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Experimental Study of Spray Characteristics, Engine Performance and Emission Levels of Acetone-Butanol-Ethanol Mixture-Diesel Blends in a Diesel Engine.

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Abstract

This paper investigates spray and engine performance of an acetone-butanol-ethanol (ABE) mixture blended with diesel fuel in a single-cylinder direct injection (DI) diesel engine**.** Spray images were evaluated using a high-speed camera under 300 bar injection pressure. Engine performance such as brake power (BP), brake-specific fuel consumption (BSFC) and in-cylinder pressure were measured. Exhaust gas emissions such as oxides of nitrogen (NO_x), carbon monoxide (CO) and unburned hydrocarbon (UHC) were also assessed. The test was carried out at three engine speeds (1400, 2000 and 2600 rpm) at full load. The experiment results showed that: liquid penetration of ABE-diesel is longer than that of diesel. BP of ABE-diesel blends was comparable with pure diesel at 2600 rpm, while the peak in-cylinder pressure was higher compared to diesel at 2000 rpm. UHC and CO emissions were significantly reduced as a result of the addition of ABE to the neat diesel, while NO_x emissions were slightly increased.

1 Introduction

With the high demand for environmental security, more attention is being paid to utilising renewable alternative fuels in diesel engines. Alcohol blends have the potential to reduce exhaust emissions as well as improve fuel efficiency due to their high oxygen content. Using alcohols as additives could also reduce dependence on fossil fuel because the alcohols are derived or produced from renewable materials such as agricultural waste. Ethanol and methanol are being widely researched in diesel engines, but some difficulties have been reported such as storage safety and low cetane number [1].

Currently, the ABE mixture has the potential to be an alternative biofuel due to its manner of production and the advantages of its properties. The volumetric ratio of ABE was 3:6:1 after fermentation processes [2-5]. Several researchers have experimentally investigated ABE blends in constant-volume chamber and diesel engines [6, 7]. These studies demonstrated that: (1) engine efficiency was improved; (2) NO*x* and soot emissions were decreased [8].

The aim of this paper is to assess the impact of ABE-diesel blends on spray characteristics, engine performance and emission levels in a DI diesel engine.

2 Methodology

2.1 Fuel Preparation and Properties

Normal butanol (B) and acetone (A) were used at 99.8% analytical grade and obtained from Chem-Supply Australia. Ethanol (E) was used at 100% analytical grade. Diesel was obtained from a local petrol station in Toowoomba, Australia as a baseline. The ABE mixture was prepared with a ratio of 3:6:1 by volume, which was used to simulate the intermediate fermentation production. Then 10% and 20% ABE was blended with diesel, referred to as 10ABE90D and 20ABE80D respectively. Miscibility and stability of the ABE-diesel blends were monitored over a one-month period before the tests were carried out on the engine. The samples were stored in glass bottles and visually observed every week, with all blends maintaining a good homogeneous mixture. Table 1 shows the properties of the separate fuel and blends.

Properties	A	E	B	D	ABE	10ABE	20ABE
Viscosity (mm^2/s) @ 40 ºC	0.35	1.08	2.22	1.9-4.1	1	2	1.8
Calorific value (MJ/kg)	29.6	26.8	33.1	42.8	31.4	41.6	40.5
Cetane number	-	8	17-25	48	-	-	-
Surface tension (mN /m)	22.6	-	24.2	23.8	-	-	-
Flash point ºC	17.8	8	35	74	-	-	-
Latent heat (MJ/kg) @ 25 ºC	518	904	582	270	595	300.4	331.2

Table 1. Fuel properties [8].

2.2 Experimental Apparatus

2.2.1 Spray Test Setup

The spray experimental test was carried out on a constant volume vessel (CVV) at atmospheric pressure. An air-driven high-pressure fuel pump was used in the fuel injection system using a solenoid Bosch-type injector with six holes (each 0.18 mm in diameter) and an injection pressure of 300 bar. A Photron Charge-Coupled Device (CCD) camera was used to capture the

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spray blends images. The camera has a resolution of 1024×1024 pixels. An LED light was used for illuminating the fuel spray to ensure constant background light for the camera. For each fuel test, the fuel tank and fuel system line were cleaned and emptied and the fuel filter was replaced with a new one. After ensuring all the injection systems were cleaned and emptied, the spray testing started with some preliminary injection tests for at least five minutes before recording the new images.

