# Methods for Evaluation of Firefighting Capacity of Microencapsulated Halon 21711 and Fire-extinguishing Gas Act-45 Tapes

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***Abstract.*** **Human security is one of the main tasks of the fire protection system; great attention should be devoted to situations, where evacuation is not possible and extinguishing gas leak takes place. It is, therefore, important to study the firefighting efficiency of gases, their toxicity and impact on living organisms and the environment in general. The studies carried out showed that at the early stage of fire the microencapsulated gas bands free of ozone-depletion potential are the most effective means of fighting fire in small, enclosed spaces.**

***Keywords:*** **Extinguishing gases, fire safety, gas microencapsulated tapes, halon.**

## I. Introduction

### A. Basic Firefighting Principles, Using Extinguishing Gases

Combustion is an exothermic oxidation reaction of a combustible substance, where usually flame and smoke are released [8] (see Fig. 1).

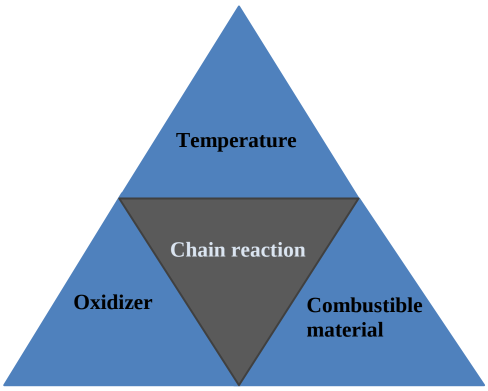


Fig. 1. Combustion process framework.

To stop the combustion process, it is necessary to hamper one of the burning chain reaction components, thereby disrupting this reaction. There are four basic firefighting principles:

- cooling;
- insulation;
- dilution;
- chemical inhibition (braking).

Various fixed gas fire-extinguishing systems perform at once several of these fire-extinguishing types, thereby increasing their efficiency ratio and safety. Most often this occurs in systems, where one of fluorinated hydrocarbon gases is used; it both affects the combustion chain reaction and escapes into protected volume (room) and, thus, reduces its overall temperature [12], [16].

Cooling – a rate of any chemical reaction, including burning, – is dependent on temperature. This dependence is subject to Van't-Hoff equation (see Eq. 1) [13]:

$$V2 = V1 \times t\ (T2-T1) / 10 \qquad (1)$$

where t – the temperature coefficient, which takes the value of 2–4;

T2 – the starting temperature, °C;

T1 – the final temperature, °C.

From this equation it is possible to determine that upon temperature reduction by 10°C the reaction rate will reduce by 2–4 times. This reduction in a chain reaction is very important, because it develops in an avalanche-type manner and also descends in the same way. Therefore, rapid cooling can lead to a complete stop in the combustion process.

**Insulation** – a combustion reaction does not involve the object or substance itself but rather the gaseous products, which move from this substance to the combustion area. They may be the vapors of this product or substance or also its breakdown products (primary combustion products). But at the same time the burning progress requires a constant influx of oxygen since if it is suspended, the combustion reaction will stop. This method is not used in gas extinguishing systems since the oxygen concentration is reduced and it is not simple to isolate oxygen.

**Dilution** – in the atmosphere there is only about 21% of oxygen. Other atmospheric components are unable to maintain combustion but they participate in the gas exchange process within the phase separation limits, competing with oxygen. Therefore, to stop the fire it is not necessary to isolate all oxygen from the fire place, it is sufficient to reduce its concentration to 12%, which is no longer able to ensure the continuation of burning.

**Chemical inhibition (retarding)** – it is a chemical reaction that makes the main reaction slow down.

During the burning process the number of the active particles, radicals, is growing in an avalanche-type manner.

Oxygen impact upon hydrocarbons results in the formation of two active particles-radicals. Each of the particles attacks the neutral hydrocarbon molecule to create two radicals, and the chain reaction is started. Further, if an inhibitor is introduced in the reaction zone, such as trifluormethane known as HFC-23, its reaction with the radical destroys it and creates two neutral molecules. In this way, the number of active particles in the reaction zone decreases, which means that the reaction goes down.

