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Experimental and Numerical Investigation on the Macroscopic Characteristics of Hydrotreated Vegetable Oil (HVO) Spray

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Abstract

The macroscopic characteristics of Hydrotreated vegetable oil (HVO), a renewable biodiesel, were investigated by both experimental and numerical approaches in this paper. The experiment on spray of 0.6ms injection duration was conducted in a constant volume vessel (CVV) at 1800 bar common rail pressure, 70 bar ambient pressure and 100°C ambient temperature, and the numerical work with the Wave breakup model and RNG k-ε turbulence model was done on a corresponding 2D geometric model at the same condition. The results indicated that the spray tip penetration grew with a decreasing tip velocity and the cone angle increased gradually after a dramatic growth and slight drop. Moreover, the prediction of numerical method, when used in conjunction with experimental studies, was proven effective in elucidating the macroscopic characteristics of HVO spray. The error between the predicted spray tip penetration and the experimental one was no more than 4% except that within 0.2ms flow time after SOI. In addition, the predicted cone angle was in similar trend to the experimental one and the error was within 10% after 0.2 ms.

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Keywords: Biodiesel, spray, numerical calculation, constant volume vessel

1. Introduction

Hydrotreated vegetable oil (HVO) is the mixture of paraffinic hydrocarbons with high cetane number and absence of aromatics, sulphur and oxygenates benefiting to better engine performance and reduction of emissions. Meanwhile, unlike ester-based biodiesel fuels, it also has no problems such as deposition, poor storage stability and poor cold properties, which makes it a superior sustainable biodiesel fuel [1, 2]. Therefore, some researches have

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been done on the application of HVO [3] as a renewable energy source for vehicles. Lehto et al. [4] compared the NO_x and smoke emissions of HVO with diesel fuel EN590 in a single-cylinder engine with 30% EGR and found that HVO produced lower smoke emissions and enabled higher EGR than diesel fuel. Liu et al. [5] investigated HVO blends with diesel fuel at high EGR rate and reported increased soot emissions caused by the higher combustion temperature of HVO blends. Singh et al. [6] also studied the emissions and fuel consumption of a heavy duty diesel engine fuelled with HVO and found the particulate matter, carbon monoxide, unburnt hydrocarbon and brake specific fuel consumption (BSFC) were all lower than diesel fuel. Nevertheless, these investigations of HVO were about the engine performance, and no detailed spray characteristics were mentioned.

As known, spray characteristics of liquid fuels influence the performance of combustion in engines, and finally determine the level of pollutant emissions. Therefore, the spray characteristics are important factors to evaluate the quality of a renewable fuel for engine application. Accordingly, Thomas et al. [7] did experiments on the spray of several biofuels including HVO in a constant volume vessel (CVV) and found HVO had shortest penetration and largest cone angle. Besides, a modified empirical equation was also developed for the prediction of the length of spray penetration. To explore a more detailed numerical approach on liquid fuel spray, Battistoni and Grimaldi [8] adopted the Wave model in a CFD simulation to predict the macroscopic spray characteristics of several biofuels. The result proved good prediction of Wave breakup model [9] for spray tip penetration, but HVO was not studied in this work. Meanwhile, Gong et al. [2] tested the spray properties of HVO at both non-evaporating (room temperature) and the evaporating (high temperature) conditions via RANS and large eddy simulation (LES), and found HVO produced similar droplet size and spray tip penetration to diesel fuel at room temperature but slightly smaller ones than diesel at high temperature. However, both RANS and LES strongly depend on high-performance hardware and are too time consuming, and the spray cone angle was not mentioned in this study.

As a promising renewable energy source for diesel engines, HVO has not been fully studied on its spray properties. Meanwhile, the spray characteristics of HVO also need cheaper and more convenient numerical methods to investigate. Therefore, the main macroscopic spray characteristics of HVO would be studied by a numerical approach with the Wave breakup model and the corresponding experiment would also be done in a CVV to validate it in this paper.

2. Experiments

2.1. Apparatus

The experimental system consists of a fuel delivery system, a constant volume vessel (CVV), a monitor and control system and optical diagnostic devices, as shown in Fig. **1**. The common rail in the fuel delivery system can provide up to 1800 bar fuel pressure. The CVV has an internal volume of 5.65 litres and four 90 mm viewing size silica windows 90° apart from each other. With an external 4.5 kW ceramic band heater on the wall and an external LAUDA Integral XT 150 chiller to cool down the windows and pressure

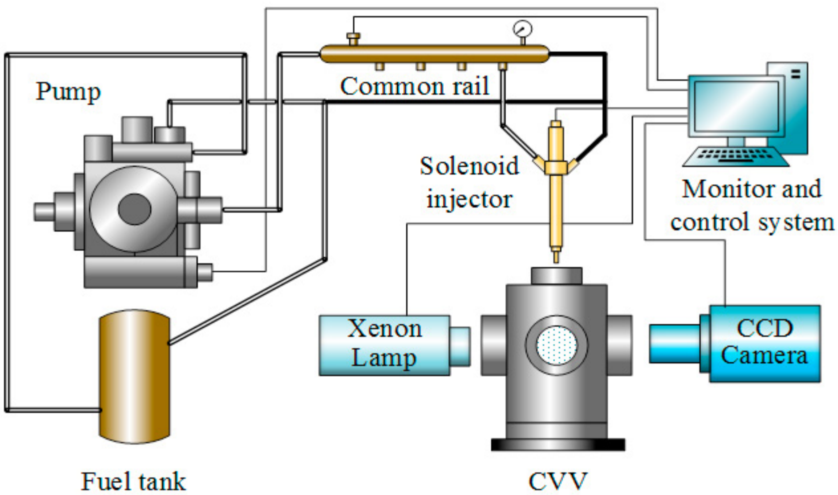

Fig. 1. The experimental system