Study of the combustion process of flammable liquids in open areas and its impact on the environment

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Abstract. The combustion of flammable substances in an open area negatively affects the environment and environmental safety. Emissions of harmful substances, including carbon dioxide and nitrogen oxides, pollute the atmosphere, threatening air quality and contributing to the greenhouse effect. Combustion of flammable liquids also entails contamination of soil and water resources, with a negative impact on the natural environment. Fires and accidents are associated with threats to the environment and society. Studies of the dynamics of the combustion temperature of flammable liquids have identified three main stages: flame propagation, combustion during evaporation of the liquid, and combustion during boiling of the liquid. The experimental data obtained have the potential for environmental assessment and improvement of models that predict emissions parameters and their impact on natural ecosystems, and calculations of heat flows that have a detrimental effect on the environment. These data can also be used to estimate the heat flux generated by the combustion of hydrocarbons in open air, a key parameter for environmental impact assessment. Research has made significant contributions to the field of environmental safety, helping to reduce risks to ecosystems and reduce negative impacts on the environment.

1 Introduction

Experimental study of the combustion of flammable liquids in an open area plays an important role in science and practice, providing a deep understanding of this process and having significant applied significance in the field of environmental safety, environmental damage assessment and, especially, emergency response [1-5]. This study also contributes to the formation of a database of scientific research results for the combustion of various types of substances, which is a necessary component for the creation and analysis of reliable models and methods for predicting the consequences of emergency situations and environmental disasters [6-10].

Studying the combustion of flammable liquids in an open area creates the basis for the development of innovative approaches to managing and reducing the negative impact of human activities on the environment, which is critical for the sustainable development and

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conservation of the natural resources of our planet. Using the data obtained, it is possible to develop more effective monitoring and early warning systems for possible accidents, which will allow a quick response to emergency situations and minimize their consequences. These systems include the identification of potentially hazardous and high-risk areas, as well as optimized evacuation procedures and measures to prevent the spread of contaminants [4-14].

In addition, data obtained from studies of flammable liquid combustion can be used in the development of innovative technologies for eliminating environmental damage after accidents. Effective methods of cleaning and restoring contaminated areas help reduce the negative impact on the environment and accelerate the process of restoration of ecosystems.

As a result, the integration of experimental studies of flammable liquid combustion with technologies for eliminating environmental damage and waste disposal not only increases the level of safety and environmental sustainability, but also contributes to the development of innovations necessary to effectively respond to the environmental challenges of our time [15-18].

2 Materials and methods

The acceleration of the pace of development and expansion of the scale of production activities of the petrochemical industry in modern conditions necessitates an analysis and assessment of the dangers of possible accidents because of the formation of spills of flammable liquids at hazardous production facilities. Objects using flammable liquids pose a particular danger, since when they are released, intense vaporization occurs with the formation of extended fire and explosion hazardous zones, including within the strait.

Prediction and modeling of processes that occur during emergency depressurization of equipment with hazardous chemicals have become an important point in minimizing their consequences and organizing work to localize and eliminate accidents [13-18]. When determining dangerous fire zones, the temperature of the flame is of particular importance since the impact on remote objects occurs mainly due to radiation [9-13].

This paper presents the results of measuring the flame temperature over time and height during the combustion of a freely poured liquid in an open area.

3 Experimental technique

An open area with grass was chosen for the experiments. At a distance of more than 10 meters there are no obstacles on all sides. In the experiment, when studying the temperature profile of the flame front of the combustion of ethyl alcohol and acetone, the ambient temperature was 19°C, the wind speed varied from 0.3 to 1.5 m/s and the pressure was recorded at 755 mm Hg. In the second experiment, the ambient temperature was 27°C, the wind speed varied from 0.1 to 2.1 m/s and the pressure was fixed at 755 mmHg; white spirit was used during combustion [3-5].

The experimental setup (Figure 1) consists of container 1 with overall dimensions 0.5x0.5x0.05 m made of hot-rolled steel. Plates 2 are installed along the perimeter of the tank. To avoid contact with the ground, the plates were installed at a height (0.176 m - T1; 0.257 m - T2; 0.370 m - T3). They are made of the same material, 0.05 m wide and 0.3 m long.

Weather conditions (wind speed, air temperature) were considered using the ATE-1033 weather station; the temperature of the plates was measured with a DL700E+ thermal imager.

