



Verification of the combustion process of selected technical materials

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ABSTRACT: This paper deals with the practical verification of the combustion process of selected technical materials. The proposed experiment answers some questions regarding the behavior of these materials during their exposure to direct fire and after its extinction. Experimental device enables you to analyze the release of harmful combustion gases during burning and to conduct a study of the rate of accumulation and spread of heat as well as the possible ignition or self-ignition of these materials occurs. Based on the results of the experiments it is possible to recommend the material with the most suitable fire-safety properties for practical use under the specified conditions.

KEYWORDS: Burning, Combustion, Combustion Gases, Thermal Imager, Safety

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I. COMBUSTION PROCESS

Burning is a complex physicochemical process, the essence of which is rapid oxidation accompanied by heat release [5]. It is actually an exothermic reaction of the surface of the material with the oxidant [6]. Some flammable materials enter the reaction with oxygen directly, others after a previous thermal decomposition. One of the variables describing the behavior of materials during thermal load is the activation energy of their decomposition [7]. The heat required for thermal decomposition may be supplied by a particular external source or may be produced in a chemical, thermal, photo- or bio-oxidative way.

When burning, there is a reaction between the flammable material and the oxygen. This mixture starts to burn only when it is heated to a certain temperature [8, 9]. For starting the flame, the material must be heated to a critical degradation temperature and the release rate of the volatile products must be sufficient to achieve a combustible mixture with oxygen. The decomposition temperature, which in most synthetic carbon polymers ranges from 300°C to 500°C, affects the ignition of solids in which thermal decomposition occurs before melting.

The solid material during combustion process does not react directly with oxygen, but the heat itself prevents thermal decomposition to produce volatile products. If a mixture of volatile products is flammable, flame burning occurs under favorable conditions in contact with oxygen. Burning usually ends at a certain concentration of flammable volatile products. The carbon-enriched residue can further be oxidized by flameless burning, which is manifested by molding or heating.

II. GASEOUS COMBUSTION PRODUCTS

There are several factors affecting the quantity and type of products in combustion products:

- chemical composition of the burning matter;
- type of combustion;
- access of air;
- temperature.

In the flame burning of organic carbonaceous compounds (e.g., plastics), the combustion products always contain carbon dioxide, carbon monoxide, water vapor and oxygen, and usually also various hydrocarbons and oxygenated organic compounds. When burning nitrogen-containing polymers, hydrogen cyanide, nitriles and other nitrogenous substances are present in the combustion products. Upon burning the halogenated polymers, hydrogen chloride and hydrogen fluoride are released again.

Depending on the access of air (oxygen), the different amounts and the percentage of exhausts are formed during the combustion of the same substance. Generally speaking, when burning with sufficient oxygen access, the entire thermo degradation process leads to the formation of oxidation products. For example, the alkanes are gradually oxidized to alcohols, aldehydes, ketones, carboxylic acids and ultimately to carbon dioxide (CO₂), carbon monoxide (CO) and water. The production of carbon monoxide is suppressed in such burning, therefore the CO₂/CO ratio is high. In the absence of oxygen, the carbon is oxidized to carbon monoxide, so the CO₂/CO ratio decreases and, on the contrary, the proportion of organic "unburned" substances is increased and the substance decomposes to smaller molecules. Thermal decomposition occurs with a decreasing concentration of oxygen more toxicologically relevant since it is accompanied by the formation of toxic compounds, e.g. carbon monoxide and hydrogen cyanide.

The burning temperature also greatly affects the amount and composition of exhausts. At temperatures of 300-400 ° C, there are relatively few products, the concentration of which is low because of the intense decomposition and oxidation reactions at these temperatures. Such temperatures arise by burning in confined spaces, when oxygen is depleted, resulting in suffocation of flame or flameless fire (eg, smoulder). The exhausts resulting from the burning of polymers at such low temperatures contain a large amount of monomers substance. Most of the exhausts with the highest concentration are generated in the mid-range of the combustion temperature (400-700 ° C). Above this temperature limit, the amount and concentration of the products in the exhausts again decreases, but the proportion of substances that do not undergo thermal decomposition is increasing. As the temperature rises, the CO concentration increases.

