B priedas. Autoriaus mokslinių publikacijų disertacijos tema kopijos

ZBIGNEVO KARPOVIČ MOKSLO PUBLIKACIJŲ DISERTACIJOS TEMA SĄRAŠAS

Straipsniai recenzuojamuose mokslo žurnaluose

Karpovič, Z.; Šukys, R.; Gudelis, R. 2012. Toxicity research of smouldering and flaming pine timber treated with fire retardant solutions (Antipireniniais tirpalais impregnuotos smilkstančios ir degančios liepsna pušies medienos toksiškumo tyrimai). *Journal of Civil Engineering and Management* 18(4): 600–608. ISSN 1392-3730 (*ISI Web of Science),* doi:10.3846/13923730.2012.709195.

Galaj, J.; Karpovič, Z.; Jaskółowski, W. 2011a. Investigation into the influence of impregnation on pine timber combustion using a cone calorimeter and large scale tests (Impregnuotos pušies medienos degimo tyrimai panaudojant kūginį kalorimetrą ir natūrinių tyrimų įrangą). *Engineering structures and technologies (Statybinės konstrukcijos ir technologijos).* 3(3): 91–104 (ISSN 2029-2317), doi: 10.3846/skt.2011.11.

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ISSN 1392-3730 print

Volume 18 Number 4 August 2012

JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS
SAPERE AUDE

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SUBSCRIPTION INFORMATION

***Journal of Civil Engineering and Management*, Print ISSN 1392-3730, Online ISSN 1822-3605, Volume 18, 2012.**

Journal of Civil Engineering and Management (http://www.tandfonline.com/TCEM) is a peer-reviewed journal co-published four times a year in March, June, September and December by Vilnius Gediminas Technical University (VGTU) Press Technika, Sauletekio al. 11, Vilnius, LT-10223, Lithuania and Taylor & Francis, an Informa business, 4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN, UK.

Annual Subscription, Volume 18, 2012
Institutional Subscription Rate (print and online): $720/£436/€576
Institutional Subscription Rate (online-only): $648/£393/€518 (+ VAT where applicable)
Members of the International Council for Research and Innovation in Building and Construction (CIB): €70

An institutional subscription to the print edition includes free access for any number of concurrent users across a local area network to the online edition (ISSN 1822-3605).

Ordering Information: Please contact your local Customer Service Department to take out a subscription to the Journal: **India**: Universal Subscription Agency Pvt. Ltd, 101–102 Community Centre, Malviya Nagar Extn, Post Bag No. 8, Saket, New Delhi 110017, India. **USA, Canada and Mexico**: Taylor & Francis, 325 Chestnut Street, 8th Floor, Philadelphia, PA 19106, USA. Tel: +1 800 354 1420 or +1 215 625 8900; fax: +1 215 625 8914; email: customerservice@taylorandfrancis.com. **Europe/Rest of the World**: T&F Customer Services, Informa Plc., Sheepen Place, Colchester, Essex, CO3 3LP, UK. Tel: +44 (0)20 7017 5544; fax: +44 (0)20 7017 5198; email: subscriptions@tandf.co.uk.

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Back Issues: All enquiries related to back issues of journals should be addressed to Vilnius Gediminas Technical University (VGTU) Press Technika, Sauletekio al. 11, Vilnius, LT-10223, Lithuania.

ISSN 1392–3730 print
ISSN 1822–3605 online

Volume 18 Number 4 August 2012

JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT

International research and achievements

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JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT

Volume 18, Number 4, August 2012

http://www.tandfonline.com/loi/tcem20

Journal Scope: The Journal provides an international forum for the dissemination of the latest original research, achievements and developments in all areas of civil engineering and management. The Journal aims to provide a multidisciplinary forum for researches, designers, users and manufacturers involved in the different fields of civil engineering and management. Topics include building materials and structures; structural mechanics and physics; geotechnical engineering; road and bridge engineering; urban engineering and economy; construction technology, economy and management; information technologies in construction; fire protection, thermoinsulation and renovation of buildings; and labour safety in construction.

History: *Journal of Civil Engineering and Management* formerly known as *Statyba – Civil Engineering* (Vol. 1–7, 1995–2001, ISSN 1392-1525) has been published since 2002 in place of the previous research proceedings of Lithuanian high schools: *Lithuanian Proceedings in Mechanics* (No. 1–33, 1967–1994, ISSN 0460-2242), *Reinforced Concrete Structures* (No. 1–16, 1967–1989, ISSN 0372-3070), *Building Materials and Structures* (Vol. 1–9, 1971–1981, ISSN 0202-3210), *Building Structures* (Vol. 10–20, 1983–1995, ISSN 0208-2500), *Building Economy and Organization* (Vol. 1–17, 1971–1990, ISSN 0202-3210), *Building Economy and Management* (Vol. 18, 1993, ISSN 0208-2497), *Construction Technology and Management* (Vol. 1–7, 1984–1993), and *Structural Repair and Strengthening* (No. 1 and 2, 1992 and 1995). From 2011 (Volume 17), the journal is co-published with Taylor & Francis. Since 2012 the '*Journal of Civil Engineering and Management*' will be published in volumes (six issues per year).

Abstracts & Indexing: Thomson Reuters: Science Citation Index Expanded, Web of Science; Elsevier Bibliographic Databases: SCOPUS, Compendex, The Engineering Index Monthly; ICONDA (The International CONstruction DAtabase); CSA (Cambridge Scientific Abstracts): Advanced Polymers Abstracts, Aerospace & High Technology Database, Aluminum Industry Abstracts, CSA Civil Engineering Abstracts, CSA Engineering Research Database, CSA High Technology Research Database with Aerospace, CSA Materials Research Database with METADEX, CSA Mechanical & Transportation Engineering Abstracts, CSA Technology Research Database, Ceramic Abstracts/World Ceramic Abstracts, Composites Industry Abstracts, Computer and Information Systems Abstracts Journal, Corrosion Abstracts, Earthquake Engineering Abstracts, Electronics and Communications Abstracts Journal, Engineered Materials Abstracts, Environmental Engineering Abstracts, Environmental Sciences and Pollution Management, International Aerospace Abstracts, Materials Business File, METADEX, Solid State and Superconductivity Abstracts, Water Resources Abstracts; INSPEC; Gale®: Academic OneFile, InfoTrac Custom; VINITI RAN; ProQuest: Ulrich's, Summon™; EBSCO*host*: Academic Search Complete, Current Abstracts, TOC Premier; IndexCopernicus.

Submissions: All submissions should be made online at the *Journal of Civil Engineering and Management* ScholarOne Manuscripts site (http://mc.manuscriptcentral.com/scem). Complete guidelines for preparing and submitting a manuscript to this Journal are provided at the Journal website.

Co-Published with Taylor & Francis from 2011
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Eleonora Dagienė
Director of VGTU Press
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Phone: +370 5 2745038, Fax: +370 5 2370602
Email: *Eleonora.Dagiene@vgtu.lt*

17/08/2012. 19,5 printer's sheets. Print-on-Demand (POD). Published by Vilnius Gediminas Technical University Press Technika (Saulėtekio al. 11, LT-10223 Vilnius, Lithuania, http://leidykla.vgtu.lt) and Taylor & Francis (4 Park Square, Milton Park, Abingdon, Oxfordshire, OX14 4RN, UK)

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JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT
ISSN 1392-3730 print/ISSN 1822-3605 online
2012 Volume 18(4): 600–608
doi:10.3846/13923730.2012.709195

TOXICITY RESEARCH OF SMOULDERING AND FLAMING PINE TIMBER TREATED WITH FIRE RETARDANT SOLUTIONS

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Received 29 Jan. 2011; accepted 15 Jun. 2012

Abstract. The emission of toxic gaseous combustion products from timber constructions influences on the time required for evacuation of people from a building during a fire. In order to prolong the time interval until inflammation of timber constructions, fire retardant solutions are used. It is relevant and very important to determine how the emission of toxic gaseous combustion products from pine timber non-treated and treated with fire retardant solutions used in Lithuania differs during thermal destruction. Measuring carbon monoxide (CO) emissions, the paper focuses on toxicity analysis determined by nonstandard and standard research methods of smouldering and flaming pine timber, both non-treated and treated with fire retardant solutions. The description comprises specimens used in research and their preparation, nonstandard and standard research equipment and methods determining toxicity of smouldering and flaming pine timber, both non-treated and treated with fire retardant solutions. The article presents the analysis of experimental results processed by statistical methods.

Keywords: pine timber, smouldering, flaming, toxicity, carbon monoxide.

1. Introduction

Timber is one of the main building materials, long-time used in construction as well as most widely applied. There are many building materials produced from raw materials however many villagers live in wooden buildings. Many household buildings are wooden (Nagrodzka, Maloziec 2011; Teischinger 2010).

Use of timber in construction is limited due to easy flammability and quick spreading of fire. Even at the temperature of 300 °C timber under thermal destruction emits a sufficient amount of flammable gas causing inflammation and combustion (Drysdale 1998).

Timber combustion is a complicated process. Thermal destruction of timber has been analysed and presented thoroughly by a number of authors (Jeguirim, Trouvé 2009; Windeisen, Wegener 2008; Hosoya *et al.* 2007; Frey *et al.* 2009). Two types of timber combustion may be distinguished: smouldering and flaming. The first one is considered to be more dangerous as it remains invisible for a period of time. Besides, smouldering results in greater emissions of toxic gaseous combustibility products. The intensity of combustibility, the quality and quantity of the emitted toxic gaseous combustibility products depend on the type of timber, its moisture, and circumstances of combustion (Stec, Hull 2010).

Combustion produces smoke – the mix of gas, fumes and soot. Researches prove that toxic gaseous combustibility products that are found in smoke impede breathing, reduce range of visibility and prolong time needed for evacuation of people (Papinigis *et al.* 2010; Tserng *et al.* 2011). It poses 60–80% of all deaths in fires. During the last five years, on an average 262 people died in fires in Lithuania annually (Brushlinsky *et al.* 2012). In 2011, 8 people per 100 thousand people died in fires in Lithuania. This indicator is one of the highest among the European Union countries. In 2008 and 2011, in terms of this indicator Lithuania overtook Latvia and Estonia (Fire and Rescue Analysis 2012).

According to the fire safety requirements, the combustibility of timber constructions in a building must be reduced. Usually, the combustibility of timber constructions is reduced by treating them with fire retardant solutions (Wang *et al.* 2008). During combustion, the temperature of timber treated with fire retardant solutions is lower, the layer of carbon is thicker, the rapidity of heat emission and weight reduction is decreased (Jiang *et al.* 2010; Hagen *et al.* 2009).

Timber (Šaučiuvėnas *et al.* 2011; Kängsepp *et al.* 2011; Mačiulaitis, Praniauskas 2010; Bednarek *et al.* 2009; Juodeikienė 2009; Bednarek, Kaliszuk-Wietecka 2007), fire retardants (Glenn *et al.* 2012; Babrauskas *et al.* 2011; Gałaj *et al.* 2011a; Grigonis *et al.* 2011; Karpovič *et al.* 2010; Karpovič 2009; Vobolis, Albrektas 2009; Pereyra, Giudice 2009; Półka 2008), timber treated with fire retardant solutions in connection with its toxicity during combustion (Gałaj *et al.* 2011b; Šukys, Karpovič 2010; Karpovič, Šukys 2009; Paul *et al.* 2008; Lestari *et al.* 2006) and computer modelling for combustion (Capote *et al.* 2012; Keshavarz *et al.* 2012; Fouladgar *et al.* 2012; Vaidogas *et al.* 2012; Cheng, Hadjisophocleous 2011; Gałaj 2009) have been already analysed in the field of fire safety. However the toxicity of smouldering and flaming pine timber which is non-treated and treated with fire retardant solutions has not yet been studied within an integrated approach. This issue is very important in Lithuania and globally. Toxicity of construction products and (or) interior decoration products during fire is regulated in few countries (Gann *et al.* 2011). The toxicity of construction products in Lithuania is not regulated either. Such research and analysis could open up opportunities for making required decisions in order to reduce number of victims in fires.

The aim of the work: using nonstandard and standard research equipment and methods, to determine the toxicity by assessing CO of smouldering and flaming pine timber, both non-treated and treated with fire retardant solutions.

2. Specimens, research equipment and research methods

Pine timber specimens non-treated and treated with fire retardant solutions used in tests were cut from defect-free (i.e. crack-free) pine timber boards of 0.2 m in width, 0.02 m in thickness and 530 kg/m^3 of average density. Pine timber boards were naturally dried to humidity of less than 15%. It was treated with fire retardant solutions Flamasepas-2 and BAK-1 (with K_2CO_3 as the main component) according to the recommendations of the producers, i.e. brushing the surface with not less than 500 ml/m^2 of the fire retardant solution. To ensure fire retardant solutions do not evaporate and penetrate the treated timber as deeply as possible, surfaces of the pine timber boards were covered with foil for 24 hours. The pine timber boards treated with fire retardant solutions were naturally dried to humidity of less than 15%.

The fire retardant solutions Flamasepas-2 and BAK-1 (hereinafter – A and B) used for the treatment of timber have been certified and used in Lithuania.

This research was performed for three groups of specimens:

- pine timber specimens non-treated with fire retardant solutions;
- pine timber specimens treated with the fire retardant solution A;
- pine timber specimen treated with the fire retardant solution B.

The nonstandard research on toxicity of smouldering pine timber – both non-treated and treated with fire retardant solutions – was performed in the Main School of Fire Service in Warsaw. The research equipment for toxic combustions products emitted from solid materials after the impact of a heat flux was used (Fig. 1).

The aforementioned equipment can be used to determine toxic combustibility products and their quantity emitted while affecting a specimen with different heat fluxes. The possible range of a heat flux was from 2 to 80 kW/m^2. The necessary condition for the research was set: thermal destruction had to proceed without breaking into flames, i.e. the tested specimens had to be smouldering. Two heat fluxes – one of 8 kW/m^2 and another of 10 kW/m^2 – were used in this research. By affecting the specimen with heat fluxes of 8 kW/m^2 and 10 kW/m^2, the conditions were established for the emission of the main amount of toxic combustion products. At the heat fluxes of less than 8 kW/m^2, the temperature on the specimens did not reach 160 °C; while at the heat fluxes higher than 10 kW/m^2, the specimens inflamed.

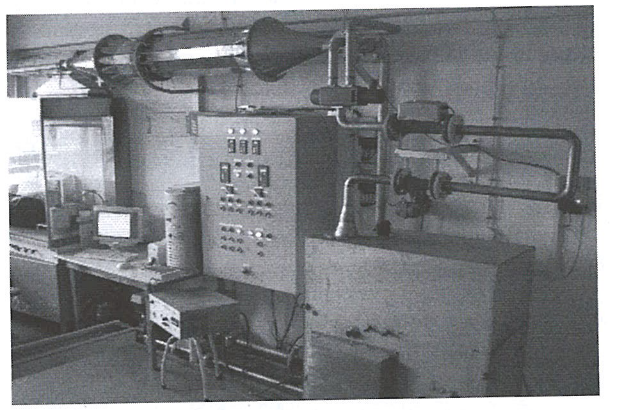

Fig. 1. Research equipment for toxic combustion products emitted from solid materials affected by a heat flux

5 specimens in every group were tested. The timescale for one test course was up to 55 min. The dimensions of the specimens were 0.2×0.2×0.02 m.

The standard research on toxicity of smouldering pine timber – both non-treated and treated with fire retardant solutions – was performed in the Main School of Fire Service in Warsaw using the cone calorimeter that corresponds to the requirements of the ISO 5660-1:2002 standard. The cone calorimeter is depicted in Fig. 2.

Before each of the tests, a specimen of 0.1×0.1×0.02 m dimensions was weighted and folded in foil except for the surface exposed to a heat flux. The prepared specimen was placed in the special frame, which was laid onto the scale under the heating cone.

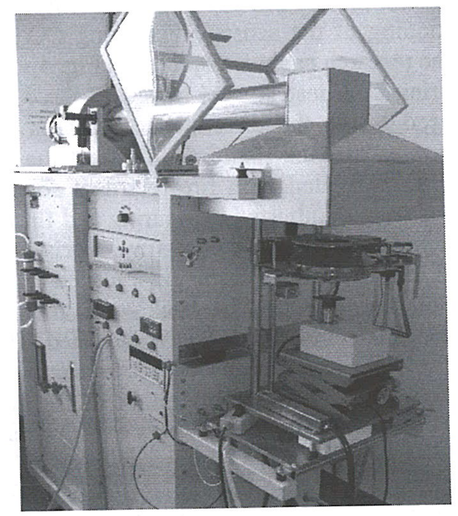

Fig. 2. A view of the cone calorimeter

5 specimens in every group were tested. During the tests, the specimens were affected by the heat flux of 30 kW/m^2. No piloted ignition was used. Affecting the specimens with the given heat flux and with no piloted ignition, the conditions for smouldering were established and the temperature on the surface of the specimens did not exceed 270 °C. The duration of each toxicity test of the smouldering pine timber non-treated and treated with fire retardant solutions amounted to 15 min.

The nonstandard research on toxicity of flaming pine timber – both non-treated and treated with fire retardant solutions – was performed in the Main School of Fire Service in Warsaw. The confined cabin containing the research equipment was used. The interior of the confined cabin is depicted in Fig. 3.

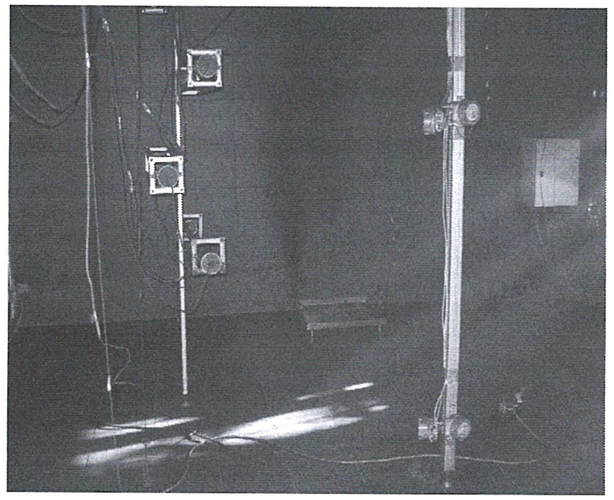

Fig. 3. Interior of the research equipment

The two walls of the cabin of 5×5×2.8 m were made of aluminium and glass. The other two brick walls were covered with ceramic tiles. The measuring equipment for CO concentration was located in the cabin. During the research, the concentration of CO was measured by nine electrochemical sensors of "ALTER SA MG 72" type, accurate to 1 ppm. The sensors were mounted on three columns at three heights in the research cabin: 0.35 m, 1.4 m and 2.5 m. The scheme of the vertical and horizontal positioning of the sensors measuring CO concentration in the research cabin is depicted in Fig. 4.

During each test, a steel tray with three specimens was placed inside the unventilated research cabin and combusted so that the flame could affect the surface of the specimens treated with fire retardant solutions. The specimens were combusted by pouring and firing up 0.4 *l* of denatured alcohol in the steel tray. During every test, the steel tray with specimens was placed in the same place of the test cabin near the back wall.

9 specimens in every group were tested. The dimensions of the specimens were 0.2×0.2×0.02 m. After inflammation of a specimen, the doors of the cabin were closed. During the tests, the changes in CO concentration level were measured and saved in different points of the test cabin every 5 s. When fire parameters stopped altering, the ventilation system was started and the test was closed.

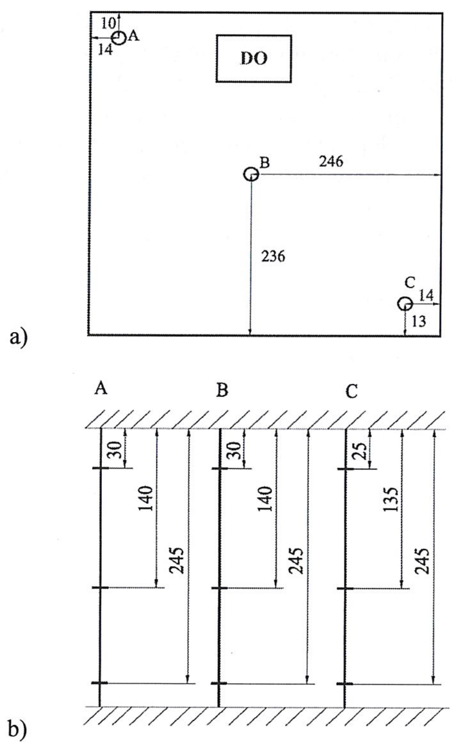

Fig. 4. Scheme of vertical (a) and horizontal (b) positioning for the sensors measuring CO concentration, installed on A, B and C columns (numbers – in cm; DO – burning object)

The standard research on toxicity of flaming pine timber non-treated and treated with fire retardant solutions was performed in the Main School of Fire Service in Warsaw. The cone calorimeter that corresponds to the requirements of ISO 5660-1:2002 standard was used. The description of the cone calorimeter and research methods for the determination of toxicity of flaming pine timber – both non-treated and treated with fire retardant solutions – which was described above was the same as the standard research methods used for testing smouldering pine timber, both treated and non-treated with fire retardant solutions.

During the tests of flaming timber, the specimens were affected by the heat flux of 30 kW/m^2 together with piloted ignition of 10 kV. Affecting the specimens with the given heat flux together with piloted ignition, the conditions for flaming were established.

The piloted ignition source was formed from two parallel electrodes located at the height of 1 cm above the surface of a specimen. The electrodes were attached to the mechanism of piloted ignition, which regulates the electrodes to approach the surface of the specimens and to distance from it. When approaching the surface of the specimens, the electric current was transmitted through the electrodes at a fixed periodicity. It created a spark at the ends of the electrodes.

Subjected to time, the obtained results of toxicity of smouldering and flaming pine timber – both non-treated and treated with fire retardant solutions – determined by nonstandard and standard research equipment were analysed statistically. The arithmetic averages were developed to the statistical selections of the results $x_1, x_2, \ldots. x_n$ (Sakalauskas 2003).

The arithmetic averages of the statistical selections of the results were processed using the programme "Statistika 8". The negative exponential function high-reflecting test results was applied. The correlation coefficients r and linear and non-linear curve regression equations formed by the programmes "Statistika 8" and "TableCurve 2D" are also presented (Sakalauskas 2003; Kleiza 2003).

3. Experimental results and discussion

The results of the nonstandard research on toxicity of smouldering timber

The average emission of CO depending of the heat flux and the specimens is shown in Figs 5–6.

Affecting pine timber specimens with the heat flux of 8 kW/m^2 in 300 s on the average, after the surface temperature of the specimen reached the average of 140 °C, the sensor started registering CO (Fig. 5). The temperature was reached at which pine timber specimens emitted CO during thermal destruction.

Affecting pine timber specimens treated with the fire retardant solution A with the heat flux of 8 kW/m^2 in 420 s on the average, after the surface of the specimen reached the mean temperature of 165 °C, the sensor started registering CO (Fig. 4). Affecting pine timber specimens treated with the fire retardant solution B by the heat flux of 8 kW/m^2 in 365 s on the average, after the surface of the specimen reached the mean temperature of 156 °C, the sensor started registering CO (Fig. 5). Due to the protective features of fire retardants to impede gas emission during thermal destruction, the emission of CO from pine timber specimens treated with the fire retardant solutions A and B started after a longer period of time and at a higher surface temperature as compared to the emission of CO from the non-treated pine timber specimens.

Affecting the non-treated pine timber specimens with the heat flux of 10 kW/m^2 in 170 s on the average, after the surface of the specimens reached the mean temperature of 135 °C, the sensor started registering CO (Fig. 6).

Affecting pine timber specimens treated with the fire retardant solution A with the heat flux of 10 kW/m^2 in 270 s on the average, after the surface of the specimen reached the mean temperature of 170 °C, the sensor started registering CO (Fig. 6).

Affecting pine timber specimens treated with the fire retardant solution B by the heat flux of 10 kW/m^2 in 300 s on the average, after the surface of the specimen reached the mean temperature of 178 °C, the sensor started registering CO (Fig. 6).

Increasing the heat flux and the speed of temperature rise, the emission of CO during thermal destruction from pine timber specimens non-treated and treated with fire retardant solutions started after a shorter period of time.

At the beginning of the tests, pine timber specimens treated with the fire retardant solutions A and B emitted CO more intensely as compared to the non-treated pine timber specimens in the period up to 2700 s (8 kW/m^2) and up to 1900 s (10 kW/m^2). However, this emission altered insignificantly after 1500 s at 8 kW/m^2, when the surface of the specimens reached the mean temperature of 211 °C and after 1000 s at 10 kW/m^2 when the surface of the specimens reached the mean temperature of 260 °C. The emission of CO from non-treated pine timber was growing during the entire research (Figs 5–6).

In the course of the tests during the initial 2700 s, the non-treated pine timber specimens affected by the heat flux of 8 kW/m^2 emitted 2.8 times less CO; and during the initial 1900 s, the non-treated pine timber specimens affected by the heat flux of 10 kW/m^2 emitted 3.1 times less CO as compared to the pine timber specimens treated with the fire retardant solutions A and B (Figs 5–6).

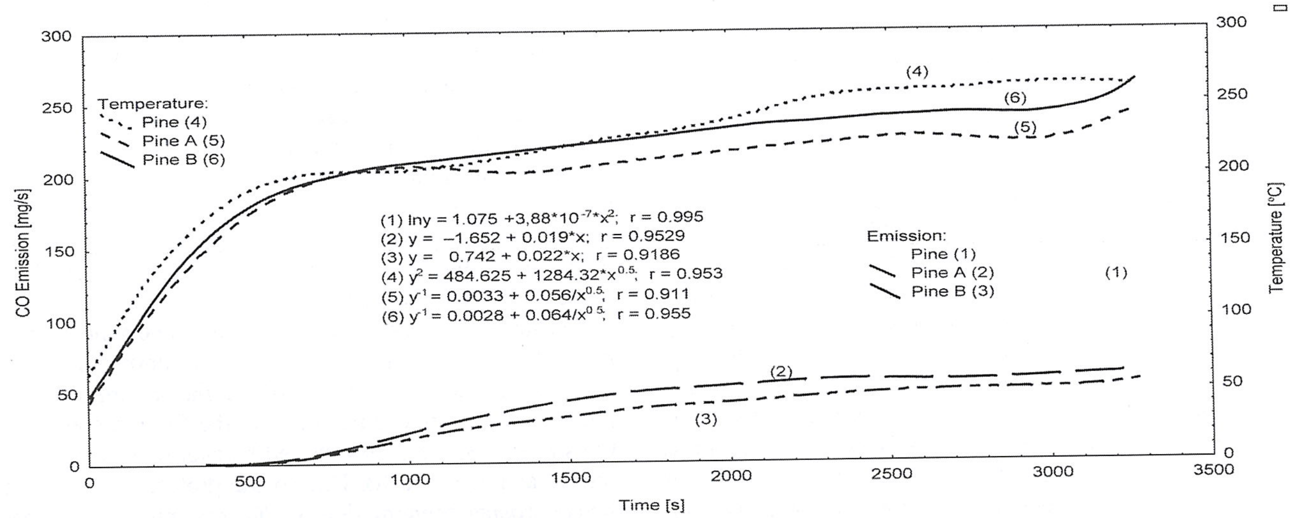

Fig. 5. Average emissions of CO from tested specimens and alternation of average temperature on the surface of tested specimens affected by heat sources of 8 kW/m^2 subjected to time: (1) – non-treated pine timber specimens; (2) – pine timber specimens treated with A; (3) – pine timber specimens treated with B; (4) – non-treated pine timber specimens; (5) – pine timber specimens treated with A; (6) – pine timber specimens treated with B

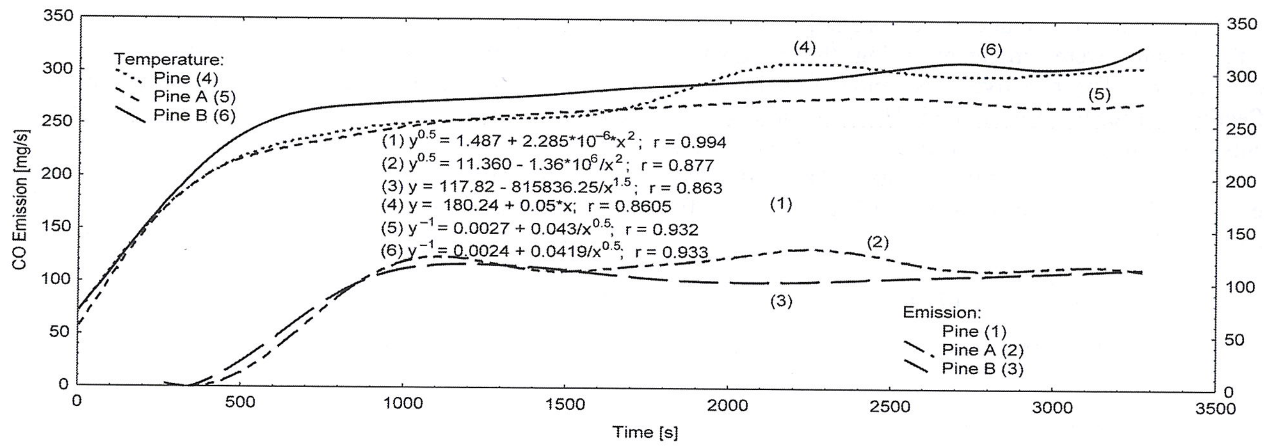

Fig. 6. Average emissions of CO from tested specimens and alternation of average temperature on the surface of tested specimens affected by heat sources of 10 kW/m^2 subjected to time: (1) – non-treated pine timber specimens; (2) – pine timber specimens treated with A; (6) – pine timber specimens treated with B

The fire retardants reduced the temperature on the surface of the specimens and the delivery of oxygen to the pyrolisis zone. It increased the emission of CO – thermal destruction product of partial oxidation – at the beginning of the tests. In the course of the tests, the emission of CO from the pine timber specimens treated with the fire retardant solutions A and B as compared to the non-treated pine timber specimens altered insignificantly. The protective features of fire retardants impeded the penetration of temperature to the deeper layers of timber and stopped the emission of thermal destruction gas.

Comparing pine timber specimens treated with the fire retardant solution A with specimens treated with the fire retardant solution B, pine timber specimens treated with the fire retardant solution A affected with the heat flux of 8 kW/m^2 emitted on average 1.2 times more CO than pine timber specimens treated with the fire retardant solution B. Pine timber specimens treated with the fire retardant solution A affected by the heat flux of 10 kW/m^2 emitted on average 1.1 times more CO than pine timber specimens treated with the fire retardant solution B (Figs 5–6). The difference in the emission of CO depended on the unequal microscopic structure, inequality in wood tar content and in the composition of fire retardants.

The results of the standard research on toxicity of smouldering timber

The average alternation of CO concentration depending on the specimens is depicted in Fig. 7.

At the beginning of the research concentration of CO for pine timber specimens treated with the fire retardant solutions A and B in the period up to 300 s was growing intensely. After 300 s the concentration of the CO for pine timber specimens treated with the fire retardants A and B was changing insignificantly and did not exceed the value of 0.13 kg/kg (kg/kg – the fraction of CO mass to the mass of air). In the period up to 350 s, pine timber specimens treated with the fire retardant solutions A and B as compared to the non-treated pine timber specimens obtained the highest concentration of CO due to the same reason as mentioned above. The concentration of CO for non-treated pine timber specimens was growing during the entire research and reached the value of 0.16 kg/kg (Fig. 7).

The highest concentration of CO for pine timber specimens treated with the fire retardant solutions A and B was about 20% lower than the highest concentration of CO for the non-treated pine timber specimens. During the initial 350 s the concentration of CO for pine timber specimens treated with the fire retardant solutions A and B was about 20% higher than the concentration of CO for the non-treated pine timber specimens (Fig. 7).

Comparing pine timber specimens treated with the fire retardant solution A with specimens treated with the fire retardant solution B, the concentration of CO for pine timber specimens treated with the fire retardant solution A was on average 1.1 times lower than the concentration of CO for pine timber specimens treated with the fire retardant solution B (Fig. 7).

The results of the toxicity of the nonstandard research on toxicity of flaming timber

The average concentration of CO near the burning object, measured by the sensor mounted on the B column in the centre of the cabin at the height of 1.4, depending on the specimens is depicted in Fig. 8.

At the beginning of the research, in the period up to 260 s, the concentration of CO for all groups of pine timber specimens grew intensely. After 260 s, the concentration of the CO for pine timber specimens treated with the fire retardant solutions A and B altered insignificantly and did not exceed the value of 6x10^{-5} kg/kg. The concentration of CO for the non-treated pine timber specimens grew during the entire research and reached the value of 7.2x10^{-5} kg/kg (Fig. 8).

During flaming of the non-treated pine timber specimens, the sensor started registering CO during initial seconds of the tests. In the case of the flame combustion of pine timber specimens treated with the fire retardant solutions A and B, the sensor started registering CO after 62 s on the average (Fig. 8). Due to the protective features of fire retardants, the emission of CO from pine timber specimens treated with the fire retardant solutions A and B started after a longer period of time comparing with the emission of CO from the non-treated pine timber specimens.