**Extinguishing gas selection criteria**

Depending on the principle of extinguishing, gases are divided into two groups: inert gases (air diluents) and chemical agents [11].

1) Inert gases – this group comprises classic inert gases, such as nitrogen N2, argon Ar, mixtures thereof, as well as hydrogen dioxide – CO2.

2) Chemical agents – this group includes halogenated hydrocarbons and fluoro-substituted hydrocarbons. In recent years, in many countries, including the European Union, halons are prohibited in relation to environment protection (they cause ozone depletion) [4], [5], and currently only fluoro-substituted hydrocarbons are used.

Extinguishing efficiency – in case of early fire detection all fixed gas fire protection systems can be considered equally effective. Extinguishing efficiencies of firefighting gases differ when applied to extinguish different classes of fire [6], [7].

**Human safety –** its assurance is one of the main tasks in fixed fire protection systems. In addition to the organizational and technical measures (early detection, warning and evacuation), attention should be devoted to the safety of persons when for some reason evacuation is not possible and extinguishing gas leak took place. Therefore, the impact of various gases on living organisms is studied in cases when inflammation took place and when did not.

Gas extinguishing system toxicity – this factor features the physicochemical impact of gas fire protection systems upon living organisms. The lowest toxicity is inherent in inert gases (nitrogen, argon, inergen); the least harmful of chemical agents is HFC-23. At the same time, high toxicity is inherent in CO2. It is explained by the fact that living organisms (including people) have a specific mechanism of CO2 impact upon the respiratory regulation processes. Even at 2% concentration tachypnea appears, while 5% concentration causes severe disorders in respiratory regulators, leading to death [13].

Different extinguishing agents have different efficient firefighting capacity concentrations. Manufacturers emphasize that CO2 (about 8%) in their composition due to faster breathing ensures that people stay safe in the premises. Oxygen quantity in premises, where inert gas emission took place (usually at 45–50% concentration), will amount to approximately 13%. It corresponds to the amount of oxygen in the atmosphere at 4.5–5 km altitude. In case of appropriate release of extinguishing agents, the air composition changes within 30–60 seconds. In such cases, a human being usually is at risk of rapid asphyxia. Oxygen concentration of 12.3% is the level of expected 100% of asphyxia. It is, therefore, unlikely that rapid breathing will help an ordinary person in these situations [16], [17], [18].

**Preservation of values** – in this aspect all gas systems demonstrate equally good results.

**Technological effectiveness** – as the economic issue is important enough in the selection of a fire protection system, the assessment of its technological effectiveness could be employed as the main criterion of the system compactness, that is, the quantity of extinguishing agent, number of bottles and pressure in the system. The higher each of these indicators, the more difficult it is to install and maintain such a system. In terms of compactness, chemical agent systems and Novec 1230 system are preferred [13].

**Environment protection** – usually users and customers do not pay particular attention to this issue as the main selection criteria are the price and efficiency. However, the authorities should certainly think about it and implement standards. Ecological hazard is assessed by ozone depletion potential indicators and global warming potential indicators.

Ozone depletion potential of almost all extinguishing gases in use today is zero in most countries of the world. However, some of extinguishing gases still have a high global warming potential, which causes the greenhouse effect, for example, extinguishing agents HFC-125, HFC-227ea, HFC-23 [13]. Extinguishing gas ozone depletion potential indicator should be equal to zero.

## II. Microencapsulated Halon 21711 Tape Parameters and Firefighting Capacity Evaluation Method

In experiments of the practical part, the authors used the microencapsulated halon tapes with the following characteristics: self-adhesive 2.5 cm wide, 20 cm long tape with the embedded microcapsules of Halon 21711.

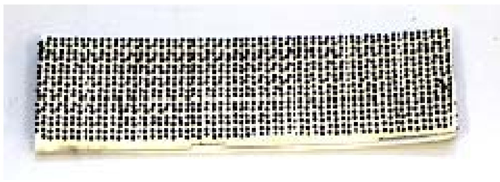

Fig. 2. Microencapsulated halon self-adhesive tape.

