International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0964

EXPERIMENTAL STUDY ON MACROSCOPIC SPARY CHARACTERISTICS OF HYDROTREATED VEGETABLE OIL (HVO) AND GAS TO LIQUID FUEL (GTL)

Zhichao Zhang [1,2], Yiji Lu [1,2*], Yaodong Wang [2], Andrew Smallbone [2], Xiaoli Yu [1,2], Anthony Paul Roskilly [1,2]

1 Department of Energy Engineering, Zhejiang University, Hangzhou 310027, China

2 Sir Joseph Swan Centre for Energy Research, Newcastle University, Newcastle NE1 7RU, UK
[*]Corresponding author Email: luyiji0620@gmail.com

ABSTRACT

Hydrotreated Vegetable Oil (HVO) and Gas to Liquid fuel (GTL) are two renewable fuels without shortcoming as traditional renewable fuels such as FAME. This project aims to research macroscopic spray characteristics of HVO and GTL during both injection and post-injection periods at high ambient temperature and pressure. The work is conducted by experiments on a constant volume vessel (CVV) system at 1800 bar rail pressure, 10 bar and 40 bar ambient pressure and 600 K ambient temperature. Results indicate that HVO and GTL have similar average cone angle to standard diesel fuel (DF), whilst their spray tip penetration during injection and post-injection periods are both smaller than that of DF. Moreover, the two renewable fuels have faster evaporation at high ambient temperature compared with DF, and thus results in the reduction of spray tip penetration with sample time.

Keywords: renewable fuels, spray, evaporation, constant volume vessel

NONMENCLATURE

Abbreviations	
HVO	Hydrotreated Vegetable Oil
GTL	Gas to Liquid fuel
FAME	Fatty Acid Methyl Esters
FT	Fischer-Tropsch
CVV	Constant Volume Vessel
LHV	Lower Heating Value
SOI	Start of Injection
EOI	End of Injection

1. INTRODUCTION

Hydrotreated Vegetable Oil (HVO) is the second generation biodiesel produced by the hydrogenation process. Compared with traditional biodiesels - fatty acid methyl esters (FAME), HVO is a mixture of n- and i-paraffin, which has high cetane number and high energy density, and excludes aromatics, naphthene, sulphur and oxygenates, which enables high oxidation stability and high percentage of blending with standard diesel fuel [1, 2]. As a result, it can improve engine output and reduce emissions. Furthermore, HVO has good storage stability and excellent cold starting without suffering from deposition and low engine output compared with traditional biodiesels [3, 4].

Apart from HVO, the synthetic fuel is another renewable fuel to replace fossil fuels as it can be produced from coals, gas or biomass by Fischer-Tropsch (FT) process [5, 6]. The gas to liquid fuel (GTL) is one type of synthetic fuel from natural gas, which has high cetane number, ultralow aromatics content and no sulphur [7]. Previous studies also indicate GTL has smaller density, higher LHV, higher flash point and closed viscosity compared with standard diesel fuel [8, 9].

As spray characteristics are important to evaluate the potential of fuels, studies were conducted on the spray of various renewable fuels. Chen et al. [10] compared the spray properties of biodiesel (FAME) derived from waste cooking oil and found biodiesel experienced longer penetration and larger size of droplets due to its larger viscosity and surface tension. Nevertheless, this study was done at room temperature and room pressure. Gao et al. [11] studied the spray structure at the near-nozzle region, and found the spray penetration increased almost linearly with increasing injection pressure at the initial breakup stage. However, they did not consider the effect of ambient temperature. Moreover, most studies were about FAMEs but not HVO or GTL. Kannaiyan et al. [12] investigated the spray characteristics of GTL in a spray chamber at various injection pressure. They noticed that the lower viscosity and surface tension of GTL lead to faster disintegration and dispersion of droplets than conventional jet fuel. Nevertheless, this work was conducted under atmospheric conditions.

Given limited studies on the spray of HVO or GTL at high ambient temperature or ambient pressure, this paper intends to investigate macroscopic spray characteristics of HVO and GTL by experiments and take into account of high ambient temperature and varying ambient pressure.

