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Experimental Study of the Effect of Castor Oil Biodiesel Fuel on Performance and Emissions of Turbocharged DI Diesel

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ABSTRACT

Experimental tests were carried out on a semi-heavy duty Motorsazan MT4.244 agricultural engine at various loads in order to evaluate performance and emissions of DI diesel engine using the blends of diesel fuel with 5, 10,15,20, 30%(by volume) Castor oil and pure diesel fuel separately. The results show that maximum decrease in PM emission compared to that of pure diesel fuel is 73.2% and observed in B15 at 50% load. Also, the maximum increase in BSFC and No when compared to those of pure diesel fuel are 10.7 and 15.6% and observed in B30 at 50% load and B20 at 50% load, respectively. The results show that in B15 and at 25% load, NO and PM emissions decreases 6 and 64% respectively and BSFC increases 1.5%.

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1. INTRODUCTION

Despite growingdemand for fuel, dwindling resources is a crisis for science and technology [1, 2]. Diesel fuel is respected in economy of countries due to it uses in a comprehensive range as heavy-duty transport vehicles, rail transportation systems, agricultural machineries and construction equipment [3]. Nowadays, many of the developed countries have found a suitable approach to overcome the fuel sources leakage and environment pollution, with mass production and commercialization of bioenergy [1, 2]. Biodiesel is known as an alternative biofuel that reduces emissions produced from combustion engines [4, 5]. Biodiesel is produced from transestrification reaction of vegetables oil (fresh or waste) or animal fats with alcohol in presence of a catalyst [5, 6]. Biodiesel fuel has positive influence on engine emissions. It reduces particulate matter (PM), CO and SO_x [3]. NO_x emissions increase as a drawback of biodiesel fuel blends, depending on its percentage in fuel, [3, 7]. Also, biodiesel has other disadvantages including lower calorific value and power output which should be improved [7]. Biodiesel will be more industrialized and commercialized when it is produced from non-edible and cheap raw oil sources [5]. Monyem et al. [8] showed that fuel properties of biodiesel might vary due to oxidation after storing for a period of time. They found that after heating and bubbling with oxygen, the commercial biodiesel had a shorter ignition delay and lower hydrocarbons (HC) emission. Dorado et al. [9] carried out experimental test in a direct injection diesel engine with olive oil methyl ester and reported the same combustion efficiency for methyl ester of olive oil and diesel, a slight reduction in brake specific fuel consumption (BSFC), reduction of 58.9% in CO, 8.9% in CO_2, 37.5% in NO and 32% in NO_x for olive oil methyl ester as compared to diesel. Puhan et al. tested mahua oil ethyl ester in a four-stroke naturally aspirated direct injection diesel engine and have reported an increase in BSFC for mahua oil ethyl ester compared to diesel.

Also, a slight increase in brake thermal efficiency, reduction in CO emission, increase in CO_2 emission, 63% reduction in HC emission, reduction in NO_x and 70% reduction in smoke are reported. Buyukkaya [7] tested neat rapeseed oil and its blends of 5, 20 and 70%, and standard diesel fuel in a diesel engine and concluded that the use of biodiesel produces lower

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smoke opacity, and higher brake specific fuel consumption (BSFC) compared to diesel fuel and the measured CO emissions of B5 and B100 fuels were found to be 9 and 32% lower than that of the diesel fuel, respectively. Jiafeng et al. [10] showed that lower heating value, lower volatility, higher viscosity, generally higher oxides of nitrogen (NO_x) and high production cost, are some of the negative attributes of biodiesels Rao et al. [11] studied the effects of the percentage of used cooking oil methyl ester (UCOME) on combustion characteristics (ignition delay, peak cylinder pressure, heat release rate). It was observed that the ignition delay periods of UCOME and its blends are significantly lower than that of diesel and decrease with increase in the percentage of UCOME. Also, the results show that the peak cylinder pressure is slightly higher for UCOME-diesel blends compared to diesel.

