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Experimental study on engine spray and combustion characteristics fueled with kerosene

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ABSTRACT

In this study, the spray characteristics of kerosene were investigated by comparing with diesel. The spray characteristics including spray penetration, spray velocity and spray angle were investigated. The engine combustion characteristics were also investigated based on a diesel engine. The result shows that the injection durations for kerosene are longer than diesel due to the lower value of viscosity in kerosene. Kerosene has shorter spray penetration and lower spray velocity compared with diesel, while the spray angle of kerosene is larger than diesel. Compared with diesel, the engine has higher break thermal efficiency fueled with kerosene, while the NO emission is not increased much.

Keywords: Kerosene, engine, spray, combustion, emission

1. INTRODUCTION

How to improve the fuel economy and to mitigate polluted emissions are always the most significant motivations for researchers to seek after new engine technologies. According to this purpose, many engine technologies were investigated and developed, including increasing fuel injection pressure and boost pressure, reducing the size of injector nozzle hole and organizing air motion in the combustion chambers. It is worth noting that, at the time being, to organize air-fuel mixing by optimizing the fuel spray performance is the most important part during the engine development.

During the injection process, fuel spray break-up occurs and the fuel is atomised into small droplets. This allows for the fuel and intake air to be mixed. The smaller droplets allow for quicker evaporation of the fuel for combustion to take place. One of the phenomena that helps in fuel spray break up is cavitation that occurs in the fuel injector nozzle [1]. Som et al. [2] states that cavitation can improve fuel spray development which can allow more complete combustion, better fuel efficiency and lower emissions. Bergwerk was one of the firsts in 1959 to conduct an experimental study which concluded that cavitation affects fuel spray break-up [3]. Cavitation occurs when the pressure within the liquid falls below the vapour pressure of the liquid at a given temperature. The fuel injector nozzle has sharp corners. This causes stream line contractions which reduces the effective cross section of the flow. Because of this, the fuel in the injector nozzle undergoes rapid acceleration. Due the increase in velocity, the pressure of the liquid decreases according to Bernoulli's principle. The pressure can reduce until the pressure is below the vapour pressure of the fuel and the fuel undergoes phase change to a gas, or cavitation [4]. When the bubbles of vapour fuel enter the combustion chamber, they implode and a cause the fuel spray to disintegrate further.

After the Second World War, the idea of using a single military fuel was conceived to simplify the logistic supply chain for petroleum products, which has been called single fuel concept (SFC). Kerosene, which had been used as an aviation fuel, has been considered as the SFC. Actually, quite a number of researchers have investigated the effect of kerosene in diesel engines [5], and it was found that kerosene, as a substitution for diesel, showed no critical limitation [5].

However, most studies performed just focused on emission measurements, which give little information about macroscopic spray characteristics for kerosene. In this paper, the spray characteristics of kerosene were investigated by comparing with diesel. The spray characteristics including spray penetration and spray angle were investigated. The engine combustion characteristics were also investigated based on a diesel engine.

2. EXPERIMENT SETUP

2.1 Spray test

The experimental setup for fuel spray study consists of constant volume chamber (CVC), visualization system, common rail high pressure fuel injection system and an intelligent control system, as shown in Fig.1. In order to reproduce the operation conditions of practical engines, high back pressure in the CVC can be made for spray characteristics study. The CVC is developed to

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allow optical access to the injected fuel sprays for dynamic measurement. The inert nitrogen gas was used to pressurize the CVC and the utmost back pressure is up to 60 bar under room temperature. The CVC has volume of 6 litres, while the thickness and diameter of the optically quartz glass window are 60 and 150 mm respectively.

