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Experimental research of heat transfer conditions influence on the distillate fuels ignition characteristics

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Abstract. The experimental studies results of diesel fuel ignition regularities by hot single metal particles and fuel droplets on a heated metal plate surface are presented. The ignition delay time dependences on the initial heat source temperature were determined. The results are a basis for the development of typical liquid fuels ignition models in terms of heat and mass transfer processes in a small neighborhood.

Liquid fuels are widely used in road transport and under certain conditions (storage, transport, congestion) are sources of increased danger. They can cause a fire during thermal exposure of high intensity. Heat sources can be different, as well as the conditions of exposure [1–3]. To date, mathematical models and solving methods for the ignition of solid [4, 5] and liquid [2, 3] fuels are worked out. Experimental conditions and the ignition characteristics of solid monolithic [9] and dispersed [7] fuels with a local heating source are established. Ignition regularities for films and drops of distillate fuels are studied much worse.

The purpose of this work is an experimental study of diesel fuel ignition conditions and characteristics. Two of the most important options for practice are considered: a single fuel film heated up to high temperatures and particle droplets on the heated metal plate surface.

Film fuel ignition process research was conducted on the plant [9], the concept of which is shown in Fig. 1, and drop method [1] (the experimental scheme is shown in Fig. 2). In all experiments a video registration of the investigated processes was conducted. The time moments of heat source (particle or plate) contact with a liquid (film or drop, respectively) and the ignition delay time were registered. As the heat sources the steel particles (diameter of $d_p = 6 \cdot 10^{-3}$ m and a height of $h_p = 3 \cdot 10^{-3} \div 7 \cdot 10^{-3}$ m) and the steel plate (size $5 \cdot 10^{-2} \times 5 \cdot 10^{-2}$ m and a height $h_w = 5 \cdot 10^{-3}$ m) were used. Particles fall from a small height (0.01 m) onto the fuel film surface. A possible change in its temperature is due to heat sink in the air. It is established that during the fall of the particles temperature is reduced by not more than 5 K, which is about ±0.5% depending on the absolute value of the initial particle temperature. Experiments at constant heat source temperature T_0 is repeated at least 7 times under identical conditions. Random error in τ_{ign} determining is no more than ±10% in the experiments with the particle heat source and up to ±16% in the experiments with hot plate.

The dependences of the diesel fuel ignition delay times from the initial heat source temperature obtained from the experiments results are shown in Fig. 3. Measurements have shown that the temperature of the massive plate during the experiment remained virtually unchanged (droplet sizes

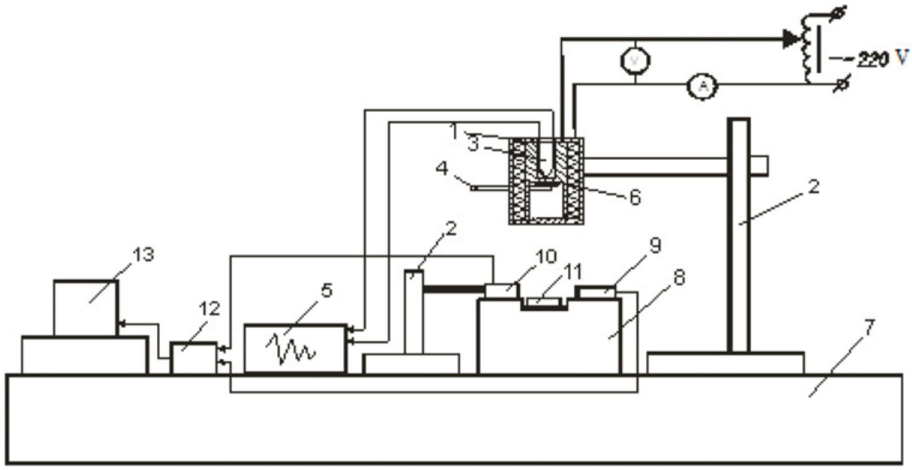

Figure 1. Schematic diagram of the experimental installation: (1) heating device; (2) support; (3) chromel-alumel thermocouple; (4) ceramic rod; (5) temperature control device; (6) metal particle; (7) experimental setup working surface; (8) fire-resistant area; (9) radiation receiver and flame recorder; (10) radiation source; (11) glass cylindrical vessel with a liquid fuel film; (12) analog-to-digital converter; (13) personal computer.

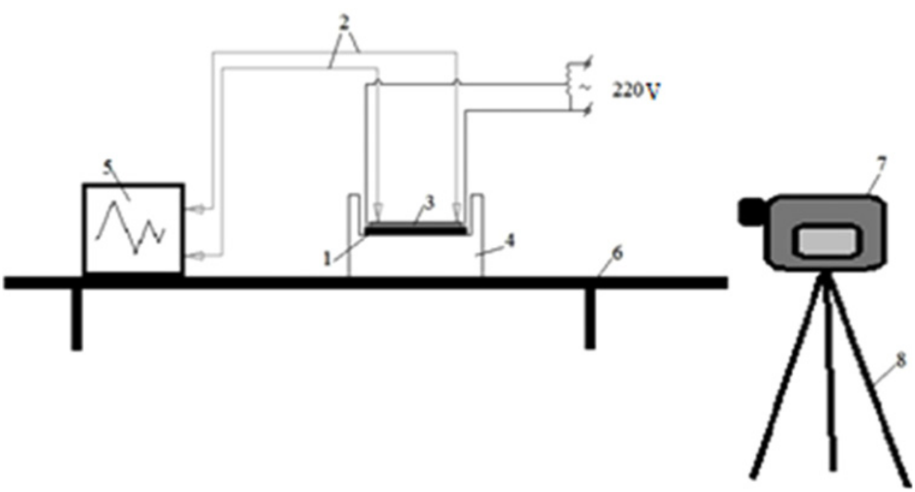

Figure 2. Schematic diagram of the experimental installation: (1) heating device; (2) chromel-alumel thermocouple; (3) metal plate for heating drops; (4) fire-resistant area; (5) temperature control device; (6) experimental setup working surface; (7) digital video camera; (8) support.

were much less than the characteristic plate dimensions), and the temperature of the particle heat source decreases with time due to cooling by relatively cold fuel vapour.