2. METHODOLOGIES

2.1 Constant volume vessel (CVV) system

The experimental rig contains a common rail fuel delivery system, an optical diagnostic device, a cooling system and a CVV. The fuel is delivered by a high pressure pump to a common rail, which enables as high as 1800 bar fuel pressure. Then, it reaches a single-hole injector at the top of the CVV. A high-speed PHANTOM V710 CCD camera is employed to observe the spray during experiments with the background light from a 100W Xenon lamp. The cooling system is used to keep important parts of the CVV from overheating.

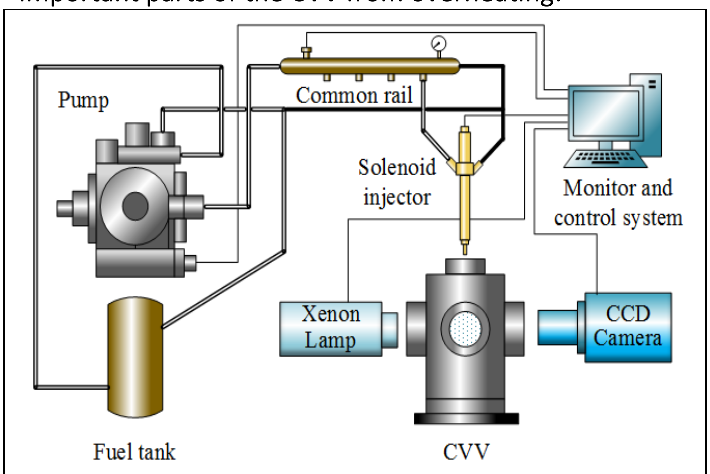

Fig. 1 Layout of the CVV system

The CVV is designed to withstand internal air pressure and temperature at up to 100 bar and 1000 K respectively. A 4.5 kW ceramic band heater is around the wall of the vessel and heats the internal air temperature to about 700K. A three-blade impellor is installed at the bottom for agitation inside and driven by a Micro Mag Drive motor outside. A high-pressure nitrogen bottle provides up to 70 bar internal air pressure for the CVV. Four fused silica glass windows with 90 mm viewing size and 70 mm thickness are equally located on the wall for optical diagnostics. The windows and the seal are cooled by the cooling system to stay within 150 ℃ and 260 ℃ respectively. The internal pressure of the CVV is monitored by a Grems 3100b pressure transducer, and the internal temperature as well as the temperature of the windows and the heater are measured by 1mm K-type thermocouples. The accuracy of the pressure transducer and thermocouples are 1.5% and 0.75% respectively.

2.2 System configurations

The camera is used to observe spray with a Nikon AF Zoom-Nikkor 24-85 mm f/2.8-4D lens. Its resolution was set to 256 × 256 pixels at 50,000 fps sampling rate to capture the spray pattern every 0.02ms. The high speed CCD camera was triggered by the same signal as the injector. The renewable fuels for the experiments are the Gas to Liquid fuel (GTL) and Hydrotreated Vegetable Oil (HVO). Their properties are listed in Table 1.

Table 1. Fuel properties

Fuel	Density at 15 °C (kg/m3)	Viscosity at 40 °C (mPa·s)
DF	840.4	2.82
HVO	780.1	3.02
GTL	780	2.72

In the experiment, the fuel is injected at 1800 bar rail pressure, and the ambient pressure and ambient temperature are listed in Table 2. The injection duration is set to 0.6ms, defined from start of injection (SOI) to the end of injection (EOI). The SOI is the time when the injected fuel becomes visible, and the EOI is the time when the tail of the spray leaves the injector. The time before and after the EOI can be respectively called the injection and post-injection periods. The spray tip penetration is the length from the head to the tail of the liquid spray, whilst the angle formed by two lines from the tail of the spray to the outer periphery of the spray at 1/3 length of the spray tip penetration.

Table 2. Experimental conditions

Rail pressure (bar)	Ambient pressure (bar)	Ambient temperature (K)
1800	10	600
	40	

3. RESULTS AND DISCUSSION

3.1 Average cone angle

The average cone angle of the three test fuels at both 10 bar ambient pressure are very closed, as shown in Fig 2. At 40 bar ambient pressure, DF has the largest average cone angle and HVO has the smallest one. It is because HVO has the largest viscosity among the fuels and thus experiences the weakest breakup process. Meanwhile, HVO has lighter compositions than DF and thus easier to evaporate. These two factors enable the smallest average cone angle for HVO.

