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Parametric study of the micro-explosion occurrence of W/O emulsions

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ABSTRACT

When a water-in-oil (W/O) emulsion droplet is heated, a phenomenon called micro-explosion (μ-exp) may occur. Micro-explosion can be defined as the burst of the continuous phase (i.e. oil) by the energy of evaporation of dispersed droplets (i.e. water) and the volume expansion that goes with it. In the paper are presented results that show a strong correlation between size average value (and distribution size) of water droplets and micro-explosion occurrence rate. Emulsion dispersed phase size, when using micro-channel techniques, depends highly on the emulsion composition and the energy provided to the system (Oil flow rate). A (3–18) μm diameter range was measured in the tests discussed in the paper. Micro-explosion occurrence can reach 70% for larger droplet sizes (about 20 μm). It declines to less than 20% for small sizes (between 5 and 10 μm). Influence of other parameters on micro-explosion occurrence like temperature heating or physical properties is also studied. Ohnesorge number seems to be an adequate parameter to study micro-explosion occurrence because of its direct relation with the relevant emulsion properties: droplet size, oil viscosity and interface tension. Micro-explosion rate achieves its maximum rate (60%) for Oh = 0.12, in other words, for emulsion where dispersed droplets move easily (low viscosity) with a great ability to coalesce (larger droplets and no surfactant).

1. Introduction

Adding water on oily fuels, in the form of W/O emulsion seems to be an appropriate way to replace pure liquid fuels, causing reduced exhaust emissions. Presence of water reduces the flame temperature (a part of the heat energy provided is dedicated to the water droplet evaporation) resulting in decrease of NOx emissions. Moreover, soot formation decreases due to the presence of OH [1–5].

Another aspect of W/O emulsions is the occurrence of a thermal phenomenon called micro-explosion. It strongly relies on the difference of boiling temperatures between oil and water (respectively 300 and 100 °C at 1 atm). Micro explosion is defined as the rapid disintegration of an emulsion droplet caused by explosive boiling of embedded water droplets with a lower boiling point [1–6].

Micro-explosion, that generates a secondary atomization, leads to a better and cleaner combustion. This can be explained by the emulsion droplet break up, which in turn, causes fast fuel evaporation and hence an improved air fuel mixing. This results in the reduction of emissions of unburnt fuel, PM and other exhaust [7–13].

Size of dispersed droplets is one of the most important parameter influencing micro-explosion occurrence. In fact, if the water droplets are too small, their evaporation may not be powerful enough to break the oil phase. This leads to the well-known phenomenon called puffing [14,15]. However, as emulsions are fundamentally unstable systems [16], the dispersed droplet size is continually evolving as phenomena like coalescence, sedimentation/settling and Ostwald ripening are occurring. Numerous authors showed that coalescence, even partial, favors μ-exp [17–28].

As it was stated, micro-explosion is not a systematic phenomenon, and its occurrence is strongly related to the size distribution of the dispersed phase, which is linked to emulsion stability (coalescence, sedimentation/settling …). Several works showed that correlation, but there is a lack of data [17–19] leading to a quantitative criterion like a dimensionless parameter that would emphasize the occurrence of micro-explosion. Thus, the aim of this work is to clarify the relation between micro-explosion occurrence and different parameters like water droplet size, heating temperature and physical properties of fluids. Some of these parameters are already discussed in other papers [20,29,30], however, the great amount of emulsion drops studied in the present paper (± 4500) allows a statistical approach, which represents one of the innovative aspects of this work. Micro-explosion ratios of occurrence is then calculated and confronted to the data about water drops sizing and other parameters cited. Moreover, the use of a dimensionless parameter could extend the results presented in this paper

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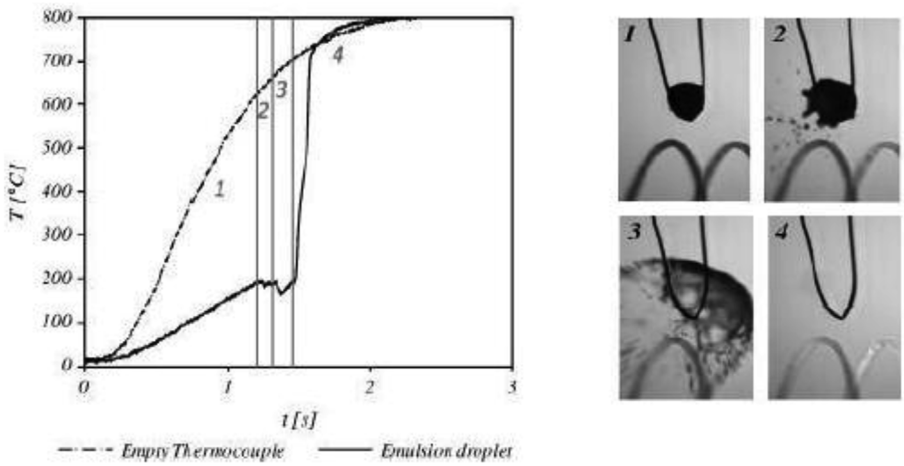

Fig. 1. Temperature evolution and identification of 3 different phases before micro-explosion [27].

to other conditions.