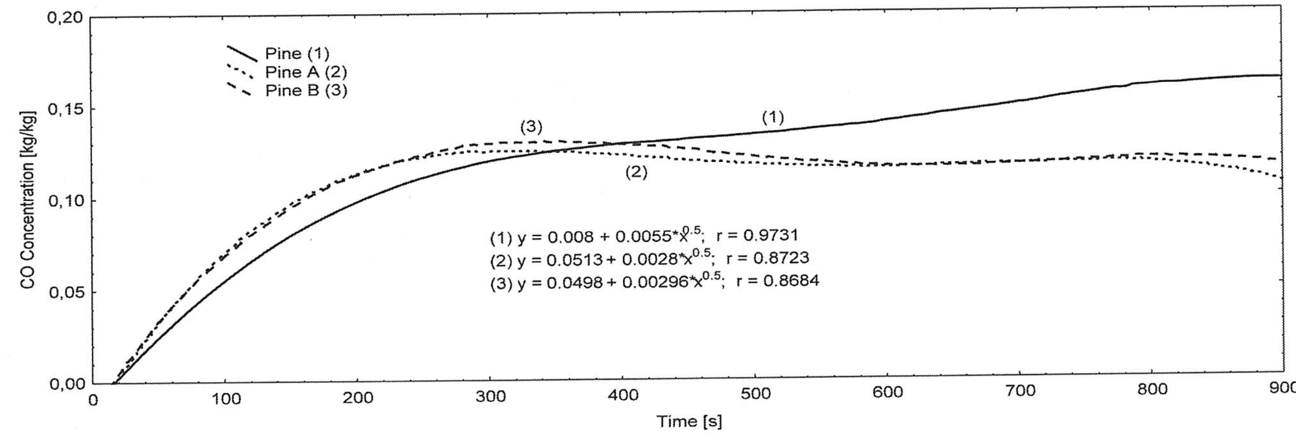

Fig. 7. Alternation of average CO concentration obtained during smouldering of tested specimens subjected to time: (1) – non-treated pine timber specimens; (2) – pine timber specimens treated with A; (3) – pine timber specimens treated with B

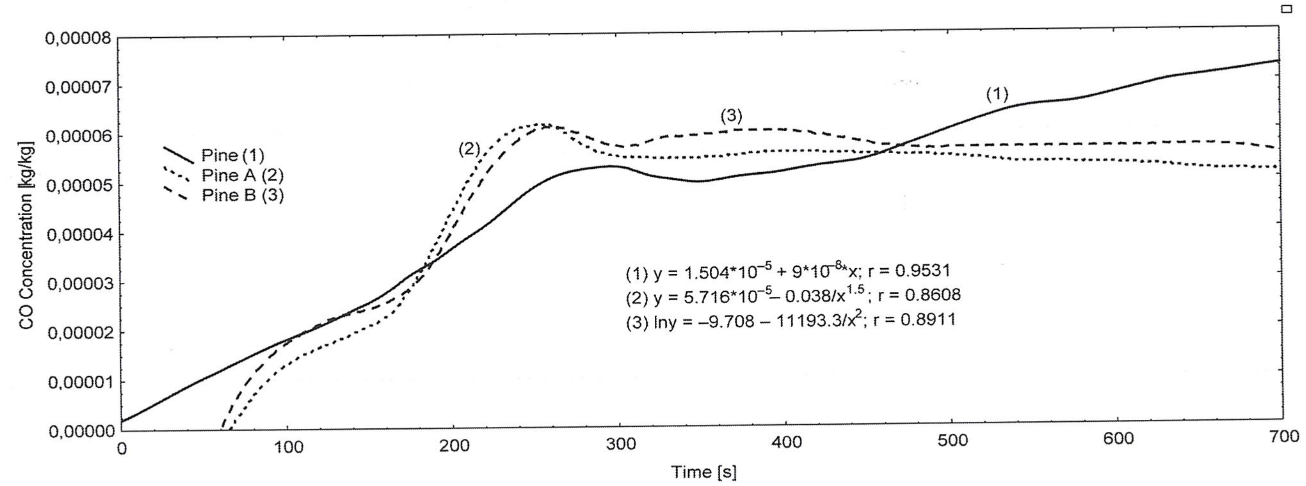

Fig. 8. Alternation of average CO concentration measured by the sensor in the centre of the compartment at the height of 1.4 m obtained during flame combustion of tested specimens subjected to time: (1) – non-treated pine timber specimens; (2) – pine timber specimens treated with A; (3) – pine timber specimens treated with B

The highest concentration of CO for pine timber specimens treated with the fire retardant solutions A and B was on average 1.2 times lower than the highest concentration of CO for the non-treated pine timber specimens. During the initial 180 s the concentration of CO for pine timber specimens treated with the fire retardant solutions A and B was averagely 1.4 times lower than the concentration of CO for the non-treated pine timber specimens. At the time interval of 180–460 s the obtained concentration of CO for pine timber specimens treated with the fire retardant solutions A and B was 1.2 times higher than the concentration of CO for the non-treated pine timber specimens (Fig. 8).

Comparing pine timber specimens treated with the fire retardant solution A with specimens treated with the fire retardant solution B, the concentration of CO of pine timber specimens treated with the fire retardant solution A was on average 1.2 times lower than the concentration of CO for pine timber specimens treated with the fire retardant solution B (Fig. 8).

The results of the standard research on toxicity of flaming timber

The average alternation of CO concentration depending on the specimens is depicted in Fig. 9.

At the beginning of the tests in the period up to 200 s, the concentration of CO for pine timber specimens treated with the fire retardant solutions A and B grew intensely and reached 0.019 kg/kg and 0.022 kg/kg respectively. After 200 s, the average concentration of CO for pine timber specimens treated with the fire retardant solutions A and B began reducing. The concentration of CO for the non-treated pine timber specimens was growing up to 400 s on the average and did not exceed the value of 0.005 kg/kg (Fig. 9).

The highest concentration of CO for pine timber specimens treated with the fire retardant solutions A and B was on average 4.4 times higher than the highest concentration of CO for the non-treated pine timber specimens. During the research, the concentration of CO for pine timber specimens treated with the fire retardant solutions A and B was on average 1.8 times higher than the concentration of CO for the non-treated pine timber specimens (Fig. 9). The fire retardants reduced the delivery of oxygen to the pyrolisis zone by increasing the emission of thermal destruction product of partial oxidation – CO.

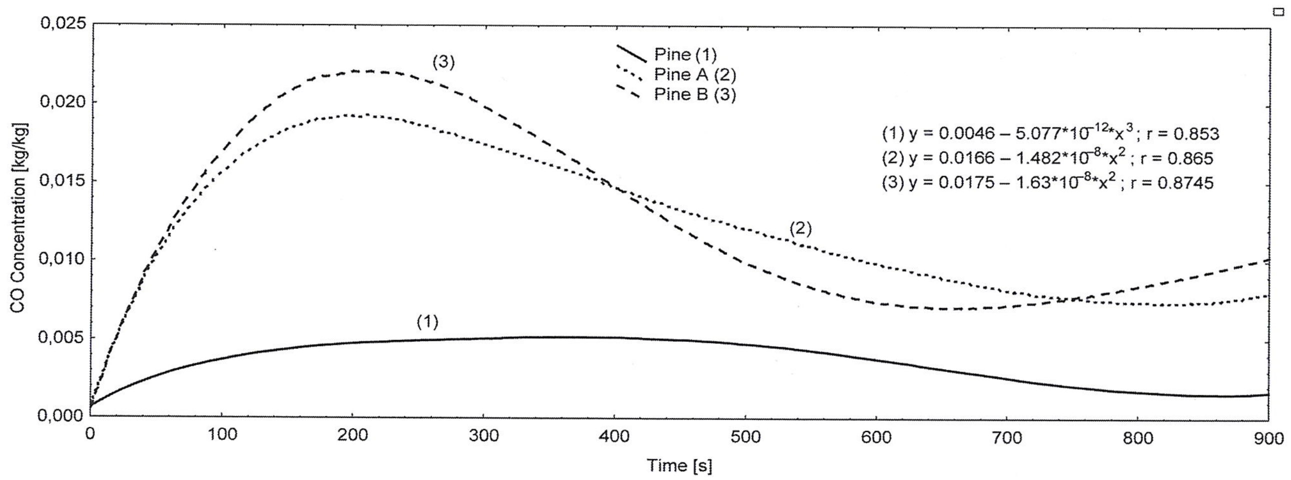

Fig. 9. Alternation of average CO concentration obtained during flame combustion of tested specimens subjected to time: (1) – non-treated pine timber specimens; (2) – pine timber specimens treated with A; (3) – pine timber specimens treated with B

Comparing pine timber specimens treated with the fire retardant solution A with specimens treated with the fire retardant solution B, the concentration of CO for pine timber specimens treated with the fire retardant solution A was on average 1.1 times lower than the concentration of CO for pine timber specimens treated with the fire retardant solution B (Fig. 9). The difference in the emission of CO depended on the unequal microscopic structure, inequality in wood tar content and in the composition of fire retardants.

4. Conclusions

1. The beginning of the emission of CO from smouldering pine timber non-treated and treated with fire retardant solutions depends on the temperature and time at which it starts emitting. On average, the emission of CO from pine timber treated with fire retardant solutions starts after a 1.5 times longer time period after the beginning of the test and at the temperature is on average 1.2 times higher as compared to the non-treated pine timber. This is explained by the protective features of fire retardants to stop the emission of thermal destruction gas from pine timber treated with fire retardant solutions.

2. During smouldering of pine timber non-treated and treated with fire retardant solutions:

- fire retardants reduce the temperature on the surface of timber and the delivery of oxygen to the pyrolisis zone by increasing the emission of CO;
- the emission of CO from treated smouldering pine timber is higher during the initial seconds of the test than the emission of CO from the non-treated smouldering pine timber;
- during the test the emission of CO from pine timber treated with fire retardant solutions alters insignificantly while the emission of CO from the non-treated pine timber intensifies;
- on average, pine timber treated with the fire retardant solution A emitted 1.2 times more CO than pine timber treated with the fire retardant solution B (nonstandard research equipment);
- on average, pine timber treated with the fire retardant solution A emitted 1.1 times less CO than pine timber treated with the fire retardant solution B (standard research equipment).

3. The results of toxicity research obtained using nonstandard research equipment on flaming pine timber non-treated and treated with fire retardant solutions showed that:

- on average, the emission of CO from the non-treated pine timber starts at the beginning of the test while from pine timber treated with fire retardant solutions starts after 62 s from the beginning of the test;
- during the initial 180 s the emission of CO from pine timber treated with fire retardant solutions is 1.4 times lower than from non-treated pine timber;
- at the time interval of 180–460 s the emission of CO from pine timber treated with fire retardant solutions is 1.2 times higher than from the non-treated pine timber;
- the concentration of CO for flaming non-treated pine timber grows during the entire test while the concentration of CO for pine timber treated with fire retardant solutions alters insignificantly after 260 s.

4. The results of toxicity determined by the standard research equipment on flaming pine timber non-treated and treated with fire retardant solutions prove that the emission of CO from pine timber treated with fire retardant solutions is 4.4 times higher than from non-treated pine timber.

5. Flaming pine timber treated with the fire retardant solution A emitted on average 1.15 times less CO than pine timber treated with the fire retardant solution B.

6. While performing tests using the standard and non-standard research equipment, at the beginning of the tests the emission of CO from smouldering and flaming pine timber treated with fire retardant solutions is higher than from the non-treated pine timber. This is subjected to the reason that fire retardants reduce temperature on the surface of the specimens and the delivery of oxygen to the pyrolisis zone.

7. The correlation coefficient r used for data analysis and defining the strength of dependence between curves and regression equations has shown that correlation link is strong enough. The lowest value of the correlation coefficient r is 0.853.

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STATYBINĖS KONSTRUKCIJOS IR TECHNOLOGIJOS
ENGINEERING STRUCTURES AND TECHNOLOGIES
ISSN 2029-2317 print / ISSN 2029-2325 online
2011 3(3): 91–104
doi:10.3846/skt.2011.11

INVESTIGATION INTO THE INFLUENCE OF IMPREGNATION ON PINE TIMBER COMBUSTION USING A CONE CALORIMETER AND LARGE SCALE TESTS

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Received 27 July 2011; accepted 25 August 2011

Abstract. Fire safety is one of the main requirements with respect to the regulations on the buildings involved into the category of human hazards. Human safety measures are applied equally to inhabitants, users, customers, spectators, etc., as well as to fire brigades taking part in the activities connected with rescue actions. Methods for emission research were applied to estimate thermo-kinetic parameters related to smoke and toxic gases. The methods fall into two types: full scale methods reflect fire conditions and small laboratory scale methods having a significantly lower degree of reflection. This paper presents the results of studies on the influence of BAK-1 and Flamasepas-2 fire retardants produced in Lithuania and applied for timber on the selected parameters of the fire environment. Experimental studies were conducted using a cone calorimeter (small scale) in the closed compartment equipped with measuring devices (full scale). The undertaken studies have demonstrated that considering some parameters, such as heat release rate (HRR), a positive effect of the lower amount of the released heat can be obtained. Unfortunately, in case of the major part of the studied parameters, including time to ignition, CO concentration and extinction parameter reflecting smokiness, worse results (shorter time, higher CO values and higher extinction coefficient) have been observed for the treated timber rather than for the non-impregnated one. The obtained results have showed combustion with piloted ignition. In case of no piloted ignition, the results were slightly different. For all studied specimens treated with fire retardants, no ignition was observed and tests were terminated following 15 minutes. CO concentration and extinction parameter (smokiness) were higher for non-impregnated timber. Full scale experiments have confirmed the above provided information; moreover, it has been found that the application of fire retardant has no significant impact on temperatures in the compartment.

Keywords: pine timber, fire retardant, treatment, fire, toxicity, heat source, combustion product, carbon monoxide.

1. Introduction

Fire is an out-of-control phenomenon creating a direct danger to human's health and life. There are factors to be encountered that endanger not only people inside the building but also those performing rescue works during fire occurrence. These factors include (Buhanan 2002; Kolbrecki 2000):

– toxic combustion products,
– flame and high temperature (heat),
– reduction in oxygen concentration,
– instability of constructions,
– reduced visibility (smoke).

Each of the above introduced factors and its effect on escape behaviour is briefly discussed below.

Time available for escape is a period between the time of ignition and that following conditions preventing occupants from safe evacuation. In the United States of America and Great Britain, more than 50% of all deaths in fires have been caused by toxic combustion products constituting smoke (Stec, Hull 2010; Brushlinsky *et al.* 2009).

Unfortunately, this opinion is not sufficiently stressed in fire studies, standards and other legal documents. For instance, in building standards, fire models are based on the structural properties of the building, building materials and evacuation routes. Recently, though the effect of finishing materials has been assessed, the impact of toxic combustion products has not been sufficiently and accurately considered. Time to ignition, heat conductivity, flame propagation, and in some cases, smoke produced of building materials have been taken into account. The above mentioned parameters connected with the fire hazard of building materials can be obtained performing standard tests. The toxicity of building materials can be determined by applying other standards, depending on legal documents valid in the given country or region. For instance, in Europe, the classification of building materials based on reaction to fire is obligatory (EN 13501), which does not consider the emission of combustion products during fire. The impact of toxic combustion products is taken into account in fire models by means of transportation. For example, the International Maritime Organization (IMO) classifies finishing materials applied in ships according to the toxicity of the emitted fire smoke (IMO 1998). Similar requirements with regards to toxicity evaluation during fire are used for finishing materials in aircrafts (Airbus Industry document ABD0031).

Generally, it can be concluded that still there are no standards or other legal documents including regulations regarding fire smoke toxicity generated during the fire in the building (Gann 2004).

Gaseous combustion products form a toxic mixture from smoke during fire, which has a big influence on time required for evacuation from the building. Smoke significantly reduces visibility and obstructs breathing. The most important combustion product, with regards to which toxicity is estimated, is carbon monoxide (Tewarson 2002; Tuovinen 2002). The results of material combustion and release of gaseous combustion products described in literature often consider small scale methods. However, in order to validate them, they should be compared with the study results obtained in a full scale and under real conditions prevailing during fire (Stec, Hull 2010). Peacock *et al.* (2004) have stated that toxic combustion products emitted during real fire are rarely described and found in literature (Hansen 2002; Konecki 2007).

The determination of risk to human's health and life is caused by material effects during fire and is crucial from the stand point of fire safety engineering. A correct estimation of the concentration of gaseous products during real fires in a full scale is not easy. The results currently taken into account significantly differ from those occurring during fires. Laboratory studies conducted in a small scale usually are suitable for comparing emitted combustion products.

In the recent decades, the number of studies conducted in a full scale has significantly decreased. Taking into account the whole range of full scale studies, only in a few cases (see a list below), concentrations of combustion products are obtained (Stec, Hull 2010):

a) ISO 9705: "Room corner test";
b) ISO 24473: "Open calorimeter";
c) EN 13823: "Single burning item" (SBI);
d) IEC 60332-3-10/EN 50266-1: "Large scale cable test";
e) IMO: "Fire test of a fixed gaseous fire extinguishing system" and IMO: "Sprinkler test".

All the above mentioned methods can be modified; for example, to determine larger quantities of gaseous combustion products. Full scale studies described above belong to standard studies. There are other full scale studies estimating risk emerging in the buildings during different types of fires: fire in the room with furniture (Konecki 2007), fire in the hospital, propagation of gaseous combustion products in corridors (Robinson *et al.* 2007; Hertzberg *et al.* 2005), fire in transportation (Hammarstrom, Axellson 2008; Arvidson *et al.* 2008), fire in industry (Blonqvist, Persson 2008; Persson, Blonqvist 2007) etc.

The consequences of fire such as extinguishing before spreading may be reduced by performing effective prevention actions during the emergence of fire (Buhanan 2002). One of the possibilities of implementing effective prevention is the usage of materials protecting from the impact of fire, i.e. fire retardants (Ozkaya *et al.* 2007; Gu *et al.* 2007). For building materials, i.e. timber constructions impregnated with fire retardants, time to flame combustion is longer and flame propagation rate is lower (Karpovič 2009a; Gu *et al.* 2007). The field of fire protection examines fire resistance of ceramics (Abraitis, Stankevičius 2007; Žurauskienė, Nagrockienė 2007), concrete (Chung *et al.* 2007; Abramowicz, Kowalski 2007), ferro-concrete (Zavalis, Šneideris 2010; Bednarek, Ogrodnik 2007), steel (Bednarek, Kamocka 2006), the application of the zone model for investigating the combustion of different flammable materials (Gałaj 2007), the combustion of polymeric materials (Konecki, Półka 2009) as well as the impact of isolating materials on timber strength (Bednarek, Kaliszuk-Wietecka 2007), the combustion of timber treated with fire retardants, the effectiveness of fire retardants (Karpovič 2009b; Półka 2008), the hazardousness of pine timber and cork-oak while fuming (Karpovič, Šukys 2009), the variability of charring along wooden wall studs (Just, Tera 2010) and reaction-to-fire of nine different wood species having different density and thickness (Harada 2001). Lewin (2005) emphasized the need for research on timber treated with fire retardants. There are many unanswered questions concerning the protection of timber against fire. One of the above discussed issues is the toxicity of timber impregnated with fire retardants during thermal degradation. The toxicity of timber impregnated with fire retardants has been partly analysed in work by Šukys and Karpovič (2010).

The present paper presents a sequence of studies on the influence of fire retardant agents in a form of two types of fire retardants BAK-1 and Flamasepas-2 applied for timber produced in Lithuania. The aim of this work was to conduct small scale studies using a cone calorimeter and full scale studies applying the closed compartment and suitable measuring equipment. The main objective of analysis was to compare the values of fire parameters (HRR, CO concentration, extinction coefficient etc.) selected during the combustion of non-impregnated and impregnated pine timber using two above mentioned fire retardants and employing two methods.

The authors have focused on drawing a conclusion of applying some fire retardants for pine timber used for building engineering based on the conducted studies.

2. Small Scale Tests: Tested Materials and Testing Methods

Small scale tests were performed in the Main School of Fire Service using a cone calorimeter (open test). The testing method using the cone calorimeter is based on the fact that the total combustion heat is essentially proportional to the amount of oxygen required for combustion. The calculated ratio shows that the use of 1 kg of oxygen releases 13.1×10^3 kJ of heat.

To investigate the influence of impregnation on combustion properties, tests for the following three main groups of specimens were performed:

- non-treated pine timber,
- pine timber treated with fire retardant Flamasepas-2,
- pine timber treated with fire retardant BAK-1.

Fire retardants applied for the treatment of pine timber specimens were manufactured and used in Lithuania.

The dimensions of all specimens were 100×100×20 mm. Each specimen was exposed to the surface heat source of 30 kW/m^2. The tests were performed two times (with and without piloted ignition) for the same type of timber.

The samples were tested in a horizontal position. For each specimen, the following values were obtained: time to ignition (TTI [s]), maximum heat release rate (HRR_{max} [kW/m^2]), time to maximum heat release rate (T_{HRRmax} [s]), total heat released (THR [MJ/m^2]), mass loss rate (MLR [g/s]), specific smoke extinction area (SEA [m^2/kg]) and efficient heat of combustion (EHC [MJ/kg]). Besides changes in HRR, mass loss, the concentration of oxygen, carbon monoxide, dioxide etc. were obtained. General views of the cone calorimeter and specimens before and during the tests are shown in Figs. 1–3.

Fig. 1. A cone calorimeter

Fig. 2. Pine timber specimen prepared for experimentation

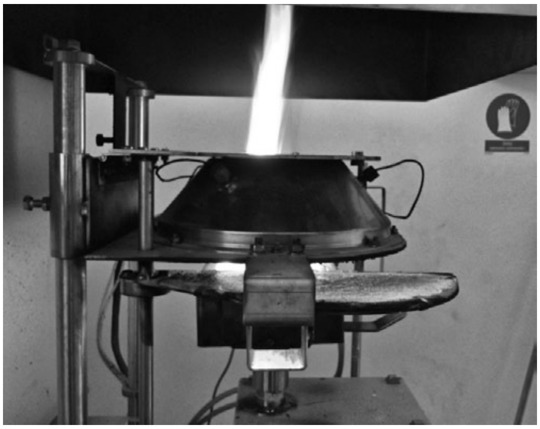

Fig. 3. Pine timber specimen during the experiment

3. Small Scale Test Results and Analysis

Maximum values and corresponding times for non-treated and treated pine timber specimens of combustion parameters such as HRR (heat release rate), EHC (effective heat combustion), MLR (mass loss rate), SEA (specific extinction area), CO_y (carbon monoxide yield) and CO_{2y} (carbon dioxide yield) are given in Table 1 to show combustion with piloted ignition and in Table 2 to indicate combustion without piloted ignition. In addition, time to ignition, the mean values of the parameters mentioned above, the total oxygen consumed, mass lost, TSR (total smoke release) and TSP (total smoke production) are included in Table 3 to point out combustion with piloted ignition and in Table 4 – without piloted combustion. The average time to ignition in case of ignition stimulus was:

a) 31 s for timber impregnated with Flamasepas-2,
b) 46 s for timber impregnated with BAK-1,
c) 74 s for non-impregnated timber.

There was no ignition of material during the combustion of each of the three samples without ignition stimulus during a 15 minute test. Thus, it can be assumed that in this case, time to ignition is equal to infinity. The results of cone calorimeter tests with piloted ignition for non-treated and treated specimens are presented in the form of graphs as a function of time: HRR (Fig. 4), THR (Fig. 5), CO concentrations in two time intervals (Fig. 6 and 7), CO production rate in two time intervals (Figs. 8 and 9) and extinction coefficient (Fig. 10).

Table 1. Maximum values of selected combustion parameters and corresponding times for non-treated and treated pine timber specimens (with piloted ignition)

Parameter	Units	Non-treated	Treated with F*	Treated with B**
		time value	time Value	time value
HRR	kW/m^2	85 204.7	1010 166.74	980 146
EHC	MJ/kg	1215 48.87	1250 70.25	1210 46.63
MLR	g/s	80 0.155	985 0.1612	960 0.145
SEA	m^2/kg	1215 264.25	995 343.75	1080 262.90
CO_y	kg/kg	1255 0.32	1250 0.39	1300 0.23
$CO2_y$	kg/kg	1215 3.533	1250 5.681	1210 3.166

* Flamasepas-2
** BAK-1

Table 2. Maximum values of selected combustion parameters and corresponding times for non-treated and treated pine timber specimens (without piloted ignition)

Parameter	Units	Non-treated	Treated with F*	Treated with B**
		time value	time value	time value
HRR	kW/m^2	545 24.42	60 11.25	900 37.26
EHC	MJ/kg	685 26.31	500 2.037	5 65.68
MLR	g/s	0 0.103	335 0.1	900 0.2075
SEA	m^2/kg	875 2546	825 1477	200 635.9
CO_y	kg/kg	875 0.423	825 0.873	200 0.4057
$CO2_y$	kg/kg	875 2.74	825 1.858	5 7.107

* Flamasepas-2
** BAK-1

Table 3. Some characteristic parameters obtained during the combustion of non-treated and treated pine timber (with piloted ignition)

No.	Parameter	Units	Non-treated	Treated with F	Treated with B
1	Time to ignition	s	74	31	46
2	Mean HRR	kW/m^2	82.74	79.87	71.42
3	Mean EHC	MJ/kg	11.04	11.27	10.38
4	Mean MLR	g/s	0.066	0.063	0.061
5	Mean SEA	m^2/kg	28.8	20.62	22.04
6	Mean CO_y	kg/kg	0.005	0.016	0.0143
7	Mean $CO2_y$	kg/kg	0.938	0.941	0.870
8	Total HRR	MJ/m^2	102.22	104.32	90.74
9	Total oxygen consumed	g	59.07	118.19	63.31
10	Mass lost	g	81.93	82.07	77.57
11	Average specific MLR	g/s·m^2	7.566	8.207	8.307
12	TSR*	m^2/m^2	226.78	784.36	316
13	TSP**	m^2	2	6.93	2.79

* total smoke release
** total smoke production

Table 4. Some characteristic parameters obtained during the combustion of non-treated and treated pine timber (without piloted ignition)

No.	Parameter	Units	Non-treated	Treated with F	Treated with B
1	Time to ignition	s	∞	∞	∞
2	Mean HRR	kW/m^2	13.52	–1.048	130
3	Mean EHC	MJ/kg	2.16	–0.195	2.33
4	Mean MLR	g/s	0.055	0.0473	0.049
5	Mean SEA	m^2/kg	391.31	191.526	168.2
6	Mean CO_y	kg/kg	0.111	0.108	0.1043
7	Mean $CO2_y$	kg/kg	0.2304	0.196	0.277
8	Total HRR	MJ/m^2	12.178	0.935	11.707
9	Total oxygen consumed	g	10.5	2.71	10
10	Mass lost	g	49.71	42.73	44.37
11	Average spec. MLR	g/s·m^2	6.71	5.48	5.7
12	TSR*	m^2/m^2	2200	926	844.1
13	TSP**	m^2	19.45	8.18	7.46

* total smoke release
** total smoke production

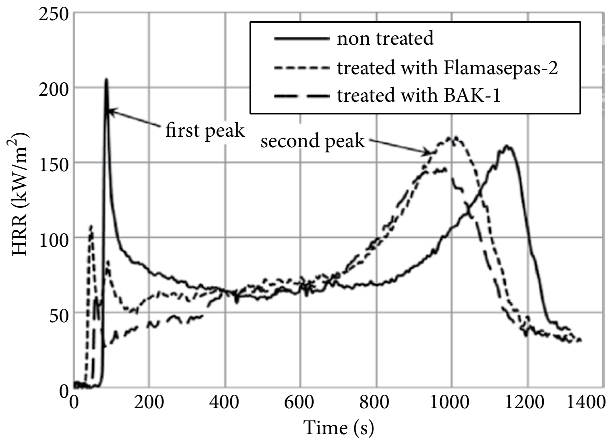

Fig. 4. Heat release rate (HRR) obtained during the combustion of non-treated and treated specimens in the cone calorimeter at the heat flux of 30 kW/m^2 (with piloted ignition)

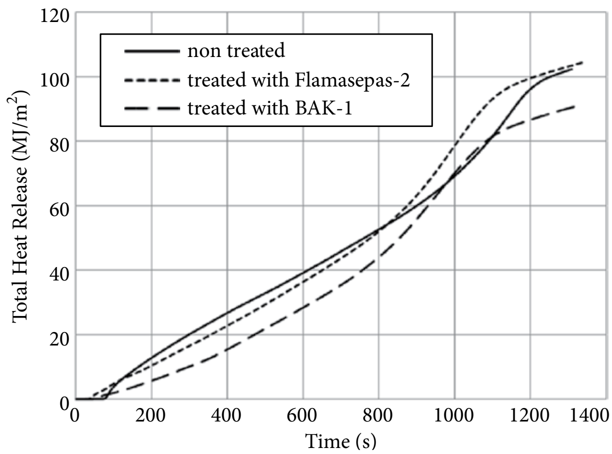

Fig. 5. Total heat release (THR) obtained during the combustion of non-treated and treated specimens in the cone calorimeter at the heat flux of 30 kW/m^2 (with piloted ignition)

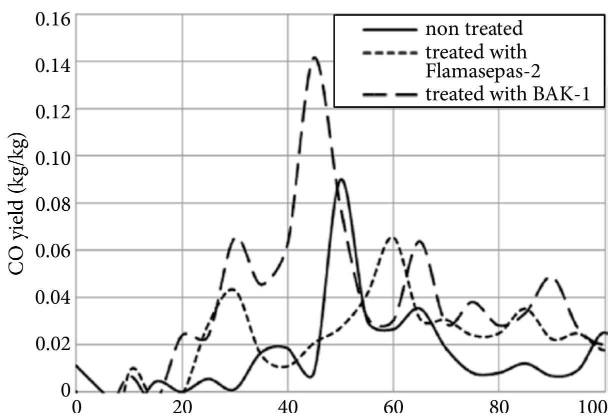

Fig. 6. A peak of CO yield obtained during the first stage of combustion (time interval: 0–100 s) of non-treated and treated specimens in the cone calorimeter at the heat flux of 30 kW/m^2 (with piloted ignition)

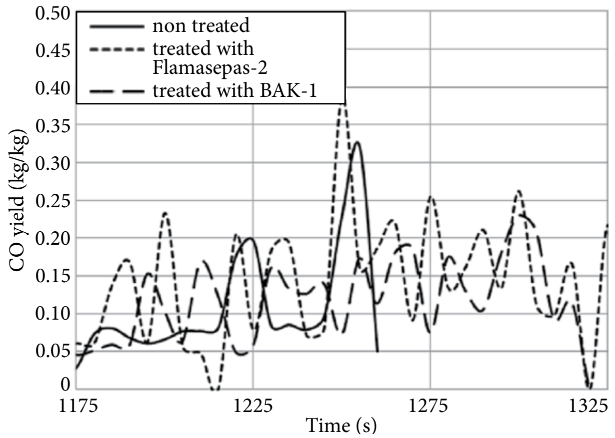

Fig. 7. A peak of CO yield obtained during the last stage of combustion (time interval: 1175–1325 s) of non-treated and treated specimens in the cone calorimeter at the heat flux of 30 kW/m^2 (with piloted ignition)

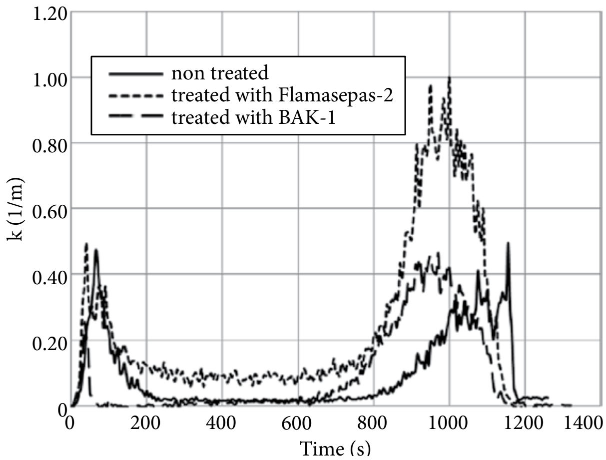

Fig. 10. The extinction coefficient obtained during the combustion of non-treated and treated specimens in the cone calorimeter at the heat flux of 30 kW/m^2 (with piloted ignition)

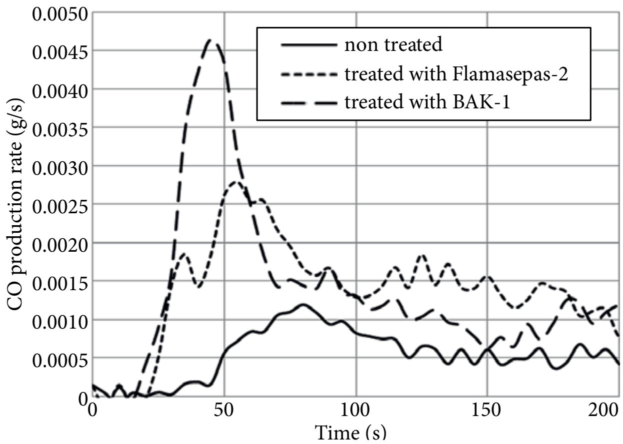

Fig. 8. CO production rate obtained during the first stage of combustion (time interval: 0–200 s) of non-treated and treated specimens in the cone calorimeter at the heat flux of 30 kW/m^2 (with piloted ignition)

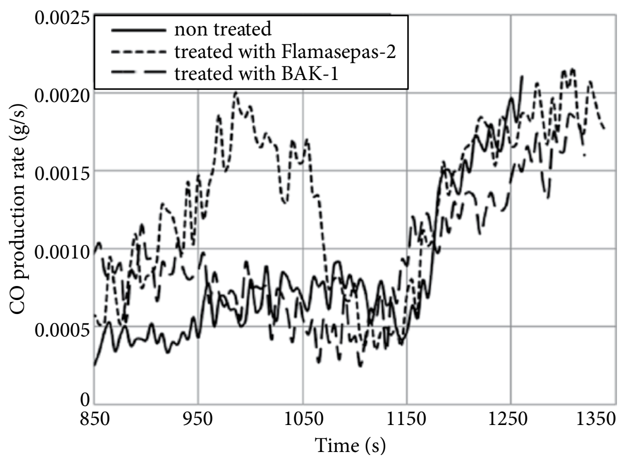

Fig. 9. CO production rate obtained during the last stage of combustion (time interval: 850–1350 s) of non-treated and treated specimens in the cone calorimeter at the heat flux of 30 kW/m^2 (with piloted ignition)

For comparison, the graphs presenting CO concentration and extinction coefficient obtained during the combustion of the same type of specimens without piloted ignition are given in Figs. 11 and 12.