This shows that the peak pressure is not very much affected using UCOME and its blends compared to diesel. The maximum heat release rate decreases with increase in percentage of UCOME in the blend. It can also be observed that maximum heat release rate occurs earlier with the increase in the percentage of UCOME in the blend. Tsolakis, A., Megaritis, A., Wyszynski, M.L., and Theinnoi [12] studied the combustion of rapeseed methyl ester (RME) pure or blended with ultra-low sulphur diesel (ULSD) at 20% and 50% by volume (B20 and B50) was investigated on a single-cylinder direct injection diesel engine with pump–line–nozzle injection system. The combustion of RME, B20 and B50 resulted in advanced combustion compared to ULSD. The advanced RME combustion resulted in the reduction of smoke, HC and CO while both NO_x emissions and fuel consumption were increased. The combustion of different fuel blends did not affect significantly the engine efficiency.

The increased amount of oxygen in the RME molecule and hence in the locally fuel-rich combustion zones is believed to be an additional reason for the reduced smoke. The increase in fuel consumption is mainly due to the lower calorific value (LCV) of RME compared to ULSD. The use of EGR was more effective in the case of biodiesel blends combustion compared to ULSD combustion. The NO_x emissions were reduced at levels similar to those of ULSD with the use of similar volumetric percentages of EGR, while the smoke was kept low.

A survey in the relevant literature shows that only few attempts have been done up to now in order to study the effect of Castor oil concentration in the blend of biodiesel and diesel fuels on the emissions and performance characteristics of biodiesel fueled engine. The goal of this study is to improve diesel fuel properties and reduce engine emissions with adding Castor oil biodiesel to it.

2. EXPERIMENTAL SET UP AND PROCEDURE

The experiments were carried out on a semi-heavy duty Motorsazan MT4.244 agricultural engine mainly used for tractors. The engine is a 3.99 litters, turbocharged, four-cylinder direct injection diesel engine. The main specifications of the engine are given in Table 1.

An eddy current dynamometer with a load cell was coupled to the engine and used to load the engine. An AVL GU 13G pressure transducer, mounted at the cylinder head and connected via an AVL Micro IFEM piezo amplifier to a data acquisition board, was used to record the cylinder pressure. The crankshaft position was measured using an AVL 365C digital shaft encoder. The test rig included other standard engine instrumentation such as thermocouples to measure oil, air, inlet manifold and exhaust temperatures, and pressure gauges mounted at relevant points. Normal engine test bed safety features were also included. Atmospheric conditions (humidity, temperature, pressure) were monitored during the tests. The maximum fuel injection pressure was measured using another pressure transducer that was fitted to the high pressure fuel pipe between the pump and the injector. Data acquisition and combustion analysis were carried out using in-house developed Lab VIEW-based software. An AVL DiCom4000 gas analyzer was used to measure NO_X, CO, and CO_2, by NDIR (non-dispersive infrared gas analysis), and oxygen (O_2) concentrations in the exhaust manifold (electrochemical method). Smoke measured using an AVL 415S smoke meter. Table 2 shows measurement accuracy of instruments involved in the experiment for various parameters.

TABLE 1. Specifications of test engine

Type	Turbocharged
Maximum power	61kW@2000rpm
Maximum torque	360N.m@1300rpm
Bore × stroke	100 × 127 mm
Compression ratio	17.5:1
Number of cylinders	4
Number of valves per cylinder	2
Combustion chamber type	Bowl-in-piston
Injection system	Pump-line-nozzle
Number of injection holes	4
Opening pressure of nuzzles	250 bars
Fuel	Diesel

TABLE 2. Measurement accuracy

NO_X (AVL DiCom4000)	1 ppm
Smoke (AVL 415S smoke meter)	0.1%
CO (AVL Digas4000)	0.01%
Inlet & exhaust CO_2 (AVL Digas4000 Light)	0.01%

TABLE 3. Repeatability of measurements

Emissions	NO_x	PM	Fuel Cons.
Std. Dev./Mean %	0.85	4.2	0.3

To ensure the accuracy of the measurements, all emission analyzers were calibrated before and after each test run. The emission measurements at each mode were repeated five times. The averaged values of repeated measurements were used in the analysis. From the repeated data points, the repeatability of the engine experiments can be estimated. The standard deviations over the means of the emission data are shown in Table 3. It can be seen from Table 3 that NO_x emission measurement repeatability is excellent, whereas all other measurements have good repeatability.