2.2.2 Engine Test Setup

The engine test was conducted using a single-cylinder, four stroke, water-cooled, DI diesel engine. An electrical dynamometer connected to the engine was used to control the load. The crank angles were measured using a crank angle encoder set up on the shaft of the engine. A Kittler 6052C pressure transducer (CT400.17) and charge amplifier connected to a data acquisition system with software (CT 400.09) were used to record cylinder pressure values at one crank angle revolution for 50 cycles each test. The exhaust gas emissions were analysed using a Coda gas analyser to measure NO_x, CO and UHC. The test was conducted at a compression ratio of 19:1 with three engine speeds (1400, 2000 and 2600 rpm) under full load. The test began at least 20 minutes before recording commenced. The experiments were carried out in triplicate to reduce the experimental error. Table 2 contains the engine specifications. Fig.1 shows operating setting of engine.

Engine model	G.U.N.T. Hamburg
Combustion type	Direct Injection Engine
Number of cylinders	1
Compression ratio	5:1-19:1
Maximum power (kW)	Approx. 6kW
Speed range (rpm)	900-3000
Bore	90mm
Stroke	74mm
Capacity	$470cm^3$
Maximum compression pressure	60-80 bar
Nozzle injection pressure	300 bar
Injection type	Direct Injection

Table 2. Engine specifications

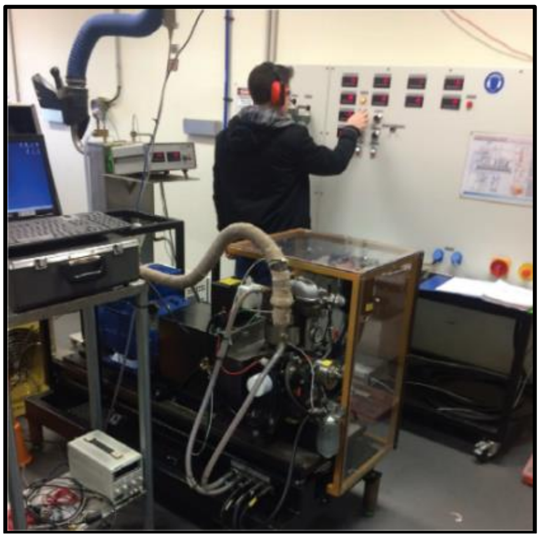


Figure 1. Operating setting of G.U.N.T engine.

3 Results and Discussion

3.1 Spray Characteristics

The macroscopic characteristics of ABE-diesel blends were obtained using a high speed- camera under various after start of injection (ASOI). Fig. 2 illustrates the spray images analysis from a Bosch type injector. Because the engine used in the experimental test was only equipped with mechanical injectors, the injection pressure used was 300 bar. Liquid spray penetration of ABE-diesel is longer than that of diesel. Fuel properties of blends have a significant impact on liquid penetration especially; under evaporating or burning conditions. According to Table 1 ABE features a much higher latent heat and lower viscosity than pure diesel, which leads to enhanced vaporisation and atomisation. Therefore the penetration length will be shorter and the plume narrower at high ambient pressure and temperature inside the diesel engine cylinder. Because almost all the physical properties change with increased ambient temperature, there is a decrease in viscosity and surface tension while there is an increase in vapour pressure. These changes significantly accelerate the atomisation and evaporation of the liquid spray.

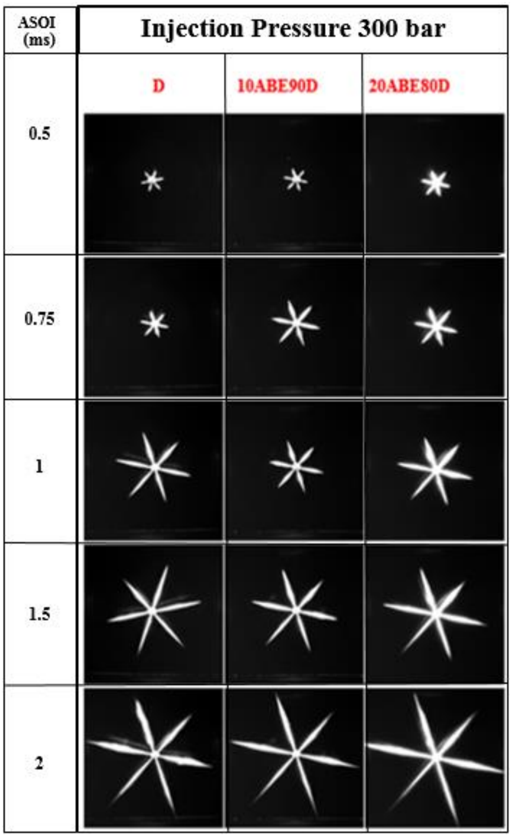


Figure 2. Spray images of test fuels.

