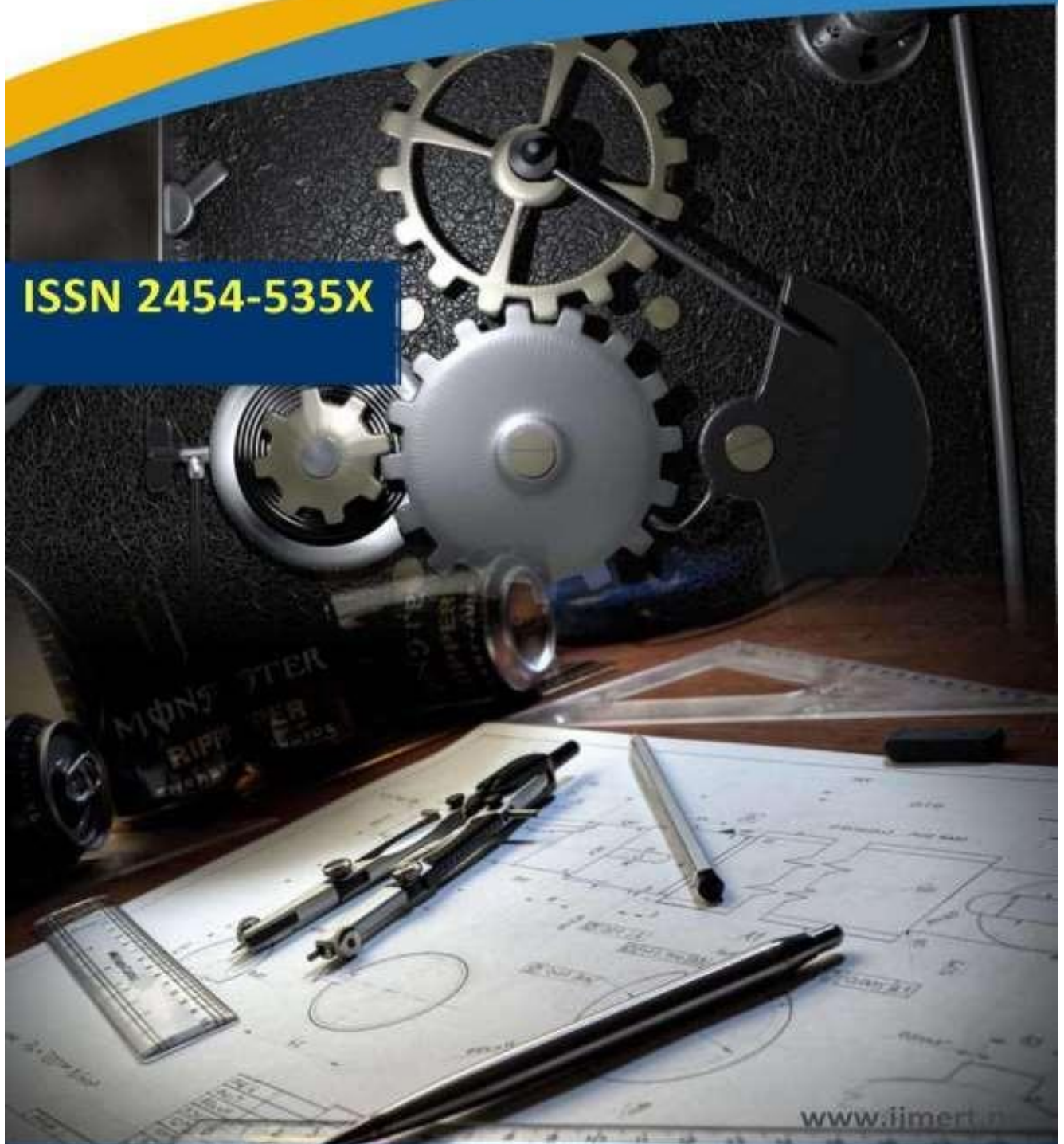




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Experimental Investigation of the Performance and Emissions of a Diesel Engine Using Blended Diesel Fuels of Ethanol and Biodiesel

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ABSTRACT:

In order to lessen reliance on fossil fuels and environmental degradation, using biofuels is a widespread trend in the transportation industry in many nations, including Vietnam. In this study, a 4-cylinder, naturally-aspirated diesel engine running on a combination of diesel fuels containing ethanol and biodiesel was compared for engine performance and emissions. DE10 (90% diesel-10% ethanol), DE5B5 (90% diesel-5% ethanol-5% biodiesel), and DE10B5 (85% diesel-10% ethanol-5% biodiesel) were among the blends. In addition to testing the engine at 100% load while varying the engine speed from 1000 rpm to 3500 rpm, the engine was also tested at 75%, 50%, and 25% load while maintaining a constant engine speed of 3500 rpm. The results demonstrated that the DE5 and DE10 blends only slightly altered engine torque and

KEYWORDS: Alternative fuels; Biodiesel; Ethanol; Diesel fuel; Blends; Emissions

INTRODUCTION

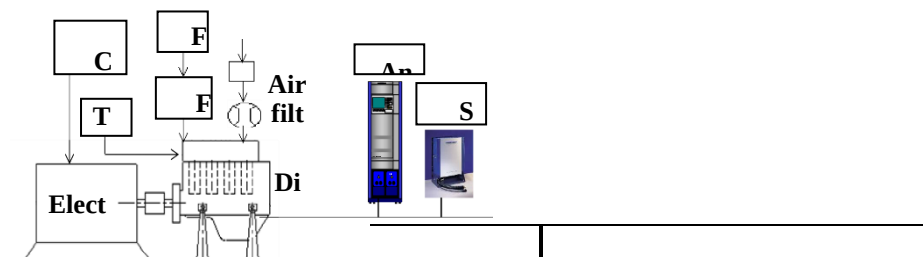
Research into alternative fuels is essential due to the rising demand for clean engine exhaust gas and the rising usage of petroleum-based fuels. Biofuels like ethanol and biodiesel have significantly contributed to the transportation sector's increased sustainability. They can be utilized to minimize hazardous emissions, create less CO₂, and partially replace fossil fuels [1-3]. Ethanol is a potential alternative fuel since it is oxygenated and made from

sustainable bio-based resources, which can improve combustion and lower exhaust gas emissions. When used as a commercial fuel, ethanol is often blended with gasoline to replace a portion of the fossil fuel used in gasoline engines [4-5]. Utilizing mixes with a low amount of ethanol, such as 5%, for gasoline engines

EXPERIMENTAL

Experimental apparatus

The experimental set up consisted of a diesel engine, engine test bed and exhaust measurement system (Figure 1). The test engine was a naturally aspirated, 4-cylinder Hyundai D4BB diesel engine, its specifications are shown in Table 1. An electrical dynamometer was coupled to the engine to provide brake load. The consumption of fuel and air was measured by an AVL Fuel Balance and Air Flow Meter. For emission analysis, an AVL Combustion Emission Bench (CEB II) and a Smoke Meter AVL 415 were installed and sampled the raw exhaust gas at the tail pipe, and lambda value was detected by a lambda sensor. The CEB II comprises analysers for HC, CO and NO_x measurements.



**Lambda
sensor**

Exhaust pipe

Figure 1. Experimental setup

Table 1. Engine specifications

Specifications	Value s
Engine model	Naturally aspirated, 4 stroke, 4 cylinder diesel engine
Injection sequence	1-3-4-2
Bore (mm) x Stroke (mm)	91.1 x 100
Rate power (kW) at speed (rpm)	59/4000
Rate torque (Nm) at speed (rpm)	165/2200
Compression ratio	22
Type of injection pump	Mechanical in-line

Test modes

In order to assess the effect of fuels on maximum engine power, the test was carried out at full load condition at which the speed varied from 1000rpm to 3500rpm with an increment of 500rpm. Then assessment at partial loads were done at 75%, 50%,

25% of loads while the engine speed was kept constant at 2000rpm. Before measuring with a new fuel blend, the engine was run for sufficient time to consume the remaining fuel from the previous experiment. The engine was not modified or adjusted throughout the test.