In contrast, GTL has the lowest viscosity which tends to enlarge the cone angle. However, it has similar light compositions to HVO and thus make it faster to evaporate. Consequently, the average cone angle is larger than HVO but smaller than DF. At 10 bar ambient pressure, the breakup of all fuels is not relatively strong as that at 40 bar, which narrows the gap between DF and HVO and thus results in closed cone angle.

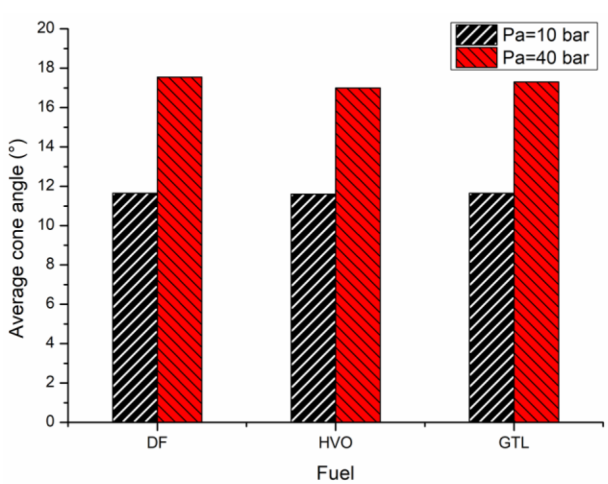

Fig. 2 Average cone angle

3.2 Spray tip penetration

As illustrated in Fig 3, the spray tip penetration of all fuels increases with time before the EOI and then drops to zero. During injection, the penetration of GTL and HVO are almost the same, because the difference of density and specific heat between them are not significant. In contrast, the penetration of DF is significantly larger than that of the two renewable fuels, which is mainly attributed to its higher density.

During post-injection, the spray tip penetration of GTL stays at the lowest level, because GTL is a mixture of relatively lighter paraffin and thus easier to evaporate compared with DF. The penetration of HVO becomes larger than that of GTL during post-injection due to its larger viscosity.

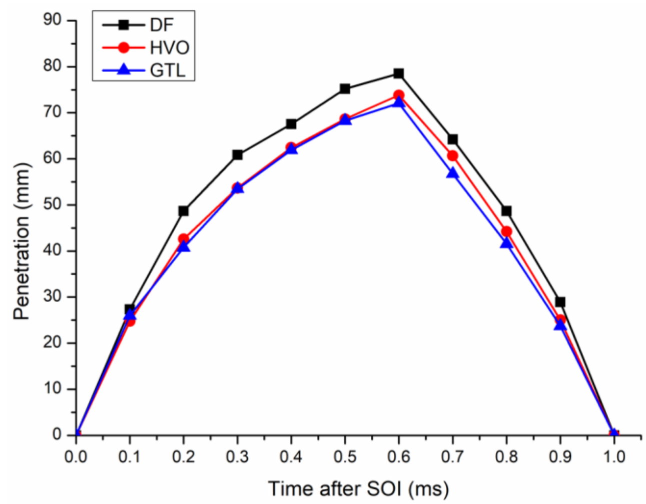

Fig. 3 Spray tip penetration of renewable fuels at 10 bar ambient pressure

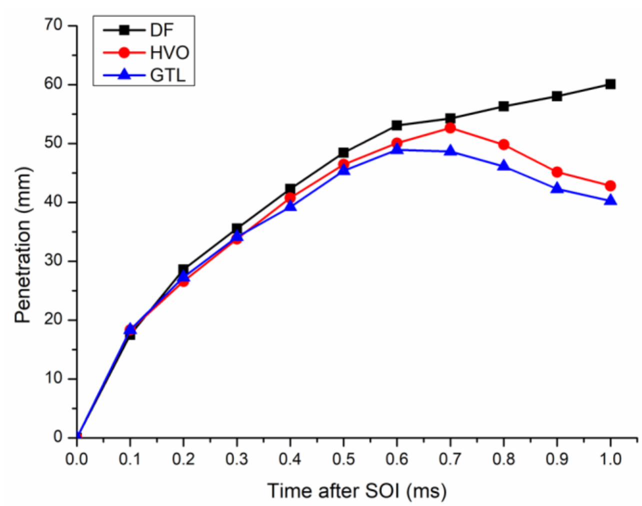

Fig. 4 Spray tip penetration of renewable fuels at 40 bar ambient pressure

When the ambient pressure rises to 40 bar, the spray tip penetration of all fuels increases with sample time, and the penetration of HVO and GTL are almost at the same level during injection. It is because the ambient pressure and density dominate the breakup process at constant rail pressure, whilst the impacts of other fuel properties and ambient temperature are not comparable.

