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Microexplosive grinding of droplet water-fuel oil emulsion with the addition of specialized additives

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The results of experimental studies of microexplosive fragmentation of water-fuel oil droplets with the addition of the ION-M additive are presented. The studies were carried out at a gas-air temperature of about 800°C. The characteristics of the formation of secondary fragments during microexplosive fragmentation of water-fuel oil droplets were studied by varying the concentration of the ION-M additive. It has been shown that the addition of the ION-M additive (0.5 vol.to an increase in the number of secondary fragments by almost 60%, as well as a decrease in their average size by 30−50%. It has been established that when adding the ION-M additive (0.5 vol.ratio of free surface areas after and before fragmentation increases by almost 65% compared to that for water-fuel oil fuel without the additive. Key words: water-fuel oil emulsion, microexplosion, fragmentation, secondary fragments, additives. DOI: 10.21883/0000000000

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The use of water-oil fuels provides an opportunity to reduce the cost of thermal energy generation and reduce environmental risks associated with the emission of pollutants [1]. Approximately 10 vol.% of water are normally added to fuel oil to achieve efficient combustion [2]. With this concentration of water in fuel oil, the fuel atomization characteristics are improved, and the concentrations of anthropogenic emissions (NO_x, CO_x, etc.) are reduced. This effect is attributable to the phenomenon of microexplosion. The primary mechanism of microexplosion in such fuels is overheating of the non-combustible component (water) relative to the temperature of liquid–vapor equilibrium. This results in the formation of pressurized vapor. This vapor starts expanding and accumulating inside a droplet, creating pressure that eventually causes the droplet to break up into a multitude of secondary fragments [3]. This improves the efficiency of fuel oil atomization, resulting in uniform filling of the combustion chamber with fuel mixture droplets. It was established in [4] that microexplosive breakup occurs when a droplet of water-oil fuel enters a high-temperature environment. This effect results in finer atomization of fuel in the combustion chamber, enhancing the efficiency of mixing of fuel with air [5].

Additional specialized additives are used to reduce harmful emissions and improve the fuel combustion efficiency [6]. They allow one to reduce the cost of generated thermal energy. Thus, fuel additives offer a number of advantages, such as enhancement of the performance characteristics of boilers and reduction of the fuel consumption [7]. Therefore, the examination of effects of droplet fragmentation (e.g., the sizes of secondary fragments) is an important aspect of studies into the process of microexplosive breakup of water-oil fuel droplets. At the same time, the determination of the optimum concentration of additives in water-oil fuel should help improve the efficiency of operation of process equipment, minimize the fuel consumption, reduce anthropogenic emissions, and stabilize the atomization process. It is imperative in this context to determine the characteristics of secondary fragments at various concentrations of the additive. The above objectives motivated the present study.

A magnetic stirrer was used to prepare a water-oil emulsion (90 vol.% of fuel oil and 10 vol.% of water). A tube muffle furnace was used as a heating system (the temperature range was 300–1300°C). The droplets under study were introduced into the recording area using a coordinate mechanism with a holder (with nichrome wire 0.2 mm in diameter) at the end of it. The coordinate mechanism was connected to a computer, which tracked the position of fuel droplets. The heating temperature varied within the range from 700 to 900°C. A Phantom Miro M310 high-speed video camera was used to record the processes of heating and microexplosive breakup of water-oil droplets. The framing rate was 3200 frames per second at a resolution of 768×576 pixels. The obtained video fragments were processed in Phantom Camera Control. The following parameters were determined via high-speed video recording: droplet sizes R_d, number of secondary fragments N, and their sizes r_d. The systematic error in measurement of r_d was 0.025 mm. Experiments with comparable initial conditions were repeated 15 times in order to minimize the random error of measurement of the indicated parameters [8].

Four water-oil emulsion compositions with the concentration of the ION-M additive varying from 0 to 1 vol.% were examined experimentally. The ION-M combustion catalyst is an additive for various types of fuel oils and heating fuels. The ION-M additive is a combination of positive and negative ions the electrostatic fields of which have an ordering