Under effect of temperature (approximately 130 °C), the tape releases halon. Extinguishing principle of halon is based on inhibition of the combustion reaction. Once in the combustion zone, this gas quickly dissolves to form free radicals, which come into contact with the combustion products and develop with them chemical reactions that make the combustion reaction slow down and eventually stop burning.

### *A. Development of Testing Method*

The method for evaluation of firefighting capacity of microencapsulated extinguishing gas tape in enclosed space volume was developed at the Fire Testing Laboratory of Fire Safety and Civil Protection College, the Department of Applied Research. To assess the firefighting capacity of the tape, the expected tape application site was chosen, as well as the model fire that would correspond to the type of tape application.

TABLE I

AMOUNT OF EQUIPMENT AND MATERIALS USED IN TESTING

| **Equipment and materials used** | **Q-ty** |
|---|---|
| Metal power distribution cabinet (33 x 28 x 10) cm, inner volume is 9240 cm$^3$, with a glazed door and the following openings: 2 openings made at upper edge, each of 5.5 mm in a diameter, the total area of upper edge openings together with openings in a rear wall is 118 mm$^2$ ; 6 cable mounting openings at lower edge, each of 22 mm in adiameter, of which three are filled with seals, one is filled with electric lighter, two openings are filled partially about 50%, the total area of unclosed openings of lower edge is 400 mm$^2$; the total area of openings in power distribution cabinet is 518 mm$^2$ . | 1 piece |
| Metal power distribution cabinet (56 x 40 x 17) cm, inner volume is 38080 cm$^3$, with a glazed door and the following openings: 4 openings made at upper edge, each of 6.5 mm, the total area of upper edge openings is 26 mm$^2$; top and bottom openings between a rear wall and cabinet housing. Top opening is 3 mm*320 mm; bottom opening is 5 mm* 320 mm. Total area of openings is 2550 mm$^2$; 9 cable mounting openings at lower edge, each of 6.5 mm; the total area of lower edge openings is 58.5 mm$^2$; the total area of openings in a power distribution cabinet is 2644.5 mm$^2$. | 1 piece |
| Cabinet holder | 1 piece |
| Fire test model holder | 1 piece |
| Electric lighter | 1 piece |
| Thermoelectric converter | 3 pcs |
| Computer with signal converter EBW-1 | 1 piece |
| Scales | 1 piece |
| Mechanical chronometer | 1 piece |
| Fire test model materials | 1000 g |
| Barometer | 1 piece |
| Thermohygrograph, type 874E No. 659.01 | 1 piece |
| Measuring ruler 30 cm | 1 piece |
| Seals | 10 pcs |
| Rotameter | 1 piece |
| Gas burner | 1 piece |

Upon agreement with the manufacturer, a power distribution cabinet was specified as one of anticipated places for end use of the band. The electric installation cable КРПТ-4* 6mm2 was chosen as a fire model. Since the manufacturer of the product had not made any testing, it was not possible to assess the efficiency of the tape firefighting capacity in a distribution cabinet of particular volume. In order to evaluate the efficiency of the tape firefighting capacity, the tape was provided in two volume distribution cabinets with the following volumes: 9240 cm3 and 38 088 cm3. When developing the method it was taken into account that the larger volume cabinets had higher fire load, so that in the smaller cabinet the average amount of combustible material ranged from 4.1 to 4.7 g, while in the second cabinet the average amount of combustible material comprised 33 g. To more accurately evaluate the firefighting capacity efficiency, about 10 tests in each distribution cabinet were carried out at the laboratory; during these tests it was found that in the smaller cabinet the combustible material burnt for an average 6–11 minutes to complete extinction, while in the bigger cabinet – for 8–9 minutes to complete extinction. To prove the firefighting capacity efficiency of the tape, it would be necessary to significantly reduce the independent burning time of the combustible material in the distribution cabinet.

**Objective of testing** – to identify the firefighting capacity of microencapsulated halon adhesive tape (on the fire test model of certain size and fire load) in a closed room volume with natural ventilation.

**Equipment and materials** – the amount of equipment and the materials used for testing are presented in Table I. Schematic drawing of equipment as well as layout of temperature measuring devices is depicted in Fig. 3.