The combustion process of the studied pine timber has got some local peaks of HRR:

a) the first peak at the initial stage of combustion with piloted ignition (between 40 and 100 s) with the highest value of about 204 kW/m^2 (t = 80 s) for non-impregnated pine timber, 107 kW/m^2 (t = 45s) for timber impregnated with Flamasepas-2 and 61 kW/m^2 for timber impregnated with BAK-1;

b) the second peak at the final stage of combustion with piloted ignition (between 900 and 1200 s) with the highest value of about 161 kW/m^2 (t = 1145 s) for non-impregnated pine timber, 165 kW/m^2 (t = 1000 s) for specimen impregnated with Flamasepas-2 and 146 kW/m^2 (t = 980 s) for specimen impregnated with BAK-1 (see Fig. 4).

The observed peak values taken from the moment of ignition are approximately equal to 14 s for non-impregnated and 11 s for impregnated timber. A rapid increase in HRR occurred at the moment of ignition for all tested specimens. The highest value of HRR slope exceeding 18 kW/(m^{2}s) for non-treated pine timber and the lowest one below 5 kW/(m^{2}s) for specimen treated with BAK-1 have been observed. The rate of HRR increase in the last stage of combustion was significantly lower and did not exceed the value of about 1 kW/(m^{2}s).

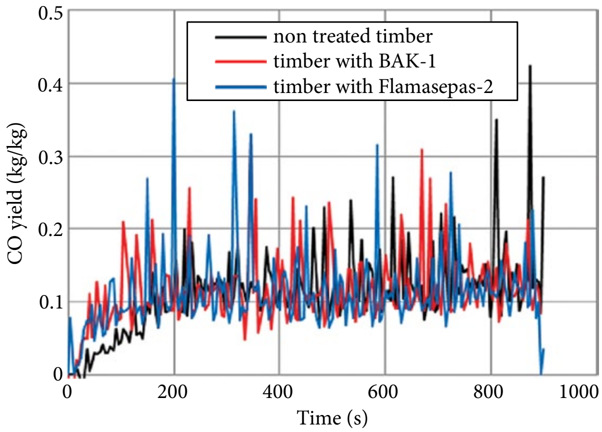

Fig. 11. A peak of CO yield obtained during the combustion of non-treated and treated specimens in the cone calorimeter at the heat flux of 30 kW/m² (without piloted ignition)

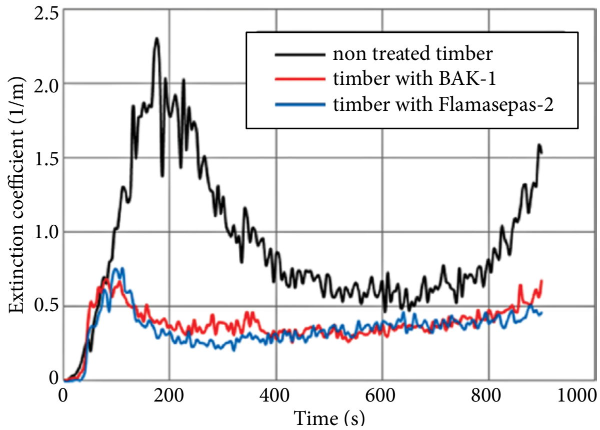

Fig. 12. The extinction coefficient obtained during the combustion of non-treated and treated specimens in the cone calorimeter at the heat flux of 30 kW/m²
(without piloted ignition)

CO concentration during the combustion process with piloted ignition is characterized by rapid growth in the first stage following approximately 30 s from the start of the experiment, and in the final combustion stage, following approximately 1175 s (see Figs. 6 and 7). Maximum CO concentrations for different specimens at the initial and final combustion stages are given in Table 5. The results show that in the first case, the highest value of about 0.14 kg/kg was obtained for pine timber impregnated with BAK-1 (after 45 s) and the lowest one of about 0.065 kg/kg for pine timber impregnated with Flamasepas-2 (after 60 s). For the remaining non-treated specimen, this value occurred following 50 s and was about 0.09 kg/kg (see Fig. 6 and Table 5). In the final stage of combustion, after 1175 s, one more growth of CO concentration can be observed. This time, the highest value of approx. 0.39 kg/kg (at 1250 s) for timber impregnated with Flamasepas-2 and the lowest value of approx. 0.23 kg/kg (at 1300 s) for timber impregnated with BAK-1 can be noticed. The maximum value of CO concentration for non-impregnated timber was about 0.32 kg/kg at 1255 s.

The CO function (see Fig. 8 and 9) indicates that the biggest changes in CO concentrations were obtained for impregnated specimens. For instance, for the sample containing BAK-1, the maximum CO value was about 0.0046 g/s (at t = 45 s), whereas for the non-treated sample this value was slightly higher than 0.001 g/s. At the end of combustion, between 850 s and 1100 s, the highest value of CO for the specimen treated with Flamasepas-2 was observed. A visible increase in CO concentration up to about 0.002 g/s for all tested specimens after t = 1150 s was noticed (see Fig. 9).

Table 5. Maximum values of CO concentration in kg/kg and corresponding times in sec obtained during the initial and combustion final stages of non-treated and treated pine timber (without piloted ignition)

Phase of combustion	Non-treated	Treated with F*	Treated with B**
	time value	time value	time value
Initial	50 0.09	60 0.065	45 0.14
Final	1255 0.32	1250 0.39	1300 0.23

* Flamasepas-2
** BAK-1

Concerning smokiness based on the function of extinction coefficient *k* (see Figs. 10 and 12) the following can be stated:

a) in the initial stage, the highest degree of smokiness for non-impregnated specimen (k_{max} = 0.47 1/m) and specimen impregnated with Flamasepas-2 (k_{max} = 0.50 1/m) was observed. The application of BAK-1 contributed to reduced smokiness (k_{max} = 0.25 1/m);
b) in the final stage, for specimen impregnated with Flamasepas-2, the highest degree of smokiness with the extinction coefficient of 1.0 1/m was shown, whereas for specimen with BAK-1 this value was 0.46 1/m and for the non-impregnated one – 0.49 1/m. Additionally, with reference to data disclosed in Table 6, the maximum val-

ues of coefficient *k* are shown with corresponding times for all three specimens; two combustion stages are presented and a significant shift in time of the following peaks can be seen.

Table 6. Maximum values of extinction coefficient *k* in 1/m and corresponding times obtained during the initial and final combustion stages of non-treated and treated pine timber (without piloted ignition)

Phase of combustion	Non-treated	Treated with F*	Treated with B**
	time value	time value	time value
Initial	65 0.47	40 0.50	35 0.25
Final	1155 0.49	1000 1.00	970 0.46

* Flamasepas-2
** BAK-1

4. Large Scale Tests: Methods, Tested Materials and Results

To confirm the results presented in the previous section in a large scale, fire tests have been performed in a special cabin (2.5×2.5×2.8 m) having two walls made of fire-resistant glass and two - covered with wall ceramic tiles. The compartment had a single doorway, 0.80 m wide and 2.0 m high, centred in the front wall and a controlled horizontal ventilation system mounted under the ceiling. During fire, the doors were closed and the ventilation system was off. Temperatures, CO concentration and optical smoke density were measured during fire tests. 20 K-type thermocouple trees were fixed in the compartment – 5 thermocouples on each tree fixed at the same five different levels - 0.8 m (level 1), 1.5 m (level 2), 2.0 m (level 3), 2.5 m (level 4) and 2.7 m (level 5).

Special measurement heads MG 72 produced by ALTER SA were used for registering CO concentration. Sensors MG 72 are connected with control equipment MSMR-4 that gives the output signal of standard format RS 485. Four sensors were mounted on two aluminium columns at two heights: 2.7 m (important from a ceiling jet point of view) and 1.6 m (important from evacuation conditions point of view). A view of the column with sensors is shown in Fig. 13.

Six sensors of optical smoke density were installed in the cabin and mounted on the aluminium column. The used sensors were designed and made by Cobrabid-Optica Ltd. A general scheme is drawn in Fig 14. A view of the aluminium column with the sensors is shown in Fig. 15. A principle of measurement consists of reducing the ultraviolet or infrared light beam energy which is 930 nm in length and is emitted by a transmitting photodiode generating a power of 50 mW. The light beam is received by the photodiode the surface of which covers 1 cm^2 (larger than the coming beam).

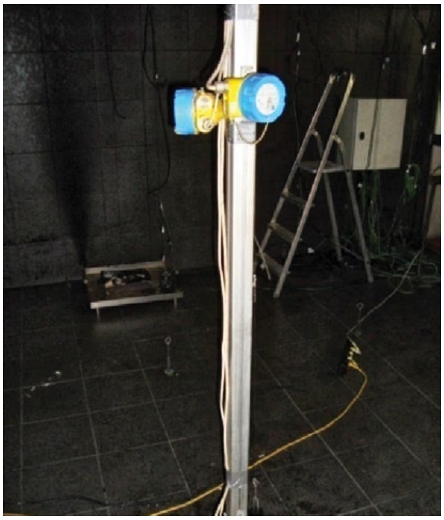

Fig. 13. A view of the aluminium column with mounted sensors MG 72

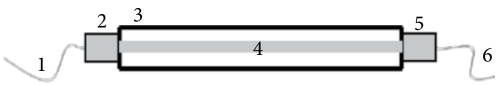

Fig. 14. The scheme of the smoke density sensor: 1 – a cable supplying a transmitting photodiode; 2 – a module with a transmitting photodiode; 3 – a mounting frame; 4 – a beam of ultraviolet or infrared rays emitted by a transmitter in the direction of a receiving photodiode; 5 – a module with a receiving photodiode; 6 – a cable transmitting signals from the receiving photodiode (Gałaj 2008)

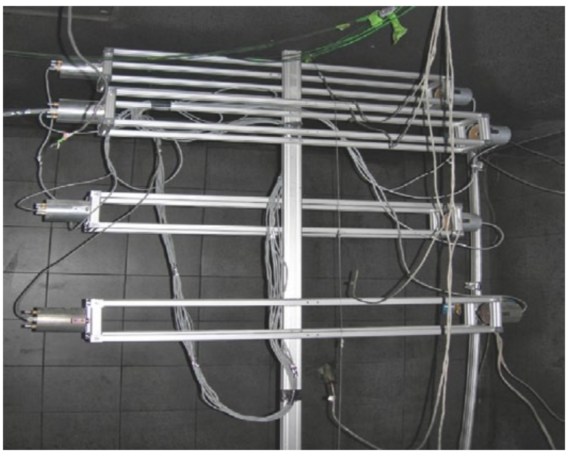

Fig. 15. A view of the column with smoke density sensors

A low output signal obtained from a receiving photodiode is then transformed into the analogue one by a special converter in the range of 0–10 V. The same device is also utilized for power supply to the sensors. The analogue signal is then transmitted to the analogue-digital converter (module ADAM 4017).

Using special module ADAM 4520, the output signals of format RS 485 are converted into format RS 232C, which can be read by a standard serial port of the computer. Then, input data are processed in the computer using special program "Adam View" enabling to display and save data in MS Excel format.

The output digital values obtained from the measuring system correspond to the voltage signals of maximal range 0–10 V. To calculate optical smoke density, the proportion between the intensity of light and voltage was assumed. It seems to be justified because of several reasons. First, smoke density determination, only the quotient of light intensities, not their values, is necessary. Second, a principle of measurement by used smoke density sensors enables to accept this solution.

The equation for optical density D can be written in the form (Gałaj, Bajko 2009):

$$D = \log \frac{U_0}{U}, \tag{1}$$

where U_0 – voltage signal proportional to light intensity I_0 corresponding to maximum voltage signal measured at the beginning of the test (air without smoke) [V], U – voltage signal proportional to light intensity I corresponding to the current voltage signal measured during the test (air with smoke) [V].

On the basis of value D, more frequently used extinction coefficient was determined according to the following formula:

$$k = \frac{1}{x} \ln\left(\frac{U_0}{U_x}\right), \tag{2}$$

where x – the distance between a transmitter and a receiver [m].

Visibility Z in accordance with the following relationship was also calculated at $C = 2$ (reflected light objects) and $x = 1$ m.

$$Z = \frac{C \cdot x}{(2.303) \cdot D}, \tag{3}$$

where C – a constant depending on lighting conditions.

Three combustion processes were performed: first, using non-treated pine timber, second, using timber treated with BAK-1 and the third one using timber treated with Flamasepas-2. Views of specimens with and without timber preservative are shown in Fig. 16.

Three pieces of pine timber, each having the size of 200×200×20 mm, two placed vertically and one put on them horizontally (the impregnated side was inside the structure) were combusted in each experiment. Such structure was put on the steel tray and placed near the wall opposite to the door. The source of ignition was 250 ml of denatured alcohol. Burning samples are shown in Fig. 17.

The cabin was closed just after ignition. When fire parameters stopped increasing (steady stage of combustion), the ventilation system was started. The samples were observed after the experiment and the remains were analyzed (see Fig. 18). All specimens were tested under the same conditions.

The following selected graphs obtained during experiments with fire are presented in the paper:

a) temperature measured by the selected thermocouple located near the fire source at a height of 1.6 m (Fig. 19),
b) CO concentration measured by the sensor located in the centre at a height of 1.6 m (Fig. 20),
c) extinction coefficient at a height of 1.6 m (Fig. 21),
d) visibility range calculated on the basis of the extinction coefficient (Fig. 22).

The following specific parameters of the obtained graphs are included in the tables below:

a) the maximum values and average speed of temperatures during the first stage of combustion (Table 7),
b) the maximum values and average speed of CO concentration during the first stage of combustion as well as the time of the first appearance of carbon monoxide registered by the sensors (Table 8).

a)  b) 

Fig. 16. A view of timber specimens: a – without preservative; b – with preservative

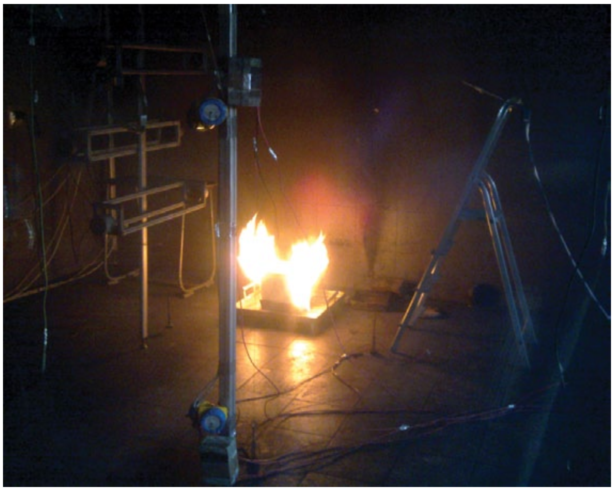

Fig. 17. A view of burning pine timber

Fig. 18. A view of the remains after combustion (treated timber – on the top, non-treated – on the bottom)

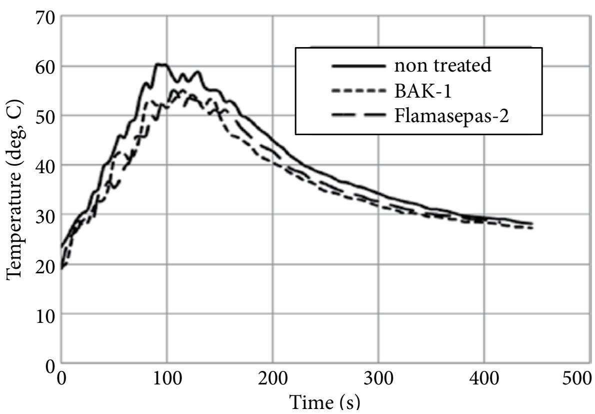

Fig. 19. Temperature during the combustion of non-treated and impregnated pine timbers measured by the thermocouple 18,3 located near the fire source at a height of 1.6 m

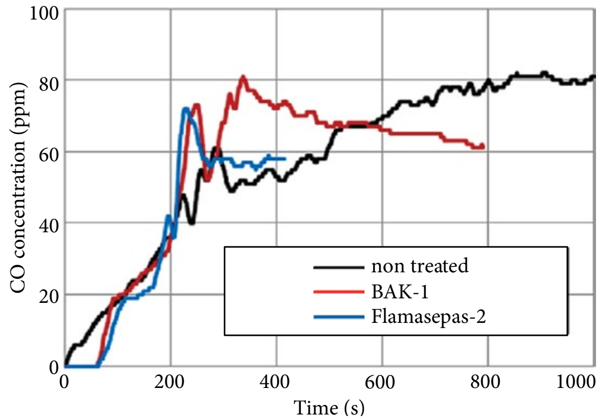

Fig. 20. CO concentration during the combustion of non-treated and impregnated pine timbers measured by the sensor in the centre of the compartment at a height of 1.6 m

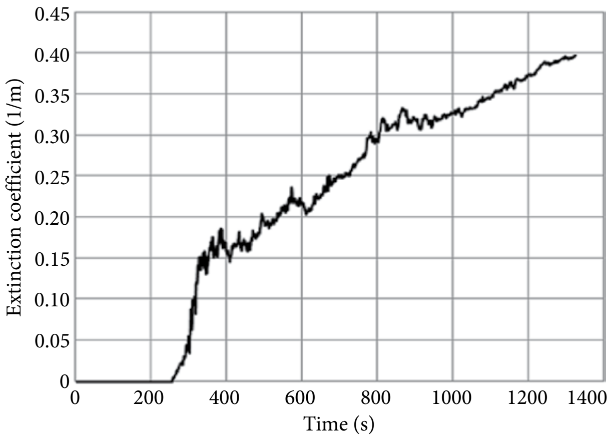

Fig. 21. The extinction coefficient during the combustion of non-treated pine timbers measured by the sensor located at a height of 1.6 m (for treated pine timbers, the extinction coefficient was equal to zero during the experiment)

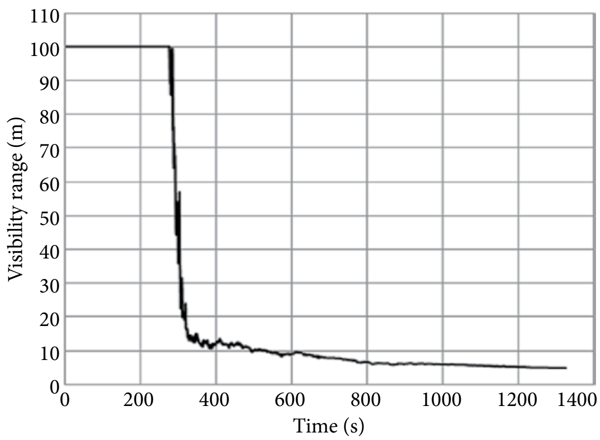

Fig. 22. Visibility range during the combustion of non-treated pine timbers measured by the sensor located at a height of 1.6 m (for treated pine timbers, visibility was equal to zero during the experiment)

Table 7. The maximum values and average speed of growth in temperature during the first stage of combustion

Material	Maximum values [deg C]	Average speed [deg C/s]
Pine timber	58.8	0.39
BAK-1	55.0	0.37
Flamasepas-2	54.9	0.37

Table 8. The maximum values and average speed of growth in CO concentration during the first stage of combustion and time for the first appearance of carbon monoxide

Material	Maximum values [ppm]	Average speed [ppm/s]	Time of appearance [s]
Pine timber	82	0.22	0
BAK-1	81	0.48	61
Flamasepas-2	72	0.62	63

Conclusions arising from the analysis of the results of the fire test have been formulated and are listed in the next chapter.

5. Conclusions

After analyzing the results obtained using the cone calorimeter and full scale fire, the following general conclusions can be formulated:

1. The treatment of pine timber with fire retardant causes a significant reduction in the time of specimen ignition in the case of piloted ignition only. Ignition time for timber treated with Flamasepas-2 (31 s) and BAK-1 (46 s) are evidently less than that for non-treated timber (74 s). This surprising property was confirmed in many experiments. The tests carried out by other scientists in Lithuania showed that the opposite situation might occur in the case of combustion without piloted ignition.

   The presented studies have confirmed the above displayed information, since in case of three studied specimens, during the tests without ignition stimulus, ignition did not occur during 15 minutes. Considering the above results, it can be concluded that the use of tested additives can bring unexpected results in some circumstances.
2. The impregnation of pine timber with Flamasepas-2 and BAK-1 significantly reduces (almost twice) the rate of the heat released in the initial combustion period (first 100 s) crucial for the safety of people evacuation. It reflects the rate of temperature increase in the compartment, which is much slower in the case of pine timber treated with fire retardant. In the final combustion stage (over 800 s), differences are insignificant and do not exceed 25 kW/ m^2.
3. The treatment of pine timber with fire retardant does not reduce the maximum value of CO concentration (in case of ignition with flame); moreover, it can even increase its value in the initial stage of combustion, as was observed in case of BAK-1 (difference was about 0.05 kg/kg compared to non-impregnated specimen). The treatment of specimen with Flamasepas-2 reflected lower maximum concentration making approx. 0.025 kg/kg. After 70 s, the observed values of CO rapidly decreased for all studied specimens and stabilized at the level of 0.02 kg/kg. After 1200 s, CO concentrations increased repeatedly with the maximum value for this stage obtained for specimen treated with Flamasepas-2 (about 0.39 kg/kg) and with the lowest value for specimen treated with BAK-1 (about 0.23 kg/kg).
4. In the initial combustion stage, the highest CO emission rate was observed for specimen impregnated with BAK-1 (the maximum value of 0.0045 g/s) and the lowest one for non-impregnated specimen (the maximum value of about 0.0011 g/s). The maximum emission rate for specimen with Flamasepas-2 was about 0.0028 g/s. The above data indicate an unfavourable influence of impregnation on the flammable properties of pine timber.
5. The application of fire retardant has an impact on smokiness (extinction coefficient) in the initial combustion stage, which is crucial for evacuation actions as well as for the final combustion stage. BAK-1 has proven to be the most suitable. Its treatment reduced smokiness twice in the first minutes of specimen combustion compared to non-impregnated pine timber. The influence of Flamasepas-2 was not significant; however, it also caused a reduction in the extinction coefficient for approx. 0.2 *l*/m. On the other hand, due to shorter ignition time, smokiness appeared faster in the case of impregnated wood compared to the non-impregnated one. In the final combustion stage, the highest degree of smokiness (twice as high as in the initial combustion stage) along with the extinction coefficient of about 1.0 *l*/m for specimen treated with Flamasepas-2 was observed.

6. The application of fire retardant has no significant impact on the temperatures in the compartment. The only difference consists in a slightly higher maximum value and average increase rate during the fire development stage for non-impregnated timber. Difference makes about 4°C and 0.02 °C/s respectively, without regard to the type of fire retardant.
7. The maximum value of carbon oxide concentration is slightly lower (approx. 10 ppm) (full scale experiments) for timber treated with Flamasepas-2 fire retardant comparing to non-impregnated timber and makes about 72 ppm. In case of BAK-1 fire retardant, maximum concentrations were almost the same and made 82 ppm. In addition, for non-impregnated timber, a constant increase in CO concentration up to 80 ppm have been observed while in other cases, the values have oscillated, and after a shorter time (about 260 s) for Flamasepas-2 and longer (about 480 s) for BAK-1, CO values have stabilized at 60 ppm (about 20 ppm lower than non-impregnated timber).
8. The average increase rate of CO values in the first stage of fire is significantly higher for timber treated with fire retardant (0.48 ppm/s for BAK-1 and 0.62 ppm/s for Flamasepas-2) rather than for non-impregnated one (0.22 ppm/s). However, the time of CO detection in case of non-impregnated timber is almost instantaneous while in case of timber treated with fire retardants, it took approx. 1 minute, which enables safety evacuation of people from the compartment (full scale experiments).
9. After 252 s from the start of fire, a rapid increase in the extinction coefficient reflecting smokiness degree in the compartment can be observed only in case of non-impregnated timber. Between 250 and 320 s, a rapid decrease in visibility up to the safety level of approx. 5 m have occurred. During the whole test on impregnated timber, the extinction coefficient was at zero level, which indicates no smoke in the compartment (full scale experiments).

Taking into account the results obtained from both experiments with the combustion of non-treated pine timber specimens treated with two different fire retardants, including Flamasepas-2 and BAK-1, it can be concluded that impregnation influences the combustion process decreasing (see conclusion 2) the rate of heat release and increasing CO emission (in case with piloted ignition). Generally, lower concentrations have been observed for specimens impregnated with Flamasepas-2. Concerning only CO concentrations, the results are not that unequivocal, since treatment with BAK-1 can increase its concentration in the initial stage of combustion. However, taking into account the results obtained during timber combustion in full scale tests, especially CO values and visibility ranges, it can be stated that the use of fire retardants increases human safety by delayed toxic CO occurrence, its lower concentrations and a lack of smoke if compared to non-impregnated timber. Although the obtained fire parameters in all combustion cases in full scale do not pose any real danger for people, since they do not exceed limit values (60°C in case of temperature, 100 ppm in case of CO concentration and 5 m in case of visibility range), considering a limited amount of flammable material, it can be expected that the values will be exceeded when a larger amount is used. However, the curves of fire parameters should remain the same. Taking into account all obtained results, the following general conclusion can be made: both studied fire retardants partly fulfil their tasks while Flamasepas-2 shows slightly better performance than BAK-1 from the human safety point of view.

In order to choose suitable fire retardant and reducing an unfavourable impact of combustion on human during potential internal fire, each situation should be analysed independently, considering the smokiness and generation of toxic combustion products.

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IMPREGNAVIMO POVEIKIO PUŠIES MEDIENOS DEGUMUI TYRIMAI TAIKANT KŪGINĮ KALORIMETRĄ IR NATŪRINIŲ TYRIMŲ METODĄ

J. Gałaj, Z. Karpovič, W. Jaskółowski

Santrauka. Gaisrinė sauga – vienas pagrindinių reikalavimų, kurį privalo atitikti pastatai. Gaisrinės saugos užtikrinimas svarbus ir pastato gyventojams, naudotojams, klientams, žiūrovams, ir gelbėtojams, vykdantiems gelbėjimo darbus. Vertinant termokinetinius dydžius, susijusius su dūmais ir nuodingais degimo produktais, taikomi degimo produktų vertinimo tyrimo metodai. Šie metodai skirstomi į natūrinius, geriausiai pakartojančius gaisro parametrus, ir mažų bandinių, kuriuose šis pakartojimas gerokai mažesnis. Straipsnyje pristatyti antipireninių tirpalų BAK-1 ir Flamasepas-2, gaminamų Lietuvoje ir naudojamų medienai impregnuoti, poveikio gaisro parametrams tyrimai. Tyrimai atlikti naudojant kūginį kalorimetrą (mažų bandinių tyrimai) uždaroje patalpoje su įrengta matavimo įranga (natūriniai tyrimai). Tyrimai parodė, kad antipireniniai tirpalai sumažina šilumos išskyrimo greitį (HRR). Atvirkštinė situacija susidaro vertinant laiką iki užsiliepsnojimo, CO išsiskyrimą ir dūmingumą. Šie antipireniniais tirpalais impregnuotos medienos gaisro parametrai, palyginti su neimpregnuota mediena, pablogėja (trumpėja laikas iki užsiliepsnojimo, padidėja CO išsiskyrimas ir dūmingumas). Šie rezultatai gauti naudojant papildomą šaltinį, uždegantį bandinio paviršių. Atliekant tyrimus, kuriuose šis šaltinis nebuvo naudotas, gauti priešingi rezultatai. Nė vienas iš tiriamų impregnuotų bandinių neužsiliepsnojo, o tyrimai buvo nutraukiami praėjus 15 min., CO išsiskyrimas ir dūmingumas buvo didesnis neimpregnuotos medienos. Tai patvirtinta natūriniais tyrimais, kurių metu nustatyta, kad pušies medienos impregnavimas neturi didelės įtakos temperatūros pokyčiams kilus gaisrui patalpoje.

Reikšminiai žodžiai: pušies mediena, antipireninis tirpalas, impregnavimas, gaisras, toksiškumas, šilumos šaltinis, degimo produktas, anglies monoksidas.

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ISSN 1895-8443

CNBOP-PIB

Bezpieczeństwo i Technika Pożarnicza
Safety & Fire Technique

Wydawnictwo Centrum Naukowo-Badawczego Ochrony Przeciwpożarowej
im. Józefa Tuliszkowskiego
Państwowego Instytutu Badawczego
http://czytelnia.cnbop.pl
Vol. 23/3/11
September 2011

Przygotowanie do wydania
mgr Joanna Cybulska

Projekt okładki:
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Zamówienia na kolejne wydania oraz prenumeratę przyjmuje
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tel. 22 850 11 12, fax 22 433 50 09
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ISSN 1895-8443

Wydawnictwo Centrum Naukowo-Badawczego
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Nakład 500 egzemplarzy

Publikacja przeznaczona dla kadry Państwowej Straży Pożarnej oraz specjalistów z zakresu ochrony przeciwpożarowej i bezpieczeństwa powszechnego.

Wydawnictwo dofinansowywane ze środków Ministra Nauki i Szkolnictwa Wyższego.

Artykuły zamieszczone w numerze są dopuszczone do druku decyzją Komitetu Redakcyjnego na podstawie recenzji naukowo-badawczych i inżynieryjno-technicznych przygotowanych przez niezależnych recenzentów.

Kwartalnik CNBOP „Bezpieczeństwo i Technika Pożarnicza" jest czasopismem punktowanym z listy Ministra Nauki i Szkolnictwa Wyższego (6 pkt.). Informacja na podstawie Komunikatu nr 16 Ministra Nauki i Szkolnictwa Wyższego z dnia 21 czerwca 2010 roku.

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INVESTIGATION OF THE INFLUENCE OF IMPREGNATION ON THE PINE TIMBER COMBUSTION USING FLOW THROUGH TESTS

Badanie wpływu impregnacji ogniochronnej na skład i ilość produktów toksycznych powstałych podczas spalania drewna sosnowego

Summary

Millions of people have lost their lives during fire in the recent decades, the majority died from inhalation of toxic fire effluents. Toxic fire effluents cause death in fire, as any incapacitation is likely to impede escape, and increase the chance of becoming trapped. Better understanding of this problem will contribute to the reduction in the number of such deaths in the future. This paper analyses emissions of carbon monoxide (CO), hydrogen chloride (HCl), hydrogen cyanide (HCN) and ammonia (NH_3) during the combustion of non-impregnated and impregnated pine timber with fire retardants in research equipment for toxic combustion products emitted from solid materials after the impact of the heat source (e.g. flow through test). The toxicity of pine timber specimens was investigated at two powers of external heat source of 8 kW/m^2 and 10 kW/m^2.

Streszczenie

Co roku wielu ludzi traci życie w czasie pożaru. Większość ginie z powodu wdychania toksycznych produktów rozkładu termicznego i spalania. Produkty te stanowią nie tylko bezpośrednią przyczynę śmierci ale także mogą utrudniać skuteczną ewakuację. Lepsze zrozumienie problematyki toksyczności produktów spalania przyczyni się do zmniejszenia liczby tych zgonów w przyszłości. Artykuł ten przedstawia wyniki badań emisji tlenku węgla (CO), chlorowodoru (HCl), cyjanowodoru (HCN) i amoniaku (NH_3) podczas spalania bezpłomieniowego drewna naturalnego sosnowego, jak i impregnowanego przeciwogniowo dwoma komercyjnymi środkami ogniochronnymi produkowanym na Litwie. Do badań eksperymentalnych wykorzystano nie normatywną technikę pomiarową. Próbki poddano oddziaływaniu strumienia promieniowania cieplnego o gęstości 8 i 10 kW/m^2.

