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The characteristic of spray using diesel water emulsified fuel in a diesel engine

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HIGHLIGHTS

- Water in oil emulsion is produced using ceramic membrane.
- Surfactant type affect stability performance and droplet size distribution.
- Evaporation characteristic of DE is poor compared with neat diesel.
- Coefficient of variation maintains below 2.0% both DE and neat diesel.

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ABSTRACT

In this study, it was applied to the diesel–water emulsified (DE) fuel that carried out the experiment for the characteristic of sprat using diesel water emulsified fuel in a diesel engine, and the possibility of its application to conventional diesel engines was evaluated from the fundamental characteristics of diesel–water emulsified fuel. According to the results of the spray characteristics such as spray penetration and spray distribution were measured in the experiment, and then analyzed through digital image processing. The DEs were applied to actual diesel engines and their combustion, emission, and fuel consumption characteristics were compared with those of diesel. The results showed that the experiments were confirmed as the spray atomization characteristics at the various emulsified fuels.

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1. Introduction

The world is now plagued by global warming and increasing of energy consumption. As the air pollution accelerates, the emission regulation become more severe, and the climate changes lead to drastic changes in the ecological system over the globe. The increase in energy consumption, on the other hand, causes the depletion of fossil fuel. Thus, the diversification of energy resources is required to solve this problem. Therefore, in the automotive field, these two factors are considered as primary problems, and therefore most of the major automobile manufacturers and research organizations in the world are putting forth a lot of efforts into developing alternative fuels and low emission engines with a high fuel efficiency.

Diesel–water Emulsified Fuel (DE) used in this study means the water-in-oil (W/O) type fuel where water droplets are dispersed in diesel. Since W/O type fuel does not involve direct exposure of water upon fuel injection, the low risk of corrosion, enhancement of spray atomization characteristics through the micro-explosion phenomenon, and combustion temperature decrease as a result of latent heat of water evaporation makes possible simultaneous reduction of NOx and PM [1–9]. In the 'micro-explosion phenomenon,' as illustrated in Fig. 1, the difference in the boiling point between diesel and water upon fuel injection in a combustion chamber results in evaporation (explosion) of water droplets and more thorough splitting of fuel droplets. As a result, secondary atomization contributes to enhancing the air–fuel mixture and reducing the incomplete combustion [10–13].

The concept of DE, simultaneous reduction of NOx and PM, was demonstrated already through the theory and experiment about 30 years earlier, but the research progress has been insignificant due to the limit of emulsion manufacturing technology (stability, homogeneity, miniaturization, production cost) [14–16]. In

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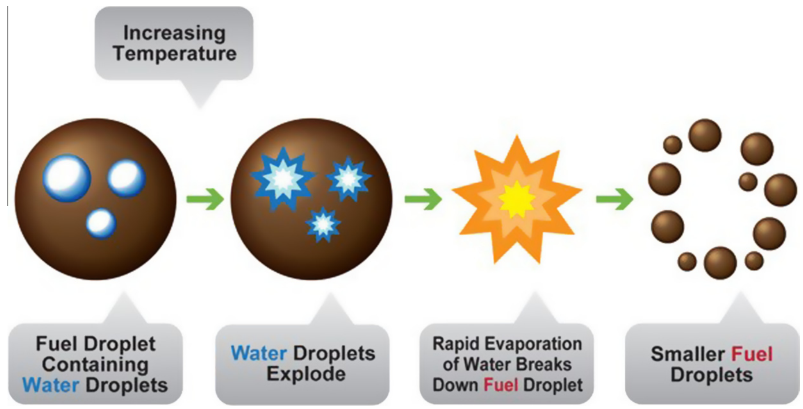

Fig. 1. Mechanism of micro-explosion phenomenon.

addition, DE has several expected problems. The first issue is related to the low temperature solidification. According to previous studies, the emulsion has a low freezing point than pure materials. The emulsion has a dispersed phase tiny water droplets present. Therefore, the solidification delays and water droplets are still observed under the freezing points of pure material [17–18]. Because this phenomenon emulsion can be applied to diesel engine, even though the DE contains water droplets. The corrosion by containing the water is the second issue. This issue also occurs due to the water droplets in the DE. The surfactants used for the production of DE were the role of corrosion inhibitors. The surfactants are proved to be one of eco-friendly corrosion inhibitor to protect material from the corrosion [19]. Therefore, the corrosion issue was not considered in this study.