Test fuels

Blends of ethanol-diesel and ethanol-biodiesel-diesel were used as fuels for the diesel engine and the engine performance and emission characteristics were compared with that when fueled by diesel. The blends included 5% ethanol - 95% diesel (DE5), 10% ethanol - 90% diesel

(DE10), 5% ethanol - 5% biodiesel - 90% diesel (DE5B5), 10% ethanol - 5% biodiesel - 85% diesel (DE10B5) by volume. Properties of diesel fuel that has 0.05% sulfur available in Vietnam market, ethanol and biodiesel are provided in Table 2. These blends were mixed by a stirrer to form homogeneous mixture right before testing.

Table 2. Properties of the test fuels



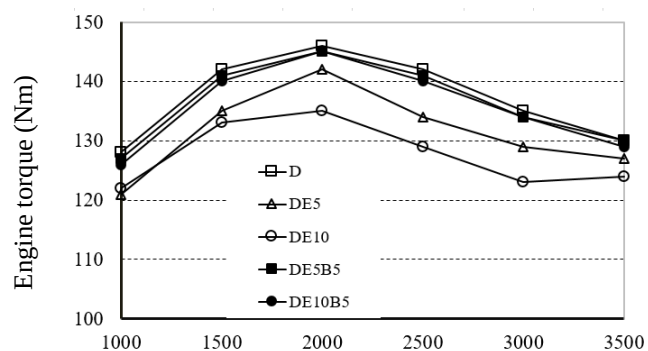
Fuel properties	Diesel	Ethanol	Biodiesel
Density at 15°C(kg/m ³)	837	789	869
Kinematic viscosity at 40°C (mm ² /s)	3.14	-	4.1
Lower heating value (MJ/kg)	43	26.8	39.9
Flash point (°C)	60		152
Oxygen (% weight)	0	34.7	8.4
Cetane number	49	-	60
Octane number	-	113	-

RESULTS AND DISCUSSION

At each test point, the values of engine performance and emissions were measured repeatedly 3 times, then the average values were calculated. The difference between measured values and average values was in the range of 3% to 6% for engine performance measurement, and from 5% to 10% for engine emission measurement. These average values are presented and compared below.

Engine performance

Firstly, the variation of engine torque and specific fuel consumption at full load with all test fuels is plotted versus engine speed (Fig.2). The measured maximum torque values when using the blends, which are of 142Nm, 135Nm, 145Nm and 145Nm correspond to DE5, DE10, DE5B5 and DE10B5 fuels, are lower than 146Nm with diesel. It is observed that the higher the ethanol content in ethanol blended diesel, the higher the reduction in maximum torque.



This is attributed to the lower heating value of ethanol which is 26.8MJ/kg as compared to 43MJ/kg that of diesel

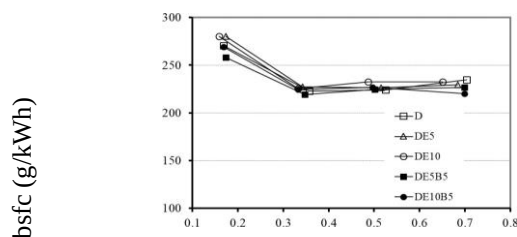


and also the lower density of ethanol which may reduce the mass of fuel injected per cycle. However, this reduction can be negligible when 5% biodiesel was added, maybe due to the improvement of cetane number and lubricity of the blends. On average over speed range, with DE5, DE10, DE5B5 and DE10B5 fuelling the engine torque decreased by 4.3%, 6.9%, 0.6% and 1.1%, respectively as compared to diesel fueled.

Speed (rpm)

Figure 2. Comparison of the engine torque at full load

The brake specific fuel consumption (bsfc) in g/kWh as a function of load at speed of 2000rpm with all these test fuels are also compared (Figure 3). Even though there was a lower heating value but the bsfc with all the blends was not changed much as compared to that with diesel. At 2000rpm, on average the bsfc increased 1.1% and 1.9% with DE5 and DE10 but decreased 2.3% and 1.2% with DE5B5 and DE10B5. It seems that the ethanol and biodiesel in blends helps to improve the combustion efficiency and compensate partly for the loss in heating value.



