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Experimental Study On Performance And Emissions Of A Diesel Engine Using Ethanol And Biodiesel Blended Diesel Fuels

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ABSTRACT: Using biofuels is a general trend in transportation sector in many countries including Vietnam that aims to reduce both dependence on fossil fuel and environmental pollution. This paper presents the comparative experimental results of engine performance and emissions of a 4-cylinder, naturally aspirated diesel engine fueled by ethanol and biodiesel blended diesel fuels. The blends included DE5 (95% diesel-5% ethanol), DE10 (90% diesel-10% ethanol), DE5B5 (90% diesel-5% ethanol-5% biodiesel), DE10B5 (85% diesel-10% ethanol-5% biodiesel). The engine was tested at 100% of load while the engine speed varied from 1000 rpm to 3500 rpm, and at 75%, 50%, 25% of loads while keeped the engine speed constant at 3500 rpm. Results showed that the DE5 and DE10 blends caused a minor change in engine torque and fuel consumption whereas reduced quite clearly HC, CO and smoke emissions but increased NO_x emissions as compared to the conventional diesel. However, blending 5% biodiesel in the DE5B5 and DE10B5 blends could help reduce a bit NOx emissions whereas the engine torque and fuel consumption nearly did not change and the other emissions in exhaust gas still significantly reduced.

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

INTRODUCTION

The increasing consumption of petroleum fuels and the growing requirements for clean engine exhaust gas promote necessary researches on alternative fuels. Biofuels, such as ethanol and biodiesel, have had a significant role in improving the sustainability of transport sector. They can be used to partly subsitute for fossil fuel, reduce toxic emissions and produce less CO_2 [1-3]. Ethanol is a potential alternative fuel because it comes from renewable bio-based resource and it is oxygenated, thereby possible to improve the combustion process and reduce emissions in exhaust gas. Ethanol has been normally used as commercial fuel in term of blending with gasoline to replace a part of fossil gasoline for gasoline engines [4-5 For gasoline engine, using blends with low percentage of ethanol such as 5% (E5), 10% (E10) and up to 20% (E20) can improve engine power and fuel consumption as well as reduce remarkably HC and CO but increase NO_x emissions [6-10]. Beside that ethanol might also be blended with diesel to use as fuel for diesel engine. However, diesel-ethanol blend has not been commercially used due to the difference in chemical and physical properties between ethanol and diesel fuel. Recently, some investigations of the potential application of diesel-ethanol (DE) fuel blends on diesel engine have been carried out. Testing a truck engine fueled by blend of 10% dry ethanol, 1% additive and 89% diesel fuel on a test cell over 500 hours showed that the engine performance was not affected by the blend apart from the expected 4% decrease with drop of energy content [11]. The effects of blends with 5% and 10% ethanol (by volume) on the performance and emissions of a turbocharged direct injection diesel engine were studied [12-13]. It was observed that increasing the ethanol content in the fuel blend increased the brake specific fuel consumption and slightly increased the brake thermal efficiency which were attributed to the lower calorific value and the higher premixed combustion part possessed by the ethanol blends. The blends with high percentage of ethanol, such as 10% to 30%, could be unstable and separated, so they need the assistance of additive to solve the problem of the stability [14]. The effects of ethanol on emissions vary with engine operating conditions, ethanol content, additive and ignition improver. As compared to neat diesel fuel, ethanol content in blends significantly reduced smoke density and NOx [9,11], however the NOx emissions were increased or decreased some extent and there was not a stable trend for the NOx emissions [14], CO and HC emissions generally increased [14-15] but with fuel additive and ignition improver they could be equal or reduced [15]. Besides ethanol, biodiesel which basically has very similar properties as fossil diesel is another kind of biofuel. Although biodiesel fuel can be used by itself for diesel engine, it is more commonly used as a blend component with conventional diesel. Biodiesel has lower heating value, higher oxygen content, higher cetane number, higher viscocity, lower compressibility, higher density as compared to fossil diesel that may effect on diesel engine performance and emissions [16-17]. In general, biodiesel-diesel blends do not change much engine power, especially at low percentage of biodiesel [18], and brake specific fuel consumption can increase up to 14% or maybe higher with pure biodiesel used [17,19-20]. With regard to the emissions, although there is no complete consensus, the reduction in CO, HC, PM mass and the increase in NOx and fuel consumption when using biodiesel instead of fossil diesel have been observed in most studies [17-23]. Combining ethanol and biodiesel as blend components with conventional diesel is also one more solution to promote the use of biofuels replacing mineral fuel. Testing blends of 45% biodiesel - 10% ethanol - 45% diesel and 40% biodiesel - 20% ethanol - 40% diesel on a direct injected diesel engine pointed out that higher brake specific fuel consumption, higher CO and HC emissions, but lower NO emissions and no significant different in exhaust gas temperature when fueling the blends as compared to diesel [24]. Other studies showed that blending biodiesel into diesel-ethanol blends allowed higher amounts of ethanol mixing with diesel, and increasing amount of ethanol in ethanol – biodiesel - diesel blends reduced PM and CO but increased NOx emissions [20-25]. All studies above provide the ability to use blends of ethanol, biodiesel and diesel as fuel for diesel engine. However, the effect of blends on engine performance and emissions depends on engine operating conditions as well as engine configuration and fuel properties. This paper investigates the performance and emission characteristics of an in-use diesel engine fueled by blends of 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. The ethanol and biodiesel fuel were produced in Vietnam and the experimental works were carried out at Laboratory of Internal Combustion Engines, Hanoi University of Science and Technology.