In post-injection, the penetration of DF increases with time, whilst that of HVO and GTL becomes to drop. The phenomena are mainly because the evaporation dominates in the post-injection period and thus enables shorter penetration for the renewable fuels due to their lighter compositions, as HVO and GTL have lower 100% distillation temperature than DF (EN590).

4. CONCLUSIONS

This paper investigates the macroscopic spray characteristics of two renewable fuels (HVO and GTL) by experiments in the CVV system at different conditions. The main conclusions are below:

- HVO and GTL have closed average cone angle to DF.
- DF has the largest spray tip penetration during both the injection and post-injection periods due to its larger density, whilst GTL has the smallest penetration caused by its smallest density and viscosity.
- During the post-injection period, high ambient temperature reduces spray tip penetration at low ambient pressure due to faster evaporation.
- HVO and GTL are easier to be evaporated at high ambient temperature regardless of other conditions.

REFERENCE

[1] F. Millo, B. K. Debnath, T. Vlachos, C. Ciaravino, L. Postrioti, and G. Buitoni, "Effects of different biofuels blends on performance and emissions of an automotive diesel engine," *Fuel,* vol. 159, pp. 614-627, 2015.

[2] T. Bohl, A. Smallbone, G. Tian, and A. P. Roskilly, "Particulate number and NOx trade-off comparisons between HVO and mineral diesel in HD applications," *Fuel,* vol. 215, pp. 90-101, 2018.

[3] G. Labeckas, S. Slavinskas, and I. Kanapkienė, "The individual effects of cetane number, oxygen content or fuel properties on performance efficiency, exhaust smoke and emissions of a turbocharged CRDI diesel engine–Part 2," *Energy Conversion and Management,* vol. 149, pp. 442-466, 2017.

[4] H. Aatola, M. Larmi, T. Sarjovaara, and S. Mikkonen, "Hydrotreated vegetable oil (HVO) as a renewable diesel fuel: trade-off between NOx, particulate emission, and fuel consumption of a heavy duty engine," *SAE International Journal of Engines,* vol. 1, no. 2008-01-2500, pp. 1251-1262, 2008.

[5] A. C. Vosloo, "Fischer–Tropsch: a futuristic view," *Fuel processing technology,* vol. 71, no. 1-3, pp. 149-155, 2001.

[6] H. C. Heng and S. Idrus, "The future of gas to liquids as a gas monetisation option," *Journal of Natural Gas Chemistry,* vol. 13, no. 2, pp. 63-70, 2004.

[7] D. A. Wood, C. Nwaoha, and B. F. Towler, "Gas-to-liquids (GTL): A review of an industry offering several routes for monetizing natural gas," *Journal of Natural Gas Science and Engineering,* vol. 9, pp. 196-208, 2012.

[8] T. Wu, Z. Huang, W.-g. Zhang, J.-h. Fang, and Q. Yin, "Physical and chemical properties of GTL−diesel fuel blends and their effects on performance and emissions of a multicylinder DI compression ignition engine," *Energy & Fuels,* vol. 21, no. 4, pp. 1908-1914, 2007.

[9] P. Soltic, D. Edenhauser, T. Thurnheer, D. Schreiber, and A. Sankowski, "Experimental investigation of mineral diesel fuel, GTL fuel, RME and neat soybean and rapeseed oil combustion in a heavy duty on-road engine with exhaust gas aftertreatment," *Fuel,* vol. 88, no. 1, pp. 1-8, 2009.

[10] P.-C. Chen, W.-C. Wang, W. L. Roberts, and T. Fang, "Spray and atomization of diesel fuel and its alternatives from a single-hole injector using a common rail fuel injection system," *Fuel,* vol. 103, pp. 850-861, 2013.

[11] Y. Gao, M. Wei, F. Yan, L. Chen, G. Li, and L. Feng, "Effects of cavitation flow and stagnant bubbles on the initial temporal evolution of diesel spray," *Experimental Thermal & Fluid Science,* vol. 87, 2017.

[12] K. Kannaiyan and R. Sadr, "Experimental investigation of spray characteristics of alternative aviation fuels," *Energy Conversion and Management,* vol. 88, pp. 1060-1069, 2014.