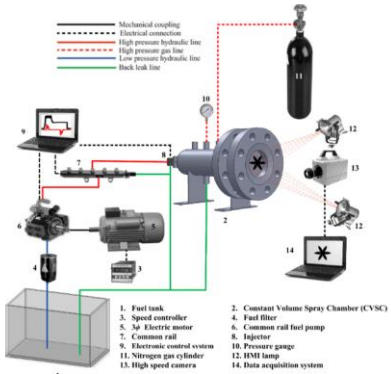


Fig.1 Experimental setup for spray study

An embedded control system was built in-house with FPGA real-time technology. Based on this control system, the excitation current and voltage can be flexibly adjusted to adapt most kinds of solenoid and piezoelectric injectors as well as high pressure fuel pumps. The common rail high pressure fuel injection system consists of fuel injectors, a high pressure fuel pump, an electric motor for running fuel pump, a common rail and some high pressure fuel lines. The highest injection pressure for this system can be up to 2000 bar. The fuel injector in the experimental study is shown in Fig.2 and the specifications is presented in Table 1. A high speed camera of Photron Fastcam SA5 was used for spray visualization. The sensor of the camera is 12 bit monochrome with a spatial resolution of 20 mm pixel with a minimum exposure time of 1ms. The images are captured at 20000 frames per second with a maximum spatial resolution of 832 x 448 pixels and temporal resolution of 0.05 ms.

Fig.2 piezoelectric fuel injector

The method of spray momentum measurement is similar to the one used by Payri et al. [6]. According to the principle of momentum conservation, the momentum flux from the nozzle of injector can be obtained from the injection force measured by a force sensor (Kistler 9207, piezoelectric type capable of measuring force between ±50N with sensitivity of < ±0.05N). A round block is mounted on the top of the sensor to suffer the spray impingement so as to acquire the injection force data. The force sensor is mounted close to the nozzle exit of injector and the distance between the nozzle hole exit and the top of the sensor can be adjusted from 12 to 0 mm along the spray axial direction.

Table 2 Injector specifications

Injector type	Piezoelectric
Hole number	8
Diameter of orifice (μm)	138±5
Orifice length (μm)	947±5
Spray angle (o)	154±2

2.2 Engine test

The engine used in this study is a single-cylinder research diesel engine with displacement of 0.638 L. The rated continuous output is 7.8 KW at 2400 rpm. For exhaust gas emissions measurement, the AVL gas analyzer was used. In the engine test, a NUS built in-house “Next-cycle control” system was used, as shown in Fig.3.

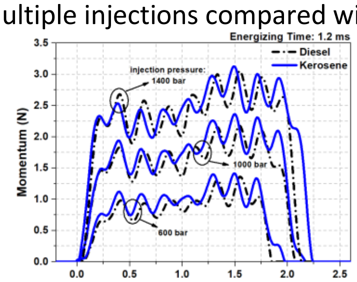
Next-cycle control is the process of rapidly collecting cylinder pressure data and doing the post process for use in a control loop with enough time to adjust engine control parameters and command actuators for the next combustion cycle. With next-cycle control, certain combustion conditions (such as CA50) can be targeted and accurately controlled between every cycle of the engine. FPGAs with the PXI real-time computing hardware from National Instruments are used.

Fig.3 Engine Next-cycle control system

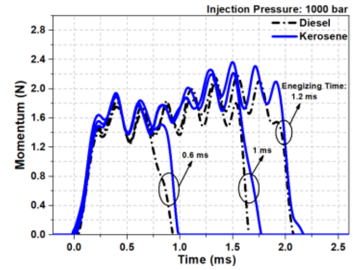
3. RESULT AND DISCUSSION

The injection behaviours of diesel and kerosene can be seen in Fig.4. It can be found that during the closing of the needle valve at different injection pressures and energizing times, the end-of-injections for kerosene are longer than diesel fuel, which means the closing of the needle valve fueled with kerosene is slower than that with diesel. In Fig.5, the end-of-injection corresponding to three injection pressures (600, 1000, 1400 bar) and six energizing times including 0.4, 0.6, 0.8, 1.0, 1.2, 1.4 ms are involved. It is shown that, for each energizing time, the end-of-injections for diesel are shorter than that for kerosene, especially with higher injection pressures. The phenomenon can be attributed to the following two reasons. Firstly, once the injector is going to close, the viscous force from the fuel can assist the needle to descend to its initial position. The lower viscous force the less assistance can be obtained during the closing of the needle valve. Because the viscosity of kerosene is lower than that of diesel, as such more time will be needed during the closing of the needle valve caused by lack of viscous force assistance. This is similar to the result was reported in [7]. Secondly, due to the fact that the viscosity of kerosene is lower than that of diesel, both the turbulent kinetic energy and injection velocity for kerosene are higher, which implies that the resistance from kerosene against needle valve closing is higher than diesel, thus leading to slower closing of the needle valve.

