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Emulsion fuel with novel nano-organic additives for diesel engine application

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HIGHLIGHTS

- A novel emulsion fuel with nano-organic additives is introduced in this work.
- The brake thermal efficiency of the engine can be improved by 14.2%.
- The NO_x emissions can be reduced by 30.6%.

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ABSTRACT

A novel emulsion fuel with nano-organic additives is introduced in this work. Unlike other emulsion fuels (opaque and milky in color) developed around the world, it is transparent and light green with superior stability. The performance and emissions of the emulsion fuel in a diesel engine with common-rail fuel supply system are tested and compared with pure diesel. The results indicate that the micro-explosion phenomenon of the nano-sized water droplets in the emulsion fuel can accelerate fuel evaporation and its mixing process with air, reducing the overall combustion duration. When 10% emulsion fuel was used, the brake thermal efficiency of the engine was significantly improved by 14.2% compared to pure diesel, and the NO_x emissions was also reduced by 30.6%.

1. Introduction

Transportation is the major contributor to the world's energy consumption and greenhouse gases emissions. The United States alone consumes about 21 million barrels of oil per day, of which, about 65% is used in transportation, while the world's oil consumption amounts to 90 million barrels per day. The resulted rising fuel costs and more and more stringent emission standards have driven researchers to look into new solutions for increased engine efficiency and reduced emissions for future transportation system. The need for increased engine efficiency has placed diesel engine in the spotlight due to its superior engine efficiency compared to a gasoline engine. However, diesel engines also face the major disadvantage of increased NO_x emission. Future legislation to control vehicle exhaust emissions will restrict NO_x emission to very low levels, and low fuel consumption will also be required [1].

As the formation of NO_x emissions highly depends on the operating temperature [2,3], various methods including exhaust gas recirculation (EGR) technology [4] and retarding fuel injection timing [5] have been developed to bring down the peak temperature, thereby reducing NO_x emissions.

Water injection is also an effective method to reduce NO_x emissions. Water can be injected directly into the cylinder with a fuel injector [6–8], or injected into the intake manifold with a separate injection system [9,10]. Most of the research indicates that NO_x can be reduced with water injection, but accompanied by a significant increase of HC and CO emissions. Meanwhile, the presence of liquid water in the combustion chamber results in oil contamination and an increase in engine wear.

To overcome the adverse effects of direct water injection on the performance and engine design, water–diesel emulsion fuels have been developed, which is the addition of surfactants to reduce the oil and water surface tension, activate their surface, and maximize their superficial contact areas, thereby forming a continuous and finely dispersed droplets phase [11]. It eliminates the need for separate water storage and feeding system. Quite a number of researchers have studied the effect of various emulsion fuels on the performance and emissions of diesel engines [12–14], and it has been reported that 5–20% water in the diesel can give a reduction in NO_x emissions of 10–35%. However, it is noted that most those emulsion fuels are opaque, milky in color and not very stable. In this work, a novel emulsion fuel with nano-organic additives is introduced. It is transparent, light green in color and very stable. The performance and emissions of the engine fueled by the emulsion fuel and pure diesel were tested and compared.

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Table 1
Specifications of the emulsion fuels and pure diesel.

	Diesel content (Mass%)	Water content (Mass%)	Organic additives (Mass%)	Heat value (MJ/kg)	Viscosity at 40 °C	Density (kg/m^3)
Diesel	100	0	0	45.00	2.8	0.85
E10	78.5	10.0	11.5	38.25	8.8	0.88
E15	75.0	15.0	10.0	36.16	11.4	0.89
E10 by [16]	90%	10%	–	40.51	3.2	0.85

2. Experiment details

Two types of emulsion fuels with different water concentrations, i.e. 10% and 15%, were employed in this study. Organic materials such as Glycerin are employed as additives to produce a stable emulsion fuel. As the application for intellectual protection for this emulsion fuel is still in process, we cannot disclose too much about it. A detailed description on the production of the additives and emulsion fuel can be referred to [15]. Different from the previous emulsion fuels produced by other researchers, the emulsion fuel produced by this method has the color similar to fossil diesel. Table 1 lists the specifications of pure diesel and the emulsion fuels used in this test, another emulsion fuel tested by Armos et al. [16] is also listed for comparison. The emulsion fuel used in this study has a higher viscosity, but very stable. According to Mr Ng Jeremey, the CEO of Singapore Emulsion Fuel Pte Ltd., a stability test indicates that there is no significant separation observed after 1 year of storage.

A 4-cylinder diesel engine with common rail fuel injection system is used in this study, and the specifications of the engine are listed in Table 2.