In the event of burning, a number of gaseous products are released into the air which may endanger the health or even the life of the human being. They can be divided into three groups:

- **asphyxiates** - substances that cause anesthesia even death by suffocation (carbon monoxide and hydrogen cyanide);
- **irritants** - substances that irritate the sensory organs and the respiratory system (hydrogen chloride, aldehydes, nitrogen oxides, phosgene);
- **toxicants** - substances causing poisoning.

III. EFFECT OF COMBUSTION GASES ON THE HUMAN ORGANISM

3.1 Carbon dioxide (CO₂) is one of the products of combustion of organic materials rich in carbon, which is produced mainly by full combustion. It is a non-flammable gas without color and odor that is heavier than air. It arises in the breathing process as one of the main metabolic products. Under normal conditions there is about 0.03% CO₂ in the air. Increasing the concentration of CO₂ at 5% will take effect faster breathing, dizziness, sweating and general malaise. With CO₂ concentrations of 10-12% in the air, death may occur within a few minutes due to respiratory system paralysis in the brain.

3.2 Carbon monoxide (CO) is a colorless odorless, lighter-than-air odorless gas. Most CO is produced in the case of imperfect combustion, which produces a large amount of dense and dark smoke. Carbon monoxide binds to the red blood cell hemoglobin (Hb) to form carboxyhemoglobin (COHb), making it impossible to bind oxygen out of the air. The binding of CO to Hb occurs up to three times faster than the oxygen binding. At lower concentrations of CO in the air, the symptoms listed in Table 1 appear in humans. If the CO concentration rises above 1%, unconsciousness and sudden death of the affected person may occur without any previous symptoms. The time for symptom discovery is rapidly curtailed with increasing CO concentrations in the air. At 1% concentration, 50% COHb is generated in the blood after 2.5 - 7 minutes. If the CO concentration in the air rises to 5%, the same process takes just 30-90 seconds.

Table 1: Symptoms of carbon monoxide poisoning depending on its concentration in the air

CO[ppm]	CO in air [volume %]	Symptoms
100	0,01	any
200	0,02	mild headaches
400	0,04	severe headache after 1-2 hours
800	0,08	severe headache after 45 minutes, nausea, dizziness, unconsciousness after 2 h
1000	0,1	dangerous concentration - unconscious after 1 hour
1600	0,16	nausea, severe headache and dizziness after 20 minutes
3200	0,32	nausea, severe headache and dizziness after 5-10 minutes, unconsciousness after 30 minutes
6400	0,64	nausea, severe headache and dizziness after 1-2 minutes, unconsciousness after 10-15 minutes
12800	1,28	immediate unconsciousness, danger of death after 1-3 minutes

Legislatively determined maximum concentrations of carbon monoxide in ambient air are given in Table 2. All limit values refer to standard conditions: volume recalculated to 293 K and pressure 101.3 kPa.

Table 2: Limit values for CO and NOX in air

Purpose and time period	Limit value
Maximum daily 8-hour average	10 mg.m ⁻³ CO
Hourly limit value to protect human health	200 µg.m ⁻³ NO ₂ may not exceed more than 18 times per calendar year
Annual limit value for the protection of human health	40 µg.m ⁻³ NO ₂
Annual limit value for vegetation protection	30 µg.m ⁻³ NO _x

3.3 Among the nitrogen oxides (NOX), are the most dangerous for the human organism is nitric oxide (NO) and nitrogen dioxide (NO₂); nitrogen dioxide is formed by the oxidation of nitric oxide. It is a yellowish or reddish brown gas that is heavier than air and irritates the mucous membranes of the airways. It is mainly product of combustion process of fossil fuels, artificial fertilizers and plastics. The maximum allowable concentrations of nitrogen oxides in ambient air under standard conditions (293 ° K and 101.3 kPa) are shown in Table 2.

Up to 85% of inhaled nitrogen oxides are absorbed in the respiratory system. Nitrogen oxides damage the bronchi and pulmonary alveoli, resulting in pulmonary edema and decreased body defenses. In contact with mucous membranes, a small amount of nitrogen oxides dissolves in water to produce acids - nitric acid (HNO₂) and nitric acid (HNO₃). The toxic nitrates and nitrites are formed in the body in response to alkaline elements.