The experiments were carried out at various loads, injection timings 5° CA BTDC and 1400rpm (maximum torque) with the mixtures of diesel and biodiesel having 2.3. Computational domain and grid dependency test.

3. RESULTS AND DISCUSSION

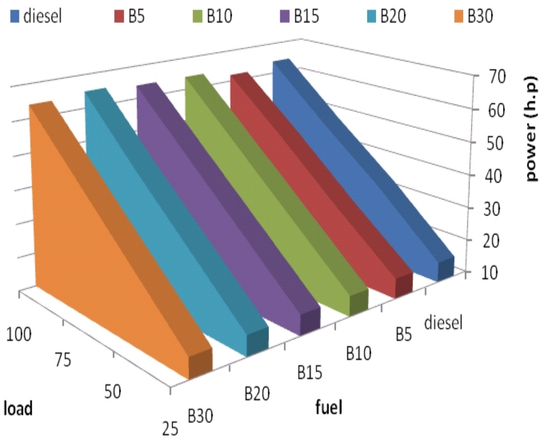
In the present work, the effects of adding Castor oil and its blends with diesel fuel on engine performance (engine power, torque, brake specific fuel consumption,), emission (NO x, CO, HC, CO_2, PM) and combustion characteristics (Exhaust gas temperature (°C)) have been studied for an unmodified diesel engine. The results are compared with corresponding data in a baseline engine fuelled with pure diesel fuel.

Figure 1a shows the variation in engine power for different fuel mixtures and loads. The results show that when using fuelsblended fuels, power output is lower than that of the diesel fuel. This trend is confirmed with the result of the work by Murillo et al. [13], who found that the loss of power was 7.14% for biodiesel compared to diesel on a 3-cylinder, naturally aspirated (NA), submarine diesel engine at full load, but the loss of heating value of biodiesel was about 13.5% compared to diesel. This power loss is due to lower heating value and higher viscosity of biodiesel. In the present work, maximum decreasing of engine power showed to be 6.1 % and was observed in B5 at 50% load.

Figure 1b shows the variation in engine torque for different fuels and loads. Torque for B20 at full load state is slightly higher than that of diesel fuel. A contributing factor here may be the injection timing advancement and more complete combustion. For other fuel blends, torque reduces and maximum decrease in engine torque is 3 % and observed in B5 at full load operation. These results are confirmed by the work of Buyukkaya [7], who tested biodiesel of rapeseed oil in diesel engine and reportedthat the maximum difference of measured torques between diesel and B20, B70 and B100 fuels at the speed of 1800 rpm were 2.2, 4 and 5%, respectively. The higher viscosity of biodiesel, which may affect the engine brake effective power, especially in full-load conditions, increases the mixture momentum and consequently penetration depth in-cylinder. On the other hand, the higher viscosity and surface tension of biodiesel prevent sufficient breaking of the biodiesel during injection process, leading to higher rate of wall impingement and incomplete combustion. Also, this result is good agreement with result of the work of Supaun et al. [14], who reported that the power output for palm oil and diesel blends fuel was similar to that of diesel.

Figure 1c shows the variations in the brake specific fuel consumptions (BSFC) for different fuels at various loads. Maximum increase in BSFC compared to that of the diesel fuel is 10.7% and observed at B30 and 50% load. Also, with other blends fuel, BSFC increases. These results confirm by the work of Zheng et al. [15], who concluded that up to 23% increase in the brake specific fuel consumption (BSFC) was observed when the engine was fuelled with biodiesel. Labeckas and Slavinskas [16] claimed that higher fuel consumption of the blend fuels could be related to the lower, on average by 12.5% of net heating value of rapeseed oil methyl [17]. Another reason for the increase in BSFC with biodiesel may be a change in the combustion timing caused by the higher cetane number of biodiesel as well as injection timing changes [7].