3.2 Engine Performance

3.2.1 In-Cylinder Pressure

Figure 3 shows the relationship between the peak in-cylinder pressure trace and the crank angle of the test fuels at 1400 and 2000 rpm. 20ABE80D blend gives a maximum peak in-cylinder pressure compared to neat diesel due to the low cetane number

(CN) of the ABE blend. This results in increased ignition time and rapid in-cylinder pressure increase.

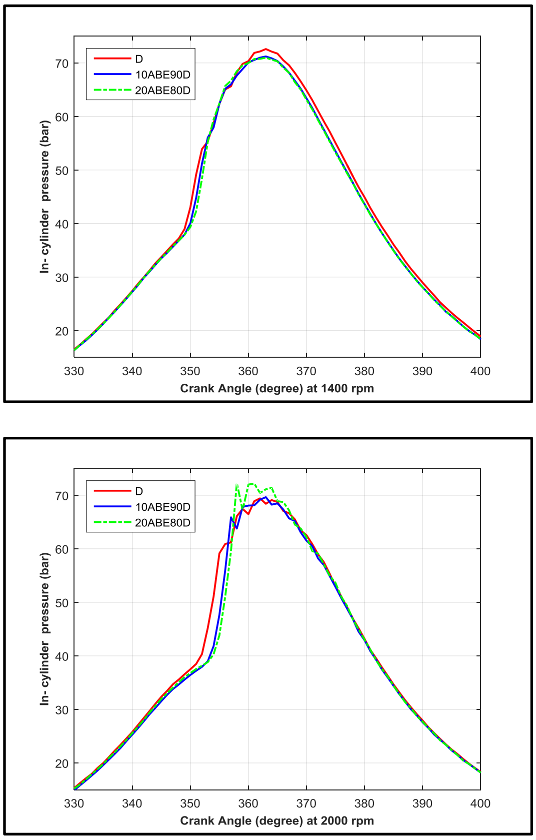
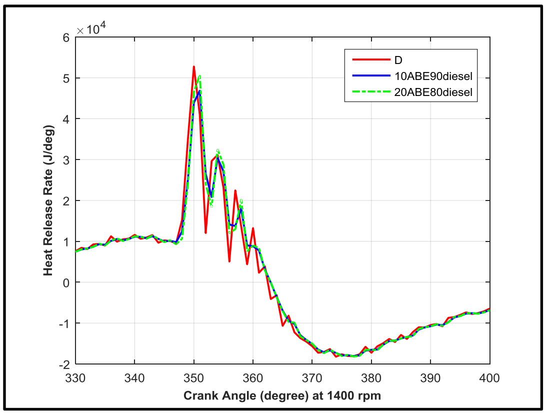


Figure 3. In-cylinder pressure at 1400 rpm and 2000 rpm.

3.2.2 Heat Release Rate (HRR)

Figure 4 presents the heat release rate of the test blends at two engine speeds. It can be seen that the diesel blend showed the highest peak HRR at the low engine speed. In contrast, the maximum HRR of 20ABE-80diesel blend occurred at 2000 rpm engine speed. The peak cylinder pressure **(**Fig. 3**)** generally corresponds to the highest HRR.



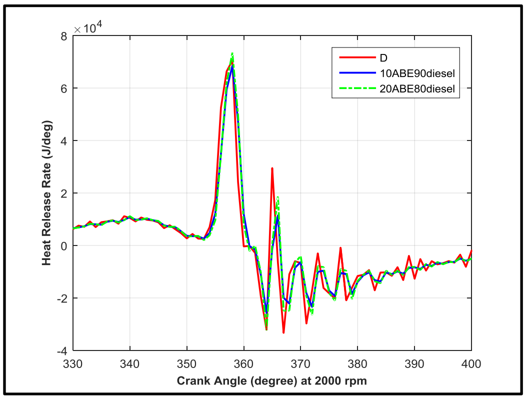


Figure 4. HRR at engine speed 1400 rpm and 2000 rpm.

3.2.3 Brake Power and Brake Specific Fuel Consumption

Figure 5 shows the variation of BP and BSFC with the engine speed of the test fuels. The BP of the ABE-diesel blend showed comparable value with diesel at the high engine speed due to its high oxygen content. BSFC was increased with both fuel blends compared to that of pure diesel due to the low calorific value of the blends (Table 1).