Acute poisoning with Nitrogen Oxides is manifested by conjunctivitis and upper respiratory tract irritation, coughing and chest pains. Inhalation of high concentrations of nitrogen oxides may cause up to the edema of the lungs. Immediately after inhalation, only mild symptoms (so-called latency time) occur, the poisoning itself occurs after a few hours (24 - 72 hours). Increased nitrite levels cause reversible methemoglobinemia, which is manifested by overall weakness, suffocation, cyanosis and cramps. Nitrogen oxides are excreted in the urine as nitrates.

IV. TESTING OF COMBUSTION PROCESS OF SELECTED MATERIALS

The combustion of selected technical materials can be tested in a propane-butane flame above the Bunsen burner with air supply control. After ignition of the burner, a luminous, little heat flame (a so-called reduction flame) is created. Then the burner flame is set by adding air, which is reflected by increasing the volume of the flame and also the sound (the burner starts making a noise). The outer blue convex envelope appears around the reduction cone inside. In the internal blue-green part of such an ignitable (oxidizing) flame where the combustion is imperfect, the flame temperature is lower (about 500 ° C). In the outer part with perfect combustion the temperature reaches 1 500 °

During combustion, the concentration of selected compounds is monitored and recorded in the combustion chamber space.

The experiment of the combustion process is carried out in the combustion chamber, which is a specially modified freight container (Figure 1). The inner walls and the door of the container are lined with fireproof insulation, and air suction is installed on the roof of the container.



Figure 1: Combustion chamber

The following measuring devices were used to analyze the results of the experiment:

- TESTO 330 LL flue gas analyzer;
- FLIR T620 industrial thermal imager.

4.1 Exhaust gas measurement of selected technical materials exposed to an external heat source

In addition to the flue gas analysis, the smoke development of the materials as well their ability to ignite during the set exposure time are monitored. The layout of the workspace during the experiment and the position of the measuring devices are shown in Figure 2.

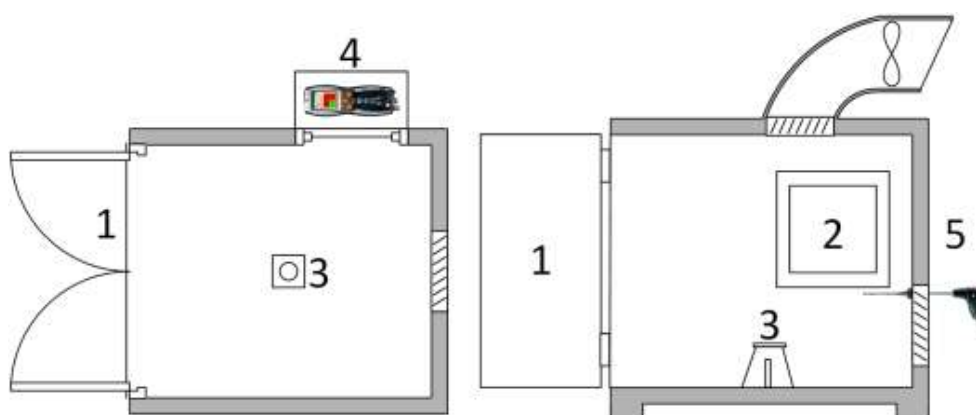


Figure 2: The layout arrangement of the workspace; entry (1), the observation window (2), gas burner (3), table with a measuring device (4), probe of the analyzer (5)

4.2 Heat dissipation in selected samples exposed to an external heat source

Dissemination of heat from an external source in the samples tested technical materials will be monitored by industrial thermal imager. During the experiment, the temperature changes occurring in individual samples of selected technical materials are monitored and recorded. In addition to heat transfer, the fumes of the materials and their ability to continue in free burning are monitored.

The layout of the workspace during the experiment and the position of the measuring devices are shown in Figure 3.

