SHORT REPORT

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A study on spray characteristics of non-esterified biodiesel fuel

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ABSTRACT: The spray characteristics of a blended fuel containing conventional diesel and non-esterified biodiesel components were investigated. Experiments were performed to analyse the effects that blending ratio and injection pressure have on the spray behaviour. The process of spray injection was analysed with a laser diffraction particle analyser. In addition, spray atomization characteristics were studied using the Sauter mean diameter (SMD) varying the droplet concentrations under various injection conditions. Fuel containing non-esterified biodiesel components exhibited different spray patterns in comparison to that containing conventional diesel due to the high viscosity and large surface tension of the fuel. The results indicate that the SMD becomes smaller by increasing injection pressure, and larger by increasing the mixing ratio.

KEYWORDS: Sauter mean diameter, laser diffraction particle analyser, kinematic viscosity

INTRODUCTION

Alternative fuel resources, which might compensate for the limited petroleum reserves, are being actively investigated as part of an effort to reduce vehicle CO_2 emissions and environmental problems[1–3]. Korea has established a scheduled goal to reduce its CO_2 emissions by 2012. One of many alternative energy sources being developed is biodiesel fuel extracted from biomass series material. Between the 1990 s and 2010, Europe has been promoting a common diesel fuel supply mixed with biodiesel fuel blends up to 12%[4].

Biodiesel fuel containing oxygen improves combustion inside an engine[5–8], reducing smoke and CO_2 without adverse effects to the engine. However, high viscosity biodiesel fuels exhibit different spray characteristics, spray atomization, and spray tip penetration than conventional fuels[9,10].

Non-esterified biodiesel fuels production process does not require glycerin, decreasing the costs of the treatment, and do not use methyl alcohol, which costs 20% of the biodiesel product. In addition, energy losses during the esterification can be reused as fuel. Thus this study compares the spray behaviour non-esterified biodiesel fuels (BD) and common diesel fuels, analysed according to spray pressures and mixing ratios using a laser diffraction particle size analyser (LDPA).

MATERIALS AND METHODS

Experimental apparatus and fuels

The fuels used during the experiments were made of common diesel as well as BD extracted from palm oil. The biodiesel was not produced through an esterification process. Biodiesel synthesis includes charging BD to a high voltage of approximately 900 kV, and then rapidly freezing the BD. Methanol was not used during the BD production. As a result, glycerin was not generated, producing a BD with a caloric value of 8330 kcal/kg, which was lower than that of diesel fuel. However, an abundant oxygen content of 11.60 wt% was observed in the biodiesel. The kinematic viscosity was measured using a viscometer (Brookfield Dial Viscosity analyser-USA). The experimental equipment consisted of injectors, an injector trigger, fuel supply equipment and a LDPA. Sympeatec's KF-Vario LDPA was used to analyse the spray behaviour. Fuel was supplied from a fuel tank through a fuel filter to an injector nozzle by a high pressure fuel pump (Haskel pump, Korea) that compressed the fuel to an area ratio of 150:1. In order to control injection, an injection drive TDA-3100A (TEMS, Korea) was used.

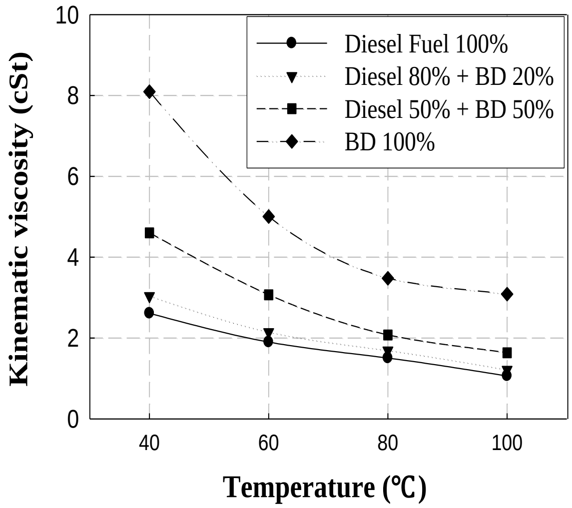

Fig. 1 Kinematic viscosity of biodiesel.