From the earlier studies, it was well known that the micro-explosion and latent heat of evaporation of DE enhance spray atomization characteristics and reduce NOx and PM simultaneously. To understand these steps, fuel properties need to be taken into consideration for accurate analysis of fuel spray, combustion, and exhaust emission characteristics. Hence, this study investigated the water droplet size inside of DEs manufactured by means of 5 surfactants using particle size analyzer and analyzed the manufacturing performance. Moreover, the stability of DE was evaluated. Finally, two surfactants of superior performance were selected through the implementation of sample filtering. The kinematic viscosity, heating value, and flash point of selected DE were evaluated because fuel properties are essential in order to understand the fuel injection rate, spray behavior, and combustion characteristics. The spray characteristics such as spray penetration and spray distribution were measured in an experiment by means of high pressure chamber and high-speed camera, and then analyzed through digital image processing.

2. Experimental apparatus and procedure

2.1. Production of emulsified fuel using ceramic membrane

DE has been manufactured generally in four different types such as jet mill, static mixer, homogenizer, and ultrasonication. In its application to actual vehicles, fuel stability and productivity are the most important factors. Hence, this study adopts ceramic membranes to improve productivity with the same particle size instead of the 4 methods stated above.

A membrane filters out certain elements selectively so that not only dissolved matters in liquid but also mixed fuels are separated by the filtering equipment of selective permeability. Membranes are classified by the materials as shown in Table 1. The characteristics are varied depending on the membrane's nature such as organic/inorganic membrane, hydrophobic/lipophilic property membrane, and porous/non-porous membrane. One membrane may contain various natures.

Table 1
Classification according to the membrane material.

Polymer membranes (organic)	Polyamide (PA), Polyethylene (PE), Polypropylene (PP), Polyvinylidene fluoride (PVDF), Polysulfone (PSF), Cellulose acetate (CA), Teflon (PTFE), etc.
Ceramic membranes (inorganic)	Alumina, zirconia, titania, etc.
Metal membrane (inorganic)	Stainless, nickel, palladium, silver, platinum, gold, etc.

The membrane selected for this study is Shirasu Porous Glass (SPG) membrane, which is a ceramic membrane item produced by means of volcanic ash of Miyazaki Prefecture, Japan. This membrane is commonly used in areas of pharmacy, semiconductor, bio, and filtering where even particle distribution through fine filtering and emulsification by means of $Al_2O_3SiO_2$ glass porous materials, and the common types are plate and tube types. The pore size designing as fine as 0.05–20.0 μm is possible for both types, but the tube type is superior to the plate type in terms of mechanical strength and heat-resistance/insulation.

This study adopts tube-type membranes whose pore size is 2 μm for DE production. As we know, the smaller the membrane pore is, the smaller the particle is. A smaller size may be advantageous in terms of stability, but producing particles smaller than 2 μm requires a quite high pressure condition, which is realistically impossible for laboratory environments. As particles of 2 μm pore size can bear a pressure condition as low as 10 bar, this size was selected for this research. Since the capacity of manufacturing ceramic membranes is controllable by adjusting the size and number of modules, this meets the requirement in terms of productivity. Fig. 2 shows the selected 2 μm ceramic membrane.

As mentioned above, a membrane may contain various properties. In making DE, it is important to produce fuel of water-in-oil (W/O) or oil-in-water-in-oil (O/W/O). Accordingly, the surface of the selected membrane was coated with a hydrophobic film.

The hydrophobic film processing was quite simple: With hydrophobic property fluid diluted in deionized water at the rate of 1.75 wt%, ceramic membranes are dipped in it. After ultrasonic treatment on the ceramic membranes dipped in the diluted liquid for 2 h, hydrophobic property fluid is absorbed on the surface of ceramic membranes, which then go through the 4-h thermoplastics process in a heating furnace heated at over 110 °C. Once this process is completed, the whole hydrophobic process comes to an end. The picture below illustrates the steps of the membrane hydrophobic process.

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