Keywords: pine timber, fire retardants, treatment, fire, toxicity, heat source, combustion products, carbon monoxide;
Słowa kluczowe: drewno sosnowe, środek ogniochronny, pożar, toksyczność, produkty spalania, tlenek węgla, chlorowodór, amoniak, cyjanowodór;

1. Introduction

There are factors to be encountered that endanger not only people inside the building but also those performing rescue works during the fire occurance. The factors include: (Buhanan 2002; Kolbrecki 2000; Seńczuk 1998; Hartzell 1993; Иванников and Клюс 1987):

- toxic combustion products,
- flame and high temperature (heat),
- reduction of oxygen concentration,
- instability of constructions,

- reduced visibility (smoke).

Each of these factors and their effect on the escape behaviour are briefly discussed below. The time available for escape is a period between the time of ignition and the time after which conditions prevent occupants from safe evacuation. In Great Britain and the United States of America more than 50 % of all deaths in fires have been caused by toxic combustion products constituting smoke (Stec and Hull 2010; Brushlinsky *et al.* 2009; Drysdale 1998).

The consequences of fire may be reduced by performing effective preventing actions during the emergence of fire, such as extinguishing it before spreading (Buhanan 2002). One of the possibilities for implementing effective prevention is usage of materials protecting from the impact of fire, i. e. fire retardants (Ozkaya *et al.* 2007; Jun-wei Gu *et al.* 2007; Koo *et al.* 2001; Nassar 1999). For building materials, i. e. timber constructions that are impregnated with fire retardants, time to flame combustion is longer and flame spread rate is lower (Karpovič 2009; Gu *et al.* 2007).

Fire science is multidisciplinary, it includes chemistry, physics, engineering as well as computer modelling. The conditions in real fires are difficult to recreate in a laboratory scale. Physical and chemical methods used for analysis of combustion of different flammable materials can be divided into small, medium and full scale.

This paper is the beginning of three-part project. Further research on the toxicity of non-impregnated and impregnated pine timber with fire retardants are to be performed in a small and full scales (second part) and with application of fire hybrid modelling (third part).

The aim of the further studies is to analyse the toxicity and compare the results obtained from small and full scales methods as well as from fire hybrid modelling (Galaj 2009, 2010).

Most small scale methods used for toxicity tests are developed to simulate a single fire source or the conditions, where real scale fires simultaneously involve different fire phases in different places. These methods can be grouped as those with constant combustion conditions, often achieving a prolonged steady state period, and those with unstable combustion conditions. The latter ones are the most suitable data for comparison and modelling, for example German tube furnace method DIN 53436, and its derivative ISO 19700. Most other small scale methods have changeable combustion conditions, such as those in closed or semi closed chambers exposed to a constant source of heat, for example NBS smoke chamber ISO 5659, cone calorimeter ISO 5660-1, stationary tube furnace test NFX 70-100 and fire propagation apparatus ASTM E 2058. The methods can be grouped according to their physical arrangement: open tests (cone calorimeter), closed tests (smoke chamber) and flow through tests (stationary and steady state tube furnaces, controlled atmosphere cone calorimeter and the fire propagation apparatus) (Stec and Hull 2010).

Fire zone during the open tests is well ventilated. The cone calorimeter has been developed specifically to determine the rate of heat release and effective heat of combustion of building materials. It has been subsequently modified to determine smoke generation (ISO 5660-2) and later applied to furnitures. The cone calorimeter is probably the most widely used apparatus for measurement of flammability properties (Schartel and Hull 2007).

Closed chamber tests attempt to direct the transition through the fire stages by enclosing the sample in a fixed volume of air, heating it, with or without ignition, and monitoring the formation of toxic gases, as the oxygen concentration falls, and the fire condition changes from well ventilated to under ventilated. The methods can be subdivided into two broad categories, where decomposition or combustion occurs in the main chamber, or in a side chamber (Schartel and Hull 2007).

In flow through methods the specimen is thermally decomposed, with or without flame, in a furnace over a known volume of flowing air, which drives the effluent to the sampling system or gas measurement devices.

The field of fire protection examines resistance to fire of ceramics (Abraitis and Stankevičius 2007; Žurauskienė and Nagrockienė 2007), concrete (Chung Kyung-soo *et al.* 2007; Abramowicz and Kowalski 2007; Jonaitis and Papinigis 2005), ferro concrete (Bednarek and Ogrodnik 2007) and steel (Bednarek and Kamocka 2006), application of the zone model to investigate the combustion of different flammable materials (Galaj 2007), combustion of polymeric materials (Konecki and Półka 2009) as well as the impact of isolating materials to timber strength (Bednarek and Kaliszuk-Wietecka 2007), combustion of timber treated with fire retardants, the effectiveness of fire retardants (Karpovič 2009; Półka 2008), the hazardousness of pine timber and cork-oak while fuming (Karpovič and Šukys 2009) and reaction-to-fire of nine different wood species having different density and thickness (Harada 2001). Lewin 2005 emphasized the need for research on timber treated with fire retardants. There are many questions unanswered concerning the protection of timber against fire. One of such questions is the toxicity of timber impregnated with fire retardants during thermal destruction. The toxicity of timber impregnated with fire retardants was partly analysed in Šukis and Karpovič (2010) work.

The aim of this work is to analyse the toxicity of non-treated and treated pine timber with fire retardants, to determine alternation of emission of carbon monoxide (CO), hydrogen chloride (HCl), hydrogen cyanide (HCN) and ammonia (NH_3) subjected to the different heat source intensity using flow through method.

2. Materials tested and test method

Tests were performed in the Main School of Fire Service by using research equipment for toxic combustion products emitted from solid materials after the impact of the heat source (flow through test). To investigate the influence of impregnation on combustion properties, three types of samples were tested: pure pine timber without impregnation and two pine timbers impregnated with fire retardants A and B:

1. The primary ingredient of fire retardant A is potassium carbonate. Used as an aqueous solution of inorganic salts. While the impact of thermal radiation. 8-10 mm is formed coating, protective wooden structures. Recommended use - 500 ml/m². Fire classification according to LST EN 13501 is B-s 2, d 0.
2. The primary ingredient of fire retardant B is potassium carbonate. Used as an aqueous solution of inorganic salts. While the impact of thermal radiation. 6-8 mm is formed coating, protective wooden structures. Recommended use - 450 ml/m². Fire classification according to LST EN 13501 is B-s 1, d 0.

The research equipment for toxic combustion products shown in Fig. 1 enables to determine concentrations of emitted toxic combustion products while impacting specimen with different heat sources. The possible range of the heat sources measured on the surface of specimens varies from 2 to 80 kW/m². During the test two heat sources were used, i. e. 8 kW/m² an10 kW/m². By impacting specimens with such heat sources the conditions were established for the emission of the main amount of combustion products. At the heat sources of less than 8 kW/m² the temperature on the specimens does not reach 160°C, while at the heat sources higher than 10 kW/m² the specimens inflame (the research equipment cannot be applied for tests when flammable combustion occurs). The computer connected to the research equipment ensured accurate control of the test and automatically recorded the results. Five specimens in every test group were tested. The timescale for one test course was 1 hour. The dimensions of the specimens were 200 mm x 200 mm x 20 mm.

Two tests were performed for the following three main groups of the specimens:

- non-treated pine timber specimens,
- pine timber specimens treated with the fire retardant A,
- pine timber specimens treated with the fire retardant B.

The fire retardants used for the treatment of pine timber specimens have been produced and used in Lithuania.

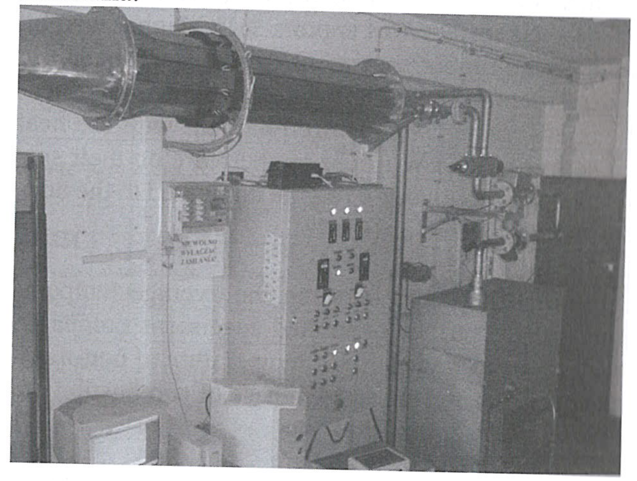

Fig 1. A view of the research equipment for the measurement of the concentration of toxic combustions products

3. Flow through test results and analysis

The results have been processed with „Statistica" programme. Correlation coefficients of the emission of CO, HCN, HCl and NH_3 are given in Tab. 1.

The variation of temperature on the surface of the specimens for two values of heat source power of 8 kW/m² and 10 kW/m² and different specimens is shown in Fig. 2. In turn, the changes in concentrations of the emission of CO, HCN, HCl and NH3 are presented in Fig. 3-6.

Analysing flow through tests results, the following observations with reference to temperature can be pointed out:

Table 1.

Correlation coefficient of the emission of CO, HCN, HCl, NH_3

Heat source, specimen	Correlation coefficient of the emission of combustion products on the same parameters			
	CO	HCN	HCl	NH_3
8 kW/m², pine	0.993	0.980	0.903	0.992
8 kW/m², pine with A	0.943	0.993	0.985	0.969
8 kW/m², pine with B	0.974	0.996	0.909	0.917
10 kW/m². pine	0.985	0.981	0.912	0.985
10 kW/m², pine with A	0.921	0.979	0.934	0.992
10 kW/m², pine with B	0.914	0.965	0.942	0.998

- the value of temperature rapidly increases during first period of combustion (from 0 to approx. 600 s) for two powers of heat source 8 kW/m^2 and 10 kW/m^2. Afterwards the changes of temperature are significantly slower not exceeding 0.2°C/s (only between 1700 and 2000 s this value is bigger in case of pine timber without retardant) (Fig. 2);
- the average temperature of the specimens non-treated with fire retardants was about 21.1° C (8 kW/m^2) and 14° C (10 kW/m^2) higher than the average temperature on the pine timber specimens treated with the A fire retardant (Fig. 2);
- after influencing non-treated specimens with the heat source of 8 kW/m^2 the temperature observed on their surface was approx. 9.4°C higher than on the pine timber specimens treated with the B fire retardant, while when impacting pine timber specimens treated with B fire retardant with the heat source of 10 kW/m^2 the temperature on their surface was about 9.5° C higher compared to the non-treated specimens (Fig. 2).

The differences between the average temperature on the surface of treated specimens compared with to the average surface temperature of non-treated specimens during steady phase of combustion are given in Tab. 2.

Table 2.

The differences of the average of temperature on the surface of treated specimens compared with the average of temperature on the surface of non-treated specimens during steady phase of combustion

Heat source	Specimens, temperature	
	pine with B	pine with A
8 kW/m^2	-9.4° C	-21.1° C
10 kW/m^2	+9.5° C	-14° C

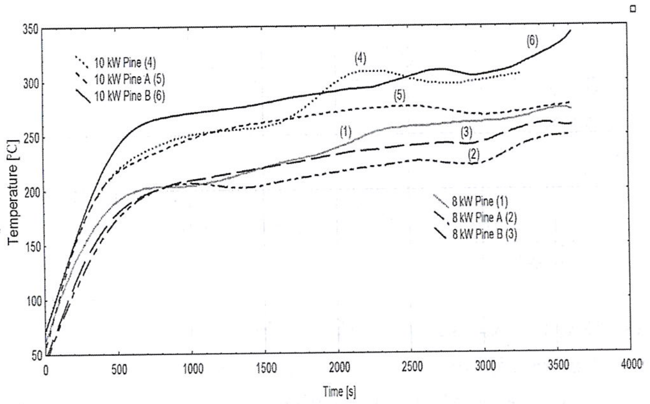

Fig 2. Temperatures on the surface of tested specimens: pine, pine treated with A and pine treated with B for heat sources of 8 kW/m^2 and 10 kW/m^2

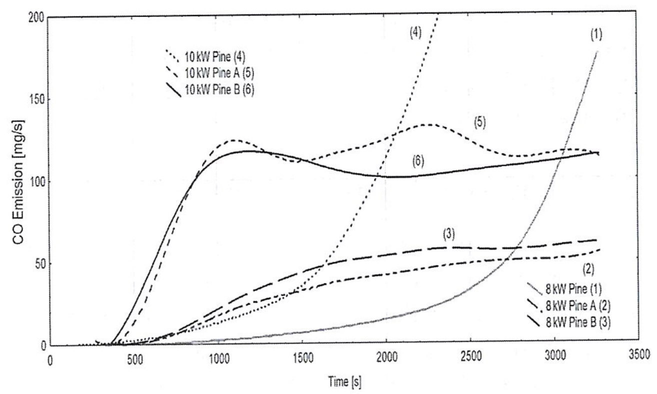

Fig 3. Emission intensity of carbon monoxide for heat source of 8 kW/m^2 and 10 kW/m^2 for all tested specimens

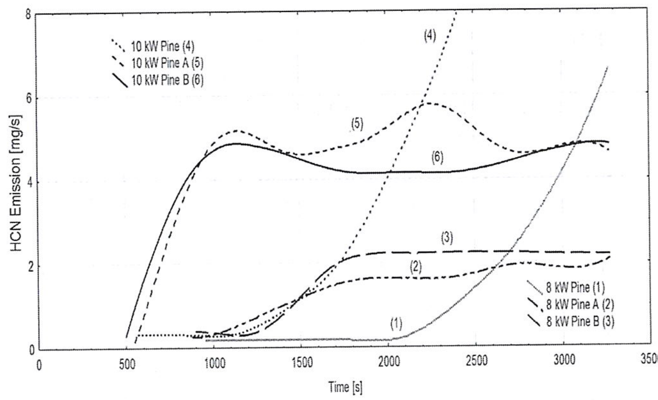

Fig 4. Emission intensity of hydrogen cyanide for two power of heat source 8 kW/m^2 and 10 kW/m^2 and all tested specimens

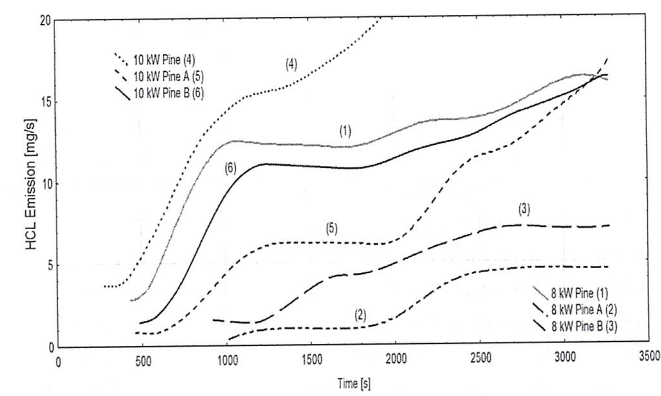

Fig 5. Emission intensity of hydrogen chloride for two power of heat source 8 kW/m^2 and 10 kW/m^2 and all tested specimens

In the following tables such parameters obtained during tests are given:

1. The average values of time τ_1 and temperature t_r corresponding to the beginning of registration of measured toxic products (CO, HCN, HCl and NH_3) for heat source 8 kW/m^2 in table 3 and 10 kW/m^2 in table 4.
2. The values of characteristic times τ_2 and τ_3 as well as steady value *SV* corresponding to the parameters of the emission intensity of measured toxic products (CO, HCN, HCl and NH_3) for heat source 8 kW/m^2 in table 5 and 10 kW/m^2 in table 6.
3. The total quantities of the toxic gases, such as CO, HCN, HCl and NH_3, emitted during the tests in table 7.

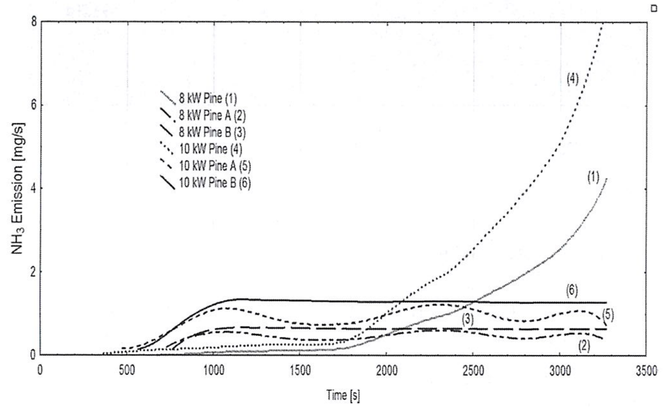

Fig 6. Emission intensity of ammonia for two power of heat source 8 kW/m^2 and 10 kW/m^2 and all tested specimens

Table 3.

The average values of time τ_1 and temperature t_r corresponding to the beginning of the registration of CO, HCN, HCl and NH_3 emissions during combustion of all tested specimens at power of heat source of 8 kW/m^2

Gas	Type of specimen	τ_1 s	t_r °C
CO	non-treated	300	140
	with A	420	165
	with B	365	156
HCN	non-treated	955	200
	with A	880	198
	with B	900	200
HCl	non-treated	430	167
	with A	1015	207
	with B	920	203
NH_3	non-treated	670	197
	with A	730	199
	with B	765	202

Table 4.

The values of time τ_1 and temperature t_r corresponding to the beginning of the registration of CO, HCN, HCl and NH_3 emissions during combustion of all tested specimens at power of heat source of 10 kW/m^2

Gas	Type of Specimen	τ_1 s	t_r °C
CO	non-treated	170	135
	with A	270	170
	with B	300	178
HCN	non-treated	570	220
	with A	550	217
	with B	500	219
HCl	non-treated	275	169
	with A	460	215
	with B	485	221
NH_3	non-treated	365	201
	with A	475	217
	with B	565	223

Table 5.

The values of times τ_2, τ_3 and steady value *SV* corresponding to the characteristic parameters of the emission intensity of CO, HCN, HCl and NH_3 during combustion of all tested specimens at power of heat source of 8 kW/m^2

Gas	Type of specimen	τ_2 s	τ_3 s	*SV* mg/s
CO	A	2600	2700	50
	B	2200	2780	60
HCN	A	1800	2600	1.8
	B	1750	2700	2.3
HCl	A	2600	*	4.5
	B	2600	*	7.0
NH_3	A	1000	2000	0.45
	B	1100	2100	0.67

*- emission intensity of HCl from non-impregnated sample is always greater than from impregnated samples

Table 6.

The values of times τ_2, τ_3 and steady value *SV* corresponding to the characteristic parameters of the emission intensity of CO, HCN, HCl and NH_3 during combustion of all tested specimens at power of heat source of 10 kW/m^2

Gas	Type of Specimen	τ_2 s	τ_3 s	*SV* mg/s
CO	A	1100	2020	130
	B	1050	1950	120
HCN	A	1100	2200	5.0
	B	1100	2010	4.2
HCl	A	1180	**	6.3
	B	1100	**	11.0
NH_3	A	1050	1990	1.1
	B	1100	2080	1.3

* - emission intensity is only steady until t=2000 s and then it systematically grows

** - emission intensity of HCl from non-impregnated sample is always greater than from impregnated samples

Table 7.

Toxic combustibility products and their quantities emitted during tests with different heat sources and type of the specimens

Heat source, specimen	Total quantity of toxic combustibility products [mg]			
	CO	HCN	HCl	NH_3
8 kW/m², pine	31539.9	1146.23	8769.05	476.27
8 kW/m², pine with A	23228.6	834.96	1233.2	195.95
8 kW/m², pine with B	27833.1	975.09	2987.9	211.29
10 kW/m², pine	94828.5	3149.22	11722.3	932.54
10 kW/m², pine with A	61299.6	2514.04	4379.94	489.87
10 kW/m², pine with B	56889.8	2317.76	6014.64	633.89

The views of non-treated and treated specimens after tests with heat source of 8 kW/m² and 10 kW/m² are presented in Figs. 7–10.

Fig 7. Views of non-treated pine timber specimen after tests with heat source of 8 kW/m²

Fig 8. Views of non-treated pine timber specimen after tests with heat source of 10 kW/m²

Fig 9. Views of treated pine timber specimen after tests with heat sources of 8 kW/m²

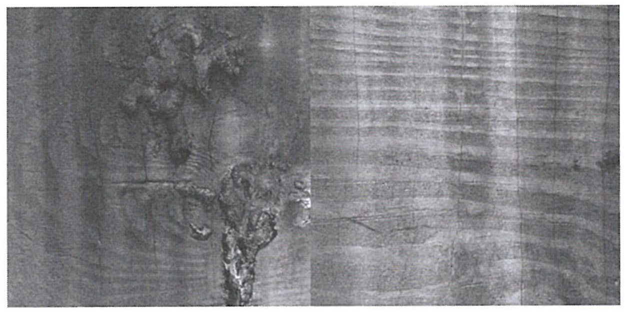

Fig 10. Views of treated pine timber specimen after tests with heat sources of 10 kW/m²

5. Conclusions

Based on the analysis of the measured emissions of combustion products the following conclusions can be formulated:

1. The treated pine timber specimens affected with the heat source of 8 kW/m² emit approximately 1.46 times less of toxic combustion products than the non-treated pine timber specimens. The treated pine timber specimens affected with the heat source of 10 kW/m² emit approximately 1.65 times less of toxic combustion products than non-treated pine timber specimens. The power of heat source influence on the emission of toxic combustibility products. The treated pine timber specimens affected with the heat source of 8 kW/m² emit 2.34 times less of toxic combustion products than pine timber specimens treated with the same fire retardants affected with the heat source of 10 kW/m². Pine timber specimens without fire retardants affected with the heat source of 8 kW/m² emit 2.64 times less of the toxic gases than the same pine timber specimens affected with the heat source of 10 kW/m² (see Fig. 3-6).
2. Time denoted by τ_I and temperature denoted by t_r as the characteristic parameters of the beginning of the registration of CO, HCN, HCl and NH_3 depend on either type of gas or power of heat source. The comparison showed longer times τ_1 (over 1.5 times) and higher temperatures (except for HCN) for impregnated specimens than for non-impregnated ones. Generally, better results for B at 10 kW/m² and for Flamesapas-2 at 8 kW/m² were obtained. For HCN these times are comparable or shorter in case of non-impregnated sample (see Tab. 3 and 4).
3. Emissions of all measured gases from all specimens were higher at 10 kW/m² than at 8 kW/m² (see Tab. 3 and 4).
4. Emission of CO, HCN and NH_3 from non-treated pine timber is of the increasing character during the whole test. It's value is lower than emission from treated timber up to time denoted by τ_3 (see Tab. 5 and 6).
5. The increases in emissions of all considered toxic products of combustion from impregnated specimens can be noticed in the initial phase of the process, which are faster for experiments with higher power of heat source (10 kW/m²). The emissions begin to oscillate around steady values *SV* after the time τ_2. Some difference in emission of HCl from specimen impregnated with A, consisting in the repeated increase, can be observed in the second period of process (see Tab. 5 and 6).
6. The steady values of emissions *SV* of all measured products of combustion were greater (about 1.5 times on average) for pine timber impregnated with B in case of lower power of heat source 8 kW/m² (see Tab. 5). A little higher values of *SV* of CO and HCN emissions were obtained for pine timber impregnated with Flamesapas-2 than BAK-1 in the case of power of heat source equal to 10 kW/m². The tendency was opposite in case of remaining gases e. g. it was almost two times lower for specimen with A (see Tab. 6).
7. After termination of combustion process the surface of treated pine timber specimens is smoother, the layer of carbon is solid and un-cracked. For non-treated surfaces – the layer of carbon is cracked, while deeper layers of timber are affected by the process of thermal destruction (see Figs. 7–10).
8. Non-treated pine timber specimens generate larger quantity of these products compared to the pine timber specimens treated with fire retardants (see tab. 7).

Taking into account the results obtained from both experiments with combustion of non-treated pine timber specimens and treated with two different fire retardants, A and B, it can be concluded that the impregnation influences the combustion process decreasing the rate and the level of emission of toxic products. Generally, lower concentrations have been observed for specimens impregnated with A. Impregnation increase emission of toxic products (except for HCl) in the initial phase of the combustion. But total quantities of all tested toxic combustibility products during complete period of experiment were significantly lower in the case of impregnated pine timber.

Considering the above, it can be concluded that in order to choose a suitable fire retardant, reducing unfavourable impact of the combustion on human during the potential internal fire, each situation should be analysed independently, based on the smokiness as well as generation of toxic combustion products. Analyzed problem requires further studies based on the results obtained during small scale tests using cone calorimeter method and full scale fire experiments.

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NIEZAWODNOŚĆ W WYSOKICH TEMPERATURACH KLEJONEGO WARSTWOWO DREWNA SOSNY POSPOLITEJ W ZAKRESIE WYTRZYMAŁOŚCI NA ZGINANIE STATYCZNE

Reliability at high temperatures of glued laminated pine timber in the static bending strength

Streszczenie
Drewno klejone ze względu na swoje właściwości, jest coraz częściej wykorzystywane. Technologia ta umożliwia wytworzenie elementów konstrukcyjnych o dużych przekrojach poprzecznych i znacznych rozpiętościach. Drewno klejone warstwowo, po odpowiedniej obróbce powierzchni i zachowaniu parametrów przekroju jest materiałem słabo rozprzestrzeniającym ogień, a dodatkowo impregnowane jest materiałem nierozprzestrzeniającym ognia. Pomimo to, drewno w wysokich temperaturach traci swoje właściwości, a co za tym idzie najprawdopodobniej spada jego wytrzymałość. W badaniach własnych dokonano analizy wytrzymałości na zginanie statyczne drewna klejonego w wysokich temperaturach, zbliżonych do temperatur pożaru. Na podstawie uzyskanych wyników określono prawdopodobieństwo zniszczenia elementu konstrukcji obciążonego statycznie w kolejnych przedziałach temperaturowych. Wykazano znaczący spadek niezawodności drewna klejonego oraz zaobserwowano zwiększoną dynamikę wzrostu poziomu zagrożenia po przekroczeniu temperatury 150°C.

Summary
Due to its properties glued timber is a commonly used material nowadays. Such technology enables production of the structural elements with large cross-sections and considerable span. The glued laminated timber after a proper surface treatment and with the preserved cross-section parameters, is a low fire spreading material, moreover it is additionally treated with a fire retardant. In spite of this, timber loses its properties in high temperatures, which most probably results in the strength reduction. In the conducted studies static bending strength analysis of the glued laminated timber in high temperatures, close to the fire conditions, was performed. Based on the obtained results, probability of failure of the structural element statically loaded, in the subsequent temperature ranges, was estimated. A significant reliability decrease of the glued laminated timber and dynamic of the hazard level growth has been observed after exceeding 150°C.

Słowa kluczowe: drewno klejone, temperatury pożarowe, wytrzymałość na zginanie, niezawodność;
Keywords: glued timber, fire temperatures, bending strength, reliability;

1. Wstęp

Drewno budowlane ma korzystne właściwości fizyczne i technologiczne, wysoką wytrzymałość oraz niewielki ciężar własny. Wraz z pojawieniem się na rynku budowlanym wodoodpornych klejów na bazie żywic syntetycznych oraz zastosowanie prostego sposobu łączenia wzdłużnego za pomocą złączy klinowych, umożliwiających znacznie szybszy sposób budowania z wykorzystaniem klejonych elementów konstrukcyjnych o wymiarach większych niż naturalny produkt wyjściowy [1].

Drewno konstrukcyjne klejone warstwowo jest materiałem coraz częściej stosowanym w budownictwie. Począwszy od budowy domów jednorodzinnych i wielorodzinnych oraz obiektów wielkogabarytowych typu hale produkcyjne, handlowe, sportowe, baseny, kończąc na mostach jednoprzęsłowych i obiektach małej architektury. Do produkcji elementów z drewna klejonego najczęściej stosowanym ga-

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

SAPERE AUDE

ISSN 2029-2341 (print)
ISSN 2029-2252 (online)

Mokslas – Lietuvos ateitis
Science – Future of Lithuania

Statyba
Civil Engineering

2009, 1(5)

ISSN 2029-2341 (print)
ISSN 2029-2252 (online)

Mokslas – Lietuvos ateitis
Science – Future of Lithuania

Statyba
Civil Engineering

Vyriausiasis redaktorius
prof. habil. dr. Raimundas Kirvaitis

2009, 1(5)

ŽURNALE „MOKSLAS – LIETUVOS ATEITIS" SPAUSDINAMI ŠIŲ MOKSLO SRIČIŲ STRAIPSNIAI

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Straipsniai, publikuojami žurnale „Mokslas – Lietuvos ateitis", referuojami tarptautinėje duomenų bazėje ***Index Copernicus***.

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The papers published in "Science – Future of Lithuania" are abstracted by international database ***Index Copernicus***.

Leidinio leidybą rėmė Lietuvos valstybinis mokslo ir studijų fondas.

Vilniaus Gedimino technikos universiteto recenzuojamas mokslo žurnalas.
Straipsniai pateikiami lietuvių, anglų, vokiečių, rusų kalbomis.

TURINYS

MOKSLAS – LIETUVOS ATEITIS
SCIENCE – FUTURE OF LITHUANIA

2009, 1 tomas, Nr. 5
2009, Vol. 1, No. 5

Statyba
Civil Engineering

ANTIPIRENINIAIS TIRPALAIS IMPREGNUOTOS MEDIENOS UŽSILIEPSNOJIMO PRIKLAUSOMYBĖ NUO MEDIENOS TANKIO

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Anotacija. Daugelyje šalių mediena yra plačiai naudojama statybai, o kai kada ji yra pagrindinis statybinių konstrukcijų elementas. Pastato konstrukciniams elementams, apdailai naudojama mediena ir jos produktai privalo atitikti priešgaisrinės saugos reikalavimus. Straipsnyje aptariami veiksniai, kurie turi įtaką medienos užsiliepsnojimui: antipireninių tirpalų įtaka degimo fazei, medienos tankis ir drėgnumas. Taip pat nagrinėjama antipireniniais tirpalais impregnuotos medienos užsiliepsnojimo priklausomybė nuo medienos tankio. Tyrimai atlikti pagal LST ISO 5657:1999 standarto „Reagavimo į ugnį bandymai – statybinių gaminių užsidegimas veikiant juos šilumine spinduliuote" reikalavimus. Impregnuotos medienos užsiliepsnojimo priklausomybė nuo medienos tankio vertinama pagal laiką iki bandinio užsiliepsnojimo.

Reikšminiai žodžiai: medienos tankis, medienos drėgnumas, impregnavimas, antipireninis tirpalas, užsiliepsnojimas.

Įvadas

Mediena ir jos produktai dažnai naudojami pastatų konstrukcijoms ir apdailai (Stevens *et al.* 2006), o kai kuriose šalyse mediena yra pagrindinis statybinių konstrukcijų elementas (Grexa 2000).

Medienos apsauga nuo ugnies poveikio yra labai aktuali (Gu *et al.* 2007). Ši teiginį patvirtina ir R. Stevens (2006). Jis pabrėžia, kad mediena, jos produktai privalo atitikti vis griežtėjančius ir tobulėjančius priešgaisrinės saugos reikalavimus.

Yra nemažai impregnavimo būdų ir cheminių junginių, naudojamų impregnuoti. Jie ilgina medienos laiką iki užsiliepsnojimo. Tačiau laikui iki užsiliepsnojimo įtaką turi ir medienos struktūra, drėgnumas ir kiti dalykai.

Tiriant antipireniniais tirpalais impregnuotą medieną, buvo tirtas ir Lietuvoje sertifikuotų antipireninių tirpalų efektyvumas (Karpovič 2009), atliekami antipirenų apsauginių savybių lyginimo darbai (Karpovič 2008). Pastebėta, kad impregnuotos medienos laikui iki užsiliepsnojimo gali daryti įtaką medienos tankis.

Literatūros šaltiniuose, nagrinėjančiuose medienos sandarą (Stevens *et al.* 2006; Wazny *et al.* 2001; Jagtoyen *et al.* 1998; Glinjer 1995; Szczuka *et al.* 1990; Czajnik *et al.* 1958), taip pat medienos impregnavimą antipireniniais tirpalais (Koo *et al.* 2001; Grexa 2000; Drysdale 1998; Su *et al.* 1997; Subyakto *et al.* 1998; Rhys 1980; Vandersall 1971), informacijos apie medienos tankio įtaką medienos užsiliepsnojimui neaptikta.

Darbo tikslas: ištirti antipireniniais tirpalais impregnuotos medienos užsiliepsnojimo priklausomybę nuo medienos tankio.

Bendrosios žinios, tyrimo objektas

Šilumos srautu veikiamoje medienoje vyksta terminis skilimas – pirolizė, kurios rezultatas – lakių, mažos molekulinės masės produktų išsiskyrimas (Nassar *et al.* 1999). Lakūs produktai reaguoja su aplinkos ore esančiu deguonimi – vyksta oksidacijos reakcija, vadinama degimu (Shafizadheh *et al.* 1979). Medienos degimas susideda iš trijų pagrindinių pakopų: kaitimo, pirolizės, smilkimo ir (arba) užsiliepsnojimo (Di Blasi *et al.* 2008). Antipireniniai tirpalai kelia degimo fazei inicijuoti reikalingą aktyvacijos energiją (Nassar 1990; Tang 1967), kartu ilgina iki medienos užsiliepsnojimo laiką.