The LDPA consisted of a transmitter and a receiver. The light source was a He-Ne laser of 632.8 nm.

Experimental method

To compare the spray behaviours, this experiment used pure BD (BD100) and commercial diesel blended fuel with 25% and 50% of the volume mixed ratio of BD (B25 and B50, respectively). The injection pressure was varied from 30 MPa to 60 MPa at 10 MPa intervals. The spray time was configured as 4 ms using a TDA-3100A. The measured outputs from the experiment were SMD, span factor, and representative diameter of volume accumulation mass of 10% ($D_{0.1}$), 50% ($D_{0.5}$), and 90% ($D_{0.9}$). The span factor equation was based on the volume accumulation distribution and was the most suitable index for the LDPA output:

$$\text{Span Factor} = \frac{D_{0.9} - D_{0.1}}{D_{0.5}},$$

where $D_{0.1}$, $D_{0.5}$, and $D_{0.9}$ are the droplet diameter at 10%, 50%, and 90% accumulative mass, respectively.

RESULTS AND DISCUSSION

Fig. 1 shows the kinematic viscosity of the biodiesel as a function of the blended fuel temperatures and volumetric rates. The increment of kinematic viscosity depended on the increase in the BD blending ratio. However, viscosity rapidly decreased at temperatures of 80 °C and higher. The kinematic viscosity of BD 20 at 100 °C was similar to that of a common diesel before reaching the fuel spray temperature in a combustion chamber.

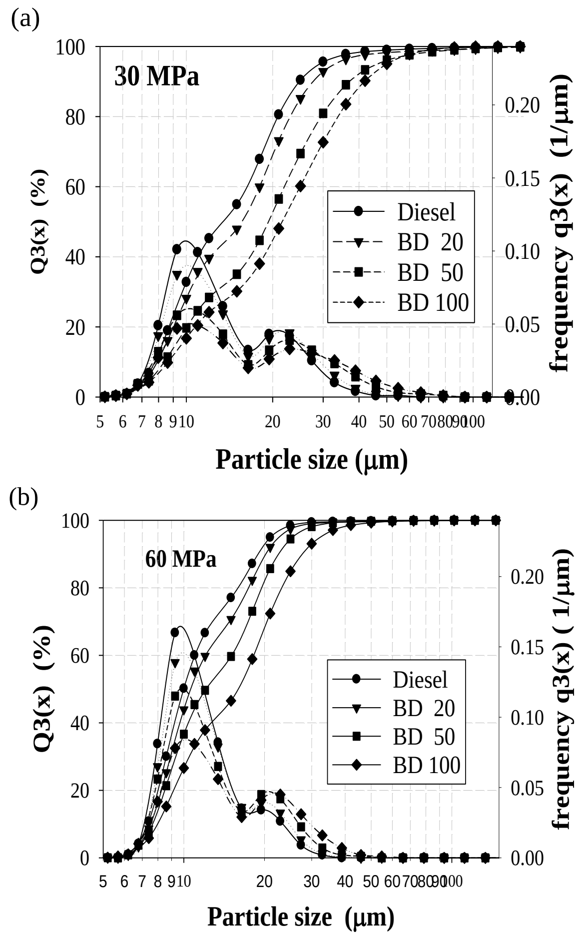

Fig. 2 Spray size distribution at various blending ratios of BD. Injection pressure: (a) 30 MPa, (b) 60 MPa.