The temperature inside the flame was determined using plate 2. It was assumed that the temperature of the plates was equal to the flame temperature.

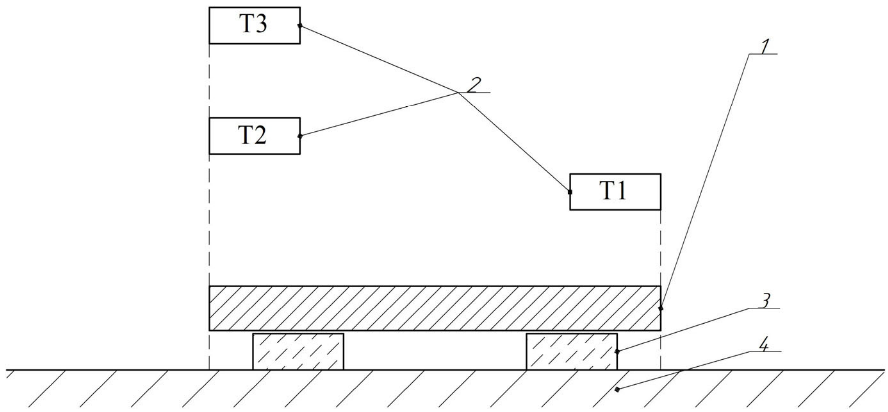

Fig. 1. Scheme of the experimental setup: 1 – container; 2 – plates, 3 – stone support, 4 – ground surface.

At the first stage of the experiment, a given amount of substance (5 liters) was poured into a tray and the values of ambient temperature and humidity were recorded. A photograph of a container with liquid was taken to measure the level of the liquid surface from the photograph. Wind speed was monitored continuously during the experiment.

At the second stage, the surface of the spill was ignited from an external fire source and the temperature profile during combustion was studied. At regular intervals (600 s), photographs of the container were taken. From the photographs, the distances between the liquid surface and the level of the upper edge of the container were measured, from the difference of which the level of the remaining liquid and its quantity were determined. Next, based on these values, the burnout rate of the substance was determined.

4 Experimental data

For all substances participating in the experiment, three stages of combustion can be distinguished. At the first stage, the formation of a flame front was observed with a gradual increase in temperature in the flame. At the second stage, the steady-state combustion process was studied, characterized by the equilibrium between the rate of evaporation and the rate of liquid burnout. At the final stage of the experiment, a sharp increase in temperature in the flame was observed due to boiling of the liquid layer.

Figures 2, 3 and 4 show the results of an experiment on the combustion of ethyl alcohol, acetone and white spirit in an open area.

The graph shows the wind speed at the time of temperature measurement.

A comparison of flame temperatures shows that for ethyl alcohol it is less than for acetone and white spirit, although the heat of combustion of acetone and ethyl alcohol is quite close (31.4 MJ/kg and 30.6 MJ/kg, respectively), for white spirit the calorific value is higher (44 MJ/kg). For the first pair of substances, the difference is most likely due to a significant difference in boiling point (56 C and 78.4 C, respectively) and latent heat of vaporization (553 kJ/kg and 887 kJ/kg). Thus, acetone evaporates more intensely and creates more flammable vapors, which is also confirmed by a number of works [19-23]. The combustion temperatures of white spirit are approximately the same as those of acetone, which is most likely since although its boiling point is higher, but the heat of vaporization (230 kJ/kg) is significantly less than that of alcohol and acetone. In addition, with increasing combustion temperature, the outflow of radiant energy significantly increases [19-23,25].

The literature provides data on flame temperature [3-5, 23, 25]. So for alcohol the flame temperature should fluctuate within 900 = 1100 C, for acetone 1200 C, white spirit 1100 = 1400 C. In the experiment, the flame temperatures are lower than described in the literature, which is most likely because the experiment was carried out in an open air in the presence of wind and, consequently, mixing of cold air into the flame zone [25-27].