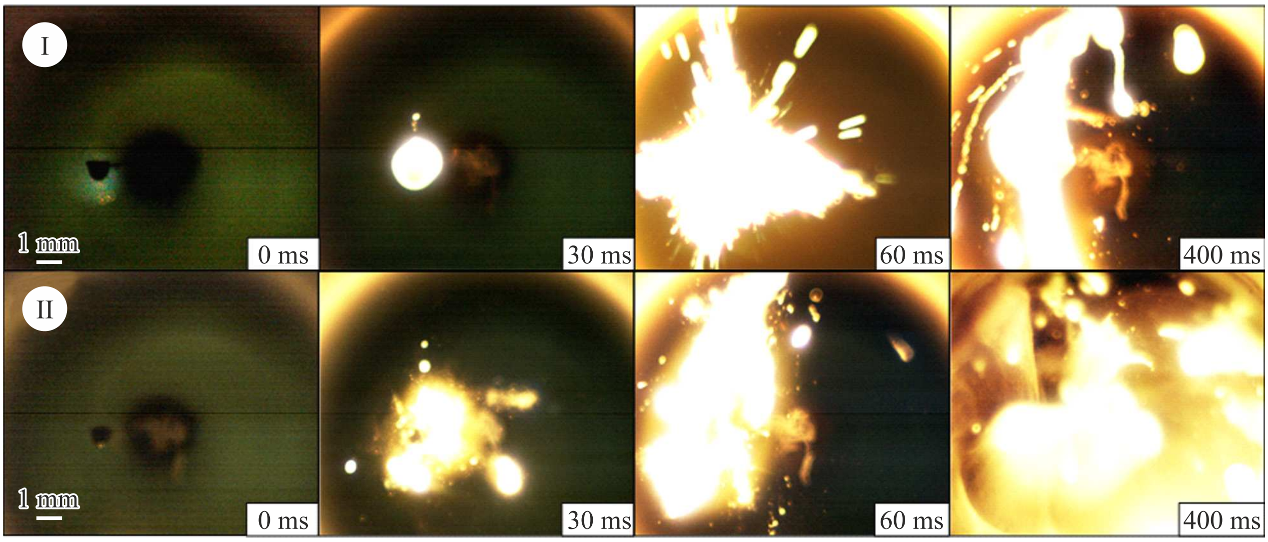

Figure 1. Still frames illustrating the process of microexplosive breakup of water-oil droplets at a gas medium temperature of about 800°C ($R_d \approx 1$ mm). I — 90 vol.% of fuel oil and 10 vol.% of water; II — 89.5 vol.% of fuel oil, 10 vol.% of water, and 0.5 vol.% of ION-M.

Key rheological properties of the used liquids

Concentration of added ION-M, vol.%	Temperature of the composition, °C	Density, kg/m^3	Dynamic viscosity, mPa·s	Surface tension, N/m
0	20/80	1021/933	1540/116	0.044/0.033
0.25	20/80	1020/933	1530/114	0.044/0.032
0.5	20/80	1016/933	1490/109	0.041/0.029
1	20/80	1018/933	1500/112	0.042/0.030

effect on molecules in fuels. This ensures fragmentation of large fuel droplets, allowing for more complete combustion of hydrocarbons and reducing significantly the emissions of soot and particulate matter. Such additives are designed to increase the efficiency of combustion of fuel oil in boilers and industrial furnaces [9]. Thus, a combustion catalyst alters the structure and rheological properties of fuels with the aim of optimizing the combustion process.

A Brookfield DV3T rotational viscometer (measurement range, 1–6 · 10^6 mPa·s; accuracy, ±1%), an SC4-18 spindle (viscosity measurement range, 50–10^5 mPa·s) and a Termex KRIO-VT-12-01 thermostat with an operating temperature range from −30 to +200°C [10] were used for viscosity measurements. The surface tension was measured with a Kruss K6 tensiometer (measurement range, 1–90 mN·m; temperature range, 1–130°C). The density of fuel mixtures was determined using this tensiometer [11]. The size distribution of droplets of the dispersed phase in water-oil emulsions was determined with an MBS-12 optical microscope. Calibration was carried out in accordance with the MI 253-87 verification procedure [12]. The rheological properties of different compositions are listed in the table.

Figure 1 presents typical frames illustrating the process of microexplosive breakup of water-oil droplets heated in a high-temperature gas medium. It was found that the evaporation of water-oil droplets proceeded in several stages. A mixture of air, vapors, and volatile substances of fuel oil ignited first. The duration of his stage varied depending on the heating conditions and other influencing factors (e.g., droplet size). Owing to the ignition of volatile substances, the temperature in the combustion zone of a droplet increased, which led to its dispersion in the microexplosion regime. Secondary fragments formed as a result of this process. At the next stage, the produced secondary fragments began to spread throughout the combustion chamber and ignited when heated. Owing to this effect, a combustion zone of a considerable extent was formed in the combustion chamber. Thus, the flaming zone became large enough to facilitate efficient combustion of fuel. This phenomenon is of great importance for stable operation of power equipment. A flaming combustion zone spreading throughout the entire chamber ensures uniform distribution of heat and energy, which contributes to an optimum combustion process. The obtained video footage revealed that the microexplosion process was more intense when ION-M (0.5 vol.%) was added to water-oil fuel. This is attributable to the fact that the ION-M additive alters the rheological properties of fuel. Heavy hydrocarbons