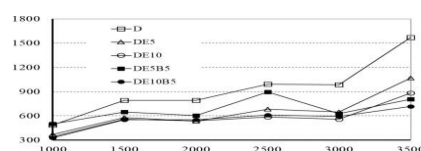
Engine emissions bmep (MPa)

Figure 3. Comparison of bsfc at 2000rpm

Emissions including CO, HC, NO_x and smoke were measured at each testing mode. The measured emissions are compared between all the test fuels at full load while the speed varied from 1000rpm to 3500rpm, and at different loads while the speed was kept constant at 2000rpm.

The CO emissions from the engine fueled by the diesel fuel were higher than that fueled by the blends, especially at high speed and high load (Figure 4, Figure 5). Ethanol and biodiesel have about 34.7% and 8.4% of oxygen respectively, so that the ethanol and biodiesel blended diesel fuels contain amount of oxygen which can reduce the lack of oxygen in combustion chamber, and enhances the complete combustion, that lead to the reduction in CO emissions. The lower C content in blends that diminishes the CO formation may also be another reason. The highest reduction in CO emissions at full load and speed of 3500rpm was from 32% with DE5 to 54% with DE10B5, and at full load and speed of 2000rpm up to 32% with all the blends. On average, over speed range at full load the CO emissions reduced by 30.1%, 36.3%, 22.4%, 37.7% and over load range at 2000rpm the CO emissions reduced by 14.9%, 9.7%, 12.8%, 14.7% for the DE5, DE10, DE5B5 and DE10B5 blends, respectively.

The similar trend was also obtained in case of HC emissions which decreased significantly for the blends as compared to that for diesel (Figure. 6, Figure. 7). This result agrees with the reduction in CO emissions mentioned above, and it shows that the combustion process with the blends were improved and more completed. The highest reduction in HC occurred at full load and medium speed, from 2000rpm to 2500rpm, that was by about 60% for the DE10 and DE10B5 blends. On average, over speed range at full load the HC emissions of the engine fueled with the DE5, DE10, DE5B5 and DE10B5 blends decreased by 37.2%, 46.3%, 33.5%, 43.3%, and by 25%, 20%, 43%, 35.8% over load range at 2000rpm, respectively, as compared to that fueled by the diesel fuel. Speed