Mediena – poringoji medžiaga, kurios ląstelių sienelės ir vidus yra pripildytas oro arba vandens (Wazny *et al.* 2001). Medienos charakteristikas galima pristatyti analizuojant jos makroskopinę, mikroskopinę, cheminę sandarą, fizikines savybes. Pagrindinės fizikinės medienos savybės yra tankis, drėgnumas, sugeriamumas ir kita. Šios ypatybės, veikiamos aplinkos veiksnių, ilgainiui gali kisti.

Medienos tankį veikia medienos poringumas, drėgnumas, medžio rūšis, metinių žiedų plotis, amžius, augimo sąlygos. Tos pačios medienos tankis gali skirtis 10–20 %. Daugelio rūšių tankiausia mediena yra kamieno apačioje. Kylant į viršų tankis mažėja (apie 1,5 % kiekvienam aukščio metrui).

Medienos tankiui taip pat turi įtaką drėgmė, dėl to šis dydis dažniausiai pateikiamas esant 12–15 % drėgnumui. Tokio drėgnumo mediena, atsižvelgiant į tankį, skirstoma į mažo tankio – $\rho \leq 550$ kg/m^3, vidutinio tankio – $\rho = 550–700$ kg/m^3 ir didelio tankio $\rho > 700$ kg/m^3. Vidutinis 1 m^3 skirtingų medienos rūšių tankis pateiktas 1 lentelėje. Pastebėta, kad spygliuočių medienos, turinčios siaurus metinius žiedus, o lapuočių medienos, turinčios plačius metinius žiedus, tankis yra didžiausias.

1 lentelė. Medienos rūšių vidutinis tankis (kg/m^3) (Wazny *et al.* 2001)

Table 1. Mean density of different kinds of timber (kg/m^3) (Wazny *et al.* 2001)

Medienos rūšis	Medienos tankis (kg/m^3)	
	sausa (15 %)	nupjauta
Kukmedis	750–940	
Akacija	810	
Ąžuolas	740–760	1020–1030
Uosis	750	924
Skroblas	740	988
Bukas	710	968
Guoba	680	
Klevas	660	
Beržas	650	878
Maumedis	590	833
Alksnis	530	
Pušis	520	863
Liepa	500	
Eglė	470	827
Balteglė	450	794
Tuopa	450	
Kedras	440	

Antipireniniais tirpalais impregnuotos medienos užsiliepsnojimo priklausomybės nuo medienos tankio tyrimuose naudota pušies ir eglės mediena. Prieš padengiant bandinius antipireniniais tirpalais, nustatytas jų drėgnumas ir tankis.

Medienos drėgnumas nustatomas dviem būdais (Wazny *et al.* 2001). Pirmas – skaičiuojamasis būdas, antras – naudojamasi elektriniu drėgmės matuokliu. Tyrimuose bandinių drėgnumas nustatomas elektroniniu matuokliu, o tankis – bandinius matuojant ir sveriant. Įvertinus pušies ir eglės medienos bandinių tankį, bandiniai padengti Lietuvoje sertifikuotais antipireniniais tirpalais *Flamasepas-2* ir *BAK-1*.

Tyrimų metodika, rezultatai

Tyrimai atlikti Priešgaisrinės apsaugos ir gelbėjimo departamento prie Vidaus reikalų ministerijos Gaisrinių tyrimų centro laboratorijoje. Tyrimų įranga ir bandymo eiga atitinka LST ISO 5657:1999 standarto „Reagavimo į ugnį bandymai – statybinių gaminių užsidegimas veikiant juos šilumine spinduliuote" reikalavimus. Bandymas buvo nutraukiamas, jei, praėjus 900 sekundžių nuo bandymo pradžios, bandinys neužsiliepsnodavo.

Tyrimai atlikti veikiant bandinius 30, 35, 40, 45, 50 kW/m^2 šilumos srautais. Medienos užsiliepsnojimo priklausomybė nuo medienos tankio vertinama pagal laiką iki bandinio užsiliepsnojimo. Tyrimuose naudotos pušies medienos bandinių vidutinis tankis – 538 kg/m^3, tankio skirtumas siekė 8 %, eglės medienos bandinių vidutinis tankis – 446 kg/m^3, tankio skirtumas siekė 10 %. Vidutinis bandinių drėgnumas – 15 %.

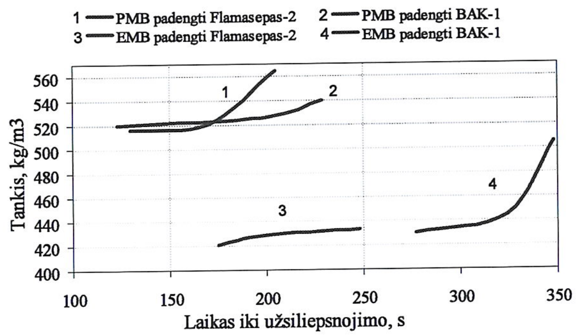
Tyrimų rezultatai esant 30, 35 kW/m^2 šilumos srautui, pateikti 2 lentelėje. Impregnuoti pušies ir eglės medienos bandiniai, paveikti 30, 35 kW/m^2 šilumos srautu, praėjus bandymui skirtam laikui, neužsiliepsnojo. Impregnuotų pušies ir eglės medienos bandinių, paveiktų 40, 45, 50 kW/m^2 šilumos srautu, vidutinis laikas iki užsiliepsnojimo, atsižvelgiant į medienos tankį ir antipireninį tirpalą, pateiktas 1, 2 ir 3 paveiksluose.

2 lentelė. Pušies ir eglės medienos bandinių tyrimo rezultatai esant 30, 35 kW/m^2 šilumos srautui

Table 2. Pine and fir timber specimen results with given heat flow of 30, 35 kW/m^2

Šilumos srautas, kW/m^2	Pušis				Eglė			
	Flamasepas-2		BAK-1		Flamasepas-2		BAK-1	
	vidutinis bandinio tankis, kg/m^3	bandymo laikas, s	vidutinis bandinio tankis, kg/m^3	bandymo laikas, s	vidutinis bandinio tankis, kg/m^3	bandymo laikas, s	vidutinis bandinio tankis, kg/m^3	bandymo laikas, s
30	529,1	>900	526,3	>900	422,1	>900	430,3	>900
	535,2	>900	541,3	>900	427,3	>900	442,7	>900
	566	>900	550,5	>900	441,5	>900	476,3	>900
35	547,5	>900	509,1	>900	424,7	>900	447,1	>900
	554,9	>900	529,7	>900	429,2	>900	453,9	>900
	563,3	>900	550,7	>900	432	>900	456	>900

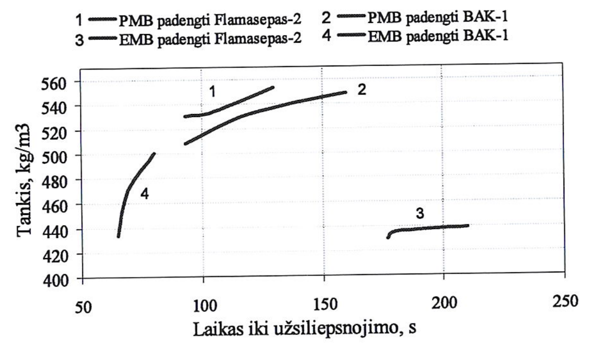
ISSN 2029-2341 print / ISSN 2029-2252 online



1 pav. Pušies ir eglės medienos bandinių, paveiktų 40 kW/m^2 šilumos srautu, vidutinio laiko iki užsiliepsnojimo priklausomybė nuo medienos tankio ir antipireninio tirpalo (pušies medienos bandiniai – PMB, eglės medienos bandiniai – EMB)

Fig. 1. Dependence of pine and fir timber specimen affected with heat flow of 40 kW/m^2 density and fire retardant type (pine timber specimens – PMB, fir timber specimens – EMB) on the mean duration before combustion

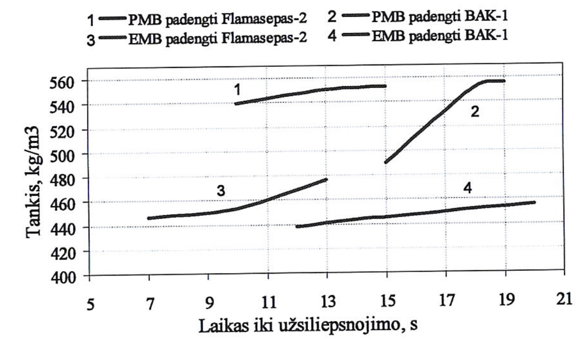
Paveikus pušies ir eglės bandinius 40 kW/m^2 šilumos srautu, nustatyta, kad pušies medienos bandinių, padengtų antipireniniu tirpalu *Flamasepas-2,* tankiui padidėjus 49 kg/m^3, laikas iki užsiliepsnojimo pailgėja 75 s, pušies medienos bandinių, padengtų antipireniniu tirpalu *BAK-1,* tankiui padidėjus 20 kg/m^3, laikas iki užsiliepsnojimo pailgėja 106 s, eglės medienos bandinių, padengtų antipireniniu tirpalu *Flamasepas-2,* tankiui padidėjus 13 kg/m^3, laikas iki užsiliepsnojimo pailgėja 73 s, eglės medienos bandinių, padengtų antipireniniu tirpalu *BAK-1,* tankiui padidėjus 75 kg/m^3, laikas iki užsiliepsnojimo pailgėja 71 s.



2 pav. Pušies ir eglės medienos bandinių, paveiktų 45 kW/m^2 šilumos srautu, vidutinio laiko iki užsiliepsnojimo priklausomybė nuo medienos tankio ir antipireninio tirpalo (pušies medienos bandiniai – PMB, eglės medienos bandiniai – EMB)

Fig. 2. Dependence of pine and fir timber specimen affected with heat flow of 45 kW/m^2 density and fire retardant type (pine timber specimens – PMB, fir timber specimens – EMB) on the mean duration before combustion

Paveikus pušies ir eglės bandinius 45 kW/m^2 šilumos srautu, nustatyta, kad: pušies medienos bandinių, padengtų antipireniniu tirpalu *Flamasepas-2,* tankiui padidėjus 23 kg/m^3, užsiliepsnojimo laikas pailgėja 37 s, pušies medienos bandinių, padengtų antipireniniu tirpalu *BAK-1,* tankiui padidėjus 41 kg/m^3, užsiliepsnojimo laikas pailgėja 67 s, eglės medienos bandinių, padengtų antipireniniu tirpalu *Flamasepas-2*, tankiui padidėjus 9 kg/m^3, užsiliepsnojimo laikas pailgėja 33 s, eglės medienos bandinių, padengtų antipireniniu tirpalu *BAK*-1, tankiui padidėjus 67 kg/m^3, užsiliepsnojimo laikas pailgėja 15 s.



3 pav. Pušies ir eglės medienos bandinių, paveiktų 50 kW/m^2 šilumos srautu, vidutinio laiko iki užsiliepsnojimo priklausomybė nuo medienos tankio ir antipireninio tirpalo (pušies medienos bandiniai – PMB, eglės medienos bandiniai – EMB)

Fig. 3. Dependence of pine and fir timber specimen affected with heat flow of 50 kW/m^2 density and fire retardant type (pine timber specimens – PMB, fir timber specimens – EMB) on the mean duration before combustion

Paveikus pušies ir eglės bandinius 50 kW/m^2 šilumos srautu, nustatyta, kad pušies medienos bandinių, padengtų antipireniniu tirpalu *Flamasepas-2,* tankiui padidėjus 13 kg/m^3, laikas iki užsiliepsnojimo pailgėja 5 s, pušies medienos bandinių, padengtų antipireniniu tirpalu *BAK-1,* tankiui padidėjus 65 kg/m^3, laikas iki užsiliepsnojimo pailgėja 4 s, eglės medienos bandinių, padengtų antipireniniu tirpalu *Flamasepas-2,* tankiui padidėjus 30 kg/m^3, laikas iki užsiliepsnojimo pailgėja 6 s, eglės medienos bandinių, padengtų antipireniniu tirpalu *BAK-1,* tankiui padidėjus 18 kg/m^3, laikas iki užsiliepsnojimo pailgėja 8 s.

Išvados

1. Antipireniniais tirpalais impregnuotos medienos tankio įtakos užsiliepsnojimui, kai šilumos srautas yra iki 40 kW/m^2, pagal naudotą bandymų metodiką nustatyti negalima. Šiuo atveju užsiliepsnojimo laikas didesnis kaip 900 s.

2. Medienos tankis daro įtaką antipireniniais tirpalais impregnuotos medienos užsiliepsnojimui, kai šilumos srautas yra nuo 40 kW/m^2 iki 45 kW/m^2:

2.1. Didėjant pušies medienos, padengtos antipireniniu tirpalu *Flamasepas-2,* tankiui, užsiliepsnojimo laikas, esant 40 kW/m^2 šilumos srautui, gali pailgėti 1,6 karto, esant 45 kW/m^2 šilumos srautui – 1,4 karto;

2.2. Didėjant pušies medienos, padengtos antipireniniu tirpalu *BAK-1*, tankiui, užsiliepsnojimo laikas esant 40 kW/m^2 šilumos srautui, gali pailgėti 1,9 karto, esant 45 kW/m^2 šilumos srautui – 1,7 karto;

2.3. Didėjant eglės medienos, padengtos antipireniniu tirpalu *Flamasepas-2*, tankiui, užsiliepsnojimo laikas, esant 40 kW/m^2 šilumos srautui, gali pailgėti 1,4 karto, esant 45 kW/m^2 šilumos srautui – 1,2 karto;

2.4. Didėjant eglės medienos, padengtos antipireniniu tirpalu *BAK-1*, tankiui, užsiliepsnojimo laikas, esant 40 kW/m^2 šilumos srautui, gali pailgėti 1,3 karto, esant 45 kW/m^2 šilumos srautui – 1,2 karto.

3. Didėjant šilumos srautui, antipireniniais tirpalais impregnuotos medienos užsiliepsnojimo laiko priklausomybė nuo medienos tankio mažėja.

4. Esant 50 kW/m^2 šilumos srautui, antipireniniais tirpalais impregnuota mediena užsiliepsnoja greičiau nei per 20 s, tai yra medienos tankis užsiliepsnojimui esminės įtakos neturi.

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THE INFLUENCE OF FLAME RETARDANT TREATED TIMBER DENSITY ON COMBUSTIBILITY

Z. Karpovič

Summary

Timber is widely used as a construction material in the majority of countries. In most cases, timber is the main structural material. Timber and timber fabrics used in building structure elements have to fulfill the requirements of fire safety. This article presents factors affecting the combustibility of timber, mainly the influence of flame retardants on the combustion phase, timber density and moisture. The influence of flame retardant treated timber density on combustibility is analyzed in this paper. Research was performed according to the requirements of the standard LST ISO 5657:1999 "Reaction to fire tests – ignitibility of building products using a radiant heat source". The influence of flame retardant treated timber density on combustibility is assessed according to duration up to the combustion of the specimen.

Keywords: timber density, timber moisture, treatment, flame retardant, combustibility.

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Visuomenės sveikata	Public Health
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Tomas 19

Vilnius, 2009

ISSN 1392-6373
http://www.sam.lt
Included in Index Copernicus database

SVEIKATOS MOKSLAI

2009'3(63)

HEALTH SCIENCES

Visuomenės sveikata | Public Health
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šviesti visuomenę ir nuo vaikystės diegti tinkamus dantų priežiūros bei mitybos įgūdžius.

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ORAL HEALTH STATE OF 7-8 YEARS OLD SCHOOLCHILDREN IN KAUNAS

Jaunė Razmienė, Simona Milčiuvienė

Summary

Key words: dental caries, prevalence, experience, DMFT, dmf, oral hygiene, gingivitis.

The aim of the present study was to evaluate the prevalence and experience of dental caries and other oral diseases of 7-8 year-olds group schoolchildren in Kaunas, especially the probability of dental caries with pulp involvement beginning were of great importance.

The study was performed using World Health Organization diagnostic criteria. The caries prevalence and experience of primary and permanent dentition were estimated, oral hygiene level was determinate using a Silness-Loe index, the prevalence of gingivitis and malocclusion were evaluated.

Distribution of dental caries in the primary dentition and in the permanent dentition were 96,6% and 38,2%, respectively. The dmf was 6,4 (3,0) and the DMFT was 1,0. The prevalence of dental caries with pulp involvement consisted 57,5-58,1% of dmf, and 0,5% of DMFT. Oral hygiene status of schoolchildren was poor (Silness-Loe index- 1,5), even 37,5% children brushed teeth infrequently or never. The increase numbers of gingivitis, non-carious diseases, malocclusion were with age. According to finding of study, it is necessary to turn attention to treatment of permanent and primary teeth at proper time, to selection of caries preventive methods to particulate this age group.

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Gauta 2009-04-20

■

PUŠIES MEDIENOS IR KAMŠTINIO ĄŽUOLO PAVOJINGUMAS SMILKIMO METU

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Vilniaus Gedimino technikos universitetas

Raktažodžiai: gaisras, degimas, smilkimas, kenksmingi degimo produktai, anglies monoksidas, pušies mediena, kamštinis ąžuolas, šilumos srautas.

Santrauka

Per paskutinius penkerius metus Lietuvoje kasmet vidutiniškai po 280 žmonių žuvo gaisruose. Apsinuodijimas kenksmingais degimo produktais yra priežastis, dėl kurios gaisrų metu miršta nuo 60% iki 80% žmonių. Galima išskirti du degimo tipus: degimą, kurio metu būna liepsna, šis degimas vadinamas smilkimu ir degimą, kurio metu pasireiškia liepsna. Smilkimas – tai lėtas, žemose temperatūrose be liepsnos vykstantis degimo procesas. Smilkimas lyginant su degimu, kurio metu pasireiškia liepsna, yra pavojingesnis, nes jo metu išsiskiria žymiai daugiau kenksmingų degimo produktų. Šiame straipsnyje analizuojama anglies monoksido (CO), azoto oksido (NO), vandenilio chlorido (HCL), vandenilio cianido (HCN) ir amoniako (NH_3) emisija pušies medienos ir kamštinio ąžuolo smilkimo metu, jos kaita keičiantis šilumos srauto intensyvumui ir įvertinta bei palyginta jos keliama grėsmė žmogaus sveikatai ir gyvybei.

ĮVADAS

Per paskutinius penkerius metus Lietuvoje kasmet vidutiniškai po 280 žmonių žuvo gaisruose. 100 tūkstančių Lietuvos gyventojų pernai teko 8 gaisruose žuvę žmonės. Šis rodiklis išlieka vienas aukščiausių tarp kitų Europos Sąjungos šalių. Be to, pernai pagal šį rodiklį Lietuva aplenkė Latviją ir Estiją [1].

Degimo metu, susiduriama su veiksniais, kurie sukelia pavojų žmonėms, esantiems pastate ar vykdantiems gelbėjimo darbus. Tokiais veiksniais yra [2-4]:

- degimo produktų kenksmingumas,
- liepsna ir aukšta temperatūra,
- deguonies koncentracijos sumažėjimas,
- konstrukcijų nestabilumas,
- matomumo sumažėjimas.

Intensyvus kenksmingų dujų ir garų susidarymas ir greitas jų sklidimas patalpose bei evakuaciniuose keliuose vyksta jau pradinėje gaisro stadijoje. Šios dujos sukelia didelį pavojų gyvybei, netgi kartą jų įkvėpus. Statistika rodo, jog apsinuodijimas toksiniais degimo produktais yra priežastis, dėl kurios gaisrų metu miršta nuo 60% iki 80% žmonių [2].

Galima išskirti du degimo tipus: degimą, kurio metu nepasireiškia liepsna, šis degimas vadinamas smilkimu ir degimą, kurio metu pasireiškia liepsna. Smilkimas – tai lėtas, žemose temperatūrose be liepsnos vykstantis degimo procesas. Kai medžiagų smilkimas stabilizuojasi, į aplinką išsiskiria daugiau kenksmingų dujų. Smilkimas gali vykti nepastebimai, esant tam pačiam greičiui arba peraugti į degimą, lydimą liepsnos [5]. Smilkimas lyginant su degimu, kurio metu pasireiškia liepsna, yra pavojingesnis, nes jo metu išsiskiria žymiai daugiau kenksmingų degimo produktų [6].

Lietuvoje analizuojami veiksniai, kurie neigiamai veikia žmogaus sveikatos būklę. Tai vibracija, triukšmas, elektromagnetinis laukas [7], stresas [8], gyvenimo kokybė [9], psichologinis organizacijos klimatas [10], lakieji organiniai junginiai (benzolas) [11], socialiniai ekonominiai veiksniai [12] ir kita.

Darbo tikslas – nustatyti kenksmingų dujų emisiją pušies medienos ir kamštinio ąžuolo smilkimo metu, aptarti ir išanalizuoti tyrimų metu gautus rezultatus, susijusius su kokybiniu ir kiekybiniu kenksmingų dujų išsiskyrimu, jo kaita keičiantis šilumos srauto intensyvumui ir įvertinti bei palyginti jos keliamą grėsmę žmogaus sveikatai ir gyvybei.

TYRIMŲ OBJEKTAS, METODAS IR REZULTATAI

Tyrimams naudota pušies mediena ir kamštinis ąžuolas, kurio produktai naudojami apdailai. Informacijos apie kamštinio ąžuolo pavojingumą gaisro metu yra nedaug, esanti yra neišsami. Tyrimai atlikti Varšuvos aukštojoje priešgaisrinės gelbėjimo tarnybos akademijoje prietaisu, kuris smilkimo metu leidžia nustatyti [13]: temperatūrą bandinio paviršiuje ir jo viduje, bandinio masės kaitą laike, emituojamas kenksmingas dujas ir jų koncentraciją, deguonies koncentraciją dujose, kurios susidarė bandymo metu.

Tyrimuose naudoti 0,04 m^2 bandiniai. Pušies ir kamštinio ąžuolo plokštėms atlikta po keturis bandymus esant skirtingam šilumos srauto tankiui. Pirmu atveju bandiniai buvo paveikti 8 kW/m^2 šilumos srautu, antru – 10 kW/m^2. Bandymas nutraukiamas tada, kai temperatūra bandymų kameroje pradėdavo staigiai kilti, tai reiškė, kad smilkimas perėjo į degimą, lydimą liepsnos. Bandymų rezultatų vidurkiai pateikti 1 – 5 pav.

Veikiant pušies bandinius 8 kW/m^2 šilumos srautu po 6 min., kai bandinio paviršiaus temperatūra pasiekė

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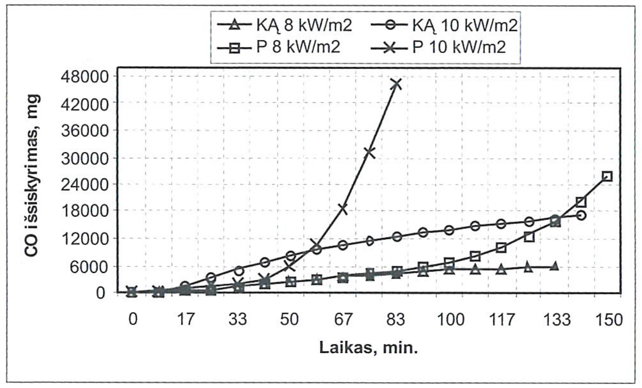
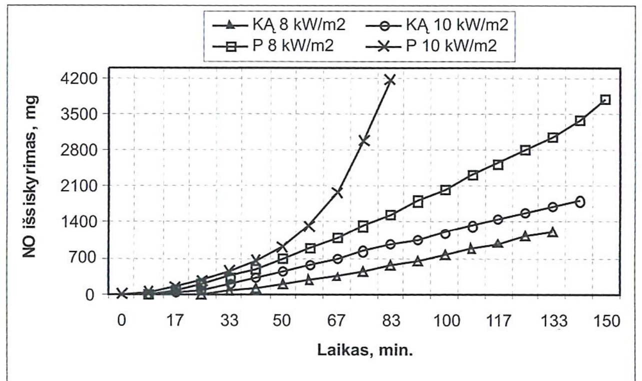
90°C, sensorius pradėdavo registruoti anglies monoksidą. Bandymo metu per 150 min. vidutiniškai išsiskyrė 26,17 g anglies monoksido. Veikiant pušies bandinius 10 kW/m^2 šilumos srautu sensorius pradėdavo registruoti anglies monoksidą po 4 min. Bandymo metu per 80 min. vidutiniškai išsiskyrė 46,04 g anglies monoksido. Veikiant kamštinio ąžuolo bandinius 8 kW/m^2 šilumos srautu po 5 min., kai bandinio paviršius pasiekė 130°C temperatūrą, sensorius pradėdavo registruoti anglies monoksidą. Bandymo metu per 135 min. vidutiniškai išsiskyrė 5,9 g anglies monoksido. Veikiant kamštinio ąžuolo bandinius 10 kW/m^2 šilumos srautu sensorius pradėdavo registruoti anglies monoksidą po 4 min. Bandymo metu per 140 min. vidutiniškai išsiskyrė 17,1 g anglies monoksido.

Veikiant pušies bandinius 8 kW/m^2 šilumos srautu po 8 min., kai bandinio paviršiaus temperatūra pasiekė 100°C, sensorius pradėdavo registruoti azoto oksidą. Bandymo metu vidutiniškai išsiskyrė 3,79 g azoto oksido. Veikiant pušies bandinius 10 kW/m^2 šilumos srautu sensorius pradėdavo registruoti azoto oksidą po 5 min. Bandymo metu vidutiniškai išsiskyrė 4,11 g azoto oksido. Veikiant kamštinio ąžuolo bandinius 8 kW/m^2 šilumos srautu po 26 min., kai bandinio paviršius pasiekė 180°C temperatūrą, sensorius pradėdavo registruoti azoto oksidą. Bandymo metu vidutiniškai išsiskyrė 1,3 g azoto oksido. Veikiant kamštinio ąžuolo bandinius 10 kW/m^2 šilumos srautu sensorius pradėdavo registruoti azoto oksidą po 10 min. Bandymo metu vidutiniškai išsiskyrė 1,8 g azoto oksido.

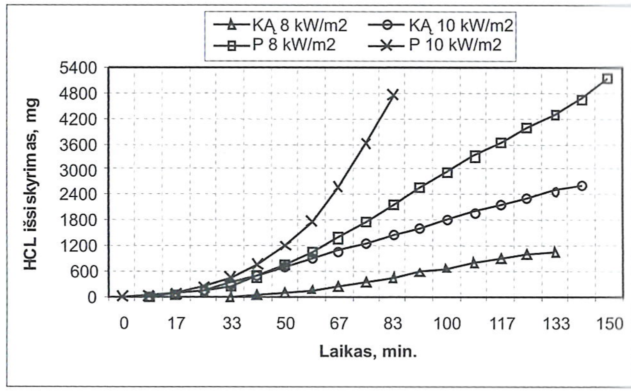
Veikiant pušies bandinius 8 kW/m^2 šilumos srautu po 9 min., kai bandinio paviršiaus temperatūra pasiekė 110°C, sensorius pradėdavo registruoti vandenilio chloridą. Bandymo metu vidutiniškai išsiskyrė 5,12 g vandenilio chlorido. Veikiant pušies bandinius 10 kW/m^2 šilumos srautu sensorius pradėdavo registruoti vandenilio chloridą po 6 min. Bandymo metu vidutiniškai išsiskyrė 4,73 g vandenilio chlorido. Veikiant kamštinio ąžuolo bandinius 8 kW/m^2 šilumos srautu po 35 min., kai bandinio paviršius pasiekė 190°C temperatūrą, sensorius pradėdavo registruoti vandenilio chloridą. Bandymo metu vidutiniškai išsiskyrė 1,1 g vandenilio chlorido. Veikiant kamštinio ąžuolo



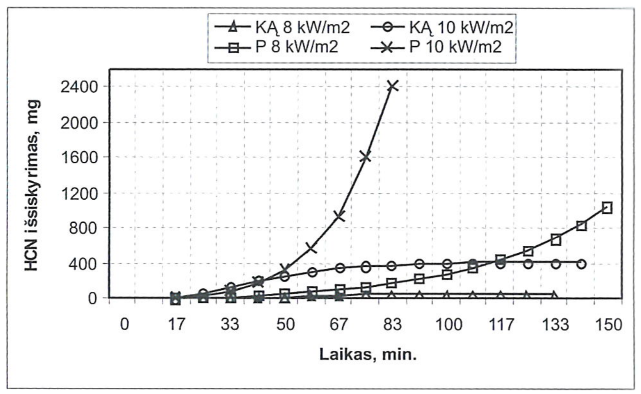
1 pav. Vidutinė anglies monoksido išsiskyrimo priklausomybė nuo bandinio (kamštinis ąžuolas – KĄ, pušis – P) ir šilumos srauto.



2 pav. Vidutinė azoto oksido išsiskyrimo priklausomybė nuo bandinio (kamštinis ąžuolas – KĄ, pušis – P) ir šilumos srauto.



3 pav. Vidutinė vandenilio chlorido išsiskyrimo priklausomybė nuo bandinio (kamštinis ąžuolas – KĄ, pušis – P) ir šilumos srauto.

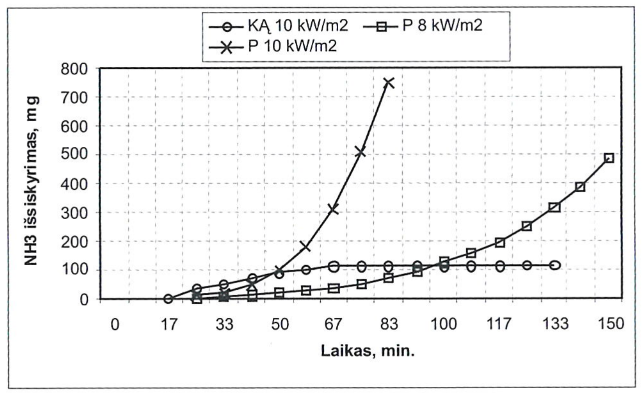


4 pav. Vidutinė vandenilio cianido išsiskyrimo priklausomybė nuo bandinio (kamštinis ąžuolas – KĄ, pušis – P) ir šilumos srauto.

bandinius 10 kW/m^2 šilumos srautu sensorius pradėdavo registruoti vandenilio chloridą po 6 min. Bandymo metu vidutiniškai išsiskyrė 2,6 g vandenilio chlorido.

Veikiant pušies bandinius 8 kW/m^2 šilumos srautu po 16 min., kai bandinio paviršiaus temperatūra pasiekė 150°C, sensorius pradėdavo registruoti vandenilio cianidą. Bandymo metu vidutiniškai išsiskyrė 1,1 g vandenilio cianido. Veikiant pušies bandinius 10 kW/m^2 šilumos srautu sensorius pradėdavo registruoti vandenilio cianidą po 15 min. Bandymo metu vidutiniškai išsiskyrė 2,41 g vandenilio cianido. Veikiant kamštinio ąžuolo bandinius 8 kW/m^2 šilumos srautu po 37 min., kai bandinio paviršius pasiekė 195°C temperatūrą, sensorius pradėdavo registruoti vandenilio cianidą. Bandymo metu vidutiniškai išsiskyrė 0,05 g vandenilio cianido. Veikiant kamštinio ąžuolo bandinius 10 kW/m^2 šilumos srautu sensorius pradėdavo registruoti vandenilio cianidą po 13 min. Bandymo metu vidutiniškai išsiskyrė 0,41 g vandenilio cianido.

Veikiant pušies bandinius 8 kW/m^2 šilumos srautu po 25 min., kai bandinio paviršiaus temperatūra pasiekė 170° C, sensorius pradėdavo registruoti amoniaką. Bandymo metu vidutiniškai išsiskyrė 0,49 g amoniako. Veikiant pušies bandinius 10 kW/m^2 šilumos srautu sensorius pradėdavo registruoti amoniaką po 19 min. Bandymo metu vidutiniškai išsiskyrė 1 g amoniako. Veikiant kamštinio ąžuolo bandinius 8 kW/m^2 šilumos srautu amoniako išsiskyrimas neužregistruotas. Veikiant kamštinio ąžuolo bandinius 10 kW/m^2 šilumos srautu po 14 min., kai bandinio paviršius pasiekė 200°C temperatūrą, sensorius pradėdavo registruoti amoniaką. Bandymo metu vidutiniškai išsiskyrė 0,12 g amoniako.



5 pav. Vidutinė amoniako išsiskyrimo priklausomybė nuo bandinio (kamštinis ąžuolas – KĄ, pušis – P) ir šilumos srauto.

1 Lentelė. Kenksmingų medžiagų kiekiai išsiskyrę iš 1 m^2 pušies medienos ir kamštinio ąžuolo.

Bandiniai	*Kenksmingos medžiagos, g*				
	CO	NO	HCL	HCN	NH_3
Pušis	902,5	98,75	123,25	44	18,75
Kamštinis ąžuolas	287,5	38,75	46,25	5,75	3

REZULTATŲ ANALIZĖ

Kenksmingų degimo produktų kiekis ir jų koncentracija patalpoje smilkimo metu labiausiai priklauso nuo smilkstančios medžiagos, jos ploto, smilkimo laiko bei patalpos tūrio. Kenksmingų degimo produktų kiekiai, kurie vertinant tyrimų duomenis išsiskirtų iš 1 m^2 pušies medienos ir kamštinio ąžuolo pateikti 1 lentelėje.