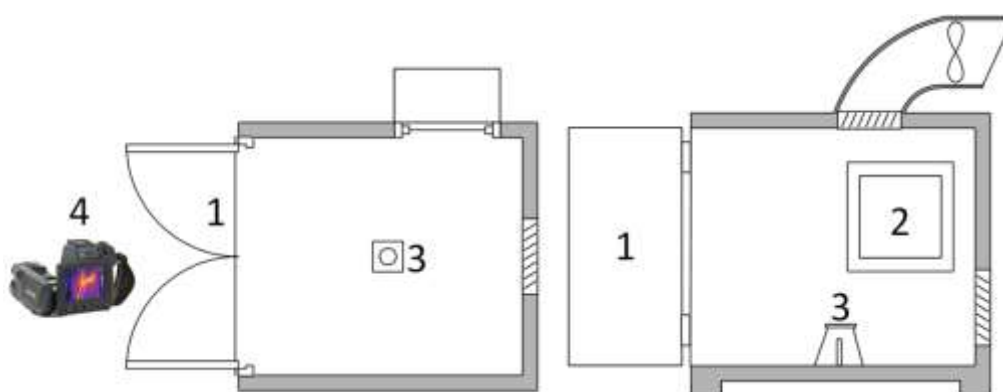


Figure 3: The layout arrangement of the workspace; entry (1), observation window (2), gas burner (3), location of thermal imager (4)

The heat dissipation in the selected sample exposed to the external heat source is shown in Figure 4.

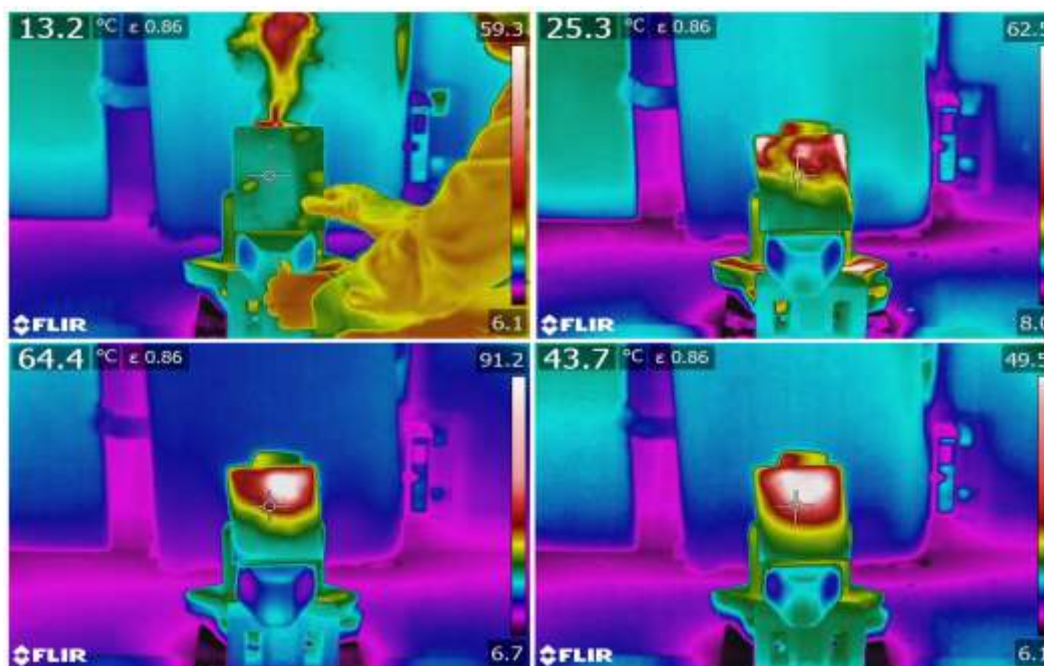


Figure 4: The heat dissipation in the selected sample

On the basis of the comparison of the measured temperatures, taking into account the thermograms of the individual samples, it is possible to select suitable technical material.

V. CONCLUSION

This paper proposes an experimental method for verifying the combustion process of selected technical materials in order to select the material with the most appropriate properties. Test samples of these materials are subjected to a combustion process in the enclosure space of the test container. As an external heat source, a laboratory burner with a propane-butane flame is used. With the TESTO 330 LL flue gas analyzer, O₂, CO₂, CO, NO and NO_x concentrations in the container area are measured during the combustion process and 180 seconds after. The combustion gases and their ability to resume free burning are monitored. From the moment of samples first contact with flame, heat transfer is recorded using the FLIR T620 industrial imager.

VI. ACKNOWLEDGEMENT

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