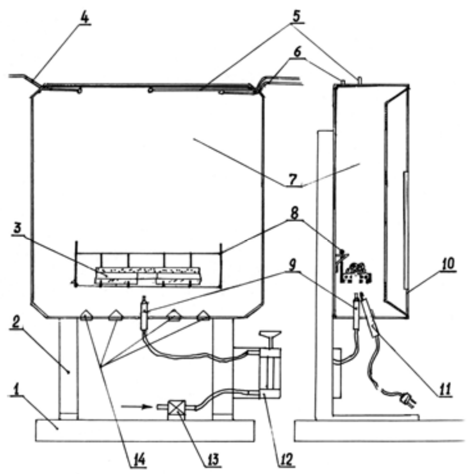


Fig. 3. Firefighting capacity determination installation:

1 – a bed, 2 – a distribution cabinet holder, 3 – fire test model materials, 4, 5, 6 – thermoelectric converters (hereinafter referred to as 4-T1; 5-T2; 6-T3), 7 – a distribution cabinet, 8 – a fire test model material holder, 9 – a gas burner, 10 – a cabinet door, 11 – electrical lighters, 12 – a rotameter, 13 – a gas supply burner, 14 – cuffs.

**Preparation for testing:**

• firefighting capacity determination installation is placed in a fume hood;

• prior to tests the samples of the tape and combustible material are weighed;

• before tests 2, 3, 4, the microencapsulated halon self-adhesive tape is placed in the distribution cabinet;

• thermoelectric converter T1 is placed and fastened in the middle of the cabinet upper edge;

• thermoelectric converter T2 is placed and fastened in the centre of the cabinet upper edge – closer to the rear edge; thermoelectric converter T3 is placed in the centre of the cabinet upper edge – closer to the front edge and the cabinet door;

• thermoelectric converters are connected to a computer with EBW signal converter - 1, which records temperature and creates graphs;

• fire test model is placed in the cabinet on the holder.

**Testing procedure, test 1:**

• turn on a computer with EBW signal converter to create a temperature–time curve;

• close glass doors of the cabinet;

• turn on the electric lighter and simultaneously start the timer;

• turn off the electrical lighter during independent combustion of fire test model.

**During the test, the following observations are recorded:**

• combustible material ignition time (t1);

• 140 °C reaching time at all thermoelectric converters (t140);

• maximum achieved temperature at the upper cabinet wall (Tmax);

• fire test model flame burning time.

When the test is finished, the firefighting determination installation should be prepared for subsequent tests. Distribution cabinet is cleaned from combustion products, wiped with alcohol moistened cotton swabs and dried.

**Testing procedure, tests 2, 3, 4**

• preparation for testing is carried out in accordance with requirements.

• during the tests, the operations described in the procedure for test 1 are performed.

**During the test, the following observations are recorded**:

• combustible material ignition time (t1);

• 140 °C reaching time at all thermoelectric converters (t140);

• maximum achieved temperature at the upper cabinet wall (Tmax);

• microcapsule operation start time (ts);

• the nature of combustion, as well as all its changes throughout the test (burning with flame, without flame, fire model material melting, etc.);

• time when the nature of burning changes;

• time of temperature changes;

• temperature changes at thermoelectric converters at T1, T2, T3.

**Operations to be carried out after the test:**

• tape samples and combustible material shall be weighed.

• when the test is finished, the firefighting determination installation should be prepared for subsequent tests. Distribution cabinet is cleaned from combustion products, wiped with alcohol moistened cotton swabs and dried.

• the obtained measurements are reflected in a temperature–time curve for each thermoelectric converter individually, but together with respective results of experiment 1.

• if no temperature changes were observed during the test, the tests should be continued with a larger number of tape samples.

• if temperature changes were observed during the test, this test should be repeated 2 more times.

• the test results shall be documented in the report.

## III. Microencapsulated Fire Extinguishing Gas Tape "Act 45" Parameters and Firefighting Capacity Evaluation Method

Pyrosticker is a thin and flexible strip with a self-adhesive surface on one side and microencapsulated extinguishing gas on the second, see Fig. 4.