The variation of exhaust gas temperature (°C) for different blends fuel and loads is presented in Figure1d. It can be seen from the figure that exhaust gas temperature (°C) increased for all blends fuel at 25% load and maximum increasing is 4.3% and is observed at B5. This caused most possibility because of improvement of combustion process at part load operation. This result is in good agreement with the work of Mohamad Y Saliem et al. [18], who studied experimentally the ignition delay period of jojoba methyl ester fuelled engine. They reported that the ignition delay of methyl ester was lower, while ignition temperature and pressure were higher that of diesel fuel. Also, at lower Castor oil concentration and load, exhaust gas temperature increases, while it decreases in other cases. Exhaust gas temperature is affected by the changes in ignition delay. Longer ignition delay results in a delayed combustion and higher exhaust gas temperature. Moreover the lower cetane number of fuel causes the longer ignition delay period.



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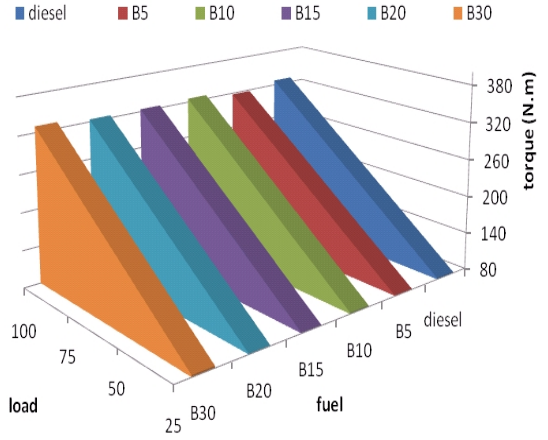

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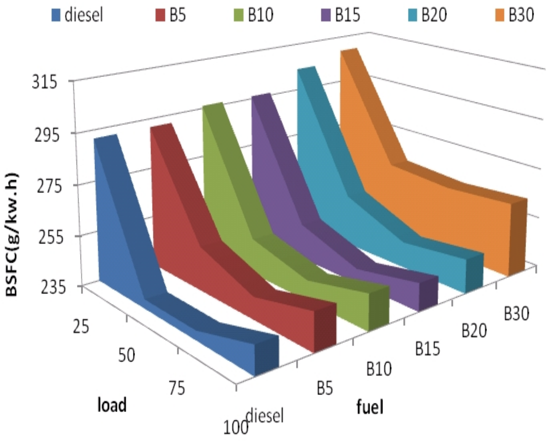

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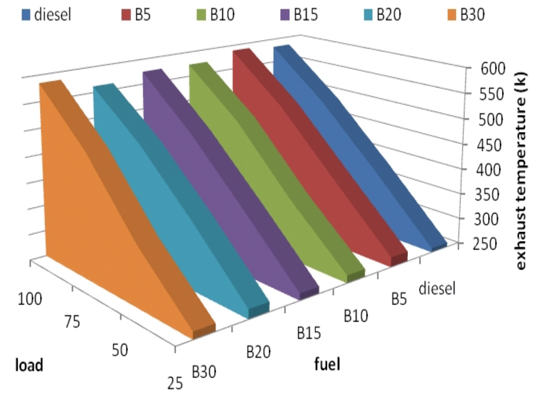

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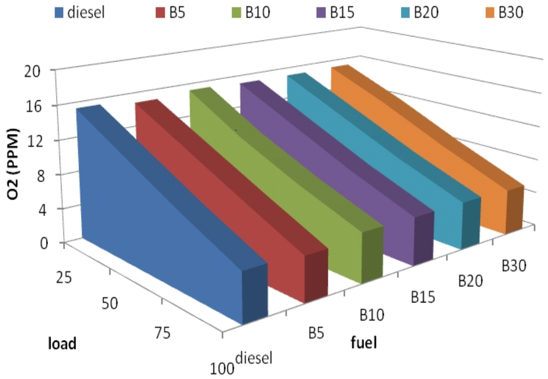

