



Research article

Experimental study of foamed emulsion combustion: Influence of solid microparticles, glycerol and surfactant



Boris Kichatov ^{*}, Alexey Korshunov, Alexey Kiverin, Eduard Son

Joint Institute for High Temperatures, Russian Academy of Sciences, 125412 Moscow, Russia

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ABSTRACT

The use of water as a part of hydrocarbon fuel represents one of the perspective directions in elaborating new types of combustible systems. This paper considers issues of foamed emulsion combustion on the basis of experimental research. Combustible foamed emulsion is a mixture of oxygen bubbles and heptane drops dispersed in a water solution of stabilizer. Such foamed emulsions possess a set of unique properties and represent a vivid example of multiphase combustible system which could contain a significant amount of water. Thus a foam containing 83 wt% of water is still combustible. Here we consider issues of foamed emulsion stability and combustion depending on the influence of magnesium oxide particles, stabilizer and glycerol concentrations. In this paper for the first time we are presenting that by addition of magnesium oxide particles the total burning rate of the foam can be changed for more than an order of magnitude. The dependence of total burning rate of the foam on the stabilizer concentration is not monotonic with a maximum at certain stabilizer content. The use of glycerol favors the shrinkage of the foamed emulsion and as a result the flame quenching.

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1. Introduction

Nowadays the issues related with elaboration of new types of hydrocarbon-based fuels containing water gain increasing interest among researchers [1–18]. One of the representatives of such fuels is the emulsion representing a blend of insoluble water and oil. As a rule one distinguishes water-in-oil and oil-in-water emulsions though there are more complex systems, e.g. three-phase emulsion [19,20]. The interest towards such systems is defined by the issues of NO_x, CO and soot emission reduce in the process of hydrocarbon fuels combustion [6,21–23]. Thus the reduction in NO_x emission can be achieved due to the decrease in the flame temperature. Possibility of soot particles formation in many ways depends on the structure of drops in the emulsion [24].

At certain conditions the process of emulsion drops combustion is accompanied by a rather useful from practical point of view phenomenon of microexplosion [15,25–30]. Microexplosion is a process of explosive boiling of the emulsion. Enhancement of mixing of fuel and air by means of microexplosion could improve the combustion efficiency. The probability of microexplosion and its strength depend on a set of factors such as oil boiling temperature [15], water droplets size in the emulsion drops [24], initial diameter of emulsion drops [31], water volumetric content in the emulsion [31]. Thus if the mean water particle diameter is smaller than a certain value then the emulsion drop

demonstrate a weak disruptive activity [24]. Such theoretical and experimental results evidence that the emulsion structure influence significantly on the mechanism of its combustion. According to this one can conclude that it is possible to change significantly the features of emulsion combustibility via regulating its structural characteristics. This paper considers the combustion of emulsion not in the form of drops in the oxidizer environment but in the form of foamed emulsion. Due to such significant change in the emulsion structure one could obtain new non-trivial properties of fuel.

Combustible foamed emulsion is a foam consisting of oxygen bubbles dispersed in the emulsion. In turn the emulsion represents a water solution of stabilizer with oil drops suspended in it. For the first time the foamed emulsion combustion was considered in [32]. One of the principle points is that the foamed emulsion decays in the process of flame propagation. Foam decay gives formation to the water drops, fuel drops and/or emulsion drops. Formed fuel drops as well as emulsion drops are combusting in the oxygen environment. Due to this fact the mechanism of foam decay determines both the combustibility of the foam and the burning rate of the foam. Due to its structure the combustible foamed emulsions obtain a set of unique properties. Thus for example the foams containing up to 83 wt% of water are still combustible. Particularly this property of foamed emulsion reveals a new opportunity of direct use of oil/water blends with a large content of water as fuels. Such a type of fuel can be utilized in the micro power devices which elaboration as usual is related with the issues of miniature systems for fuel spraying. When utilizing a foamed emulsion as a fuel one

^{*} Corresponding author.

E-mail address: b9682563@yandex.ru (B. Kichatov).

should not create a system of fuel dispersing since in the process of its combustion the foam is decaying by itself into the fuel and water drops.

When utilizing the foamed emulsion as a combustible system it should be taken into account that the foam is unstable by its nature and decays with time. Due to this it is necessary to utilize the foam as a fuel directly after its preparation. Optimum application of such a fuel is the power devices in which the fuel should be burned in a permanent regime. Herewith the generator realizing a permanent process of foam synthesis could be directly connected with burner. To elaborate such a type of device an important issue arises related with adjust of mass flows, foam generation rate and foam burning rate.

This paper pays the main attention to the analysis of methods for controlling the flame speed of the foamed emulsion. Here we present experimental results on the influences of magnesium oxide particles, stabilizer concentration and glycerol on both total burning rate and stability of the foam.

2. Experimental set-up

2.1. Method for preparation of foamed emulsion

The process of foamed emulsion preparation consists of two main stages (Fig. 1). In the first stage the emulsion is prepared. In the second stage the obtained emulsion is foamed by chemical method.