Fig. 2 shows the spray size distribution and the accumulation volume when the blending ratios of BDs were changed at several injection pressures. The accumulation volume distribution moved towards a large droplet direction depending on the increase in blending ratio. Furthermore, the accumulation volume distribution moved towards a smaller droplet direction when the injection pressure was increased at a fixed blending ratio. Depending on the increment in injection pressures, the volume frequency distribution at every injection pressure demonstrated a peak, indicating droplets of high frequency for spray sizes of 9–11 μm and 20–25 μm. Fig. 2 also shows that the highest spray size frequency occurred within a range of 9–11 μm and increased as the injection pressure increased from 30 to 60 MPa. The mixture BD 20 had a volume frequency distribution similar to that of common diesel fuel, but not so that of the BD 50 and BD 100 mixtures, which were very different. This

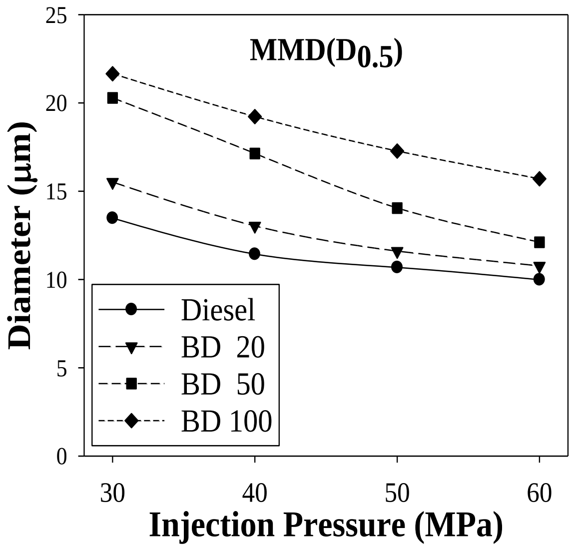

Fig. 3 Variation of MMD with various blending ratios of BD.

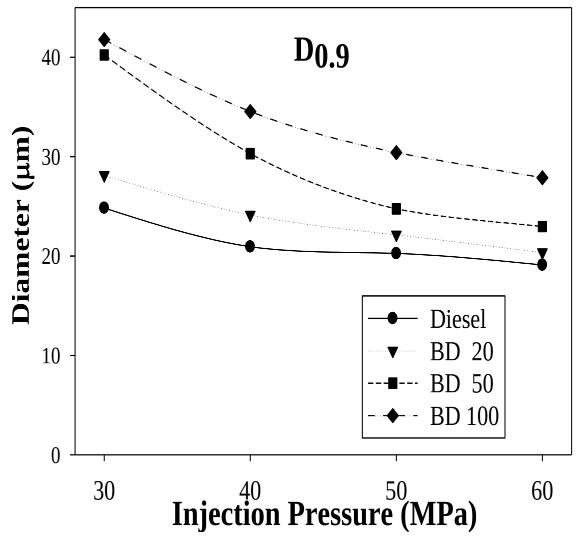

Fig. 4 Variation of $D_{0.9}$ with various blending ratios of BD.

means that the small sized droplets have decreased and the large sized droplets have increased because of an increase in viscosity. This study considers that commercial diesel fuel is more atomized than BD, because of high viscosity obstruct atomization. Spray flow is decreased under the same injection pressure due to the decreased flow velocity inside the injector.

Fig. 3 shows the mass median diameter (MMD) at an accumulation volume of 50% as a function of the injection pressure for several BD blending ratios. It can be seen that the MMD increased as blending ratio of BD increased. The frequency of large droplets increased due to increase of blending ratio and frequency of small droplet decreased. Also, BD 20 had a droplet size similar to common diesel under 60 MPa, and MMD of BD 50 sharply decreased when the injection pressure increased.