(rpm) **Figure 4.** Comparison of CO emissions at full load

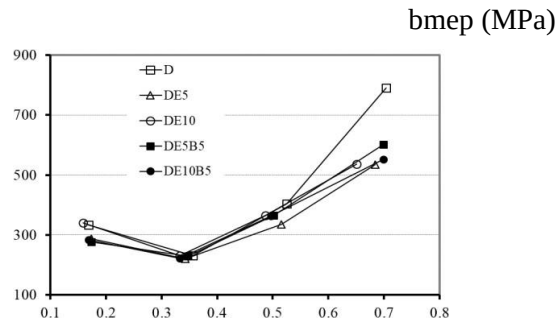


Figure 5. Comparison of CO emissions at 2000rpm

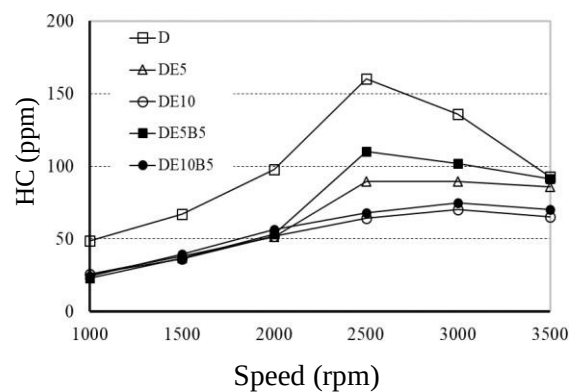


Figure 6. Comparison of HC emissions at full load

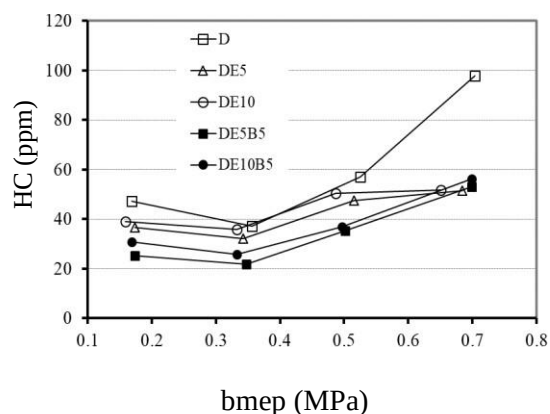


Figure 7. Comparison of HC emissions at 2000rpm

For the NO_x emissions, the slight reduction in NO_x emissions for the blends can be observed at all the test modes (Figure. 8, Figure. 9). As we know, the formation of NO_x emissions is mainly due to the peak temperature and the availability of oxygen in combustion chamber during combustion process. Adding small amount of ethanol and/or biodiesel to diesel, on one hand, supplement a little oxygen content into the blended diesel that may lead to increase in the NO_x emissions. However, in the other hand, ethanol has higher latent heat of vaporization (840 kJ/kg) than diesel (270 kJ/kg) that may cause the lower combustion temperature in the cylinder for the ethanol blended diesel, and as a result preventing the NO_x formation. Besides that, lower heating value and lower cetane number of the

ethanol and/or biodiesel blended diesel fuels may be other reasons of lower combustion temperature and reduce the NO_x . On average, over speed range at full load NO_x emissions emitted by the DE5, DE10, DE5B5 and DE10B5 blends were 10.8%, 3.5%, 2.9%, 4.6% lower, and over load range at 2000rpm they were 11.7%, 11%, 6.9%, 8.8% lower, respectively, than that by the diesel fuel.

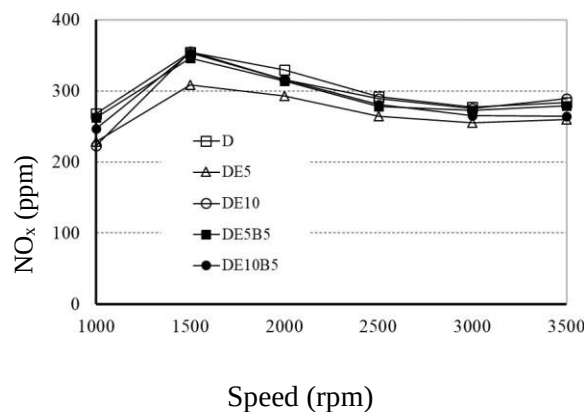


Figure 8. Comparison of NO_x emissions at full load

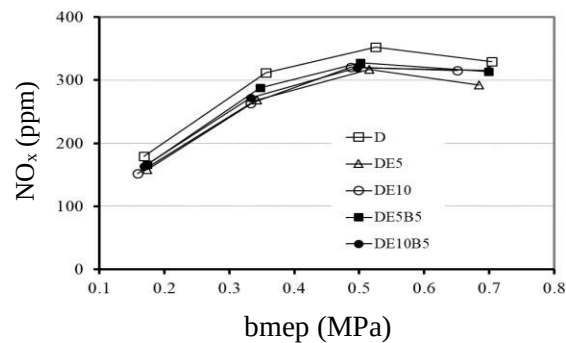
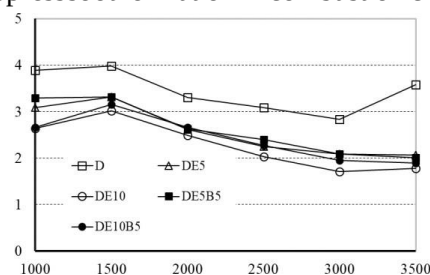