Kenksmingų degimo produktų koncentracijos priklausomybė nuo patalpos tūrio ir jų poveikis žmogaus sveikatai, smilkstant 1 m^2 pušies medienos ar kamštinio ąžuolo, pateiktas 6-11 pav. Kenksmingų degimo produktų poveikis žmogui vertintas remiantis 14-18 literatūros šaltinių duomenimis.

Mirtina anglies monoksido koncentracija smilkstant 1 m^2 pušies medienos išlieka, jei patalpos tūris yra iki 90 m^3. Tuo tarpu smilkstant 1 m^2 kamštinio ąžuolo ši koncentracija pasiekiama tik mažesnėse nei 30 m^3 tūrio patalpose (6 pav.).

Mirtina azoto oksido koncentracija smilkstant 1 m^2 pušies medienos išlieka, jei patalpos tūris yra iki 100 m^3. Tuo tarpu smilkstant 1 m^2 kamštinio ąžuolo ši koncentracija pasiekiama tik mažesnėse nei 60 m^3 tūrio patalpose (7 pav.).

Mirtina vandenilio chlorido koncentracija smilkstant 1 m^2 pušies medienos išlieka, jei patalpos tūris yra iki 50 m^3. Tuo tarpu smilkstant 1 m^2 kamštinio ąžuolo ši koncentracija pasiekiama tik mažesnėse nei 20 m^3 tūrio patalpose (8 pav.).

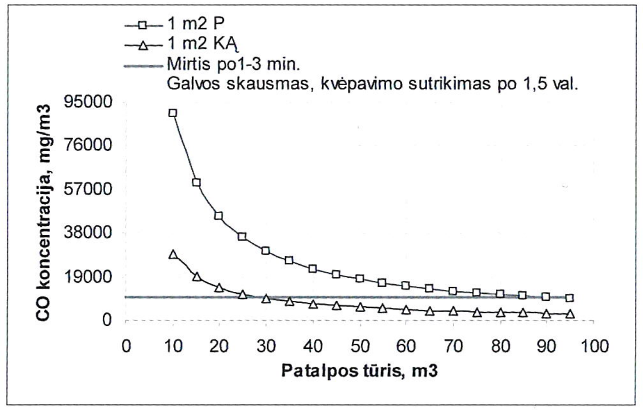
Mirtina vandenilio cianido koncentracija smilkstant 1 m^2 pušies medienos išlieka, jei patalpos tūris yra iki 100 m^3. Tuo tarpu smilkstant 1 m^2 kamštinio ąžuolo ši koncentracija pasiekiama tik mažesnėse nei 15 m^3 tūrio patalpose (9 pav.).

Mirtina amoniako koncentracija smilkstant 1 m^2 pušies medienos išlieka, jei patalpos tūris yra iki 15 m^3. Tuo tarpu smilkstant 1 m^2 kamštinio ąžuolo ši koncentracija didesnėse kaip 10 m^3 tūrio patalpose nepasiekiama (10 pav.).

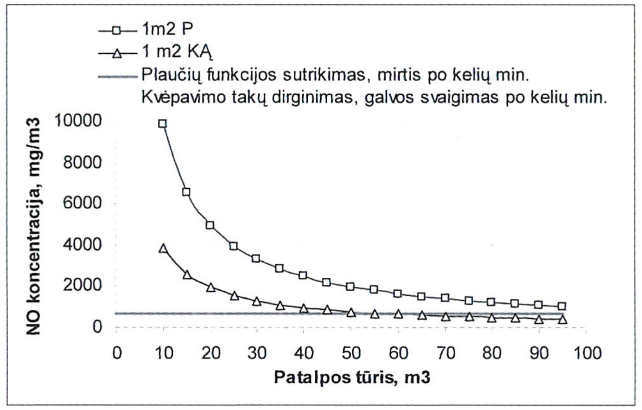
Tyrimų metu gautus duomenis galima analizuoti esant nekintamam patalpos tūriui. Šiuo atveju gaunama kenksmingų degimo produktų koncentracijos priklausomybė nuo laiko.

Mirtina anglies monoksido koncentracija smilkstant 1 m^2 pušies medienos 50 m^3 patalpoje pasiekiama vidutiniškai po 70 min. Tuo tarpu smilkstant 1 m^2 kamštinio ąžuolo 50 m^3 patalpoje ši koncentracija nepasiekiama net po 135 min. (11 pav.).

Mirtina vandenilio cianido koncentracija smilkstant 1 m^2 pušies medienos 50 m^3 patalpoje pasiekiama vidutiniškai po 68 min. Tuo tarpu smilkstant 1 m^2 kamštinio ąžuolo 50 m^3 patalpoje ši koncentracija nepasiekiama net po 110 min. (12 pav.).



6 pav. Anglies monoksido koncentracijos priklausomybė nuo patalpos tūrio ir poveikis žmogui, smilkstant 1 m^2 pušies medienos ar kamštinio ąžuolo (kamštinis ąžuolas – KĄ, pušis – P).



7 pav. Azoto oksido koncentracijos priklausomybė nuo patalpos tūrio ir poveikis žmogui, smilkstant 1 m^2 pušies medienos ar kamštinio ąžuolo (kamštinis ąžuolas – KĄ, pušis – P).

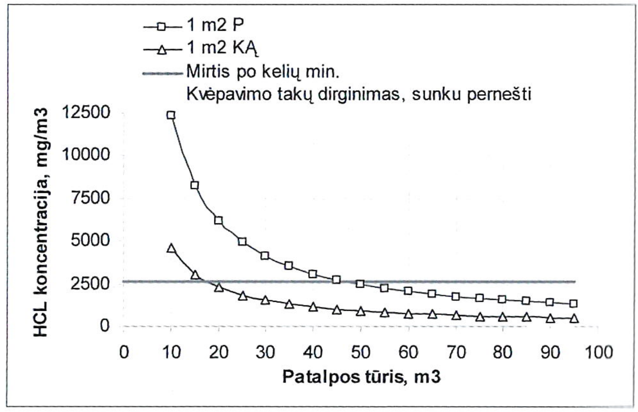
IŠVADOS

1. Intensyvus kenksmingų dujų ir garų susidarymas ir jų sklidimas patalpose prasideda pradinėje gaisro stadijoje. Šios dujos sukelia didelį pavojų žmogui. Apsinuodijimas kenksmingais degimo produktais yra priežastis, dėl kurios gaisrų metu miršta nuo 60% iki 80% žmonių.

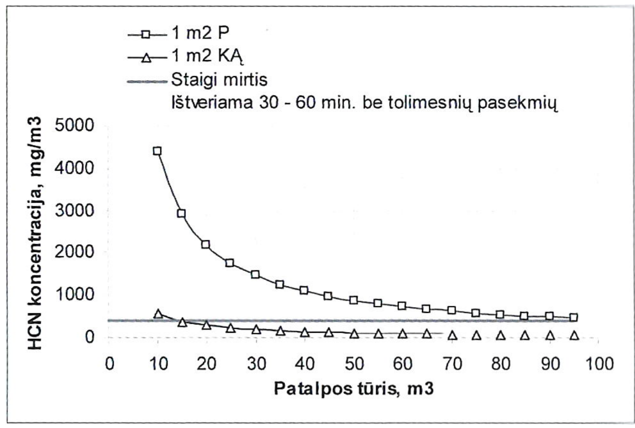
2. Smilkimas lyginant su degimu, kurio metu pasireiškia liepsna, yra pavojingesnis, nes jo metu išsiskiria žymiai daugiau kenksmingų degimo produktų. Kenksmingos medžiagos smilkimo metu pradeda skirtis prie 90°C temperatūros.

3. Įvertinus bandymų rezultatus, iš 1 m^2 pušies medienos išsiskirtų 1187 g kenksmingų medžiagų. Iš to paties kiekio kamštinio ąžuolo išsiskirtų 381 g kenksmingų medžiagų. Pušies mediena šiuo požiūriu vidutiniškai 3 kartus pavojingesnė nei kamštinis ąžuolas.

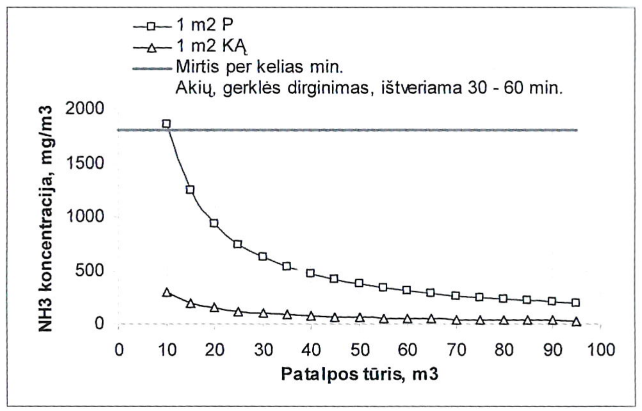
4. Pavojinga gyvybei anglies monoksido, azoto oksido, vandenilio cianido koncentracija, smilkstant 1 m^2 pušies medienos, susidaro 95 m^2 patalpoje, o smilkstant kamšti-



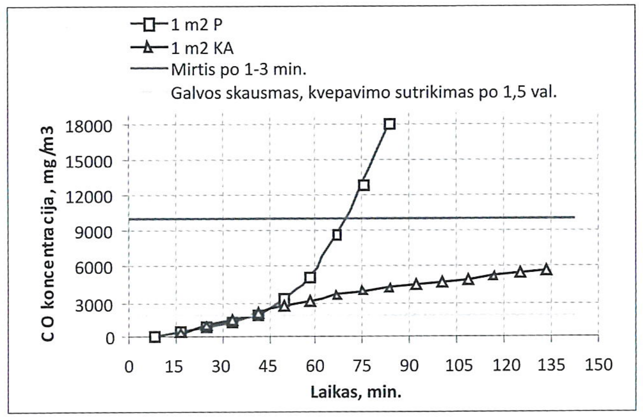
8 pav. Vandenilio chlorido koncentracijos priklausomybė nuo patalpos tūrio ir poveikis žmogui, smilkstant 1 m^2 pušies medienos ar kamštinio ąžuolo (kamštinis ąžuolas – KĄ, pušis – P).



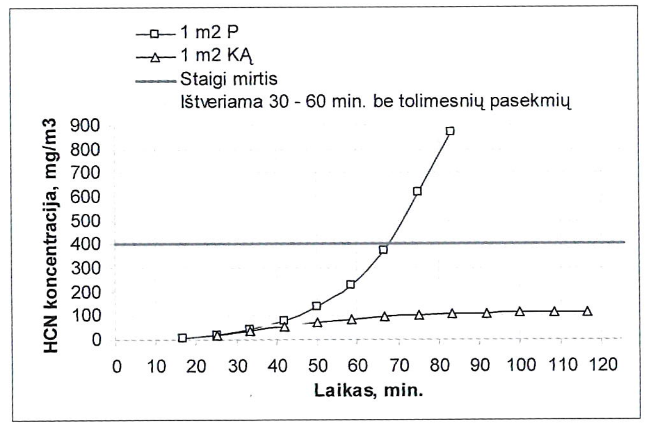
9 pav. Vandenilio cianido koncentracijos priklausomybė nuo patalpos tūrio ir poveikis žmogui, smilkstant 1 m^2 pušies medienos ar kamštinio ąžuolo (kamštinis ąžuolas – KĄ, pušis – P).



10 pav. Amoniako koncentracijos priklausomybė nuo patalpos tūrio ir poveikis žmogui, smilkstant 1 m^2 pušies medienos ar kamštinio ąžuolo (kamštinis ąžuolas – KĄ, pušis – P).



11 pav. Anglies monoksido koncentracijos priklausomybė nuo laiko ir poveikis žmogui, smilkstant 1 m^2 pušies medienos arba kamštinio ąžuolo 50 m^3 patalpoje (kamštinis ąžuolas – KĄ, pušis – P).



12 pav. Vandenilio cianido koncentracijos priklausomybė nuo laiko ir poveikis žmogui, smilkstant 1 m^2 pušies medienos arba kamštinio ąžuolo 50 m^3 patalpoje (kamštinis ąžuolas – KĄ, pušis – P).

niam ąžuolui tokia koncentracija bus daugiau nei dvigubai mažesnio tūrio patalpoje.

5. Mirtina anglies monoksido ir vandenilio cianido koncentracija, smilkstant 1 m^2 pušies medienos 50 m^3 patalpoje, pasiekiama vidutiniškai po 70 min., o smilkstant 1 m^2 kamštinio ąžuolo mirtina koncentracija nepasiekiama net po 110 min.

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RISKINESS OF SMOULDERING PINE WOOD AND CORK-OAK

Zbignev Karpovič, Ritoldas Šukys

Summary

Key words: fire, combustion, smoulder, hazardous combustion wastes, carbon monoxide, pine wood, cork-oak, heat source

Meanly 280 people per annual lost their life in fire during last five years in Lithuania. Intoxication with hazardous combustion waste is the main reason of death in 60% up to 80% cases. It is possible to divide combustion into two types: combustion without flame, this process is called smouldering, and combustion with flame. Smouldering is a slow process, processing in low temperatures without flame. In comparison with combustion, in which the flame occurs, smouldering causes higher risk. More hazardous combustion wastes are disposed in the process of smouldering. This article analysis the emission of: the carbon oxide (CO), nitrogenous oxide (NO), hydrochloric (HCL), hydrogen cyanide (HCN) and ammoniac (NH3) in the process of smouldering of pine wood and cork-oak. The changes in the emission are analysed according to the heat source intensity assessing and comparing risk to people's health and life safety.

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Gauta 2009-04-16

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International Association for Bridge and Structural Engineering

European Council of Civil Engineers

The Association of European Civil Engineering Faculties

Lithuanian Academy of Science

Vilnius Gediminas Technical University

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http://www.vgtu.lt/en/editions/proceedings

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RESEARCH ON THE TOXICITY OF PINE TIMBER TREATED AND NON-TREATED WITH FIRE RETARDANTS

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Abstract. Meanly 280 people annually in Lithuania lost their life in fires during the last five years. Intoxication by toxic combustion waste was the main reason that caused death. Flames, high temperature, failure of structures, reduced visibility – are other common reasons for causing loss of life. The time interval till inflammation and the toxicity of structures influence the evacuation time of people inside the building. The effective way to prolong time till inflammation of timber structures is to treat them with fire retardants. Depending on the heat flux fire retardants increase time till inflammation of timber structures several times, decelerates the flame spread and influences the amount of toxic waste. This paper analyses the combustion of timber, the emission of the carbon monoxide (CO), hydrochloric acid (HCL), hydrocyanic acid (HCN) and ammonia (NH_3) from pine timber treated and non-treated with fire retardants during the process of thermal destruction. The toxicity of pine timber is assessed through the intensity of heat flux.

Keywords: pine timber, fire retardants, treatment, fire, toxicity, heat flux, combustion products.

1. Introduction

Fires emerging in buildings considerably endanger health and life of people. This danger depends on the number of people, size of a building, project-based solutions, building materials used, security systems and also substances reducing combustibility of building materials (Buhanan 2002). There are factors to be encountered that endanger not only people inside of a building but also those performing rescue works during fire. Those factors include: (Buhanan 2002; Kolbrecki 2000; Seńczuk 1998; Иванников and Клюс 1987):

- toxic combustion products,
- flame and high temperature,
- decrement of oxygen concentration,
- instability of constructions,
- reduced visibility.

Almost during every fire smoke emerges – mixture of gaseous combustibility products emitting in the process of organic material burning. Fractions of highest molecular weight are emitted during the process of fumigation (Drysdale 1998). In Great Britain and the United States of America more than 50 % of all deaths in fires were caused by smoke, namely, toxic combustion products constituting smoke (Drysdale 1998).

During the last five years annually 280 people on the average died in fires in Lithuania. In 2008 in Lithuania 8 people per 100 thousand people died in fires. This indicator remains one of the highest among other countries of the European Union. Moreover, Lithuania outran Latvia and Estonia by this indicator in 2008 (Brushlinsky *et al.* 2009).

The consequences of fire may be reduced by performing effective prevention, while at emergence of fire by extinguishing it before spreading (Buhanan 2002). One of the possibilities for implementing effective prevention is usage of materials protecting from the impact of fire, i. e. fire retardants (Ozkaya *et al.* 2007; Jun-wei Gu *et al.* 2007; Koo *et al.* 2001). Time till inflammation for building materials, i. e. timber constructions that are treated with fire retardants is longer and flame spreading speed after inflammation is lower (Karpovič 2009; Gu *et al.* 2007).

Impacted with the heat flux the surface of timber starts fuming or bursts into flames. The minimum quantity of heat flux causing inflammation of timber amounts 12 kW/m^2 (Drysdale 1998). After the temperature of 125–150 °C is reached the volatile thermal dissolution products begin emitting, hemi cellulose and lignin resolve. At the temperature of 225–250 °C cellulose resolves and the surface of timber may start flaming (Szczepanska 1994, Huntierova 1995).

Fire retardants directly influence combustion of timber (Nassar 1999) – volatile and combustible substances that are released during the process of pyrolisis mix with the incombustible substances contained in a fire retardants thus making the quantity of heat accessing zone of pyrolisis lower and the layer of carbon that impedes the process of combustion – forming more intensely.

The field of fire protection examines resistance to fire of ceramics (Abraitis and Stankevičius 2007; Žurauskienė and Nagrockienė 2007), concrete (Chung Kyung-soo *et al.* 2007; Abramowicz and Kowalski 2007; Jonaitis and Papinigis 2005), Ferro concrete (Bednarek and Ogrodnik 2007) and steel (Bednarek and Kamocka 2006), characteristics of pine and cork-oak during fire (Galaj 2007), combustion of polymeric materials (Konecki and Polka 2009) as well as the impact of isolating materials to timber strength (Bednarek and Kaliszuk-Wietecka 2007), combustion of timber treated with fire retardants, the effectiveness of fire retardants (Karpovč 2009) and the hazardousness of pine timber and cork-oak while fuming (Karpovč *et al.* 2009). The toxicity of timber treated with fire retardants is not analysed. Lewin 2005 signifies that today the need for research on timber treated with fire retardants is high. There are many questions unanswered concerning the protection of timber against fire. One of such questions is the toxicity of timber treated with fire retardants during thermal destruction.

The aim of this work is to analyse the toxicity while fuming of pine timber treated and non-treated by fire retardants and to determine alternation of emission of carbon monoxide (CO), hydrochloric acid (HCL), hydrocyanic acid (HCN) and ammonia (NH_3) subject to the heat flux intensity.

2. Objective and scope of the tests

Tests were performed in the Main School of Fire Service by using research equipment for toxic combustions products emitted from solid materials after the impact of the heat flux.

The research equipment for toxic combustions products originating while solid materials are resolving with the impact of the heat flux (see Fig 1) may determine emitted toxic combustion products and their quantity while impacting specimen with different heat fluxes. The possible range of the heat fluxes vary from 2 to 80 kW/m^2.

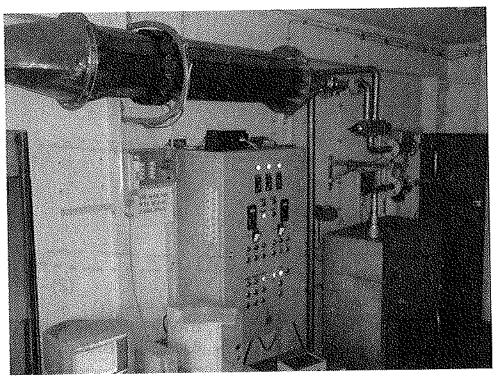

Fig 1. The research equipment for toxic combustions products originating while solid materials are resolving when impacted with the heat flux.

During the test two heat fluxes were used, i. e. of 8 kW/m^2 and of 10 kW/m^2.By impacting specimens with such heat fluxes the conditions are established for the emission of the main amount of combustion products. At the heat fluxes of less than 8 kW/m^2 the temperature on the specimens does not reach 160 °C, while at the heat fluxes higher than 10 kW/m^2 the specimens inflame (the research equipment is not applied for tests during which flammable combustion is enacted). The computer connected to the research equipment ensured accurate control of the test and automatically recorded the results. 5 specimens in every test group were tested. The time-scale for one test course was 1 hour. The dimensions of the specimens were 200 × 200 × 20.

The tests were performed for the three main groups of the specimens:

- non-treated pine timber specimens,
- pine timber specimens treated with the fire retardant Flamasepas-2,
- pine timber specimens treated with the fir retardant BAK-1.

The fire retardants used for the treatment of pine timber specimens have been produced and used in Lithuania.

3. Test results and analysis

The alternation of temperature on the surface of the specimens depending on variation of the heat flux and specimens are shown in Fig 2. The test results have been processed with the programme „Statistica", their average values are displayed graphically (Figs 2–6), Table 1 presents correlation coefficients of the results received during tests.

Table 1. Correlation coefficient of the emission of CO, HCN, HCL, NH_3, on the same parameters.

Heat flux, specimen	Correlation coefficient of the emission of combustion products on the same parameters			
	CO	HCN	HCL	NH_3
8 kW, pine	0,993	0,980	0,903	0,992
8 kW, pine Flamasepas-2	0,943	0,993	0,985	0,969
8 kW, pine BAK-1	0,974	0,996	0,909	0,917
10 kW, pine	0,985	0,981	0,912	0,985
10 kW, pine Flamasepas-2	0,921	0,979	0,934	0,992
10 kW, pine BAK-1	0,914	0,965	0,942	0,998

Impacting pine timber specimens with the heat fluxes of 8 kW/m^2 and 10 kW/m^2 in 600 s on the average the speed of the temperature rise on the surface of the specimens decreased.

The temperature on the surfaces of the pine timber specimens non-treated with fire retardants was 15,3 °C (8 kW/m^2) and 2,3° C (10 kW/m^2) higher as compared to the pine timber specimens treated with fire retardants.

The temperature of the pine timber specimens non-treated with fire retardants was meanly 21,1 °C (8 kW/m^2) and 14 °C (10 kW/m^2) higher than the temperature on the pine timber specimens treated with the fire retardant Flamasepas-2.

Affecting pine timber specimens non-treated with fire retardants with the heat flux of 8 kW/m^2 the temperature on their surface was meanly 9,4 °C higher as compared to the pine timber specimens treated with the fire retardant BAK-1, while when impacting pine timber specimens treated with fire retardant BAK-1 with the heat flux of 10 kW/m^2 the temperature on their surface was 9,5 °C higher on the average as compared to the pine timber specimens non-treated by the fire retardants (Fig 2).

Affecting pine timber specimens with the heat flux of 8 kW/m^2 in 300 s on the average, after the surface temperature of the specimens reached the average of 140° C, the sensor started recording carbon monoxide (CO). Affecting pine timber specimens treated with the fire retardant Flamasepas-2 with the heat flux of 8 kW/m^2 in 420 s. on the average, after the surface of the specimens reached the temperature of meanly 165 °C, the sensor started recording carbon monoxide (CO). Affecting pine timber specimens treated with the fire retardant BAK-1 with the heat flux of 8 kW/m^2 in 365 s on the average, after the surface of the specimens reached the temperature of 156 °C on the average, the sensor started recording carbon monoxide (CO).

Affecting pine timber specimens with the heat flux of 10 kW/m^2 in 170 s on the average, after the surface of the specimens reached the temperature of 135 °C, the sensor started recording carbon monoxide (CO). Affecting pine timber specimens treated with the fire retardant Flamasepas-2 with the heat flux of 10 kW/m^2 in 270 s on the average, after the surface of the specimens reached the temperature of 170 °C on the average, the sensor started recording carbon monoxide (CO). Affecting pine timber specimens treated with the fire retardant BAK-1 with the heat flux of 10 kW/m^2 in 300 s on the average, after the surface of the specimens reached the temperature of 178 °C, the sensor started recording carbon monoxide (CO).

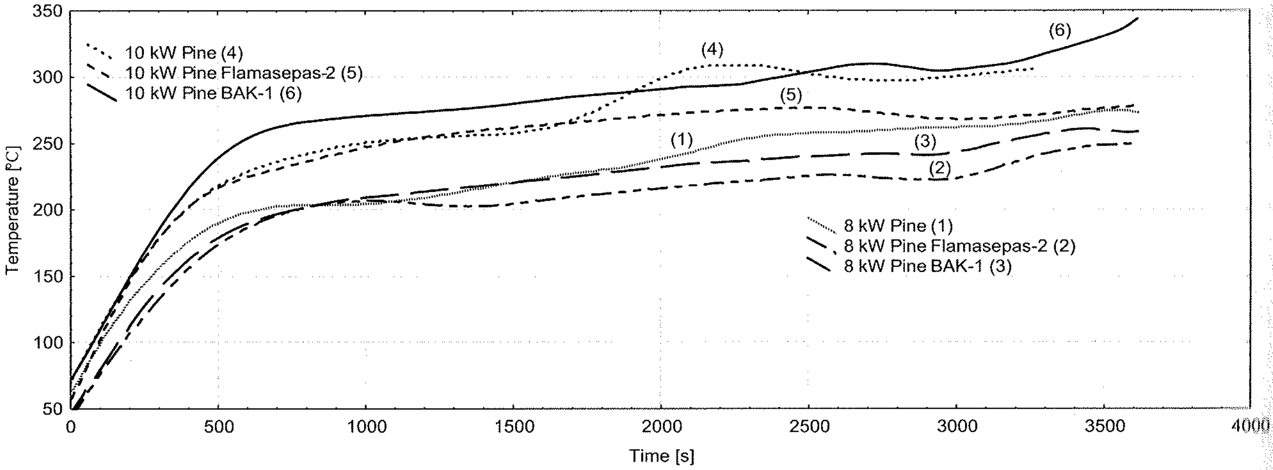

Fig 2. Alternation of temperature on the surface of specimen

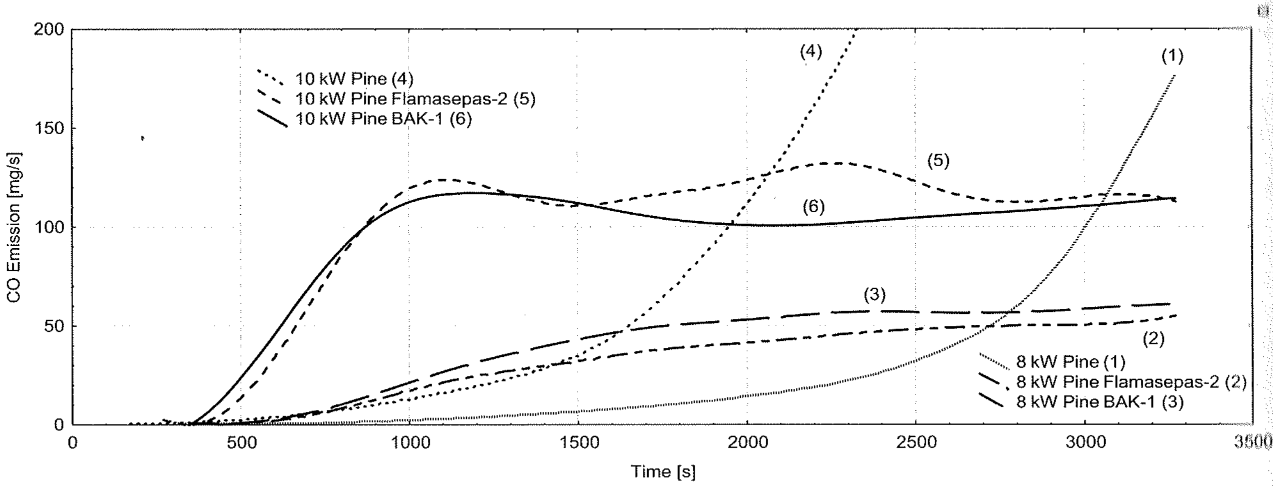

Fig 3. Average emission intensity of carbon monoxide

The pine timber specimens treated with fire retardants at the initial stage of the tests as compared to the non-treated pine timber specimens, emitted carbon monoxide (CO) more intensely, however this emission stabilised in 1500 s (8 kW/m^2) when the surface of the specimen reached the temperature of 211 °C on the average and in 1000 s (10 kW/m^2), when the surface of the specimens reached the temperature of 260 °C. The emission of carbon monoxide (CO) of the non-treated pine timber intensified in course of all test.

The non-treated pine timber specimens emitted meanly 1,24 times (8 kW/m^2) and 1,61 times (10 kW/m^2) more of carbon monoxide (CO) as compared to the pine timber specimens treated with fire retardants.

Comparing pine timber specimens treated with fire retardants, the pine timber specimens treated with the fire retardant BAK-1 affected with the heat flux of 8 kW/m^2 emitted meanly 1,2 times more of carbon monoxide (CO) than the pine timber specimens treated with the fire retardant Flamasepas-2. The pine timber specimens treated with the fire retardant Flamasepas-2 when affected with the heat flux of 10 kW/m^2 emitted meanly 1,17 times more of carbon monoxide (CO) as compared to the pine timber specimens treated with the fire retardant BAK-1.

The average emission intensity of carbon monoxide (CO) subject to the parameters of the test is shown in Fig 3.

Affecting pine timber specimens with the heat flux of 8 kW/m^2 in 955 s on the average, after the surface of the specimens reached the temperature of 200 °C on the average, the sensor started recording hydrocyanic acid (HCN). Affecting the pine timber specimens treated with the fire retardant Flamasepas-2 with the heat flux of 8 kW/m^2 after 880 s on the average, after the surface of the specimens reached the temperature of 198 °C, the sensor started recording hydrocyanic acid (HCN). Affecting pine timber specimens treated with the fire retardant BAK-1 with the heat flux of 8 kW/m^2 in 900 s on the average, after the surface of the specimens reached the temperature of 200° C on the average, the sensor started recording hydrocyanic acid (HCN).

Affecting pine timber specimens with the heat flux of 10 kW/m^2 in 570 s on the average, after the surface of the specimens reach the temperature of 220 °C on the average, the sensor started recording hydrocyanic acid (HCN). Affecting pine timber specimens treated with the fire retardant Flamasepas-2 with the heat flux of 10 kW/m^2 in 550 s on the average, after the surface of the specimens reached the temperature of 217 °C on the average, the sensor started recording hydrocyanic acid (HCN). Affecting pine timber specimens treated with the fire retardant BAK-1 with the heat flux of 10 kW/m^2 in 500 s on the average, after the surface of the specimens reached the temperature of 219 °C on the average, the sensor started recording hydrocyanic acid (HCN).

The pine timber specimens treated with fire retardants at the initial stage of the tests as compared to the non-treated pine timber, emitted hydrocyanic acid (HCN) more intensely, however this emission stabilised in 1700 s (8 kW/m^2) when the surface of the specimens reached the temperature of 221 °C on the average and in 1100 s (10 kW/m^2) when the surface of the specimens reached the temperature of 262 °C while the emission of hydrocyanic acid (HCN) of the non-treated pine timber specimens intensified in the course of all the test.

The non-treated pine timber specimens emitted 1,27 times (8 kW/m^2) and 1,3 times (10 kW/m^2) more of hydrocyanic acid (HCN) as compared to the pine timber specimens treated with fire retardants.

Comparing pine timber specimens treated with fire retardants, the pine timber specimens treated with the fire retardant BAK-1 affected with the heat flux of 8 kW/m^2 emitted meanly 1,17 times more of hydrocyanic acid (HCN) than the pine timber specimens treated with the fire retardant Flamasepas-2. The pine timber specimens treated with the fire retardant Flamasepas-2 when affected with the heat flux of 10 kW/m^2 emitted meanly 1,09 times more of hydrocyanic acid (HCN) as compared to the pine timber specimens treated with the fire retardant BAK-1.

The average emission intensity of hydrocyanic acid (HCN) subject to the parameters of the test is shown in Fig 4.

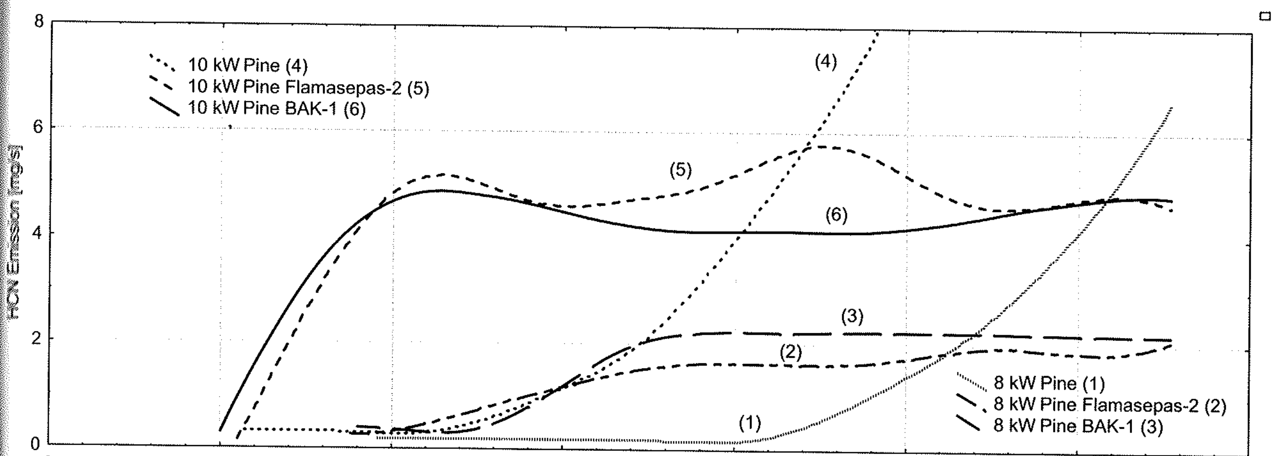

Fig 4. Average emission intensity of hydrocyanic acid

Affecting pine timber specimens with the heat flux of 8 kW/m^2 in 430 s on the average, after the surface of the specimens reached the temperature of 167 °C on the average, the sensor started recording hydrochloric acid (HCL). Affecting pine timber specimens treated with the fire retardant Flamasepas-2 with the heat flux of 8 kW/m^2 in 1015 s on the average, after the surface of the specimens reached the temperature of 207 °C on the average, the sensor started recording hydrochloric acid (HCL). Affecting pine timber specimens treated with the fire retardant BAK-1 with the heat flux of 8 kW/m^2 in 920 s on the average, after the surface of the specimens reached the temperature of 203 °C on the average, the sensor started recording hydrochloric acid (HCL).