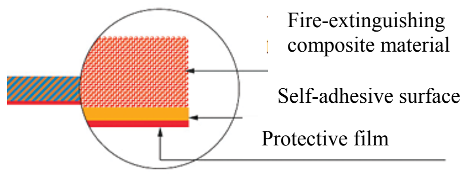


Fig. 4. Microencapsulated fire-extinguishing gas tape, cross-section [14].

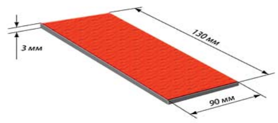

Fig. 5. Microencapsulated fire-extinguishing gas tape, dimensions [14].

Depending on the volume of protected space, dimensions of the tape also vary, but these values are small enough to be used in power cabinets, computer enclosures, server enclosures and other small electrical devices. Active components of fire-extinguishing gas consist of high-efficiency extinguishing substance (mixture of polyfluorobromomethane isomers, where the total gross composition is occupied by C – 9%, F – 29%, Br – 62%), which is placed into microcapsules: micron-sized polymer shells [9].

The base of microencapsulated fire-extinguishing gas tape is flexible, which allows placing this tape in hard-to-reach places. The tape has a relatively low weight, ensuring its easy transportation. According to the tape manufacturer's information, the fire-extinguishing substance starts releasing from the tape at about 100 °C. Direct exposure to flame to the full extent is ensured by the required temperature [10], [11].

TABLE II

EQUIPMENT AND MATERIALS USED IN TESTING

| Equipment and materials used | Q-ty |
|---|---|
| Power distribution cabinet, 565 x 410 x 190 mm, volume of 44 l | 1 piece |
| Testing pallets of fire-resistant material (ceramics), 150 x 60 x 30 mm | 2 pcs |
| Fire model, A Class fire accident – telephone wire harness of TRP type, twin conductor, conductor diameter of 0.4 mm, with PET insulation or equivalent combustible material. Wire harness consists of 9 m wires twisted 45 times and fixed by 0.4 mm wire from both sides of the harness. Harness size may not exceed 100x100x30 mm. Fixing of wires in the harness is also allowable by means of plastic clip | 9 m |
| Ignition source: gas burner with working temperature of 1000 °C | 1 piece |
| Non-automatic electronic scales, accuracy of 0.01 g | 1 piece |
| Mechanical chronometer, precision Class 2 | 1 piece |
| Thermometer, the range from 0 °C to +100 °C | 1 piece |
| Measuring ruler, 0 to 300 mm | 1 piece |
| Measuring ruler, 0 to 1000 mm | 1 piece |
| Thermoelectric converter, K type | 3 pcs |
| Computer with EBW-1 signal converter | 1 piece |
| Anemometer, the range from 0.4 to 30 m/s | 1 piece |
| Barometer | 1 piece |
| Thermohygrograph | 1 piece |

The tape is a fully autonomous device that does not require power supply and charging, as well as the gas therein used does not harm electrical equipment and other electrical components of the protected object [15].

Under normal circumstances, the fire-extinguishing gas composition can be stored in capsules completely isolated from the environment, not evaporating for years and maintaining the readiness for firefighting at any time. Optimum operating temperature of the tape ranges from -40 to 40 °C. It is designed for the extinguishing of fire of the following classes: A, B, C, and E. In the practical tests, the tape designed for protection of 45 l enclosed volume was used.

### A. *Method of Testing*

To evaluate the firefighting capacity of microencapsulated fire-extinguishing gas tape, a testing method of the tape manufacturer was used and adapted in accordance with capabilities of Fire Testing Laboratory of the Chair of Fire Safety and Civil Protection at the Fire Safety and Civil Protection College.

The methodology was provided for testing in a power distribution cabinet with a volume of 38088 cm3, 45 litres.

**Testing conditions:**

Tests were carried out with three samples of microencapsulated fire-extinguishing gas tapes ACT-45. Under normal conditions, the tests are carried at:

• ambient air temperature of 20 ± 5°C;

• relative air humidity of 45–80%;

• atmospheric pressure of 84 to 106.7 kPa; mm Hg 630–800; air speed not exceeding 1 m/s.