Fig. 4 shows the spray size when the accumulation volume was 90% as a function of the injection pressure at various BD blending ratio. Atomized fuel droplets with larger size were measured to obtain the span factor $D_{0.9}$ after the fuel was injected from the nozzle. Interestingly, when the $D_{0.9}$ parameter increased then the atomized spray performance decreased. As shown in Fig. 3, the spray size of BD 20 was similar to that of common diesel. The spray size of BD 50 at a pressure under 60 MPa decreased by 43% in comparison to the same fuel at a pressure of 30 MPa. This phenomenon was thought to occur because a high injection pressure promoted an atomization. Fig. 5 indicates the dispersion degree (span factor) of the spray size distribution for several BD blending ratios. A low span factor value signifies that the deviation of the spray size distribution from the mean diameter was small, and the spray size was narrowly distributed. The span factor of the fuel increased as the BD blending ratio increased. But the span factor was similar to common diesel even at high injection pressures. The common diesel spray distribution was similar to the mean value of the droplets. Fuels blended at high ratios were distributed in a relatively wide range and exhibited a large deviation because as the blending ratios increased, the atomization process became more inhibited. Fig. 6 shows the SMD when the blending ratios and injection pressures of BD were changed. The SMD is an index of spray sizes related to the evaporation and chemical reactions of the surrounding gas. The SMD exhibited a tendency of enlarging as the blending ratio increased. The SMD became smaller as a result of an increase in the injection pressure. For BD, the injection velocity was lower than that of the common diesel fuel due to the high friction force between the inner surface of the nozzle and the fuel. Therefore, the SMD was smaller because the atomization of the common diesel fuel was relatively faster than that of the BD.

CONCLUSIONS

In order to analyse the spray behaviour of BD, a study on fuel spray was conducted while varying the injection pressures and blending ratios of BD. The following conclusions were drawn. (1) When the BD blending ratio increased, the peak of the

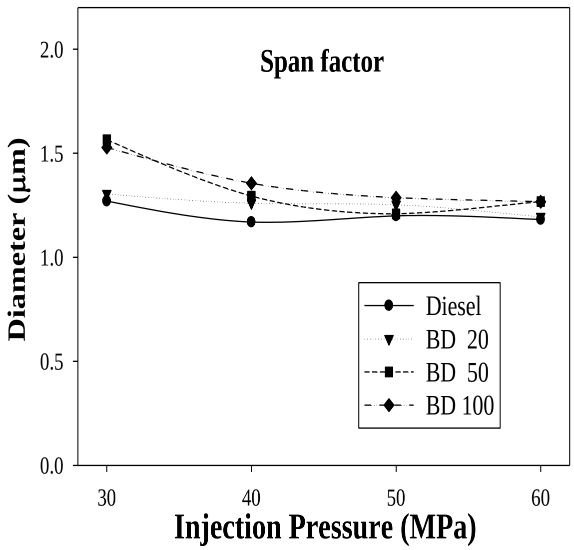

Fig. 5 Variation of span factor with various blending ratios of BD.

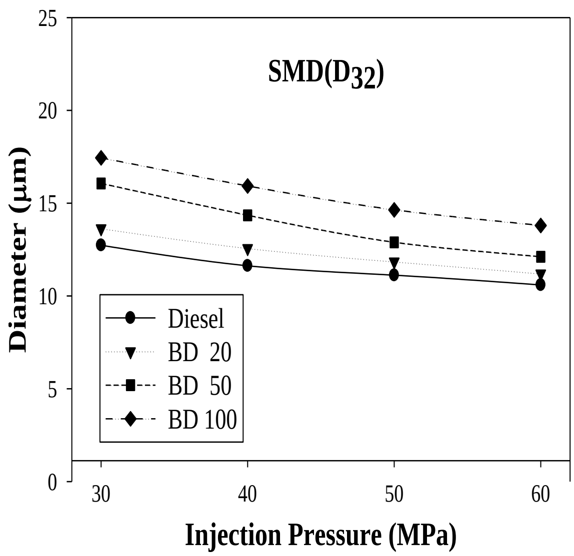

Fig. 6 Variation of SMD with various blending ratios of BD.

volume frequency distribution decreased. Also, the peak of volume frequency distribution increased as the injection pressure increased. Furthermore, the accumulation volume distribution moved towards the large droplet direction when the BD blending ratio increased. Accordingly, the spray size increased because the increase in blending ratios influenced the fuel viscosity. (2) As the BD's blending ratios increased, the MMD and span factor increased. As the blending ratios increased, the deviation between the spray size distribution and the mean diameter became large, and spray size was distributed in a wider range than that of common diesel. (3) As the BD blending ratio increased, the SMD increased.

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