The effect of injector shearing of water-in-diesel emulsion on micro-explosion behaviour

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Introduction

One of the possible and promising ways for reducing both nitrogen oxides (NOx) and particulate matter (PM) in diesel engines is the use of the water-in-diesel emulsions which have been investigated by different researchers [1].It is generally accepted that when water in diesel emulsion is subjected to high temperature in the combustion chamber, secondary atomization occurs resulting in a reduction in emissions and lower specific fuel consumption. This is attributed mainly to the phenomena of micro-explosion as suggested by different authors [2]. Micro-explosion is caused by the exposure of the primary emulsion droplet to a high-temperature environment whereby the small water droplets dispersed inside the fuel vaporize earlier than the fuel shattering the emulsion droplet into many smaller droplets known as droplets [3]. The smaller droplets tend to evaporate more quickly and form a better air-fuel mixture.

Previous observations of the occurrence of micro-explosion for isolated emulsion droplets showed that these events are influenced significantly by the number and size distributions of the dispersed phase. Fine dispersed droplets (1-2 µm diameter) did not give rise to micro-explosion[4], and the optimum dispersed droplet size was found to be of the order of 5 µm [5].The reason for fine dispersed water droplets to inhibit or delay micro-explosion is believed to be due to their lower coalescence rate [6]. A limitation of these direct observation of micro-explosion events is that the size of the isolated dispersed water (emulsion) droplets tend to be several orders of magnitude larger than the droplets found in typical diesel sprays.

There is, however, a great deal of disagreement on the performance of emulsions in engines. We believe that this may be due to the effect of the FIE equipment on the size and number distribution of the dispersed phase in the emulsion. Emulsions are subjected to intense shear in the fuel pump and injector nozzle which may lead to change in the distributions and sizes of the emulsion droplets [7]. This study was aimed investigating the impact of injector nozzle on dispersed water and thereby, its effect on micro-explosion and hence the combustion performance of the engine.

Material and methods

<u>*Emulsion preparation*</u>

The emulsions were custom-blended for this study with a mechanical stirrer using a reference diesel fuel, surfactant (Span 80) and water concentrations of 15% by volume. The emulsion properties are shown in Table 1.

Table 1. Water In diesel emulsion properties

Fuel/ Emulsion	Density at 25 ºC (Kg/m3)	Viscosity at 40 ºC (mm2/s)	Surface Tension at 25 °C (N/m)	Cal. value (MJ/Kg)
Neat diesel	825.01	3.21	43.20	27.08
15%W	856.12	9.44	37.20	26.75

<u>Experimental setup</u>

Two experimental setups were used in the current study. Firstly, a common-rail, electronically-controlled injection system was used to generate and induce the high pressure sprays into the sample collector to investigate the impact of the injection nozzle orifice on the properties of the emulsion. The emulsions were examined using a digital microscope (Olympus BX51) with 50× magnification and 10 µm depth of field to acquire high-magnification images of the dispersed water droplets. A developed MATLAB image processing algorithm was used to detect and measure dispersed water droplet sizes.

Secondly, the collected emulsions from the spray (at injection pressures of 50, 100, 150 MPa) were suspended over a hot plate at Lidenfrost conditions using a micro syringe needle to visualize the droplet micro-explosion phenomena. The complete setup for the experiments including the visualization system and temperature recording are shown in Figure 1. A National Instrument controller was employed to trigger the high-speed camera for image capturing and recording of the measured temperatures of the suspended emulsion droplet. The image acquisition rate was set at 500 fps at a resolution of 1280 × 1024 pixels throughout the experiments.