• the place of tests shall be equipped with a ventilation system. Cable outlets (3 technological openings in a diameter of 35 mm at the bottom part of the panel) should be open.

**Test preparation procedures:**

• check the product expiration date.

• check if there is no visible external damage.

• outer surface of the product may not be dirty.

**Testing procedure:**

• Active fire-extinguishing agent of microencapsulated fire-extinguishing gas tape ACT-45 is placed horizontally in the middle of the upper cover inside the protected object, active layer downwards.

• Protected object is mounted vertically on a pallet. Cable ducts at the bottom part of the object should allow free air inflow. In the working conditions, the object door must be closed.

• Fire model is positioned vertically in the middle of the protected object rear wall, at 100 ± 20 mm distance from the top cover of the protected object and at 30 mm distance from the rear wall of the protected object.

• Fire model is fastened to the protected object rear wall behind the top of the wire harness.

For the purpose of fixing the temperature at different locations, 3 thermoelectric current converters are installed in the distribution box:

• thermoelectric converter location – 250 x 370 x 100 mm (height x length x width);

• thermoelectric converter location – 480 x 370 x 100 mm (height x length x width);

• thermoelectric converter location – 520 x 205 x 60 mm (height x length x width).

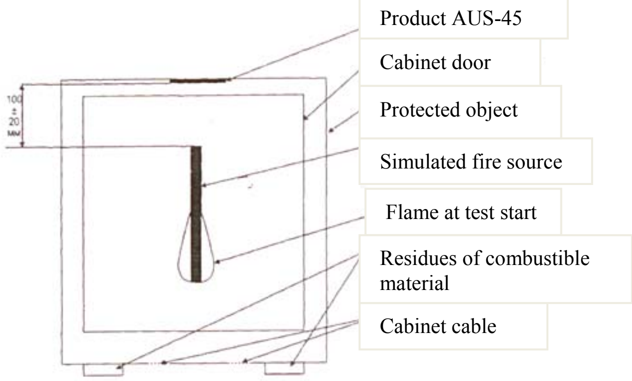


Fig. 6. General layout of the protected model and fire model.

Test without a microencapsulated fire-extinguishing gas tape:

• Test without the microdevice is carried out not installing the product in the protected object. The fire model is ignited outside the distribution cabinet within 30 seconds from one end by means of ignition source. After that the fire model is fastened inside the protected object with its burning end downwards, and the cabinet door is closed. The test is terminated 3 minutes after the fire model stops burning with a flame. Results of test without the microdevice are considered positive if the fire model combustion degree is not less than 90%.

Fire model combustion degree is calculated using (2):

$$S= \frac{M1 - M2}{Md} x\ 100\% \qquad (2)$$

where S – the object combustion degree;
M1 – the object mass before the test, g;
M2 – the object mass after the test, g;
Md – the object mass, g.

**Test with a microencapsulated fire-extinguishing gas tape:**

• test with a microencapsulated fire-extinguishing gas tape is carried out, when positive results are obtained without the microdevice. The protected object is completely cleaned from residues of previous combustion process.

**Test result processing conditions:**

• test results are considered positive if the fire is extinguished at fire model combustion degree not exceeding 30%;

• test results are considered positive if during 3 minutes after extinguishing the inflammation does not happen again;

• tests result are considered positive upon positive results of test without the microdevice and subsequent 3 tests with the microdevice.

• fire model is ignited outside the distribution cabinet within 30 seconds from one end by means of ignition source. After that the fire model is fastened inside the protected object with its burning end downwards, and the cabinet door is closed.

• the test is stopped within 3 minutes after the fire model dies out. The test is repeated 3 times.

• data obtained from thermoelectric converters during the test are fixed in a computer by means of a recording device. Fire model combustion degree is obtained from test results by Equation 2.1.

**Labour safety requirements:**

• tests should be carried out with observance of safety engineering, fire safety, sanitary requirements as well as testing methodology.

## IV. Conclusions

1. Gas fire-extinguishing systems with halon as usable fire-extinguishing gas are efficient, but their application is prohibited by the legislation of the European Union and of Latvia as its member state.