Affecting pine timber specimens with the heat flux of 10 kW/m^2 in 275 s on the average, after the surface of the specimens reached the temperature of 169 °C on the average, the sensor started recording hydrochloric acid (HCL). Affecting the pine timber specimens treated with the fire retardant Flamasepas-2 with the heat flux of 10 kW/m^2 in 460 s on the average, after the surface of the specimens reached the temperature of 215 °C on the average, the sensor started recording hydrochloric acid (HCL). Affecting pine timber specimens treated with the fire retardant BAK-1 with the heat flux of 10 kW/m^2 in 485 s on the average, after the surface of the specimens reached the temperature of 221 °C on the average, the sensor started recording hydrochloric acid (HCL).

During the tests the pine timber specimens non-treated with fire retardants not considering to the quantity of the heat flux emitted more of hydrochloric acid (HCL) as compared to the pine timber specimens treated with fire retardants. The non-treated pine timber specimens emitted 4,16 times (8 kW/m^2) and 2,26 times (10 kW/m^2) more of hydrochloric acid (HCL) as compared to the pine timber specimens treated with fire retardants.

Comparing pine timber specimens treated with fire retardants, the pine timber specimens treated with the fire retardant BAK-1 emitted meanly 2,42 times (8 kW/m^2) and 1,37 times (10 kW/m^2) more of hydrochloric acid (HCL) than the pine timber specimens treated with the fire retardant Flamasepas-2.

The average emission intensity of hydrochloric acid (HCL) subject to the parameters of the test is shown in Fig 5.

Affecting pine timber specimens with the heat flux of 8 kW/m^2 in 670 s on the average, after the surface of the specimens reached the temperature of 197 °C, the sensor started recording ammonia (NH_3). Affecting pine timber specimens treated with the fire retardant Flamasepas-2 with the heat flux of 8 kW/m^2 in 730 s on the average, after the surface of the specimens reached the temperature of 199 °C on the average, the sensor started recording ammonia (NH_3). Affecting pine timber specimen treated with the fire retardant BAK-1 with the heat flux of 8 kW/m^2 in 765 s on the average, after the surface of the specimens reached the temperature of 202 °C on the average, the sensor started recording ammonia (NH_3).

Affecting pine timber specimens with the heat flux of 10 kW/m^2 in 365 s on the average, after the surface of the specimens reached the temperature of 201 °C on the average, the sensor started recording ammonia (NH_3). Affecting pine timber specimens treated with the fire retardant Flamasepas-2 with the heat flux of 10 kW/m^2 in 475 s on the average, after the surface of the specimens reached the temperature of 217 °C on the average, the sensor started recording ammonia (NH_3). Affecting pine timber specimens treated with the fire retardant BAK-1 with the heat flux of 10 kW/m^2 in 565 s on the average, after the surface of the specimens reached the temperature of 223 °C on the average, the sensor started recording ammonia (NH_3).

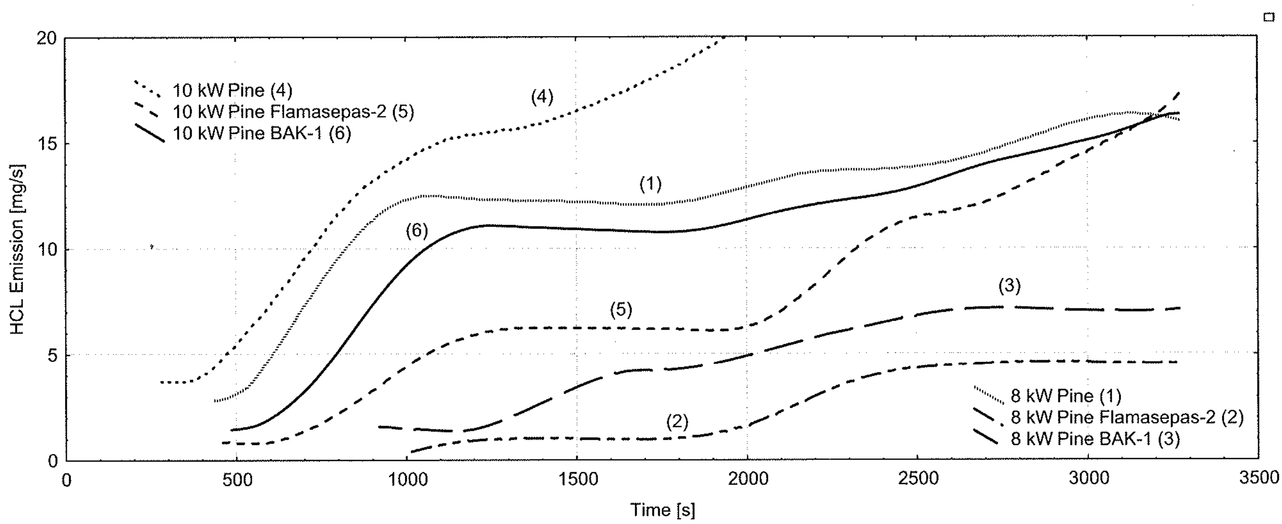

Fig 5. Average emission intensity of hydrochloric acid

The pine timber specimens treated with fire retardants at the initial stage of the tests as compared to the non-treated pine timber specimens, emitted ammonia (NH_3) more intensely, however this emission stabilised in 1000 s (8 kW/m^2, 10 kW/m^2), when the temperature of the specimens reached 211 °C (8 kW/m^2) and 255 °C (10 kW/m^2) while the emission of the non-treated pine timber specimens intensified in the course of all the test. The non-treated pine timber specimens emitted 2,33 times (8 kW/m^2) and 1,66 times (10 kW/m^2) more of ammonia (NH_3) as compared to the treated pine timber specimens treated with the fire retardants.

Comparing pine timber specimens treated with fire retardants, the pine timber specimens treated with the fire retardant BAK-1 emitted meanly 1,08 times (8 kW/m^2) and 1,29 times (10 kW/m^2) more of ammonia (NH_3) than the pine timber specimens treated with the fire retardant Flamasepas-2.

The average emission intensity of ammonia (NH_3) subject to the parameters of the test is shown in Fig 6.

After the affect of the heat flux the surface of the treated pine timber specimens is smoother, the layer of carbon is solid and un-cracked. For non-treated surfaces – the layer of carbon is cracked, deeper layers of timber are affected by the process of thermal destruction (Figs 7–8).

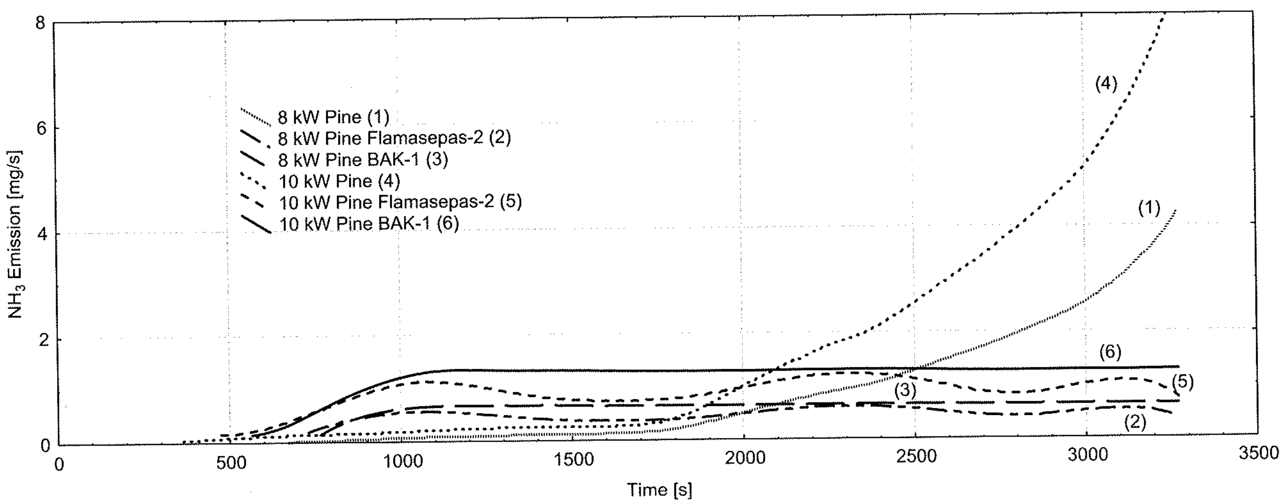

Fig 6. Average emission intensity of ammonia

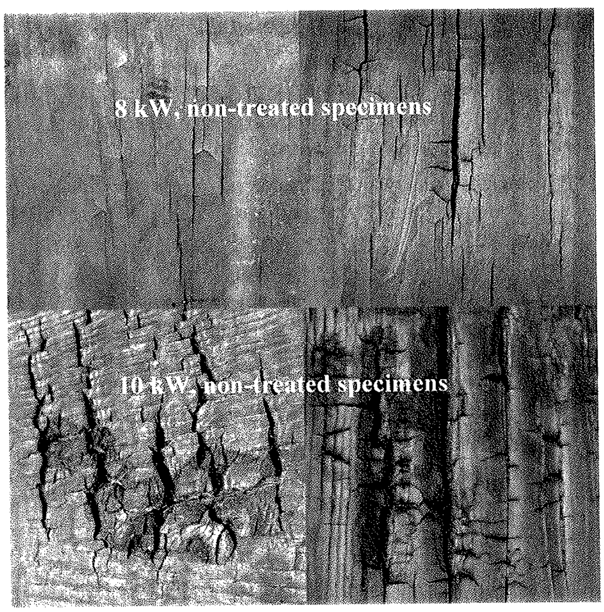

Fig 7. Non-treated pine timber specimen affected with the heat fluxes of 8 kW/m^2 and 10 kW/m^2

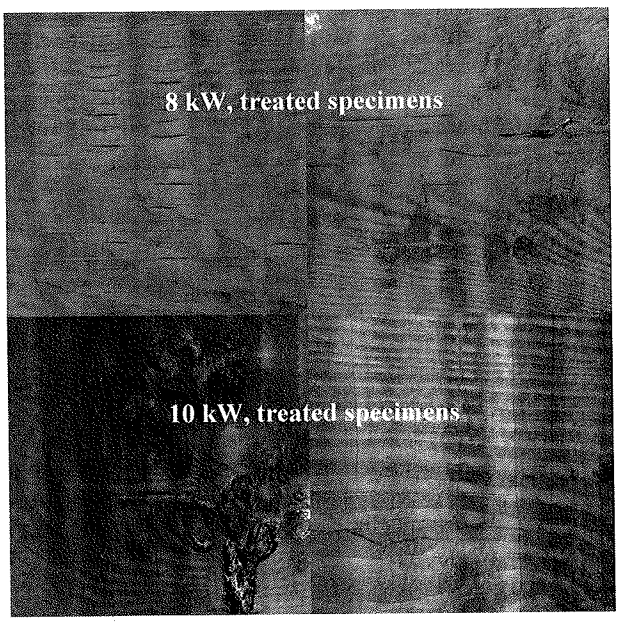

Fig 8. Treated pine timber specimen affected with the heat fluxes of 8 kW/m^2 and 10 kW/m^2

The process of thermal dissolution of non-treated pine timber specimens affected with the heat flux when estimating the quantity of the emitted toxic combustibility products is more intense. The non-treated pine timber specimens emit larger quantity of the toxic combustibility products as compared to the pine timber specimens treated with fire retardants. The quantity of toxic combustibility products emitted during the tests is presented in the Table 2.

Table 2. Toxic combustibility products and their quantity emitted during tests subject to the heat flux and type of the specimens

Heat flux, specimen	Quantity of toxic combustibility products [mg]			
	CO	HCN	HCL	NH3
8 kW, pine	31539,9	1146,23	8769,05	476,27
8 kW, pine Flamasepas-2	23228,6	834,96	1233,2	195,95
8 kW, pine-BAK-1	27833,1	975,09	2987,9	211,29
10 kW, pine	94828,5	3149,22	11722,3	932,54
10 kW, pine Flamasepas-2	61299,6	2514,04	4379,94	489,87
10 kW, pine BAK-1	56889,8	2317,76	6014,64	633,89

Conclusions

The pine timber treatment with the fire retardants significantly influences the emission of toxic combustibility products from the pine timber when affected with the heat flux. The pine timber treated with fire retardants emits less of toxic combustibility products.

- the treated pine timber specimens affected with the heat flux of 8 kW/m^2 emit 1,46 times less of toxic combustibility products than the non-treated pine timber specimens,
- the treated pine timber specimens affected with the heat flux of 10 kW/m^2 emit 1,65 times less of toxic combustibility products than the non-treated pine timber specimens.

The heat flux affects the emission on toxic combustibility products:

- the treated pine timber specimens affected with the heat flux of 8 kW/m^2 emit 2,34 times less of toxic combustibility products than the pine timber specimens treated with fire retardants affected with the heat flux of 10 kW/m^2
- pine timber specimens affected with the heat flux of 8 kW/m^2 emit 2,64 times less of the toxic combustibility products than the pine timber specimens affected with the heat flux of 10 kW/m^2.

The fire retardants influence noticeably the intensity of thermal destruction for pine timber. The thermal destruction progress of the treated pine timber specimens when estimating the quantity of the emitted toxic combustibility products is slower and the changes of the surface of specimens are visibly smaller as compared to the non-treated timber.

The effectiveness of the fire retardants used in Lithuania for reducing the quantity of carbon monoxide (CO), hydrochloric acid (HCL) hydrocyanic acid (HCN) and ammonia (NH_3) emitted in the process of fumigation is similar. The timber specimens treated with the fire retardants Flamasepas-2 and BAK-1 affected with the same heat flux emit similar amount of carbon monoxide (CO), hydrochloric acid (HCL) hydrocyanic acid (HCN) and ammonia (NH_3). The Flamasepas 2 reduces the emission of hydrochloric acid more effectively.

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Annals of Warsaw University of Life Sciences – SGGW

Forestry and Wood Technology No 71
Warsaw 2010

Contents:

Annals of Warsaw University of Life Sciences – SGGW
Forestry and Wood Technology No 71, 2010: 342-346
(Ann. WULS-SGGW, For and Wood Technol. 71, 2010)

Studies on combustibility of treated wood with fire retardant and antiseptic solutions

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Abstract: *Studies on combustibility of treated wood with fire retardant and antiseptic solutions* Many countries widely use wood in construction. In order to protect wood from the impact of environmental factors and to reduce its combustibility the chemical means such as antiseptic and fire retardant solutions are used. Wood of spruce and pine being the most popular in construction is investigated in this work while non-treated and treated with antiseptic solution *Asepas 2* and fire retardants solutions *Flamasepas-2* and *Bak-1*. The research is performed according to the requirements of the standards LST EN ISO 1716:2002 and LST EN ISO 5657:1999.

Keywords: wood, antiseptic, fire retardant, solution, heat flux, ageing

INTRODUCTION

Wood and wood products are widely used for construction and finishing of buildings (Stevens et al., 2006, Grexa, 2000). On purpose to increase wood durability and to reduce its combustibility, antiseptic and fire retardant solutions are used. In some cases for reducing wood combustibility antiseptic solutions are used instead of fire retardant solutions (Praniauskas et al., 2010). During the tests of wood treated with fire retardant solutions (Karpovič, 2009, Šukys and Karpovič, 2010) it was observed that process of ageing may affect the time to ignition of such wood.

Purpose of work: to explore the calorific value of wood treated with antiseptic and fire retardant solutions and the dependence of ignition on process of ageing of wood treated with fire retardant solutions.

RESEARCH METHODOLOGY

The research on calorific value of wood was performed using the test equipment, correspondent to the requirements of standard LST EN ISO 1716:2002 . This research method was chosen for the reason that taking samples this way, structures of a building are harmed at the least. Only 0.5 – 1.0 g of wood dust are used to perform one test. Tests of calorific value of wood were performed on samples of pine and spruce wood treated with antiseptic solution *Asepas 2* and fire retardant solution *Bak-1* and also on untreated samples of pine and spruce timber. Nine tests were performed in every series of research.

The research on dependence of ignition on process of ageing of wood treated with fire retardant solutions was performed using the test equipment, correspondent to the requirements of standard LST EN ISO 5657:1999. Test was terminated if sample did not ignite after 900 s from the start of test. During the tests samples were subjected to heat fluxes of 30, 35, 40, 45, 50 kW/m^2. Dependence of ignition on process of ageing of wood was estimated by the time to ignition of the sample. Pine and spruce wood samples used in these tests were treated with fire retardant solutions *Flamasepas-2* and *Bak-1*. Five tests were performed in every series of research. Samples during ageing were kept in the temperature of 20°–25° C and at 40–80 percent relative humidity; the humidity of samples did not exceed 15 percent.

RESEARCH RESULTS AND DISCUSSION

The calorific value of wood treated with fire retardant solutions is lower compared to the calorific value of the same kind untreated wood and the calorific value of wood treated with antiseptic solutions is higher compared to the calorific value of the same kind untreated wood. The calorific values of pine and spruce wood samples treated with fire retardant solution *Bak-1* and antiseptic solution *Asepas 2* and the calorific values of untreated samples are shown in Fig.1.

a) b)

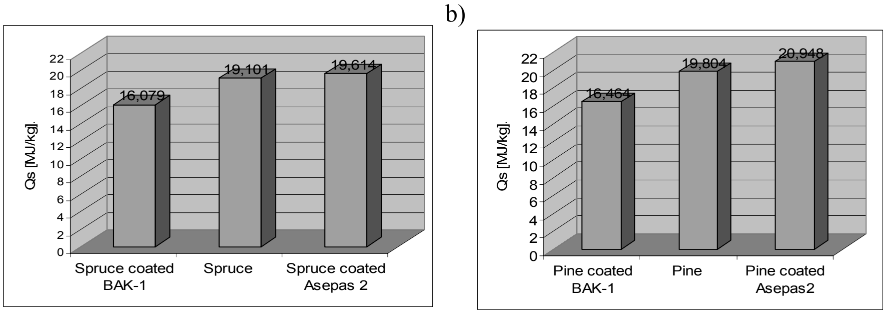

Fig. 1. Calorific values of pine (a) and spruce (b) timber samples treated with fire retardant solution *Bak-1* and antiseptic solution *Asepas 2* and the calorific values of untreated samples.

Dependence of ignition on process of ageing of wood treated with fire retardant solutions when samples were subjected to heat fluxes of 30, 35 kW/m^2 is not shown here because in the first, second and third years time to ignition of the samples was more than 900 s. Average times to ignition of the treated pine and spruce wood samples, subjected to heat fluxes of 40, 45, 50 kW/m^2, correspondent to the years, are shown in Fig. 2, 3, 4 and 5.

When pine wood samples, treated with fire retardant solution *Flamasepas-2,* were subjected to heat fluxes of 40, 45 kW/m^2, it was estimated that time to ignition of the second year (2009) samples was shorter when compared to the time to ignition of the first year (2008) samples: 40 kW/m^2 – 1.25 times, 45 kW/m^2 – 1.22 times on the average; time to ignition of the third year (2010) samples was shorter when compared to the time to ignition of the first year (2008) samples: 40 kW/m^2 – 1.33 times, 45 kW/m^2 – 1.66 times on the average (Fig. 2).

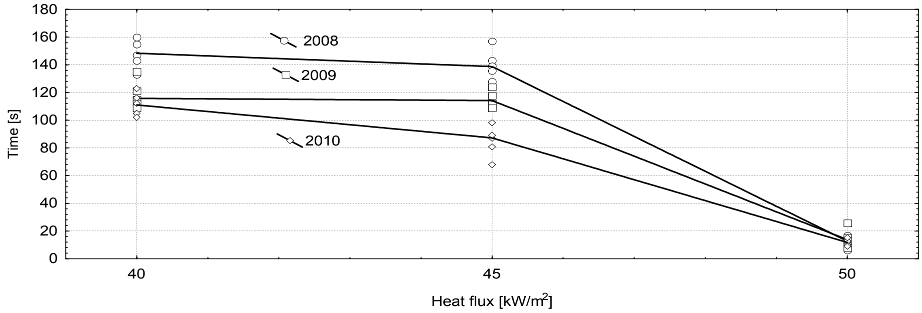

Fig. 2. Average times to ignition of the pine wood samples treated with fire retardant solution *Flamasepas-2*, subjected to heat fluxes of 40, 45, 50 kW/m^2, correspondent to the years.

When spruce wood samples, treated with fire retardant solution *Flamasepas-2,* were subjected to heat fluxes of 40, 45 kW/m^2, it was estimated that time to ignition of the second year (2009) samples was shorter when compared to the time to ignition of the first year (2008) samples: 40 kW/m^2 – 3.31 times, 45 kW/m^2 –3.33 times on the average; time to ignition of the third year (2010) samples was shorter when compared to the time to ignition of the first year (2008) samples: 40 kW/m^2 –3.65 times, 45 kW/m^2 – 4.07 times on the average (Fig. 3).

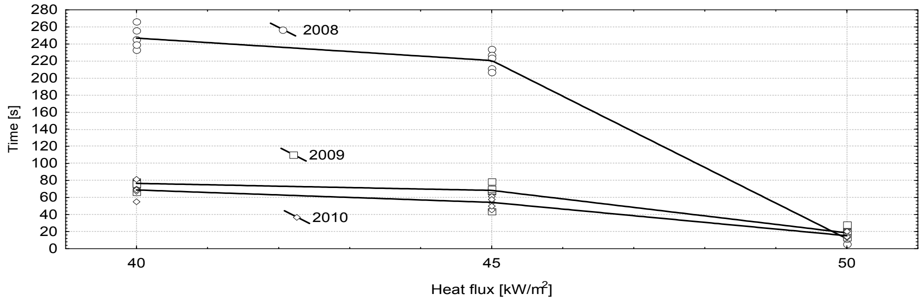

Fig. 3. Average times to ignition of the spruce wood samples treated with fire retardant solution *Flamasepas-2*, subjected to heat fluxes of 40, 45, 50 kW/m^2, correspondent to the years.

When pine wood samples, treated with fire retardant solution *BAK-1,* were subjected to heat fluxes of 40, 45 kW/m^2, it was estimated that time to ignition of the second year (2009) samples was shorter when compared to the time to ignition of the first year (2008) samples: 40 kW/m^2 – 1.58 times, 45 kW/m^2 – 2.93 times on the average; time to ignition of the third year (2010) samples was shorter when compared to the time to ignition of the first year (2008) samples: 40 kW/m^2 – 1.82 times, 45 kW/m^2 – 3.57 times on the average (Fig. 4).

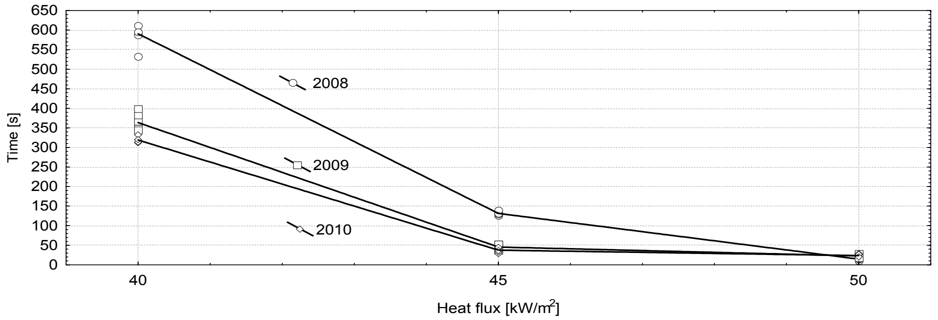

Fig. 4. Average times to ignition of the pine wood samples treated with fire retardant solution *BAK-1*, subjected to heat fluxes of 40, 45, 50 kW/m^2, correspondent to the years.

When spruce wood samples, treated with fire retardant solution *BAK-1,* were subjected to heat fluxes of 40, 45 kW/m^2, it was estimated that time to ignition of the second year (2009) samples was shorter when compared to the time to ignition of the first year (2008) samples: 40 kW/m^2 – 3.84 times, 45 kW/m^2 – 1.11 times on the average; time to ignition of the third year (2010) samples was shorter when compared to the time to ignition of the first year (2008) samples: 40 kW/m^2 – 6.11 times, 45 kW/m^2 – 1.79 times on the average (Fig. 5).

When all samples of the second (2009) and third (2010) year were subjected to heat flux of 50 kW/m^2, it was estimated that time to ignition when compared to the time to ignition of all the first year (2008) samples was similar.

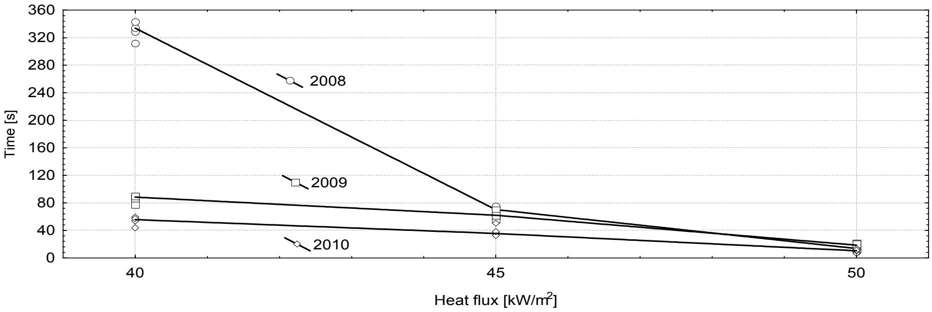

Fig. 5. Average times to ignition of the spruce wood samples treated with fire retardant solution *BAK-1*, affected by 40, 45, 50 kW/m^2 heat fluxes, correspondent to the years.

CONCLUSIONS

The calorific value of timber treated with fire retardant solution is lower when compared to the calorific value of the same kind untreated timber and the calorific value of timber treated with antiseptic solution is higher when compared to the calorific value of the same kind untreated timber.

Process of ageing influences the combustibility of wood treated with fire retardant solutions when the heat flux varies from 40 to 45 kW/m^2

It is not possible to estimate the influence of ageing on combustibility of timber treated with fire retardant solutions when heat flux is lower than 40 kW/m^2 (time to ignition is longer than 900 s) by the used research methodology. The influence of ageing on combustibility of wood treated with fire retardant solutions when heat flux is 50 kW/m^2, is not substantial.

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Streszczenie: *Badania drewna impregnowanego ognioochronnymi i antyseptycznymi środkami chemicznymi.* W wielu krajach szeroko wykorzystuje się drewno w budownictwie. W celu ochrony drewna przed wpływem czynników środowiskowych oraz w celu zmniejszenia palności są używane antyseptyczne i ognioochronne środki chemiczne. W pracy przedstawiono wyniki badań dla drewna świerkowego i sosnowego impregnowanych środkiem antyseptycznym *Asepas 2* i środkami ognioochronnymi *Flamasepas-2* i *Bak-1*. Badania przeprowadzone zgodnie z wymaganiami norm LST EN ISO 1716:2002 i LST EN ISO 5657:1999.

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Statybinės konstrukcijos

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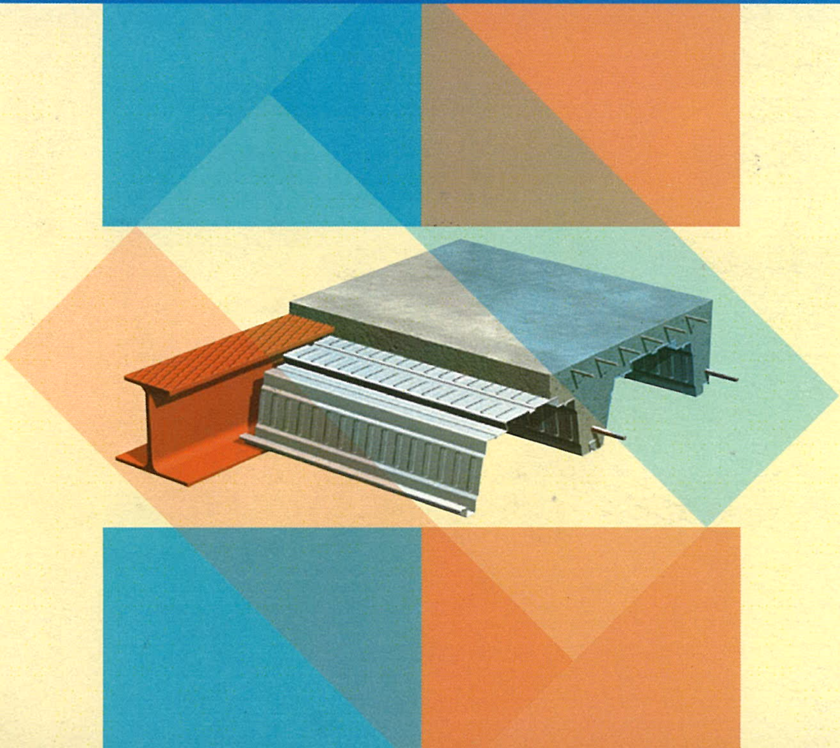
2009 m. vasario 6 d. , straipsnių rinkinys



Vilnius „Technika“ 2009

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

STATYBINĖS KONSTRUKCIJOS

Konferencijos, įvykusios Vilniuje 2009 m. vasario 6 d., straipsnių rinkinys

VGTU LEIDYKLA TECHNIKA

Vilnius 2009

UDK 624.01.04 (06)
St-113

Statybinės konstrukcijos. Konferencijos, įvykusios Vilniuje 2009 m. vasario 6 d., straipsnių rinkinys. Vilnius: Technika, 2009. 156 p.

Konferencijos straipsnių tematika apima naujas statybines konstrukcijas, konstrukcijų skaičiavimo metodus, konstrukcijų tyrimą, naudojamų konstrukcijų būklės tyrimą bei vertinimą ir konstrukcijų stiprinimą.

Leidinys skirtas projektuotojams, statybų inžinieriams, tyrinėtojams ir mokslininkams.

Spausdinami recenzuoti straipsniai.

http://leidykla.vgtu.lt

VGTU leidyklos „Technika" 1585-M mokslo literatūros knyga

ISBN 978-9955-28-396-6

TURINYS

MODERN WOODEN CONSTRUCTIONS. DESIGNING, MANUFACTURING, DEVELOPMENT IN PRACTISE

D. Mykolaitis

Summary

The innovative wooden constructions when differnent elements are jointed with pressed sheet metal connectors are analyzed. The automotive design and manufacture system is presented. The evolution of wooden constructions in Lithuanian market and its development perspectives is discussed in the article.

STATYBINĖS KONSTRUKCIJOS

Konferencijos „Statybinės konstrukcijos“, įvykusios Vilniuje 2009 m. vasario 6 d., straipsnių rinkinys

LIETUVOJE SERTIFIKUOTŲ ANTIPIRENINIŲ TIRPALŲ EFEKTYVUMO TYRIMAS

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Anotacija. Straipsnyje aptariami antipireninių tirpalų veikimo mechanizmai, pagrindinės jų savybės, medienos paviršinis impregnavimas. Straipsnyje nagrinėjamas Lietuvoje sertifikuotų antipireninių tirpalų *Flamasepas-2* ir *BAK-1* efektyvumas, jo priklausomybė nuo šilumos srauto ir medienos rūšies. Tyrimui pasirinkta eglė ir pušis – mediena, kuri dažniausiai naudojama medinių konstrukcijų gamybai. Tyrimai atlikti pagal LST ISO 5657:1999 standarto „Reagavimo į ugnį bandymai – statybinių gaminių užsidegimas veikiant juos šilumine spinduliuote“ reikalavimus, nustatant laiką iki bandinio užsiliepsnojimo.

Įvadas

Medinių konstrukcijų ir kitų medinių gaminių impregnavimas antipireniniais tirpalais gaisro metu leidžia išsaugoti iki 75 % materialinių vertybių. Todėl yra svarbu ištirti Lietuvoje naudojamų antipireninių tirpalų efektyvumą.

Literatūros apie antipireninių tirpalų rūšis, jų sudėtį ir savybes gausu, tačiau informacijos, kuria remdamiesi galėtume palyginti skirtingų antipireninių tirpalų efektyvumą, stinga, o ir esama – neišsami.