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 NOx measurements.

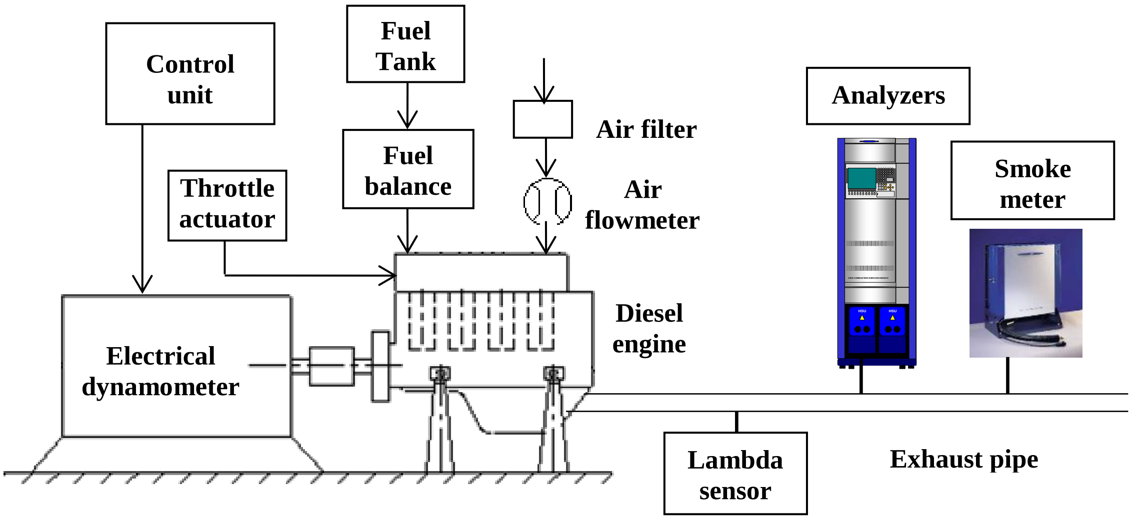

Figure 1. Experimental setup

Table 1. Engine specifications

Specifications	Values
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 15^0C (kg/m^3)	837	789	869
Kinematic viscocity at 40^0C (mm^2/s)	3.14	-	4.1
Lower heating value (MJ/kg))	43	26.8	39.9
Flash point (^0C)	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 repeatly 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 vesus 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.

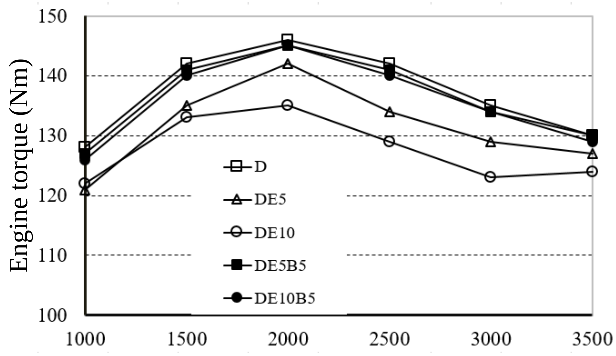

Figure 2. Comparison of the engine torque at full load

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.