Figure 9. Comparison of NO_x emissions at 2000rpm

Smoke when the engine ran at different speeds and loads are compared (Figure 10, Figure. 11). It is clearly seen that the smoke reduced for the DE5, DE10, DE5B5 and DE10B5 blends at full load but did not change much at medium and low loads as compared to the diesel fuel. The effect of the blends on smoke at low loads was slight due to low flame temperature and overall leaner mixture (Figure 12). However at fuel rich working conditions such as at full load, the effect of the blends, with the lambda value was about 6% to 10% higher than that of diesel (Figure 13), on smoke became stronger. It is due to the mixture was rich and the amount of oxygen in the blends playing as an oxidizer introduced to the fuel-rich regions and suppresses soot formation in combustion chamber. On average, over



speed range at full load the smoke reduced by 25.5%, 34.1%, 24.1%, 29.5% and over load range at 2000rpm the smoke reduced by 10.2%, 14.2%, 11.5%, 12% when fueling the engine by the DE5, DE10, DE5B5 and DE10B5

blends, respectively, as compared to the diesel fuel.
Smoke (FSN)

Speed (rpm)

Smoke (FSN)

Figure 10. Comparison of smoke at full load

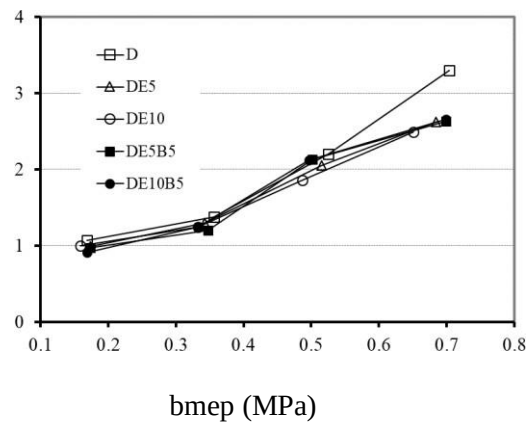


Figure 11. Comparison of smoke at 2000rpm

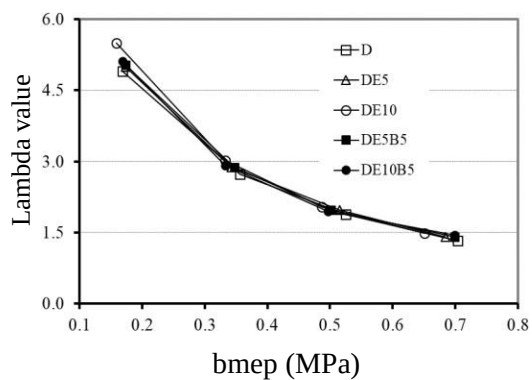
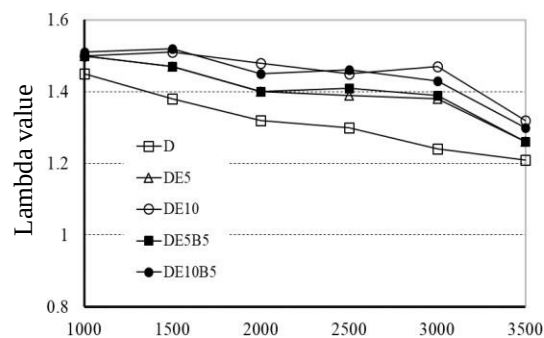


Figure 12. Comparison of lambda value at 2000rpm



CONCLUSIONS Speed (rpm)**Figure 13.** Comparison of lambda value at full load

The influences of the blends including 5% ethanol - 95% diesel, 10% ethanol - 90% diesel, 5% ethanol - 5% biodiesel - 90% diesel and 10% ethanol - 5% biodiesel - 85% diesel on performance and emission characteristic of the diesel engine has been studied by carrying out the experiments on the engine test bed. The engine was run at full load - speed varied and at constant speed of 2000rpm - load varied. The results showed that the ethanol-diesel blends reduced engine torque averagely from 4.3% to 6.9% at full load as compared to the diesel fuel, but adding 5% biodiesel to the blends could recover the torque loss. The difference in brake specific fuel consumption (in g/kWh) between these fuels was negligible. Concerning emissions, the diesel engine fueled by the blends decreased quite clearly the emissions. The highest reduction in CO, HC, NO_x and smoke could be up to 37.7%, 46.3, 10.8% and 34.1% when the engine ran with the blends as compared to that ran with diesel. These results demonstrate the initial possibility of application of ethanol and biodiesel blended diesel as fuels for diesel engine without any engine modification.

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