Atsižvelgiant į šias priežastis, buvo pasirinkti sertifikuoti antipireniniai tirpalai *Flamasepas-2*, *BAK-1* ir atlikti tyrimai: neimpregnuotų ir antipireniniais tirpalais tepant impregnuotų

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bandinių veikimas skirtingo dydžio šilumos srautais, siekiant nustatyti laiką, per kurį bandiniai užsiliepsnos.

Bendrosios žinios

Anglies pagrindo celiuliozines medžiagas, pvz., medieną paveikus šilumos srautu, vyksta pirolizė: šios medžiagos pradeda smilksti arba užsiliepsnoja (Slinka, Smulski 1997). Degant medienai formuojasi anglies sluoksnis, kuris silpnina degimą, stabdydamas degių medžiagų patekimą į pirolizės zoną. Tam, kad šis procesas būtų veiksmingesnis, o mediena turėtų mažesnį degumą, ji yra impregnuojama antipireniniais tirpalais (Baisal *et al.* 2007; Michell 1993).

Gaisrui pastatuose prasidėti ir plisti didelę įtaką turi medienos pirolizės procesas. Antipireninių tirpalų naudojimas yra vienas iš lengviausių, efektyviausių ir ekonomiškiausių būdų, norint sumažinti medienos degumą (Su *et al.* 1997; Subyakto *et al.* 1998). Antipireniniai tirpalai suteikia apsaugą nuo šilumos prasiskverbimo į medieną ir kartu stabdo pirolizės procesą, taip pat riboja liepsnos plitimą jos paviršiumi. Antipireninių tirpalų veikimo mechanizmai (Camino, Costa 1988; Nasar *et al.* 1999):

1) lakių ir degių medžiagų, išsiskiriančių pirolizės metu, maišymasis su nedegiomis medžiagomis, esančiomis antipireniniame tirpale;

2) šilumos kiekio, patenkančio į pirolizės zoną, mažinimas;

3) anglies sluoksnio, kuris stabdo degimo procesą, formavimosi suintensyvinimas.

Medienos impregnavimas gali būti paviršinis ir giluminis. Giluminis impregnavimas veikia medienos mechanines savybes. Paviršiniai impregnavimo metodai tokio poveikio neturi. Kiti paviršinių impregnavimo metodų privalumai: nedidelė kaina, mažos darbo laiko sąnaudos, juos paprasta naudoti ir kita.

Medienos degumas, naudojant antipireninius tirpalus, priklauso nuo (Subyakto *et al.* 1998):

- antipireno savybių, antipireninio tirpalo koncentracijos ir impregnavimo metodo;
- medienos struktūros, drėgnumo ir kita.

Yra daug antipireninių tirpalų, kurie efektyviai mažina medienos degumą, tačiau tik kai kurie jų plačiai naudojami. Tai yra dėl antipireninių tirpalų neatitikimo techniniams ir / arba ekonominiams reikalavimams. Antipireninis tirpalas, mažinantis medienos degumą, privalo (Wazny, Karys 2001):

- būti gana efektyvus gaisro metu;
- gebėti prasiskverbti į medieną ir išsilaikyti joje;
- neveikti medienos struktūros, joje ir ant jos esančių medžiagų;
- nekeisti savo savybių sąveikaudamas su mediena;
- būti saugus, santykinai pigus ir nekenksmingas žmogui bei aplinkai.

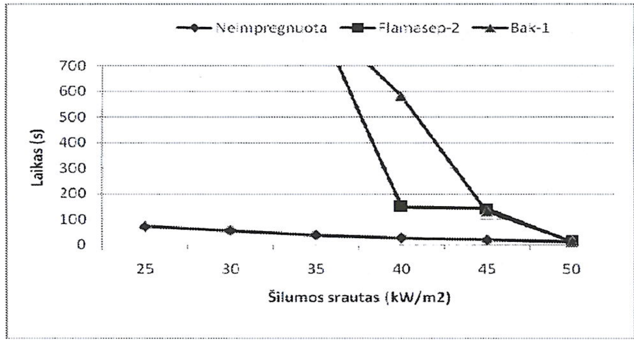
Bandymų metodika, rezultatai

Tyrimai atlikti Priešgaisrinės apsaugos ir gelbėjimo departamento prie Vidaus reikalų ministerijos Gaisrinių tyrimų centro laboratorijoje. Tyrimų įranga ir bandymo eiga atitinka LST ISO 5657:1999 standarto „Reagavimo į ugnį bandymai – statybinių gaminių užsidegimas veikiant juos šilumine spinduliuote“ reikalavimus.

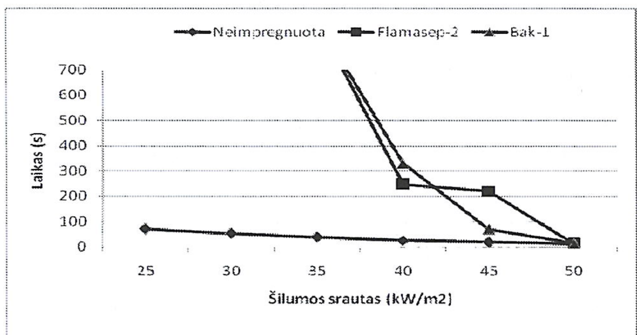
Tyrimams naudota pušies ir eglės mediena, padengta antipireniniais tirpalais *Flamasepas-2* ir *BAK-1*. Tyrimai atlikti bandinius veikiant skirtingais šilumos srautais. Jei praėjus 900 sekundžių nuo bandymo pradžios bandinys neužsiliepsnodavo, bandymas būdavo nutraukiamas. Laikas iki bandinių užsiliepsnojimo, atsižvelgiant į šilumos srauto dydį, pateiktas lentelėje. Antipireninių tirpalų efektyvumas vertinamas pagal laiką iki bandinio užsiliepsnojimo. Pušies ir eglės medienos bandinių laikas iki užsiliepsnojimo, atsižvelgiant į šilumos srauto dydį ir antipireninį tirpalą, pateiktas 1 ir 2 paveiksluose.

Pušies ir eglės medienos bandinių tyrimo rezultatai

Šilumos srautas, kW/m^2	Neimpregnuota		Flamasepas-2		BAK-1	
	pušis	eglė	pušis	eglė	pušis	eglė
	laikas iki užsiliepsnojimo, s		laikas iki užsiliepsnojimo, s		laikas iki užsiliepsnojimo, s	
25	72	71	>900	>900	>900	>900
30	56	53	>900	>900	>900	>900
35	39	38	>900	>900	>900	>900
40	27	25	148	248	583	330
45	19	19	141	220	132	70
50	13	12	13	12	15	14



1 pav. Pušies medienos bandinių laikas iki užsiliepsnojimo atsižvelgiant į šilumos srauto dydį ir antipireninį tirpalą



2 pav. Eglės medienos bandinių laikas iki užsiliepsnojimo atsižvelgiant į šilumos srauto dydį ir antipireninį tirpalą

Išvados

1. Impregnavus pušies ir eglės medienos bandinius antipireniniais tirpalais *Flamasepas-2* ir *BAK-1*, esant nedidesniam kaip 35 kW/m^2 šilumos srautui, laikas iki užsiliepsnojimo, palyginti su neimpregnuotais pušies ir eglės bandiniais, pailgėja daugiau kaip 15 kartų.

2. Antipireninių tirpalų efektyvumas vienodas iki 35 kW/m^2 šilumos srauto, neatsižvelgiant į medienos rūšį. Šiuo atveju laikas iki užsiliepsnojimo didesnis kaip 900 s.

3. Didėjant šilumos srautui antipireninių tirpalų efektyvumas mažėja:

3.1. Esant 40 kW/m^2 šilumos srautui, pušies medienos bandinių, impregnuotų antipireniniu tirpalu *BAK-1*, laikas iki užsiliepsnojimo, palyginti su pušies medienos bandinių, impregnuotų antipireniniu tirpalu *Flamasepas-2*, laiku, yra vidutiniškai 4 kartus ilgesnis.

3.2. Esant 40 kW/m^2 šilumos srautui antipireninių tirpalų *Flamasepas-2* ir *BAK-1* efektyvumas eglės medienos bandiniams yra panašus.

3.3. Esant 45 kW/m^2 šilumos srautui, eglės medienos bandinių, impregnuotų antipireniniu tirpalu *Flamasepas-2,* laikas iki užsiliepsnojimo, palyginti su eglės medienos bandinių, impregnuotų antipireniniu tirpalu *BAK-1*, laiku, yra vidutiniškai 3 kartus ilgesnis. Esant toms pačioms sąlygoms antipireninių tirpalų *Flamasepas-2* ir *BAK-1* efektyvumas pušies medienos bandiniams yra panašus.

3.4. Esant 50 kW/m^2 šilumos srautui, mediena užsiliepsnoja greičiau nei per 15 s. t. y., antipireniniai tirpalai yra neveiksmingi.

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THE RESEARCH OF THE EFFECTIVENESS OF FIRE-RETARDANT SOLUTIONS CERTIFICATED IN LITHUANIA

Z. Karpovič

Summary

This article discusses the mechanisms of action of fire-retardant solutions, their qualities and timber surface impregnation. The article analyses the effectiveness, dependence on the heat stream and timber type of fire-retardant solutions certificated in Lithuania, namely - Flamasepas-2 and BAK-1. The timber chosen for the research is spruce and pine for their incidence in wood constructions production. The research was performed according to the requirements of the standard LST ISO 5657:1999 "Reaction to fire tests - ignibility of building products using a radiant heat source", determining time until the flaming of the specimen.

STATYBINĖS KONSTRUKCIJOS

Konferencijos „Statybinės konstrukcijos“, įvykusios Vilniuje 2009 m. vasario 6 d., straipsnių rinkinys

GELŽBETONINIŲ ELEMENTŲ NORMALINIŲ PLYŠIŲ PLOČIO SKAIČIAVIMO METODŲ YPATUMAI

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Anotacija. Remiantis eksperimentinių gelžbetoninių sijų (be išankstinio armatūros įtempimo) ir surenkamų gelžbetoninių perdangos bei stogo briaunotų plokščių tyrimų duomenimis pagal skirtingas metodikas apskaičiuotas atsivėrusių normalinių plyšių plotis tempiamosios armatūros lygyje. Skaičiavimo rezultatai palyginti su išmatuotais per tyrimus plyšių pločiais. Atlikta analizė parodė, kad pagal Lietuvoje galiojantį statybos techninį reglamentą ir euronormas beveik vienodai įvertinamas normalinių plyšių atsivėrimas. Pagal Rusijos projektavimo normų metodiką apskaičiuotos plyšių pločio vertės yra daug didesnės. Pateikta plyšio parametrų tarpusavio priklausomybė gali būti panaudota apskaičiuojant plyšių atsivėrimą ar nustatant neutraliosios ašies padėtį elemento skerspjūvyje, kai atliekami konstrukcijų būklės tyrimai ir vertinimas.

Įvadas

Visose Europos Sąjungos šalyse, taip pat ir Lietuvoje, 2010 m. numatoma įteisinti naujas bendras statybinių konstrukcijų projektavimo normas. Lyginant su šiuo metu veikiančiomis gelžbetoninių konstrukcijų projektavimo normomis (STR 2.05.05:2005) būsimose naujose projektavimo normose EC-2 (Marčiukaitis *et al.* 2007) numatomos skirtingos, ypač tikrinant konstrukcijų tinkamumo ribinius būvius, skaičiavimo metodikos.

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11-osios Lietuvos jaunųjų mokslininkų konferencijos
„Mokslas – Lietuvos ateitis“

2008 metų teminės konferencijos

Statyba

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Vilnius „Technika“ 2008

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Vi-76

11-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis", 2008 metų teminės konferencijos STATYBA, įvykusios Vilniuje 2008 m. balandžio 2–4 d., straipsnių rinkinys. Vilnius: Technika, 2008. 636 p.

Leidinyje pateikta pranešimų, skaitytų jaunųjų mokslininkų konferencijoje (sekcija „Statyba"), įvykusioje Vilniuje 2008 m. balandžio 2–4 d., medžiaga. Pagrindinės konferencijos pranešimų temos – pastatų ir statinių konstrukcijų projektavimas; statybinių konstrukcijų skaičiavimo metodai; statybinės medžiagos ir jų technologija; konstrukcijų optimizavimas ir skaičiavimo metodai; sprendimų priėmimas statyboje; kokybės valdymas; statybos vadyba ir ekonomika; pastatų ūkio valdymas; pastatų ir konstrukcijų gaisrinė sauga; ergonominiai tyrimai ir žmonių sauga.

Knygos leidybą rėmė Lietuvos valstybinis mokslo ir studijų fondas

VGTU leidyklos „Technika" 1516-M mokslo literatūros knyga

ISBN 978-9955-28-319-5

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GAISRO VEIKIAMOS MEDINĖS KONSTRUKCIJOS PAŽEIDŽIAMUMO FUNKCIJOS SUDARYMAS

V. Juocevičius

Santrauka

Atsitiktiniai gaisrai pastatuose ir jų sukelti pažeidimai yra sunkiai nuspėjami ir neapibrėžti reiškiniai. Šiame straipsnyje aprašytas gaisro veikiamos masyvios medinės konstrukcijos pažeidžiamumo funkcijos sudarymo metodas. Pažeidžiamumo funkcija leido susieti tikimybinio gaisro modeliavimo rezultatus su konstrukcijos pažaidos tikimybe. Sijos pažeidžiamumo funkcija sumodeliuota pagrindiniu kintamuoju, naudojant medienos apanglėjimo gylį.

11-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis", įvykusios Vilniuje 2008 m. balandžio 2–4 d., straipsnių rinkinys

ANTIPIRENŲ APSAUGINIŲ SAVYBIŲ PALYGINIMAS

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Anotacija. Didžioji dalis kaimo gyventojų gyvena mediniuose pastatuose, dauguma ūkinių pastatų taip pat yra mediniai. Dabartinė mada ir tendencijos krypsta į senovinį stilių, o vis populiarėjantis kaimo turizmas skatina kuo plačiau naudoti medieną. Medienos naudingumą ir platų panaudojimą statyboje daugiausia nulemia medienos fizikinės savybės, leidžiančios naudoti ją konstrukciniams bei apdailos tikslams. Be daugybės medienos privalumų, yra svarbus trūkumas, kuris riboja medinių konstrukcijų naudojimą – tai degumas, keliantis gaisrų pavojų. Siekiant išvengti šio pavojaus, naudojamos cheminės priemonės nuo ugnies poveikio – antipirenai. Cheminė medienos apsauga – tai procesas, kurio metu cheminiai junginiai, turintys apsauginių nuo ugnies savybių, įsunkiami į medieną. Kokybiškas medinių konstrukcijų ir kitų medinių gaminių impregnavimas antipirenais kilus gaisrui leidžia išsaugoti iki 75 % materialinių vertybių.

Įvadas

Mediena statyboje yra svarbi ir vertinama. Iki XIV a. pradžios mediena Europoje buvo bene vienintelė statybinė medžiaga. Tik nedaugelis aukštų pastatų, pavyzdžiui, Romoje, buvo statomi iš akmens. Dėl naikinančių, dažnai pasikartojančių gaisrų laikui bėgant miestų statyboje medienos imta naudoti mažiau (Wojciechowski 1957). Mūsų laikais didžioji dalis kaimo gyventojų įsikūrę mediniuose pastatuose, dauguma ūkinių pastatų taip pat yra mediniai. Dabartinė mada ir tendencijos krypsta į senovinį stilių, o populiarėjant kaimo turizmui medienos naudojama vis daugiau. Medienos naudingumą ir platų panaudojimą statyboje daugiausia lemia medienos fizikinės savybės, leidžiančios visapusiškai ją naudoti konstrukciniams bei apdailos tikslams. Plačiai naudojami ir iš medienos arba jos atliekų pagaminti dirbiniai.

Šalia daugybės medienos privalumų yra ir labai svarbus trūkumas, kuris riboja medinių konstrukcijų naudojimą – tai didelis jų degumas, keliantis gaisrų pavojų. Siekiant sumažinti ar sulėtinti medienos degumą, naudojamos nuo ugnies poveikio apsaugančios cheminės priemonės – antipirenai, kurių veikimas pagrįstas laiko iki degimo reakcijos kilimo pailginimu ir šilumos išsiskyrimo spartos sumažinimu (Szczepanska, Jaskolowski 1998).

Cheminė medienos apsauga – procesas, kurio metu cheminiai junginiai, turintys apsauginių nuo ugnies savybių, įsunkiami į medieną (giluminio impregnavimo metodai) arba mediena jais padengiama (paviršinio impregnavimo metodai). Medinių konstrukcijų, medienos dirbinių apsauga nuo degimo, antipirenų, impregnavimo būdų ir jų kokybės analizė turi didelę reikšmę norint išspręsti problemą, susijusią su racionaliu medienos panaudojimu statyboje (Кондратьев *et al.* 1976).

Ekonomė antipirenų nauda leidinyje „Белорусская ассоцыацыя пожарных, 1996“ atskleidžiama pabrėžiant, kad kokybiškas medinių konstrukcijų ir kitų medinių gaminių impregnavimas antipirenais gaisro metu leidžia išsaugoti iki 75 % materialinių vertybių. Priemonės kokybės priklauso ne tiek nuo impregnavimo būdo, kiek nuo antipireno sudėties ir jo įmirkymo į medieną kokybės. Tas pats šaltinis nurodo, kad, taikant pažangiausias technologijas sukūrus antipirenus ir kokybiškai jais impregnuojant, didžiausią medienos atsparumą ugniai galima pasiekti ne tik giluminio impregnavimo metodais, kurie, remiantis (Bednarek, Kaliszuk-Wietecka 2004), net iki 20 % (slėginis vakuuminis metodas) pablogina medienos mechanines savybes, bet ir paviršinio impregnavimo metodais, kurie yra universalesni, pigesni ir galimi tiesiog statybos aikštelėje, apdorojant jau sumontuotas medines konstrukcijas.

Atlikti šie laboratoriniai tyrimai:

1. Dviejų rūšių medienos (pušies, eglės), dažniausiai naudojamos Lietuvos statybose, bandinių paviršinis impregnavimas Lietuvoje sertifikuotais ir prekiaujamais antipirenais.
2. Neimpregnuotų ir impregnuotų bandinių veikimas šilumos srautu, siekiant nustatyti laiką, per kurį bandiniai užsiliepsnos, o kartu ir antipirenų efektyvumą.

Gauti rezultatai bus naudingi tolesniems tyrimams, modeliuojant medienos apdorojimo antipirenais kokybės nustatymo būdus ir palaikant poveikio kokybę bėgant laikui.

Bandiniai, antipirenai

Pušies ir eglės bandiniai buvo padengti keturiais skirtingais antipireniniais tirpalais. Du iš šių tirpalų sertifikuoti, juos galima įsigyti Lietuvos rinkoje, kiti du bandomieji/palyginamieji pagaminti Priešgaisrinės apsaugos ir gelbėjimo departamento prie Vidaus reikalų ministerijos Gaisrinių tyrimų centre (toliau – GTC). Naudotų bandymuose sertifikuotų ir nesertifikuotų antipirenų charakteristikos pateikiamos 1, 2, 3 lentelėse.

1 lentelė. Bandinių charakteristikos (Drysdale 1998; Szczepanska 1994)

Mediena	Pušis	Eglė
Matmenys	150×140×25 mm	150×120×25 mm
Antipirenu padengtas plotas (m^2)	0,021	0,018
Antipireno sąnaudos (ml)	10,5	9
Tūrio masė (kg/m^3)	475	415
Užsiliepsnojimo temperatūra (°C)	360	360

2 lentelė. Klasifikuotų antipirenų charakteristikos

	BAK-1	*Flamasepas-2*
Gamintojas	UAB „Kovadis“	UAB „Retrorega“
Paskirtis	Antipireninis, antiseptinis tirpalas	Antipireninis tirpalas
Naudojimo sritis	Statybinės gyvenamųjų, ūkinių ir visuomeninių pastatų stogų medinės konstrukcijos, kurios yra pastatų viduje arba kitaip apsaugotos nuo atmosferos kritulių	Statybinės gyvenamųjų, ūkinių ir visuomeninių pastatų stogų medinės konstrukcijos. Medienai, neapsaugotai nuo kritulių, naudoti nerekomenduojama
Naudojimo būdas	Mirkymo, užtepimo, purškimo būdas. Dengiama 2–3 kartus, su ne mažesnė kaip 1 val. pertrauka. Mirkimo laikas ne mažesnis kaip 7 val. Preparato sunaudojama ne mažiau kaip 500 ml/m^2. Medienos drėgnumas neturi viršyti 30 %.	Dengiama 3 kartus teptuku, voleliu, purkštuvu arba mirkoma. Preparato neturi būti sunaudojama mažiau kaip 500 ml/m^2. Medienos drėgnumas neturi viršyti 30 %
Veikimas	Susiformuoja 5–10 mm storio puri, elastinga danga, kuri ne mažiau kaip 5 min. stabdo medienos degimą ir įsiliepsnojimą	Paviršiuje susidaro 8–10 mm storio puta, stabdanti ugnies plitimą
Degumo klasė	B-s 1, d 0 pagal LST EN 13501-1:2002	B-s 2, d 0 pagal LST EN 13501-1:2002
Tankis	1,303 g/cm^3	1,312 g/cm^3
pH	-	12–13

3 lentelė. Neklasifikuotų antipirenų charakteristikos

	Karbamidas, 30 %	Amonio sulfato 10 %, diamonio fosfato 20 % mišinys
Gamintojas	GTC	GTC
Paskirtis	Antipireninis tirpalas	Antipireninis tirpalas
Naudojimo būdas	Neturi būti sunaudojama mažiau kaip 500 ml/m^2	Neturi būti sunaudojama mažiau kaip 500 ml/m^2
Tankis	1,082 g/cm^3	1,177 g/cm^3
pH	7,45	5,84

Bandiniai antipirenais padengti tepimo būdu (teptuku). Siekiant įvertinti nepalankiausią situaciją (laiko taupymas statybų aikštelėje), mediena antipirenu buvo padengta tik vieną kartą (antipireno sąnaudos atitinka gamintojo reikalavimus).

Kritinio šilumos srauto tankio nustatymas

Bandymai buvo atlikti GTC laboratorijoje. Bandymų įranga ir bandymo eiga atitinka LST ISO 5657:1999 standarto „Reagavimo į ugnį bandymai – statybinių gaminių užsidegimas veikiant juos šilumine spinduliuote“ reikalavimus.

Bandymų įranga leido nustatyti laiką, per kurį neapsaugoti ir skirtingais antipirenais apsaugoti bandiniai, esant tam pačiam šilumos srautui, užsiliepsnoja nuo trumpalaikio papildomo degiklio poveikio.

Bandymai buvo atliekami su skirtingos medienos (pušies, eglės) skirtingais antipireniniais tirpalais (*BAK-1*, *Flamasepas-2*, karbamidu, amonio sulfato ir diamonio fosfato mišiniu) padengtais bandiniais. Siekiant nustatyti antipirenų veiksmingumą, pirmieji bandymai atlikti su bandiniais, neapsaugotais antipirenais. Visi bandiniai į bandymo prietaisą buvo įdėti vienodai, jų drėgnumas neviršijo 20 %. Bandymai atlikti esant vienam šilumos srautui (apie 20 kW/m^2). Rezultatai pateikiami 4 lentelėje.

4 lentelė. Bandymų, atliktų esant vienam šilumos srautui, rezultatai

Bandymai	Bandiniai	Bandymai	Bandiniai
1A-2A	pušis	1B-2B	eglė
3A-4A	(pušis) *BAK-1*	3B-4B	(eglė) *BAK-1*
5A-6A	(pušis) *Flamasepas-2*	5B-6B	(eglė) *Flamasepas-2*
7A-8A	(pušis) *karbamidas*	7B-8B	(eglė) *karbamidas*
9A-10A	(pušis) amonio sulfato, diamonio fosfato mišinys	9B-10B	(eglė) amonio sulfato, diamonio fosfato mišinys

Rezultatai

Atliktų bandymų rezultatai pateikiami lentelėje. Jie išdėstyti pagal bandinių laiko iki užsiliepsnojimo didėjimą (5 lentelė).

5 lentelė. Bandymų rezultatai

Pušis				Eglė			
Bandymas	*Paviršiaus temperatūra, °C*	*Laikas iki užsiliepsnojimo, s*	*Masės netektis, %*	*Bandymas*	*Paviršiaus temperatūra, °C*	*Laikas iki užsiliepsnojimo, s*	*Masės netektis, %*
1A-2A	337	134	2,7	1B-2B	350	102	2,2
3A-4A	350	134	3,2	7B-8B	340	102	1,7
7A-8A	335	140	1,9	3B-4B	415	151	4,5
9A-10A	370	300	5,3	9B-10B	405	178	3,4
5A-6A	402	387	5,6	5B-6B	498	215	5,6

Neapsaugoti antipirenais pušies bandiniai (1A-2A bandymai) nuo trumpalaikio papildomo degiklio poveikio užsiliepsnodavo vidutiniškai po 134 s, paviršiui pasiekus 337 °C temperatūrą. Analogiški eglės bandiniai (1B-2B bandymai), esant toms pačioms sąlygoms, užsiliepsnodavo po 102 s, paviršiui pasiekus 350 °C temperatūrą.

3A-4A bandymuose bandiniai užsiliepsnojo po tiek pat laiko kaip ir 1A-2A bandymuose, vidutiniškai 13 °C padidėjo užsiliepsnojimo temperatūra.

7B-8B bandymuose bandiniai užsiliepsnojo po tiek pat laiko kaip ir 1B-2B bandymuose, vidutiniškai 10 °C padidėjo užsiliepsnojimo temperatūra.

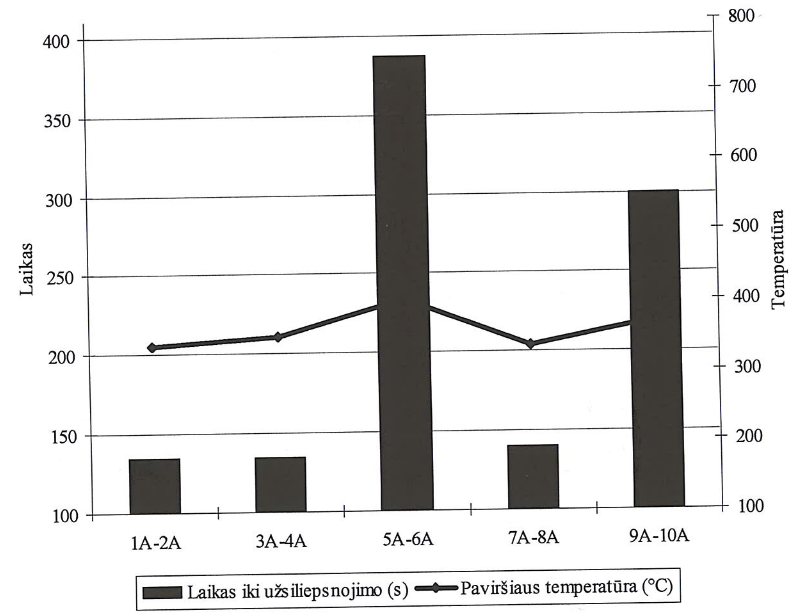
7A-8A, 3B-4B bandymuose bandiniai užsiliepsnojo vidutiniškai po 140 ir 151 s, paviršiui pasiekus 335 ir 415 °C temperatūrą.

9A-10A ir 9B-10B bandymuose bandiniai užsiliepsnojo vidutiniškai po 300 ir 178 s, paviršiui pasiekus 370 ir 405 °C temperatūrą.

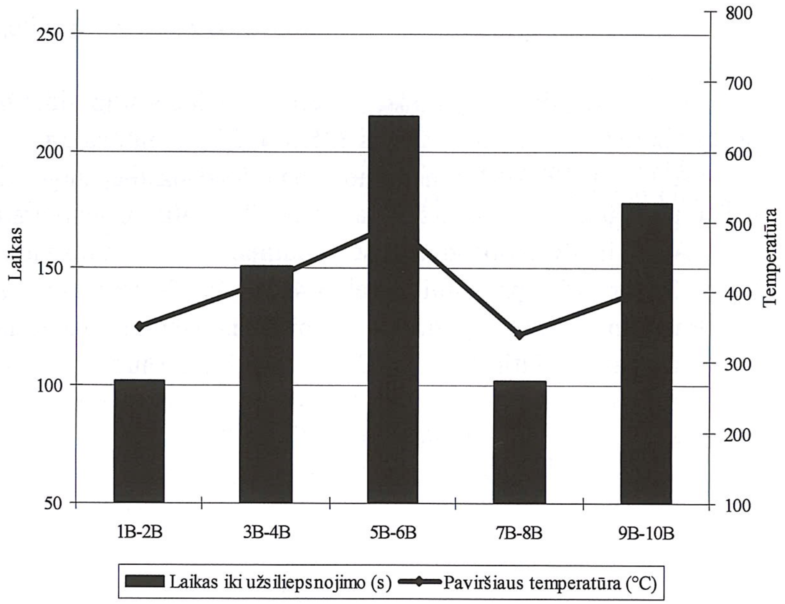
5A-6A ir 5B-6B bandymuose bandiniai užsiliepsnojo vidutiniškai po 387 ir 215 s, paviršiui pasiekus 402 ir 498 °C temperatūrą.

Bandymo metu neapsaugotų antipirenais bandinių masės netektis svyruodavo vidutiniškai nuo 2,2 iki 2,7 %, apsaugotų sertifikuotais antipirenais bandinių – nuo 3,2 iki 5,6 %, apsaugotų ne sertifikuotais antipirenais bandinių – nuo 1,7 iki 5,3 %.

Bandymų rezultatai grafiniu būdu pateikiami 1 ir 2 paveiksluose.



1 pav. Bandymų su pušies medienos bandiniais rezultatai



2 pav. Bandymų su eglės medienos bandiniais rezultatai

Išvados

1. Atlikus bandymus galima teigti, kad antipirenas BAK-1 (mediena padengta nesilaikant gamintojo rekomendacijų) nepailgina pušies medienos arba iki 50 % pailgina eglės medienos laiką iki užsiliepsnojimo nuo trumpalaikio papildomo degiklio poveikio.

2. Antipirenas Flamasepas-2 (mediena padengta nesilaikant gamintojo rekomendacijų) iki 3 kartų pailgina laika iki užsiliepsnojimo nuo trumpalaikio papildomo degiklio poveikio pušies medienos ir iki 2 kartų – eglės medienos.

3. GTC pagamintas nesertifikuotas karbamido antipireninis tirpalas pasižymi labai silpnomis antipireninėmis savybėmis. Šio tirpalo apsauginės savybės panašios į sertifikuoto antipireno BAK-1 apsaugines savybes.

4. GTC pagamintas nesertifikuotas amoniosulfato ir diamoniofosfato antipireninis tirpalas, palyginti su sertifikuotu antipirenu Flamasepas-2, pasižymi geromis antipireninėmis savybėmis, t. y. iki 2 kartų pailgino pušies ir eglės medienos bandinių laiką iki užsiliepsnojimo.

5. Bandymų rezultatai parodė, kad tik vienas iš dviejų sertifikuotų antipireninių tirpalų (antipirenai buvo naudojami nesilaikant gamintojo rekomendacijų) pasižymi geromis nuo ugnies apsaugančiomis savybėmis.

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COMPARISON OF FIRE RETARDANTS PROTECTIVE FEATURES

Z. Karpovič

Summary

Nowadays most of architectural the people in the country live in timbered buildings, the major part of buildings are also made of wood. Current fashion and tendency turns to old style and increased popularity of countryside tourism and leads to increased timber usage. The main physical features of timber determine its wide usage in constructions, which let use it in constructional and decoration matters. In addition to plenty of advantages of timber usage, there is a great disadvantage, which restrains the usage of wooden constructions, that's the risk of fire. Aiming at limiting its negative feature in the field of fire danger and spread, chemical sources against fire effect – antipyrens (fire retardant) are used. Chemical timber protection, that's the process in which chemical compound featured with combustion protective characteristics is soaked into timber. Qualitative impregnation of wooden construction and other wooden products with antypirens, in case of the fire, lets safe until 75 % of tangible property.

11-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis", įvykusios Vilniuje 2008 m. balandžio 2–4 d., straipsnių rinkinys

SELECTION FROM ALTERNATIVE PROJECTS OF BUILDING CONSTRUCTION USING RELIABILITY MEASURES

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Abstract. The paper describes an example of combined application of Multi Criteria Decision Making (MCDM) and reliability analysis. It is concerned with a comparative planning and arranging of building construction process. Reliability of alternative construction plans is taken as an attribute used in MCDM. Various normalisation methods and decision-making criteria are applied to solving the problem considered in the example. It is shown that introducing a reliability measure into the MCDM problem requires to specify numerical input information for this problem.

Problem

The organization of construction processes is often faced with the need of selecting between several technological solutions. A formal framework for such selecting is provided by the general methodology known as MCDM. In the present paper, the best alternative a^* between three building construction projects a_1, a_2, and a_3 is to be chosen. The building under consideration is a 9-storey wall frame dwelling house with roughly 65m × 65m in a plan. The projects a_1, a_2, and a_3 are represented by three construction cycle charts (CCCs). Two CCCs are shown in Fig. 1.