On ignition of combustible material in a gas explosion in the premise

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Abstract. Introduction. There are known cases of fires after gas explosions in domestic residential premises, exacerbating an already dangerous situation. Determining the conditions for the occurrence of such fires, as well as the process of behaviour of combustible materials during the short-term thermal effect of a gas explosion, allows us to hope for the possibility of reducing fire risks through research and the development of appropriate measures. Methods Experimental studies were carried out in a cubic chamber with a volume of 10 m$^3$ filled with a propane-air mixture. Explosion pressure and video inside the chamber were recorded. To assess the magnitude of the effects of flame and combustion products of a gas explosion on combustible material, specially developed indicators with a sensitive element – sheet of paper. Results. The images of sensitive elements of indicators with the level of brightness after exposure to a flame and combustion products of a gas explosion are presented. Frames from a video camera installed inside the camera are also presented. Discussion. The conditions for ignition of combustible materials are: low heat capacity, position in the volume of premise and the entry of outside air. Conclusions. It is established that combustible materials in the corners of premise are less affected by the flame and combustion products of a gas explosion. Combustible material ignites when external air enters after an explosion.

1. Introduction

Most of the incidents associated with the use of gas occur in the residential premises of residential buildings [1-3]. Among the main causes of a gas explosion are the following: gas leak, explosion of a gas cylinder, sloppy handling and rearrangement of gas equipment.

In a gas explosion, flame and high-temperature combustion products can contribute to a fire [4]. Cases of gas explosions with and without further fire are known from mass media. Obviously, the explosion, supplemented by a fire, exacerbates an already difficult situation, so there is the question about the conditions for a fire in a premise during a gas explosion. We are not aware of regulatory documents describing the conditions for the occurrence of fires during gas explosions [5–9]. Three necessary conditions for a fire are well known. The first condition is the presence of combustible material. For residential buildings, regulatory documents do not limit the use of any materials. The restrictions apply to premises where a large number of people can stay, for example, in educational institutions. The second condition is the presence of oxygen, which in any case is in the premise. The third condition is the ignition source, which can be a gas stove, incandescent lamp, etc.

One of the main indicators characterizing the fire hazard of materials is combustibility, determined by [10]. One of the criteria for assessing the fire hazard of a material and assigning it to a specific combustibility group is the degree of damage in length — ratio between the length of damage to the
material to its nominal length: the damaged part is the one that is burnt or charred. In this case, a color change is not considered to be damage, however, in [11] it is indicated that this parameter can be a result of independent propagation of the flame front by the material and, therefore, be taken into account as a sign characterizing its fire hazard.

Thus, to study the causes of the occurrence and development of a fire in a gas explosion, it is advisable to choose the material with the most hazardous characteristics and as a criterion for assessing the fire hazard - damage to the material, up to changing its color. It is assumed that the effect of flame and combustion products on combustible material located at different points of premise is not the same. The purpose of work is to evaluate the magnitude of the effect of the flame and products of the combustion of a gas explosion on combustible material at various points of the premise, and determination the ignition process of combustible material.

2. Methods
Theoretically, it is problematic to assess the magnitude of the effect of the flame and the products of combustion of a gas explosion on combustible material in relation to the volume of the room. Experimentally, it can be done with sufficient confidence, although very approximately. It is necessary to place combustible material with a known reaction to thermal influence in the studied area of the premise, which can be further determined by modeling and other methods [12-15].

The first experiment. To assess the magnitude of the effect of the flame and the products of combustion of a gas explosion on combustible material, a 10 m³ cubic chamber close in size to the kitchen premise is used, shown in Figure 1 and Figure 2.

![Figure 1. The experimental explosion in the chamber V = 10 m³.](image1)

![Figure 2. Equipment inside the chamber: fan, cables, hoses and ignition device.](image2)

Inside the chamber there were placed devices - indicators, in the amount of 35 pieces: 8 pieces in the corners, 3 pieces in the center of the chamber evenly in height, 4 pieces in the center of the discharge opening evenly in height, 5 pieces in the ceiling and 5 pieces in each wall. The indicator is a structure consisting of a sensitive element and structure - a metal ring and a bent metal strip. A sensitive element was mounted (glued) onto a metal ring. As a sensitive element, paper with a density of 80 g/m², thickness 0.1 mm, size (90x90) mm was used. General view of the indicator is shown in Figure 3. The indicators were placed in the chamber with metal staples in characteristic zones along five sections perpendicular to the axis of the Z camera. The origin of the reference system is located in the geometric center of the wall opposite from the discharge opening, the Z axis is directed toward the discharge opening, the X axis – to the left, the Y axis – to the right.
Figure 3. General view of the structure of indicator (a) and a sensitive element glued to the ring of indicator (b).

After the indicators were placed, a procedure was carried out aimed at providing an explosion: installing an ignition source in the center of the chamber, installing a reusable valve on the discharge opening of the chamber, filling the chamber volume with gas in an amount providing a stoichiometric ratio of gas and oxygen, mixing gas with oxygen using a stationary fan, ignition of the mixture – explosion. A more detailed methodology for conducting experimental explosions is given in [16–18].

After explosion, indicators were removed from the chamber, sensitive elements were removed from the structures. Sensitive elements were scanned and converted into electronic images. Using the Adobe Photoshop software, the resulting image was divided into pixels, and the brightness of each pixel in the range from 0 to 255 was determined (where 0 is an absolutely dark, 255 is an absolutely bright). Based on the results of calculating the brightness level of each pixel, the average brightness value of the image of the sensitive element was determined.