We used the following components to prepare the foamed emulsion: distilled water, heptane and stabilizer. Two types of surfactants were used to stabilize the foam: commercial detergent and sodium dodecylsulfate (SDS). Commercial detergent is a surfactant of mixed type consisting of anionic and nonionic surfactants. SDS is a surfactant of anionic type. To prepare the solution the SDS powder was mixed with distilled water. After this the solution was aged during 24 h. The emulsion was prepared by stirring oil and surfactant solution in the vessel of 300 mL with the use of two-paddle teflon stirrer during 10 min (stirring intensity, 200 rpm). The size of heptane drops was controlled using microphotographs (Fig. 2a). It was varying in the range from 5 to 80 μm . In set of cases we also added solid microparticles to the emulsion. We used magnesium oxide powder containing particles of characteristic sizes in the range from 100 nm to 2 μm .

In the second stage of foamed emulsion preparation the emulsion was foamed by chemical method. At this the emulsion was mixed with hydrogen peroxide directly inside the tube where subsequently the combustion process was initiated. In the process of hydrogen peroxide decomposition the oxygen was released $2\text{H}_2\text{O}_2 = 2\text{H}_2\text{O} + \text{O}_2 \uparrow$. We used also the ammoniac solution of copper sulfate as a catalyst for the reaction of hydrogen peroxide decomposition. The foam grew during several seconds. Immediately after the foam preparation the characteristic size of oxygen bubbles was in the range from 50 to 130 μm . A typical microphotograph of foamed emulsion is presented in Fig. 2b. To measure surface and interfacial tensions we used a duNouy ring tensiometer (*Kruss K20*, Germany). The error of tension measurements was 0.1 mN/m. The measurements results are presented in Table 1. Foam expansion ratio was determined as the ratio of foam volume to the volume of liquid phase comprised in the foam. Foamed emulsion stability was estimated on the base of foam shrinkage rate calculated using the data on “foam height fraction”. In turn the parameter “foam height fraction” was determined as a ratio of foam column height at certain time instant to the initial foam column height. Below when discussing separate experiments the concrete compositions used in the combustible foamed emulsions preparation are presented in the figures captions.

2.2. Flame speed measurements

The process of flame propagation was observed in the semi-opened tube in which the foamed emulsion was previously prepared. The tube was set-up vertically with top open end. We used two tubes of 27 and 20 mm diameters and correspondingly of 245 and 226 mm lengths. Foam ignition was performed by a pilot flame near the open end of the tube at time instant when a maximal foam expansion ratio was achieved. The foam ignition arose after a ~ 2 ms delay. Note that the ignition delay depends on the heat source power and foam composition. The flame propagated from top to bottom. The high speed color camera RedLake Motion Pro $\times 3$ (1000 fps) and the high speed monochrome camera Phantom V2012 (10,000 fps) were used to measure the flame speed. All the photographs of the combustion zone structure represented in the paper were obtained using the high speed color camera RedLake.

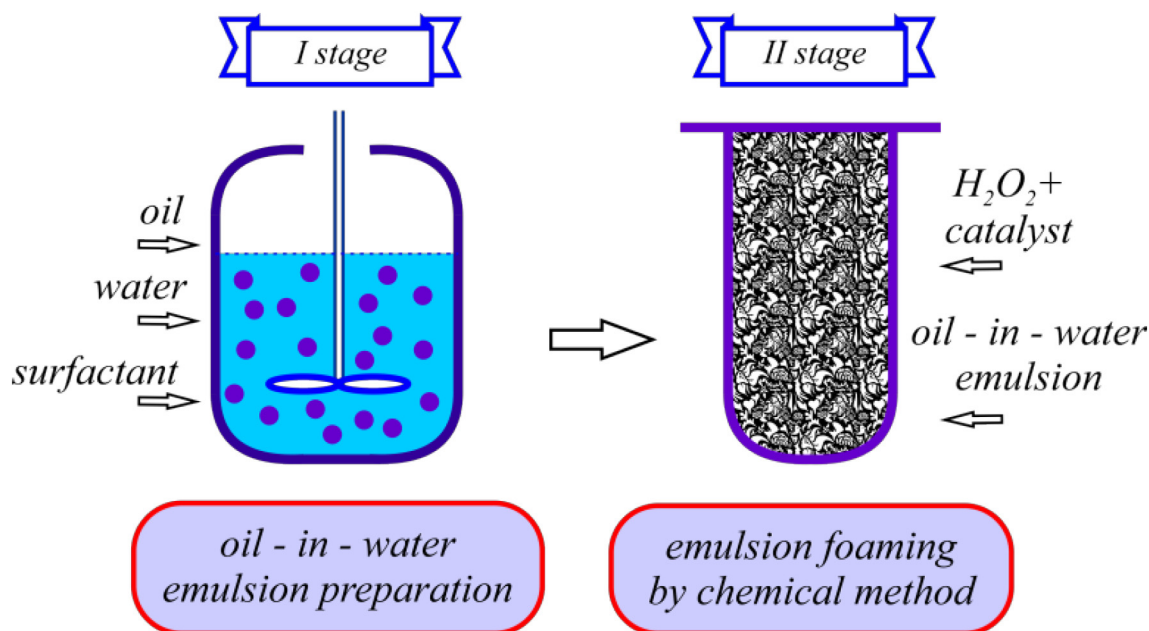


Fig. 1. Method for preparation of foamed emulsion.

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