a game-changer and provide more advantages over manned aircraft or human involvement. [4] Developing countries are generally resource-poor, especially in terms of finances and highly technological equipment. Most of their population lives in remote rural areas mostly with under-developed or damaged infrastructure which makes them highly inaccessible. Their advantages in civilian applications correspond with the military ones as discussed by the following (Bhattacharjee [4]) (Glade [36] (Odido [37]) (Dorn [38]) (Dorn [39]) such as:

– They are usually smaller, lighter and more fuel-efficient
– They are persistent, cost-effective and surveillance covers a large area at a time
– They can work faster, more accurately, and are more reliable than human observers (eye and ear are limited)
– UAVs can be launced from many locations without need for a runway
– UAVs can work effectively at night without fear for their security
– They are more difficult to hit than manned aircraft; they are difficult to detect because of less or almost no noise at all
– Low costs in case of a crash; in terms of its cost and no human life lost
– Training to control UAV is less expensive than for a manned one
– Inclusion of monitoring technology in civil unrest, such as UAVs, helps to reduce false accusations, provides a basis to deal with violations, keeps decision makers informed concerning the situation on the ground and builds confidence among involved parties
– The use of aerial surveillance could also deter perpetrators of violence from carrying it out for fear of being caught

## 10. Conclusions

This paper presented historical overview of UAVs, the classification on the basis of size. UAVs, having been initially designed for military use have found their way into the civilian arena. While the developed world uses UAVs for various applications; the developing countries benefit tremendously. This is due to their general lack of resources, remote rural locations and prevalence of various kinds of catastrophes. UAVs provide an effective, fast and less expensive solution to save more lives and the environment in developing countries. Although there are still challenges in the use of drones, they are outweighed by benefits.

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