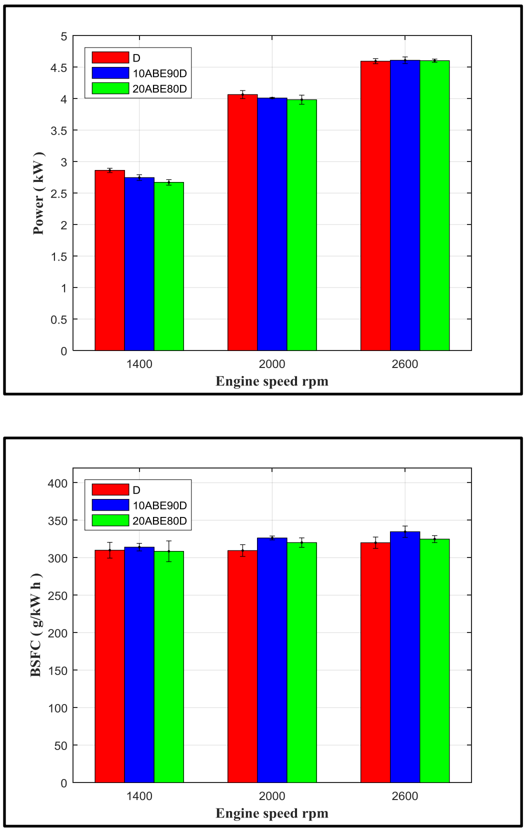


Figure 5. BP and BSFC of test fuels at three engine speeds.

3.2.4 NO_x and CO Emissions

Figure 6 presents the NO_x and CO emissions of the test fuels at various engine speeds. All ABE-diesel blends showed a slight increase in NO_x emissions at all engine speeds. CO emissions were reduced at all engine speeds. This trend could relate to: the high oxygen content and the lower cetane number of the ABE-diesel blends. These complications led to delays in ignition time and resulted in an increase in the premixed zone. This process can increase the local temperature and result in increased NO_x emissions.

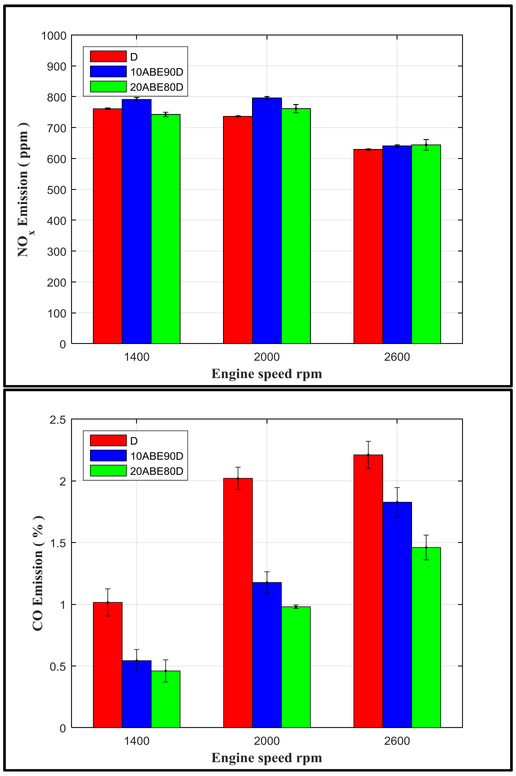


Figure 6. NO_x and CO emissions of test fuels at three engine.

3.2.5 UHC Emissions

The use of ABE-diesel blends decreased the UHC emissions compared to neat diesel at medium and high engine speeds (Fig. 7). This reduction occurred because ABE blends is a type of multi-component fuel with different volatilities, which might produce micro-explosions and thus promote combustion performance. Also, the difference in droplet lifetime between ABE (3.25 s/mm^2) and neat diesel (3.75 s/mm^2) at 823 K affects the reaction time of ABE blends, which results in increased mixing time and leads to complete reaction resulting in decreased UHC emissions [9].

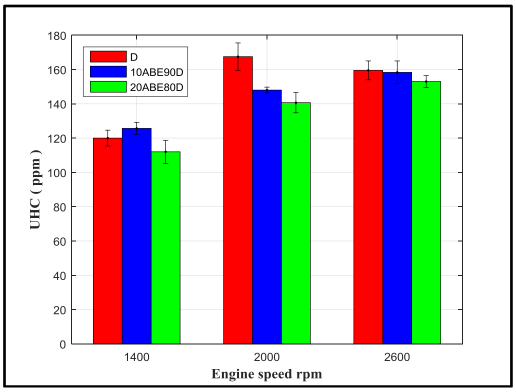


Figure 7. UHC emission of test fuels at three engine speeds.

4 Conclusions

The experimental work has concluded some significant results for the test fuels. The results are as follows:

- Liquid spray penetration of ABE-diesel blend is longer than that of diesel at ambient conditions.
- The BP of the ABE-diesel blends was comparable with neat diesel at the high engine speed, while the peak in-cylinder pressure and HRR were higher compared to diesel at the medium engine speed.
- UHC and CO emissions were significantly reduced as a result of the addition of ABE to diesel blends, while NO_x emissions were slightly increased.

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