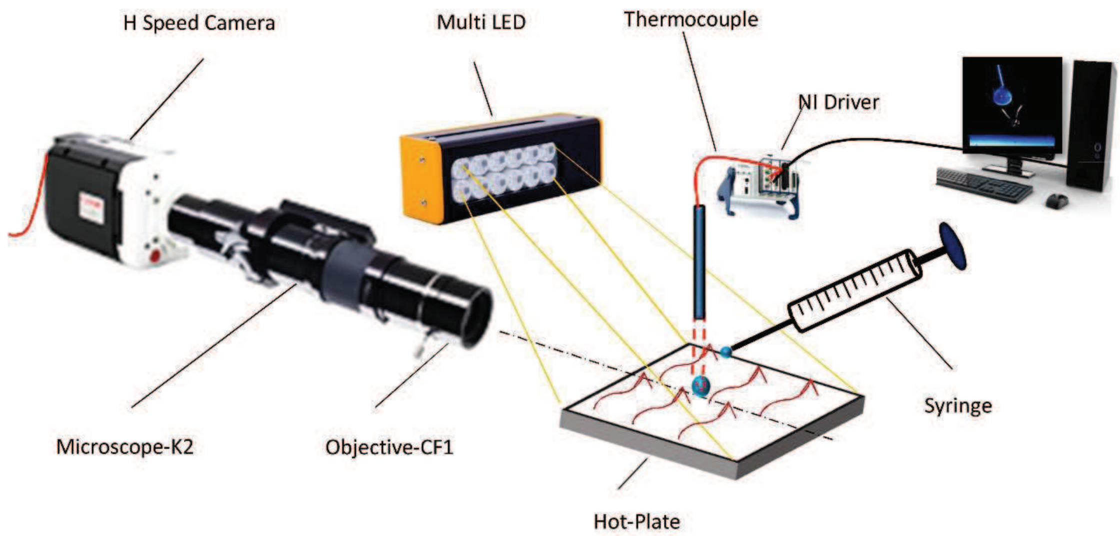

Figure 1. Experimental setup for single droplet micro-explosion

Results and Discussion

Impact of injector nozzle on the dispersed droplet size

Figure 2 shows the effect of injector nozzle shear on a water-in-diesel emulsion made with 15%W in the fuel tank (1 bar) and different injection pressure as seen under an optical microscope at 50X magnification. The injector nozzle shifted the emulsion distributions' modes to a smaller diameter and the dispersed water droplet size decreased steadily with the increase in injection pressure. This is caused by the elevated shear and temperatures exerted by the injector's nozzle onto the emulsion.

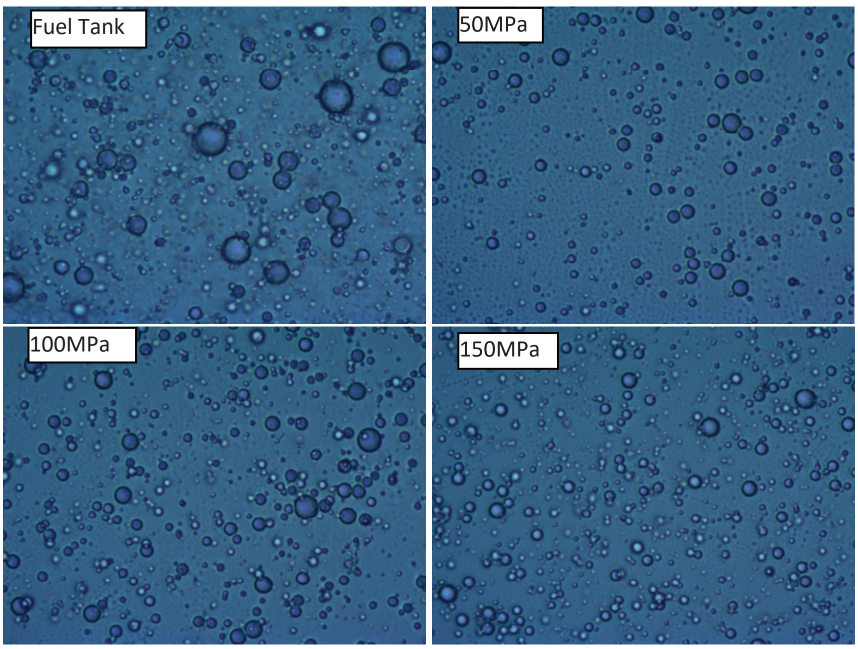

Figure 2. Images of water-in-diesel emulsion samples for 15%v/v water content, examined under an optical microscope at 50× magnification for the emulsion in the fuel tank, and after injection at 50, 100 and 150 MPa.

To ascertain whether the emulsion's water had separated out of the blends we measured the density of the samples, and then used a mixing model to compute the water concentration for each sample. Figure 3 shows the effect of different injection pressures on water concentration. As the water concentration is linearly related to the emulsion's density, this result indicates that some water separated or evaporated out of the emulsion. With the increase of injection pressure, the water concentration was reduced. The loss of water during the injection can be attributed to high temperature and pressure in the injector orifice causing the water evaporation. This evaporation can be attributed to the NOx reduction inside the engine.