This article is divided three different parts: First, the Sec.1 is dedicated to a theoretical background in order to understand the micro-explosion phenomenon and its dependence on intrinsic characteristics of an emulsion (size distribution). The experimental procedure, including the apparatus used and the different parameters and their value range, is presented in Sec.2. It is followed by the results presentation and a discussion in Sec.3.

2. Theoretical background

2.1. Micro-explosion of W/O emulsion

The concept of Micro explosion was first introduced by M.A.Saad in 1956 and then by Ivanov and Nefedov in 1965. The phenomenon of micro-explosion is observed during the combustion of fuel emulsions with relatively large differences between their boiling temperatures of continuous and dispersed phase.

Several authors [21–35] tried to understand this phenomenon by analyzing and identifying the different processes that happen when an emulsion drop is heated. Fig. 1 represents the evolution of temperature with time of an empty thermocouple and an emulsion drop in the same heating conditions. We can see that there are three phases in this process (Fig. 1):

- In the phase 1, the emulsion droplet is heated, which "catalyzes" the motion of dispersed droplets. When heated, liquid water can achieve a metastable state. This means that the water temperature can be superior than it's boiling point (100 °C) and still, it state is liquid [21–23]. Also temperature growth inside the droplet fosters the phase separation between oil and water.
- The phase 2 does not always happen. In fact, it largely depends on the size of the dispersed droplet. If the droplet is small, the energy engendered by it evaporation won't be enough to break the continuous fluid. Then we have a steam escape, a phenomenon called puffing or bubbling.
- The phase 3 is identified as being the micro-explosion: A slight fall in temperature is observed, indicating a phase change during water evaporation. This sudden phase change results in the burst of oil drop, as we can see in Fig. 2:

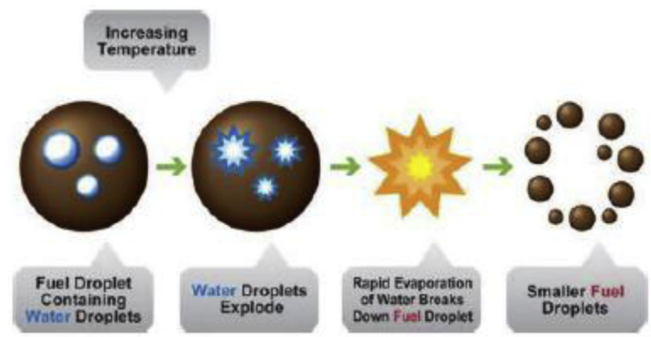

Fig. 2. Schematic micro-explosion phenomena [8].

2.2. Occurrence of micro-explosion

Several authors have shown that the micro-explosion phenomena is governed by different parameters as temperature [21], quantity of surfactant or emulsifier [24], or size distribution [25,26]. Rashid et al. [24] and Khan et al. [26] performed experiments in order to determine the effects of some parameters like surfactant quantity on the occurrence of micro-explosion. Three W/O emulsions are performed with respectively 0.5, 1 and 1.5% of surfactant (See Fig. 3):

It is observed that increasing the surfactant quantity leads to increasing the emulsion droplet life. In fact, the main effect of surfactant is to reduce the surface tension between the two phases in presence. Thus, the aggregation and coalescence rate are slowed down, which may lead to incomplete combustion which in turn could increase the exhaust emissions. This is puffing: because of their small size and their inability to coalesce, dispersed droplets vaporize without breaking the oil mother-drop.

It is first confirmed by Khan et al. [2,24,26], Mura et al. [20], Suzuki et al. [18], Tarlet et al. [31] and Califano et al. [16] that size distribution plays an important role in the occurrence of micro-explosion and puffing. However, W/O emulsions are unstable systems as the two phases (oil and water) tends to separate. Events like creaming, coalescence, Ostwald ripening can happen [18,36,37] and the principal consequence is the increase of the water droplets average size, but also a wider size distribution.

3. Experimental procedure

3.1. Emulsification procedure

Emulsification is the process in which two non-miscible fluids are mixed together, which results on a dispersion of the first fluid in the other. Several emulsification techniques exist, but the one used for the preparation of studied emulsions is the micro-channel technique [38,39].Fig. 4 illustrates the experimental procedure:

Two ARMEN-AP-TRIX-500-200 pumps are used to drain the diesel