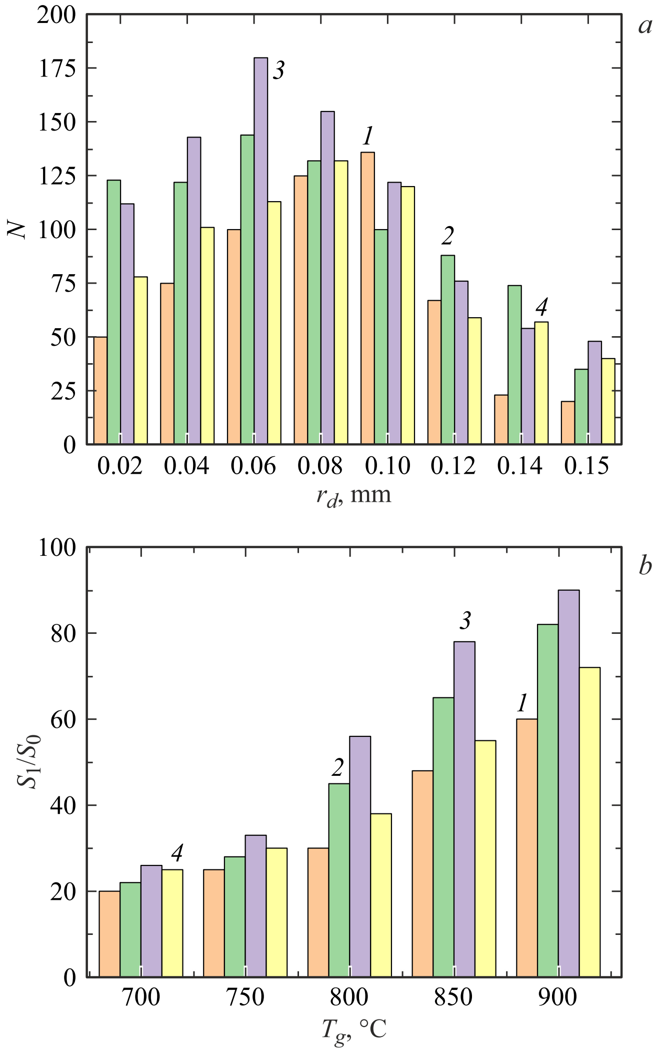

Figure 2. Size distributions of secondary fragments produced in microexplosive breakup of water-oil emulsion droplets ($R_d \approx 1$ mm) at a gas-air temperature of 800°C (a) and ratios of free liquid surface areas after and before fragmentation (S_1/S_0) (b) corresponding to different concentrations of the ION-M additive (vol.%): *1* — 0, *2* — 0.25, *3* — 0.5, and *4* — 1.

present in it are brought into an ordered state. This ensures that water is distributed evenly throughout the entire volume of a fuel oil droplet. Having analyzed the frames, we also found that the number of secondary fragments increased by 50% after the addition of ION-M. This results in finer atomization in the combustion chamber and higher efficiency of mixing of fuel with air [5]. The amount of fuel energy increases, and heat losses for fuel oil heating are reduced.

Figure 2 shows size distributions of secondary fragments $N(r_d)$ at a gas medium temperature of 800°C and ratios of free liquid surface areas after (S_1) and before (S_0) fragmentation of water-oil droplets corresponding to different concentrations of the ION-M additive. It was found that the number of secondary fragments increased following the addition of ION-M. This is attributable to the fact that the ION-M additive alters the molecular structure of the water-oil emulsion, thus affecting its rheological characteristics. According to the obtained results, the lower the viscosity of the water-oil emulsion is, the greater is the number of secondary fragments with smaller sizes forming as a result of microexplosive breakup. It was established that the concentration of ION-M most efficient in terms of its influence on the characteristics of secondary fragmentation of water-oil fuel droplets is 0.5 vol.%. The additive in this concentration raised the number of secondary fragments by 50−60% and reduced their average size by 30−50%. With a further increase in concentration to 1 vol.%, the number of secondary fragments decreased by 20%. This effect may be attributed to the fact that the viscosity and surface tension of fuel increase with increasing additive concentration [5].

A comparison of the ratios of free surface areas demonstrated that the addition of 0.5 vol.% of ION-M helped increase the S_1/S_0 ratio by 30−85% relative to the one for water-oil fuel. At an additive concentration of 1 vol.%, area ratio S_1/S_0 increased by 20−25%. The addition of 0.25 vol.% of ION-M allowed us to raise area ratio S_1/S_0 by 10−50%. The results revealed that the optimum concentration of the ION-M additive for enhancing the characteristics of microexplosive droplet breakup is close to 0.5 vol.%.

Thus, our experiments made it possible to determine the characteristics of secondary fragments produced in microexplosive fragmentation of water-oil droplets with a varying concentration of the ION-M additive. The use of an additive with a concentration of 0.5 vol.% allows one to raise the number of secondary fragments by an average of 50−60% relative to their number corresponding to water-oil fuel.

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Conflict of interest

The authors declare that they have no conflict of interest.

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