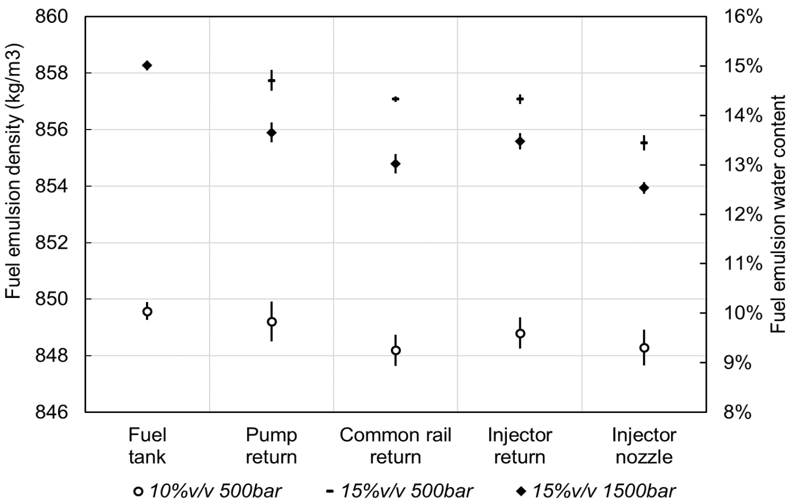

Figure3. Effect of the injection pressure on the density of the emulsified fuel and the water content in the emulsion.

<u>Impact of injector nozzle on micro-explosion behavior</u>

Figure 4 shows image sequences of a droplet for the evolution of micro-explosion phenomena of emulsion made with 15% water concentration by volume. Samples from the fuel tank (A) and after the injection pressure at 150MPa were tested at the Leidenfrost conditions to determine the effect of injection pressure on the micro-explosion phenomena. The results showed that the micro-explosion behavior was significantly affected by the injector shearing, hence. With the increase of injection pressure, micro-explosion time was delayed (from 1.4s in the fuel tank to 2.5 after the injector at 150 MPa) due to reduction in dispersed water droplet size and water content in the emulsion.

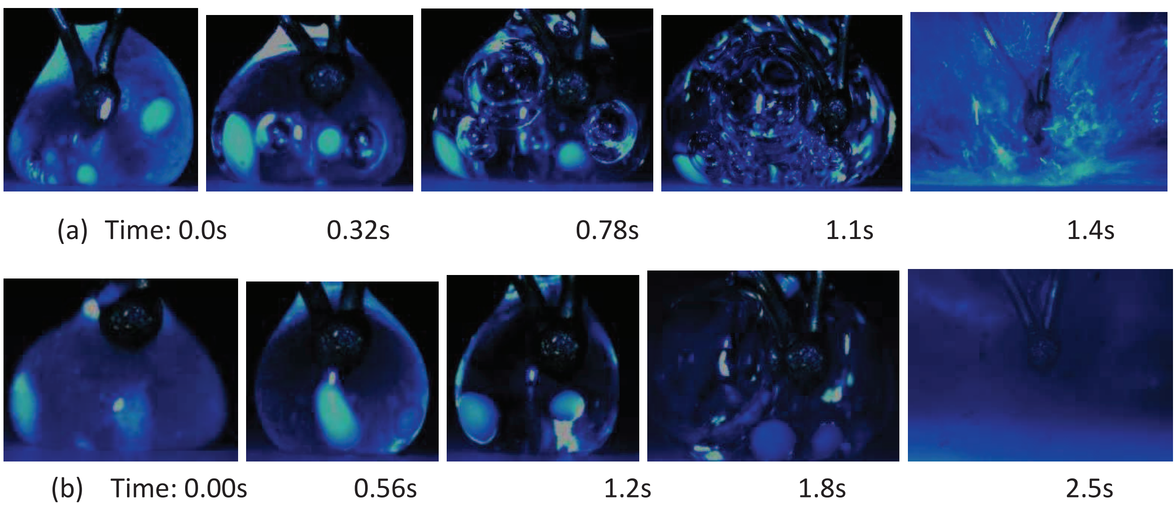

Figure 4. Sequences of images showing micro-explosion behavior of an emulsion made with 15% water content taken from the tank (a) and after the injection at 150 MPa (b).

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