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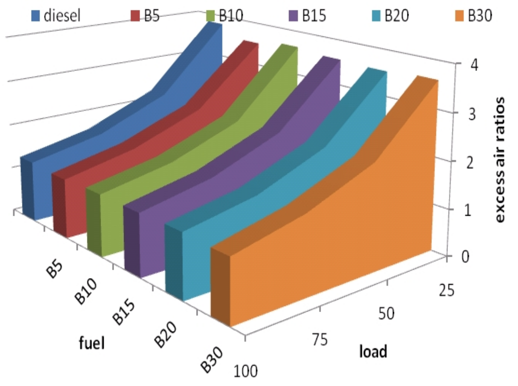


(f)

Figure 1. Variations of the power output (a), torque (b), BSFC (c), exhaust gas temperature (d), exhaust oxygen concentration (e) excess air ratio (f) with fuel composition and load.

The variations of O_2 concentration and excess air ratio coefficient at various blends fuel and loads are shown in Figures 1e and 1f respectively. As can be seen in Figure 1e with increasing the load, O_2 concentration and excess air ratio coefficient reduce but in the case of B5, this reduction reaches to maximum quantity (7.4%)

at full load operation. Also, O_2 concentration in exhaust gas at blends fuel is lower than that of diesel fuel because of higher excess air ratio coefficient in diesel fuel. Lin and Li [5] tested biodiesel from waste cooking oil and biodiesel from marine fish-oil in engine and reported the result of comparing with commercial biodiesel from waste cooking oil and showed that the marine fish-oil biodiesel has a larger O_2 emission. They believed that burning marine fish -oil biodiesel formed slightly more O_2 than did that of the commercial biodiesel from waste cooking oil, due to the slightly lower equivalence ratio of the former.

The variations of HC emissions for pure diesel fuel and blends of biodiesel and diesel fuel at various loads are shown in Figure 2a. The results show that in maximum torque revolution, HC emissions increasing for all fuels at 25% load. This is due to higher excess air ratio and more incomplete combustion at low loads. It is clear from lower exhaust gas temperature as shown in Figure1d. HC emission increases considerably at B20 for all loads. Increasing in HC emission may be due to poor injection, higher rate of wall impingement and low volatility of blends of biodiesel and diesel fuels. At full load operation the amount of HC emission for B10 and B30 decreases 15 and 29% respectively. Lin et al. [19] found the HC emissions reduced in the range of 22.47–33.15% for the 8 kinds of biodiesels. Tan et al. [20] found that compared to the petroleum diesel fuel, the HC emissions show continuous reductions with increasing biodiesel blends at the 0.10 MPa, 0.26 MPa, 0.51 MPa and 0.77 MPa engine loads.

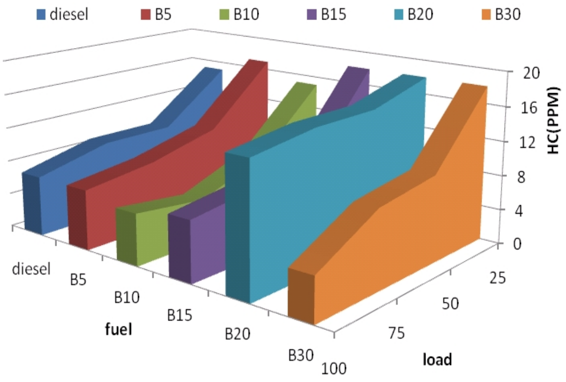
Variations of CO emission at various blends fuel and loads are shown in Figure 2b. At all fuel compositions, CO emission increases at low and high load because of lower and higher excess air ratio especially at B15, B30. The main reason for more increase in CO emission at B15 and B30 is lower O_2 concentration in exhaust (as shown in Figure 1.e), lower air fuel ratio and more incomplete combustion,namely CO emissions reduction for B10, B20 is almost 17% at full load operation. This result is confirmed by the work of Aydin and Bayindir [21], who tested the effect of B5, B20, B50, B75, B100 and D2 on the engine and reported that minimum CO emission values were observed for B50, B75 and B100 due to the higher oxygen content compared to other fuels. This decrease may be due to the oxygen content of the blends and pure biodiesel [7]. Variation of CO_2 for different fuels and loads is presented in Figure 2c. CO_2 emissions increase for each fuel at 25% load and maximum value increasing is 8% and observed in B5 and B20 in complete with diesel. At full load operation, CO_2 emission decreases (up to 4.4% in B10) for all fuels. It is assumed that the main reasons of increasing of CO_2 emission in B5 and B20 are higher exhaust gas temperature and lower O_2 concentration in exhaust and more complete combustion (as shown in Figures1.d and e). At higher loads because of higher O_2 concentration in exhaust, CO_2 emission decreases.