2. European Union market offers gas fire-extinguishing systems with different types of fire-extinguishing gases equivalent to halon in firefighting efficiency but free of ozone-depletion effect and, therefore, usable without harm to the environment.

3. Examining the legal framework that defines requirements for gas fire-extinguishing systems, the authors conclude that the series of standards LVS EN 15004 “Fixed firefighting systems. Gas fire-extinguishing systems”, parts 1 to 9, is only available in English. This series of standards sets out requirements for the design of gas fire-extinguishing systems [10].

4. In closed-type space – household power distribution cabinet (volume 9240 cm3), therein placed microencapsulated halon tape sample with area of 25 cm2 reduces the time of fire model independent burning by average of 5–6 minutes and stops the fire in about 1:30 minutes after ignition.

5. In repeated tests on the same sample of microencapsulated halon tape its base does not withstand the direct impact of flame and starts melting after the third usage time as a result of which its calorific effect contributes to further development of burning in a closed-type space.

6. In closed-type space – household power distribution cabinet (volume 38080 cm3), therein placed microencapsulated halon tape sample with area of 50 cm2, reduces the time of fire model independent burning by average of 5–6 minutes and stops the fire in about 3 minutes after ignition.

7. Tests with microencapsulated halon proved that a new approach to application of fire-extinguishing gases was efficient and usable – substituting halon prohibited in the EU for other fire-extinguishing gases allowed in the EU.

8. Microencapsulated fire-extinguishing gas tape samples with the area of 117 cm2 (length 13 cm, width 9 cm) do not have enough extinguishing compound to extinguish the fire model in a closed-type space with volume of 38080 cm3.

9. Microencapsulated gas tapes cannot be used as the sole fixed fire-extinguishing system but can be used as a fire-fighting means for the extinguishing of early-stage fire in a small closed-type space volume. Use of such tapes could possibly restrict the fire growth and reduce damages caused by fire.

10. Laboratory tests proved that the firefighting capacity efficiency of fire-extinguishing gases was high not only in their application with fire extinguishing systems but also in other physical conditions of fire-extinguishing gas – in microencapsulated form.

11. Tests with microencapsulated gas proved that the firefighting capacity efficiency was significantly influenced by the following factors: manufacturing process technology, type of usable fire-extinguishing gas, voume of protected space, fire development curve (temperature–time curve), number and size of applied microencapsulated fire-extinguishing gas tapes.

12. Test results demonstrated the need for in-depth studies and laboratory tests in order to find out the most effective type of microencapsulated fire-extinguishing gases, as well as investigate the factors that adversely affect the firefighting

capacity of tapes to allow the tape manufacturer to more accurately control the production process in order to prevent the production of low-quality tapes.

## V. Proposals

1. In order to design buildings in the Republic of Latvia in compliance with the requirements of effective construction standards (LBN 201-10 “Fire safety of structures”) [1], it is necessary to translate and register in the Standardization Bureau of LLC “Standardization, Accreditation and Metrology Centre”, in accordance with the established procedure, Latvian versions of LVS EN 15004 “Fixed firefighting systems. Gas fire-extinguishing systems” series standards.

2. Tests with microencapsulated halon have proven that a new approach to application of fire-extinguishing gases is efficient and usable but it is necessary to substitute halon prohibited in the EU for other fire-extinguishing gases allowed in the EU.

3. Microencapsulated gas tapes cannot be used as the sole fixed fire-extinguishing system but can be used as a fire-fighting means for the extinguishing of early-stage fire in a small closed-type space volume. Use of such tapes could possibly restrict the fire growth and reduce damage caused by fire.

4. Unsuccessful results of laboratory test have demonstrated the need for further tests on microencapsulated fire-extinguishing gas tapes, changing and varying the applied gases and their application types and places in order to possibly obtain, with time, new, efficient products that could reduce damage caused by fire.

Test results have demonstrated the need for in-depth studies and laboratory tests in order to find out factors that adversely affect the firefighting capacity of tapes to allow the tape manufacturer to more accurately control the production process in order to prevent the production of low-quality tapes.

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