It may be noted that if the diesel fuel ignition has been occurred, it was stable (without extinction) regardless of the heat source initial temperature. The analysis presented in Fig. 3 provides a basis for the dependency conclusions about significant differences of heat transmission processes at distillate fuels drops falling out on a massive heated plate and a "hot" metal particles on the liquid fuel film. Limiting the ignition temperature in these two cases differ at least by 280 K. Accordingly, the smaller characteristic particle size, the larger temperature difference for two ignition fuel conditions. In condition of equal

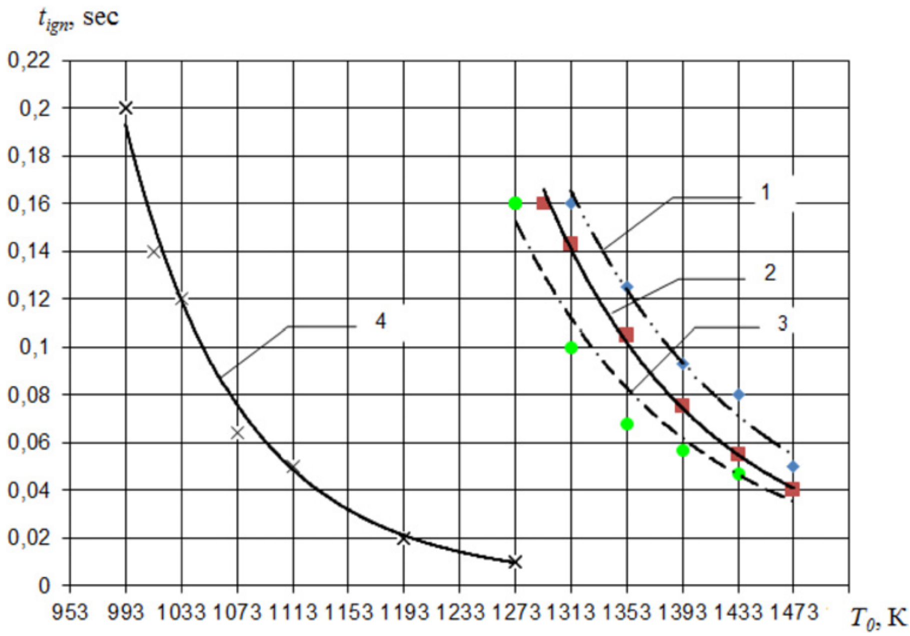

Figure 3. Experimental dependences of the diesel fuel ignition delay time from the heat source initial temperature: (1) steel particle $h_p = 310^{-3}$ m; (2) - steel particle $h_p = 510^{-3}$ m; (3) steel particle $h_p = 710^{-3}$ m; (4) steel plate.

heat source temperature values (for example, $T_0 = 1273$ K) the diesel fuel ignition delay times by single "hot" particle and by massive plate differ by almost 16 times. Obviously, the chemical mechanism of interaction between diesel fuel vapors and oxygen in both cases is identical. The reason for such large deviations in the values of τ_{ign} may be caused only by the different fuel ignition conditions.

It can be noted by the analysis of video recordings that the diesel fuel drop after deposition on the wafer surface always rolls under the force of the vapour pressure, which are formed by vigorous evaporation of the liquid fuel and in connection with metal microroughness. A particle in the form of a metal disc after immersion in the liquid fuel film is virtually immobile. Thus, the lower surface of the particle rests on the glass vessel bottom. Diesel fuel evaporation occurs only in the channel between the particle side surface and the liquid fuel film. The particle is intensively cooled due to the evaporation.

The massive plate is not cooled due to the heat outflow for the implementation of phase transition during diesel fuel evaporation. Droplet rolled over the heating surface changes the heat transfer conditions in the zones of contact with the metal. As a result at any intensive cooling point (due to the liquid fuel vaporization), the temperature decreases within the small (less than 0.1 s) period of time.

If the drop is moved to the previously cooled portion as a result of its chaotic movement along the heating surface, its temperature will not be different from temperature in any other point on the heated surface. Accordingly, despite the chaotic droplet movement on the heated surface, the conditions for heat supplying to the evaporation surface will be constant. Thus the gap between the droplet and the heating surface should be minimal thickness. It is caused by steam formation on a local site of a drop surface. The intensity of heat transfer through the vapour layer is sufficiently high.

During the liquid fuel vaporization the vapour space around the particles submerged therein is substantially greater thickness (compared to the above discussed embodiment). As a result of the heat flow in the evaporation zone is small compared with the drop heating conditions on the wafer. Particles enthalpy will decrease due to the phase transition heat and due to convection in the gap. The vapour temperature in the gap will be much lower than the particle temperature, and the speed will be sufficiently high – to 5 m/s [2, 3]. As a result, the particle surface will cool rapidly. Comparison of heat transfer mechanisms in the two considered typical cases suggests their significant differences.

The experimental dependences of the fuel ignition delay times from the heat source temperature illustrate the influence extent of heat-transfer under intensive phase transformations on the liquid fuels ignition characteristics. The experimental studies results demonstrate the possibility of well-known condensed substances ignition models [8] development in perspective of detailing the heat transfer processes in the chemical reaction zone.

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