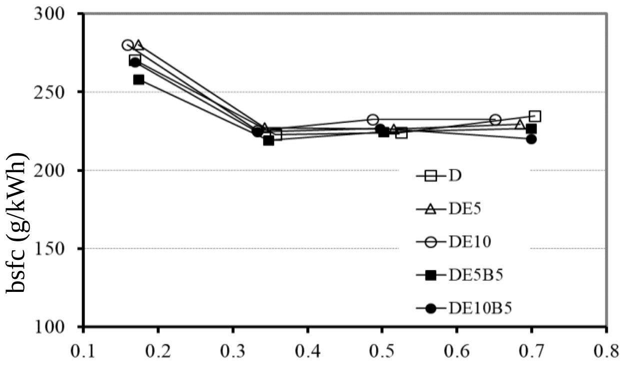

Figure 3. Comparison of bsfc at 2000rpm

Engine emissions

Emissions including CO, HC, NOx 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 diminishs 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.

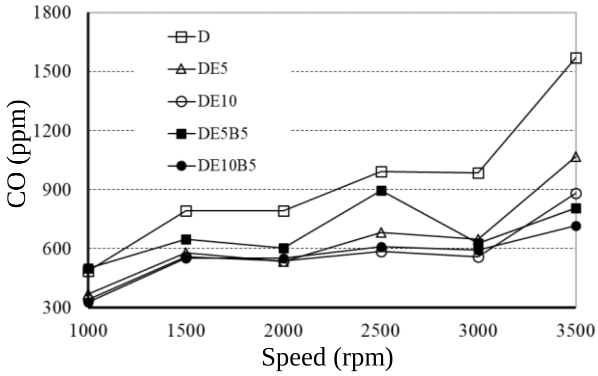

Figure 4. Comparison of CO emissions at full load

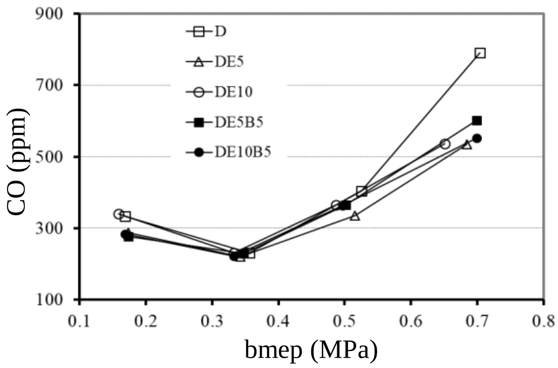

Figure 5. Comparison of CO emissions at 2000rpm

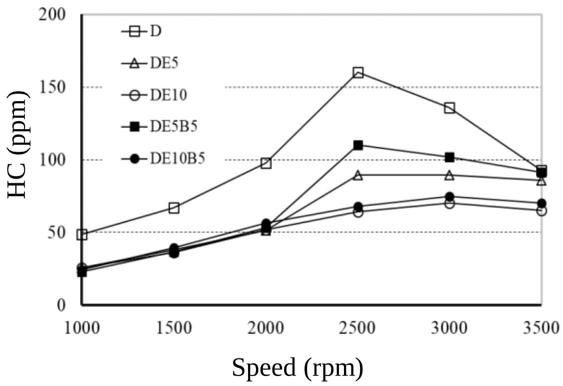

Figure 6. Comparison of HC emissions at full load

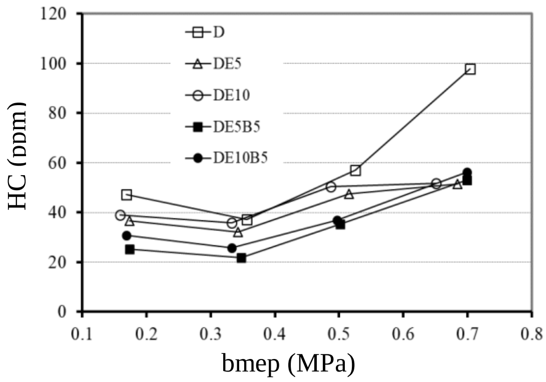

Figure 7. Comparison of HC emissions at 2000rpm

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.

