Gas-air mixture explosion behaviour research at different temperatures

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Abstract. This article discusses gas-air mixture explosion properties depending on its initial parameters. Authors use the heat flow control sensor to obtain the most dangerous concentration range at normal and low temperatures. The dependences of heat flux changes at initial moment of explosion under different conditions are analyzed. The survey setup was a plastic bag filled with a gas mixture. Experiments were carried out with (without) holding the substance and with (without) using the turbulators. The reliability of acquired data was assessed by running a tenfold repetition of each test bench under identical meteorological conditions.

1. Introduction
Currently, methods have been developed [1] for determining the dynamics of an explosion in the natural environment of gas-air mixtures under the so-called "normal conditions". However, the effect of low temperatures [2] on the development of the explosion process, at an early stage of the course, is rather poorly studied. In this regard, the study of the effect of low temperatures on the dynamics of explosion and combustion of a gas-air mixture during intensive development of fields in the Far North, associated with high risks [3-4], becomes an urgent problem.

It should be noted that high-molecular compounds of natural gas at extremely low ambient temperatures, they remain in a liquefied state, and low-molecular-weight organic compounds, including ethers, evaporate into the atmosphere, the spread of the flame through which occurs at a faster rate than under normal conditions. This work will be devoted to the study of the effect of low temperatures on the parameters of an explosion of a gas-air mixture by fixing the value of the heat flux (hereinafter referred to as HF).

2. Materials and methods
The heat flow control sensor (hereinafter referred to as HFCS) was chosen as a fixing device, the technical capabilities and parameters of which are presented in the patent [5], and are also described in detail in [6-8].

To obtain experimental data using the above equipment, a schematic diagram of the test bench was developed (figure 1).
Figure 1. Schematic block diagram of the test bench.

The experiment is based on a twenty-meter polyethylene two-layer sleeve (made in the form of a pipe) with sealed ends (1). The pipe diameter is taken equal to 1 m, the wall thickness is 1 mm.

Pre-calibrated HFCSs (according to the method described in [8]) were installed at an equal distance (figure 1), and eight points of fixation of heat flux values were formed (hereinafter - Points 1 ... 8).

With the help of a compressor (8), atmospheric air flows through a gas hose (4) and a temperature-compensated diaphragm gas flow meter (5) from one of the ends into a polyethylene sleeve (pipe) until the walls are tensioned.

Through the adjacent gas hose, in parallel with the supply of atmospheric air, in order to form a homogeneous medium in the hose line, natural gas is supplied (6). The combustion initialization source (2) was placed in the hose line and the hose was sealed.

The arm volume was 15.7 m³ and was constant. For the experimental setup, it was decided to carry out the explosion reaction with a step of 1.5% of the gas volume. The summary table 1 shows the values of air and gas.

| Table 1. Numerical value of GAM concentration. |
| Serial number | Gas concentration | Oxygen concentration |
| %            | m³              | %      | m³     |
|---------------|------------------|--------|--------|
| 1             | 2                | 0.31   | 98     | 15.39  |
| 2             | 3.5              | 0.55   | 96.5   | 15.15  |
| 3             | 5                | 0.79   | 95     | 14.92  |
| 4             | 6.5              | 1.02   | 93.5   | 14.68  |
| 5             | 8                | 1.26   | 92     | 14.44  |
| 6             | 9.5              | 1.49   | 90.5   | 14.21  |

The following conditions of the experiment were chosen as a result of the analysis of meteorological data:
- for revealing the dynamics of the explosion, the interval of temperature readings was taken from +30 °C to -42 °C (as low as possible);
- for each the test unit temperature step is 10 °C;
- minimum wind (or calm), no precipitation;
• daytime only, taking into account the features of the fixation equipment (including high-speed video cameras).

Each test consisted of five realizations of the explosion by triggering a combustion initiation source according to table 2.

**Table 2.** Conducting a GAM explosion.

| Explosion option no. | Explosive limit (%) | Clarification |
|----------------------|---------------------|---------------|
| Option 1             | 2.0                 | Identical numerical values were obtained in versions of 3.5 and 5.0 %, therefore, the concentration limit of explosiveness of 5.0% is not taken into account |
| Option 2             | 3.5                 |               |
| Option 3             | 6.5                 |               |
| Option 4             | 8.0                 |               |
| Option 5             | 9.5                 |               |

Taking into account the possibility of covering the entire probable range of temperature readings of the environment, weather conditions were selected. To increase the measurement accuracy, the following characteristics were taken into account:

• wind direction and speed (m / s) are minimal (calm);

• no precipitation.

The experiments were carried out in summer and winter for three types of initial conditions:

1. After filling the volume of the sleeve with a gas-air mixture for the formation of a homogeneous mixture and separation of the gas into fractions (only at negative temperatures), an exposure is carried out for 600 s;

2. After filling the volume of the sleeve with a gas-air mixture, exposure is not performed (instantaneous detonation of the volume occurs);

3. The turbulators are installed in the volume of the sleeve, and after it is filled with a gas-air mixture, detonation is performed without holding.