As the development of advanced engine technology, the strategy of using multiple injections is becoming a very popular methodology to achieve ideal fuel-air stratified distribution. According to the results shown in this study, it can be deduced that the minimum intervals between each injection in the multiple injections can be influenced by fuel properties. Longer injection intervals must be needed for kerosene to achieve multiple injections compared with diesel.



(a)



(b)

Fig.4 Comparison of spray momentum for diesel and kerosene

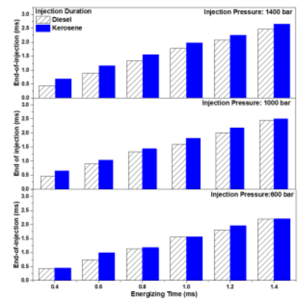


Fig.5 End-of-injection comparison for diesel and kerosene

Fig.6 shows the spray evolution captured by a high speed camera for the diesel and kerosene under three injection pressures of 600, 1000 and 1400 bar. In the experiment, the ambient temperature and pressure are 305 K and 20 bar respectively. All the injections conducted were with energizing time of 1 ms, while the spray capturing timing is 0.55 ms after start of injection. As shown in Fig.6, both diesel and kerosene, the spray penetration is longer with higher injection pressure, which is mainly because the spray momentum is increased with increased injection pressure. Compared with diesel, the spray penetration of kerosene is apparently shorter and the spray angle is larger, which is mainly because of two reasons. Firstly, the lower fuel viscosity enhances the fuel spray breaking, leading to the fuel droplets reduction. With smaller size of spray droplet, the spray momentum is lower with higher resistance [8]. Secondly, the fact that kerosene has higher cavitation trend compared with diesel results in lower discharge coefficient from the nozzle exit, which shows similar result reported in the authors previous work [9,10].

All the experiment result reveals that the differences in physical properties of diesel and kerosene will lead to apparent differences in the fuel injection performance during the closing of diesel injector needle valve and the spray evolutions. Therefore, the calibration for the engine control strategy must be redone when the researchers and engineers are going to achieve the application of kerosene in diesel engines. Besides, it should be noted that kerosene has a lower lubricity compared to diesel, so it can contribute to greater wear of the fuel injection system when kerosene is used. As such, the addition of lubricity additives may be needed or the improvement of the fuel system may be required when applying kerosene in diesel engines. The experimental durability studies of engines and fuel systems fueled with kerosene are necessary as well.

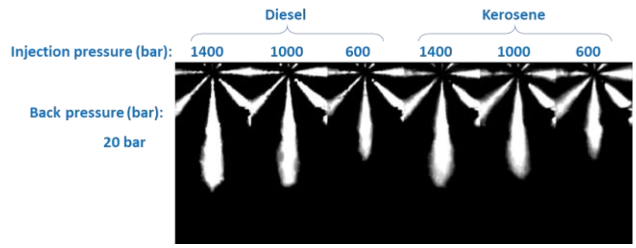


Fig.6 Spray evolutions for diesel and kerosene

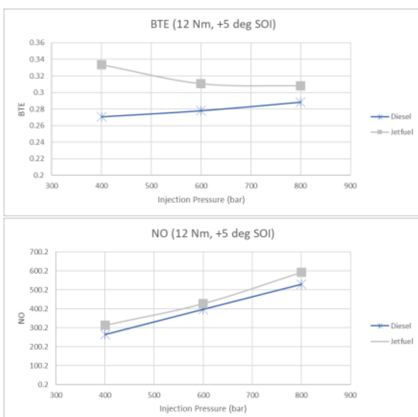


Fig.7 Engine emissions

From Fig.7 it can be seen that, the engine shows much higher break thermal efficiency fueled with jet fuel compared with diesel, which is partially due to the better spray performance of kerosene. And the NO emission for jet fuel is not only increased much compared with diesel combustion.

4. CONCLUSION

The injection durations for kerosene are longer than diesel due to the lower value of viscosity in kerosene. Kerosene has shorter spray penetration compared with diesel, while the spray angle of kerosene is larger. Compared with diesel, the engine has higher break thermal efficiency fueled with kerosene, while the NO emission is not increased much.

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