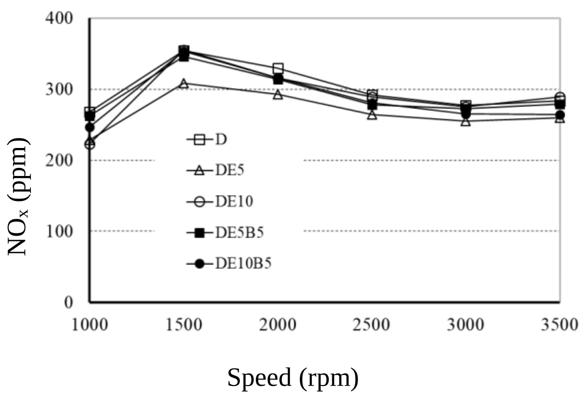

Figure 8. Comparison of NO_x emissions at full load

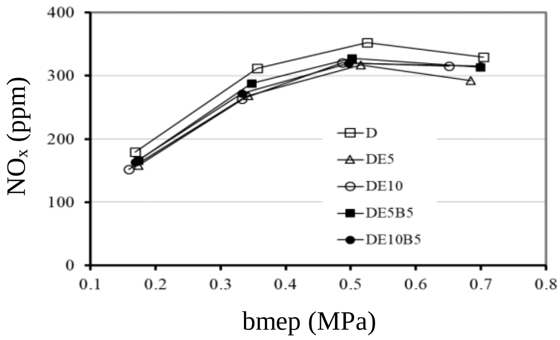

Figure 9. Comparison of NO_x emissions at 2000rpm

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 suppress 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.

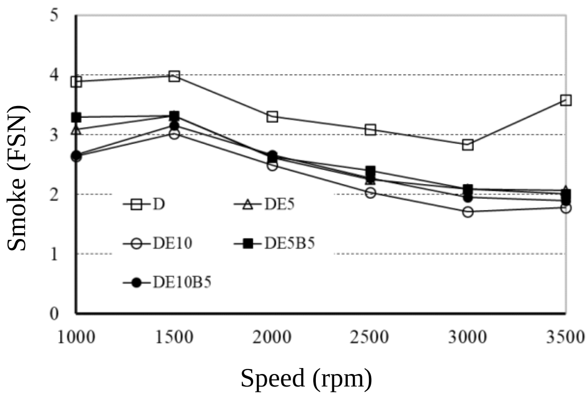

Figure 10. Comparison of somke at full load

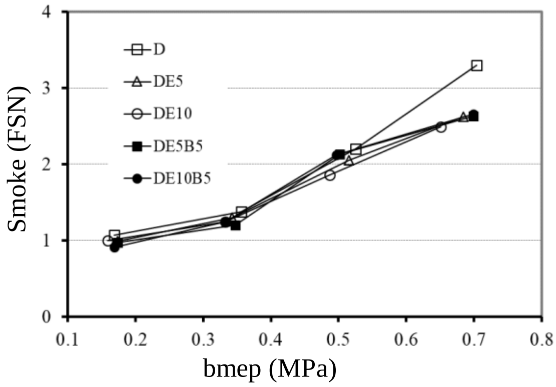

Figure 11. Comparison of smoke at 2000rpm

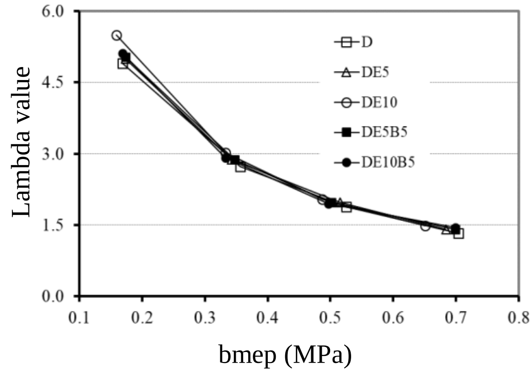

Figure 12. Comparison of lambda value at 2000rpm

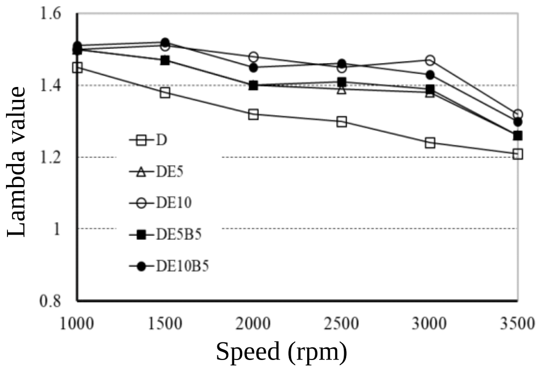

Figure 13. Comparison of lambda value at full load

CONCLUSIONS

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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