The schematic of engine test-bed used in this study is shown in Fig. 1. A precise air flow meter (AVL Sensyflow P) was used to measure the air flow rate. The fuel consumption rate was measured using an AVL 733S.18 fuel balance with an accuracy of ±1%. The cylinder pressure was measured at a resolution of 1 °CA by an AVL GH13P water-cooled pressure transducer which was mounted on the first cylinder, and it can sustain a peak pressure of 250 bars. A water cooled passive eddy current dynamometer (AVL DP 160) was coupled to the test engine to accurately control the engine speed and load. It is able to provide a peak braking power of 160 kW, maximum torque of 400 Nm with an accuracy of ±0.3%.

Important operating parameters like intake manifold pressure, air flow rate, fuel injection timing, fuel consumption rate, cylinder pressure, exhaust gas pressure, exhaust temperature, engine speed, engine torque, etc. were monitored using an indicating system (AVL Indicom). Exhaust emissions like CO, NO and NO_2 are measured using a portable gas analyzer (E instrument 4400 N). The HC emission is measured using another gas analyzer (AVL Digas 2200). The detailed specifications of the gas analyzers are listed in Table 3.

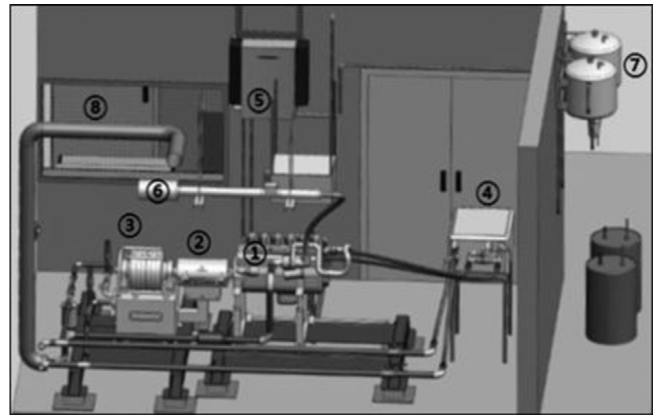

Fig. 1. Schematic of the diesel engine test-bed (1) Toyota 2KD-FTV 2.5 Liter Engine, (2) AVL dynamometer, (3) AVL coupling shaft, (4) Engine coolant conditioning unit, (5) Sensor data acquisition system, (6) Air intake, (7) Overhead fuel tank and (8) Control room.

3. Results and discussion

The performance of the diesel engine fueled by the emulsion fuels and pure diesel are tested and compared at different engine speeds and working load conditions. Figs. 2 and 3 show the variation of cylinder pressure and heat release rate with crank angle for the two types of emulsion fuels and pure diesel when the engine is operating at low speed (1200 rpm) and full load conditions. The fuel starts to inject at 1 °CA before top dead center (TDC), and ends that 9 °CA after TDC. The fuel injection pressure and temperature are 44 MPa and 48.4 °C, respectively. The intake air temperature and pressure are 35.5 °C and 0.099 MPa respectively. The air/fuel mass ratio is about 20.8, corresponding to an equivalence ratio of 1.505, 1.667 and 1.771 for the pure diesel, E10 and E15, respectively. A slight drop in the cylinder pressure can be observed for the emulsion fuels. This is due to the fact that the heat value of the emulsion fuels is lower than that of -diesel, and less energy is released during the combustion process. At the same time, the evaporation of water droplets will absorb heat energy, thereby further bringing down the temperature and pressure. However, we can see from Fig. 4 that the peak heat release rate of the emulsion fuels is a bit higher than that of pure diesel, and the combustion duration is shorter than that of pure diesel. For example, the combustion takes about 45 °CA to finish for pure diesel, while it takes only about 38 °CA and 37 CA for E10 and E15, respectively. This is the result of micro-explosion of water droplets formed in the

Table 2
Engine specifications.

Type	Toyota, four-cylinder, four-stroke diesel engine
Bore	92 cm
Stroke	93.8 cm
Swept volume	2494 cc
Compression ratio	18.5
Rated power	75 kW
Rated torque	200 Nm
Rated speed	3600 rpm
Injection system	Common rail fuel injection
EGR	Yes

Table 3
Specifications of the measurement devices.

Instrumentation		Range	Resolution	Accuracy	
E Instruments 4400 N	CO	0–8000 ppm	1 ppm	±10 ppm	0–200 ppm
				±5% measured value	201–2000 ppm
	NO	0–5000 ppm	1 ppm	±5 ppm	1–100 ppm
				±5% measured value	101–5000 ppm
	NO_2	0–1000 ppm	1 ppm	±5 ppm	
AVL Digas 2200	HC	0–20000 ppm	1 ppm	±10 ppm	