In the first case, after the formation of a cloud with a combustible component present in it in a mixture with an oxidizer in a certain concentration range, as a rule, an explosion of gas-air mixtures follows. The dynamics of the combustion process of the gas mixture and the parameters of the shock wave are determined outside the explosive cloud by the physical and technical properties of the hot water supply, the volume and shape of the cloud at the moment of the explosion, as well as by the place of the explosion (at the edge or centre of the cloud).

When holding the gas-air mixture, it is separated by fractional condensation. As a result, there is an enrichment with relatively less volatile (high boiling) components, and uncondensed steam - with more volatile (low boiling) components. To a greater extent, due to this, the “burning” of the lower fraction and an instant increment (explosion) of the upper one occurs, therefore, the power of the explosion increases [9].

In the second case, without holding the gas-air mixture, its separation into fractions does not occur. Due to this, a deflagration explosion occurs [10].
The power of the deflagration explosion in the latter case increases significantly [11] and it can be concluded that at a production facility of the oil and gas complex, in the event of an emergency, in a residential area (falling under the explosion zone) or in the presence of structures and buildings near the source of the accident, the affected area will increase.

### 3. Results and discussion

The performed block of experiments was implemented at the concentrations indicated in table 2, which is the lower and upper concentration limit (hereinafter - CL). It should be noted that at a negative temperature, the maximum value of the heat flux is shifted to the range of limits close to the upper CL. Closer to the middle of the CL interval - at positive temperatures, the value. Concentration 8.0%, as can be seen from figure 5, has the most powerful nature of the explosion.

The experimental dependences of the HF values are shown in figure 6; they were obtained for concentrations of 2% and 8%. As you can see, at the initial moment of time, the values of heat flux differ by more than 3 times.
Figure 6. Experimental HFCS data obtained at gas concentrations of 8.0 and 2.0% of the main volume of the sleeve.

The distribution of HF values for a concentration value of 8% for various temperature regimes is shown in the diagram below.

Figure 7. Dependence of the data obtained at Point 1 on temperature.

The averaged picture of the change in the magnitude of the heat flux over time over all fixed points for the boundary values of the observed temperature interval is presented in the following graph.

Figure 8. Experimental data on TP values obtained at temperatures of -42 °C and +30 °C (concentration 8.0%).
The reliability of the HFCS readings was assessed by the ratio of a tenfold repetition of each test bench under identical meteorological conditions (air humidity, ambient temperature, wind speed and presence), identical concentration of the gas-air mixture [12-13] and determining the relative and absolute errors. Using computers "Advanced Grapher" and "Excel" were calculated: correlation coefficient, standard deviation, average approximation error and regression coefficient.

The values of the random error of the measurement result are determined by the formula (1) for n observations (the method of the mean square error is taken as a basis).

\[
S_n = \sqrt{\frac{\sum_{i=1}^{n} (\bar{x}_i - x_i)^2}{n-1}}
\]  

(1)

where \( \bar{x} \) is the arithmetic mean of the indicator;
\( n \) is the number of observations;
\( x_i \) are the results of observations.

The average value of each of the indicator was determined by formula (2) as the arithmetic mean of the obtained observation results:

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i
\]

(2)

As the difference between the arithmetic mean of each of the indicators and the value obtained during a separate observation \( x_{\text{obs}} \) the absolute error of the considered device is determined:

\[
\Delta x_i = |\bar{x} - x_{\text{obs}}|
\]

(3)

The relative error is defined as the ratio of the mean square error to the arithmetic mean of the indicators:

\[
\varepsilon = \frac{1}{n} \sum_{i=1}^{n} \frac{\Delta x_i}{x} \cdot 100\%
\]

(4)

To establish a random error, data are needed in terms of the confidence interval and the value of the confidence probability, which estimates the value of the reliability of the obtained values. In measurements, one can restrict oneself to the confidence probability \( \alpha = 0.95 \), which corresponds to the confidence interval in fractions of \( \omega = 2.0 \). For measurements of the indicators of each observation at the corresponding test temperature, the confidence interval is determined by the formula:

\[
\Delta x_i = S_n \cdot \omega
\]

(5)

For ten observations, the statistical processing of the results with the indication of the confidence interval is presented in the following graph:
Figure 9. Dependences of the heat flux power of the gas-air mixture (W / m²) on the time of the explosion process at a temperature of + 30 °C (the number of repetitions of the experiment - 10).

For other temperatures, similar results were obtained.

4. Conclusions

Thus, in the course of the work, the concentration limits of the explosiveness of the gas-air mixture at negative ambient temperatures, representing the greatest danger, were determined. Also, the authors have revealed the regularities of the course of explosion processes at various initial parameters of temperature and concentration of the environment. The results of the study are planned to be used, including modelling an explosion of a gas-air mixture in a closed volume and analysing the fire hazard of the main line of gas pipelines.

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