The second experiment. To determine the moment of ignition of the sensitive element of the indicator, a Xiaomi Yi Action camera was used. Unlike the work [19], camera was installed inside the chamber and was aimed at one of the indicators mounted on the ceiling of the chamber. A hinged window was installed in the discharge opening, the wings of which were opened wide open during a gas explosion. Camera turned on, then a procedure was carried out aimed to providing an explosion.

3. Results

As a result of the effect of the flame and the products of combustion, the surface of the sensitive element was damaged and lost the brightness. Six indicators with sensitive elements that were not completely burned were located in all corners of the chamber except the upper ones located on the wall opposite to the discharge opening. Other indicators didn’t have sensitive elements. There are practically no traces of damage on the surviving sensitive elements of the indicators at the place of gluing the paper onto the steel ring. Table 1 presents images of the surviving sensitive elements of the indicators, and the average value of the brightness.

The hinged window installed in the discharge opening in the second experiment is shown in Figure 4. The pressure curve during the explosion is shown in Figure 5. Selected frames from the video camera are shown in Figure 6. The readings of camera and the pressure in chamber are synchronized.

On the frames in the interval from 5 to 124 ms, the flame front is a spherical shape. A white rectangle is visible in the upper part of the frame - a sensitive element of the indicator, to which the flame front approaches at 124 ms, already in a turbulent form. At the 250 ms, when the burning is still ongoing, and the opening of the window has already occurred, the sensitive element of the indicator remains intact. By the 333 ms in the chamber, active combustion almost ends and the mixture burns out in its corners, the pressure becomes lower than atmospheric, and the implosion stage begins. By the 417 ms, fires burn out, it becomes dark in the chamber. Further in time, the gas in the chamber becomes transparent, combustion stops completely, and by the time 833 ms the indicator paper flashes. It is clearly seen that the sensitive element does not ignite either in the flame front or in the environment of hot combustion products, but only lights up with the onset of the implosion stage, with the entry of external air into the chamber. At the end of the experiment, the operability of the equipment inside the chamber was checked. It was found that the equipment was not damaged and can be used in subsequent experiments.
Table 1. Sensitive elements of the indicators

| Indicator coordinate in chamber (x,y,z), m | (1.05 -1.05 2.0) | (1.05 1.05 2.0) | (1.05 1.05 0.1) |
|------------------------------------------|------------------|-----------------|------------------|
| Image of sensitive element               | ![Image 1]        | ![Image 2]       | ![Image 3]       |
| Average value of brightness from 0 to 255| 98               | 134             | 173              |
| Indicator coordinate in chamber (x,y,z), m | (-1.05 -1.05 2.0) | (-1.05 1.05 2.0) | (-1.05 1.05 0.1) |
| Image of sensitive element               | ![Image 4]        | ![Image 5]       | ![Image 6]       |
| Average value of brightness from 0 to 255| 75               | 131             | 107              |

Figure 4. Hinged window inserted into the chamber opening.

Figure 5. Course of the pressure curve during the explosion: A — the moment the window was opened.
4. Discussion
The complete combustion of the sensitive elements of the indicators can be explained as follows: the flame propagates from the center of the chamber in all directions and, first of all, to the exit from it, therefore, the interaction time of the combustion products and combustible material between the center and the discharge opening is the longest. It is also known that the flame propagates up faster than down, due to the action of the forces of Archimedes, therefore, at the highest points in the chamber, the values of heat fluxes are greater [20]. The flame comes last to the corners of the chamber when combustion ends and pressure begins to drop. At this time, the implosion stage begins, during which the outside air enters the chamber and cools the gas in it.

Partial damage of the sensitive elements of the indicators after the explosion can be explained by the following: the temperature of gases developed during the explosion is much higher than that during which combustible materials ignite, but the time of exposure to the flame and combustion products is very limited. Combustible material has time to cool until it has received outside air. The same applies to equipment inside the chamber, which consists of combustible materials, which, according to regulatory documents, can ignite and burn, however, it did not happen.

The absence of damage traces at the place of gluing on the ring of indicators of sensitive elements can be explained by the following: the heat capacity of the metal is sufficient so as not to heat up itself and to prevent the paper sample from heating through the adhesive layer.

According to the camera frames, the nature of the interaction of gases in an explosion with a sensitive indicator element (combustible material) can be divided into four stages. At the first stage, the combustible material interacts with the initial mixture of gases. At the second stage, the
combustible material interacts with the high-temperature flame front, at which it is heated, but not yet sufficient for ignition. At the third stage, the gases following the flame front have a high temperature and warm the combustible material to a temperature higher than the ignition temperature, but there is no oxygen. At the fourth stage, outside air enters the chamber, followed by ignition of the combustible material.

5. Conclusions
In a gas explosion in a chamber that is close in scale to real household premises, combustible materials located in the corners of a premise that is close in size to real, with the exception of the lower corners of the wall opposite the opening, are less affected by the flame and combustion products of a gas explosion than combustible materials located on the walls, ceiling, in the center of the chamber and in the center of the discharge opening. Combustible materials located in the lower corners of the wall on which discharge opening is located are more exposed to flames and products of combustion of a gas explosion than materials located in the upper corners of the room.

During a gas explosion in the zone of flame and combustion products, only carbonization (pyrolysis) of combustible materials can occur, and its ignition can occur only at the stage of implosion, when external air enters the premise. Also, ignition of a combustible material is possible only if its heat capacity is sufficiently small. The equipment located in the chamber: the fan, hoses and wires remain operable after exposure to flames and combustion products of a gas explosion.

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