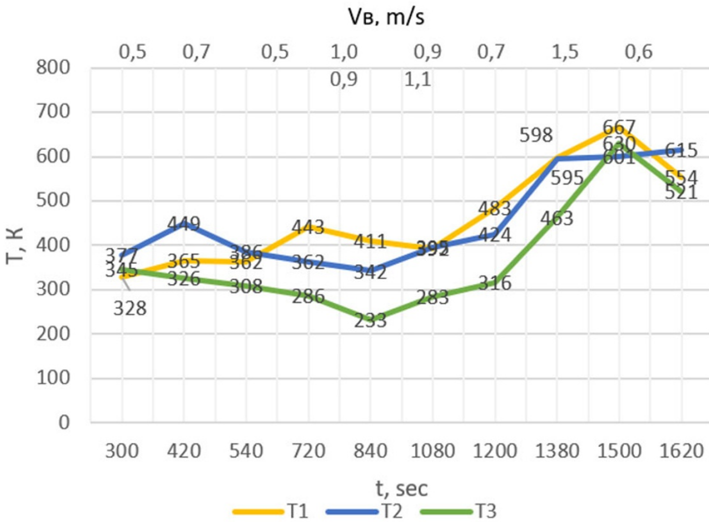

Fig. 2. Flame temperature versus time as a function of plate height for ethyl alcohol.

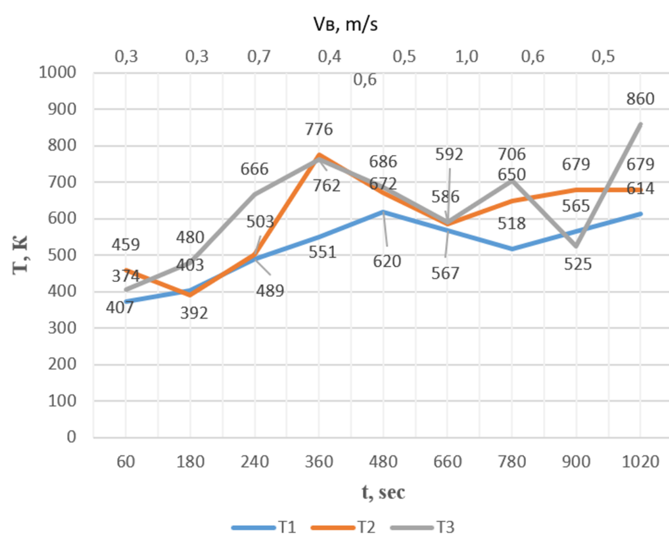

Fig. 3. Flame temperature versus time as a function of plate height for acetone.

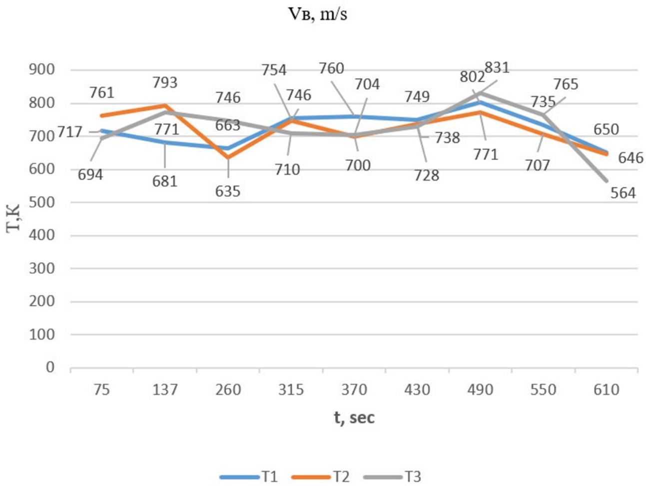

Fig. 4. Dependence of flame temperature on time depending on the height of the plate for white spirit.

5 Conclusion

As a result of the experiment, three key stages were identified considering the dynamics of combustion temperature: 1) flame propagation, 2) combustion during liquid evaporation, and 3) combustion during liquid boiling. These stages are significant from an environmental point of view, and their detailed study contributes to a better understanding of the impact of flammable combustion on the environment.

It is important to note that the experimental data obtained have great potential for additional use in the aspect of environmental assessment and prediction of consequences. These results can be used to develop more accurate and reliable models that predict the characteristics of emissions and impacts on natural ecosystems in the event of emergency situations [1,2,10-14, 28].

In addition, these experimental values can serve as a basis for estimating the heat flux that occurs when hydrocarbons burn in open air. This heat flow is a key parameter when assessing the potential impact on the environment and ecosystems.

The data obtained provide an important contribution to the field of environmental safety, allowing us to refine and expand models and methods for assessing the environmental consequences of emergencies and disasters. This helps reduce risks to ecosystems and reduce negative impacts on the environment [15-18, 28].

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