Variation of NO_x produced by running the engine when using B5, B10, B15,B20 and B30 is compared with diesel fuel in Figure 2d. At 25% load, the NO_x emissions of the B15 and B30 and diesel fuels is 222, 214, and 235 (ppm) respectively. NO_x emissions for these fuels decrease by 5.5 and 9% compared to the diesel fuel. In other fuels and loads, NO_x emission increases and maximum increasing is 15.5% and observed in 50% load of B20. Dorado et al. [9] obtained that NO_x emissions increased by over 20% for biodiesel from waste olive oil in an 8-mode test cycles. Higher oxygen content and combustion temperature in biodiesel enhances formation of NO_x, which is generally accepted [1]. This result is confirmed by the work of Labeckas and Slavinskas [16], who experimentally investigated the relationship between NO_x values and mass percent of fuel oxygen on a 4-stroke, 4-cylinder, WC, DI, NA diesel engine. The results showed that maximum NO_x emissions increased proportionally with the mass percent of oxygen in the RME-Diesel blends.

Variation of smoke opacity for different fuels and loads is presented in Figure 2e. Almost at all fuel blends and loads, soot emissions decreased as compared to diesel fuel. Maximum decrease was 73.2% and is observed for B15 at 50% load. At 50% load and with B15 fuel, exhaust gas temperature and O_2 exhaust concentration is higher than that of other fuel blends. Therefore, this increase shows that combustion is retarded to exhaust stroke and then premixed phase decreased and diffusion phase increased. At full load condition, the soot emissions of B10, B15, B20 and B30 are 21.1, 32.2, 29.1 and 14.2% lower than that of diesel fuel, respectively. There are various reasons for explaining the reductions of PM emissions when using biodiesel. The main reasons are: (1) Oxygen content of the biodiesel molecule, which enables more complete combustion even in regions of the combustion chamber with fuel-rich diffusion flames and promotes the oxidation of the already formed soot [22, 23]. The increased availability of oxygen from the combustion of biodiesel in the reaction zones results in lower production of soot precursor species and hence in reduced rates of the soot producing reactions. When sufficient oxygen is available, soot precursors species react with molecular oxygen or oxygen-containing radicals (like OH, O) and eventually produce CO rather than aromatics and soot [24]. (2) Absence of aromatics and also significantly lower sulphur content in biodiesel fuels, those being considered soot precursors [12]. (3) The combustion advance derived from the use of biodiesel. This effect enlarges the residence time of soot particles in a high temperature atmosphere, which in the presence of oxygen promotes further oxidation [25]. (4)

The higher reactivity and oxidation velocity of biodiesel soot [26, 27].

As shown in Figures 2d and 2e that in all fuel blends when load increases from 25 to 100%, PM and NO_x emissions increase considerably. This is due to lower excess air ratio and higher peak temperature in cylinder at higher load operations. Higher peak temperature causes in an increase NO_x emission, while higher fuel-air ratio with higher temperature causes an increase in PM emission. At all fuel blends and at 100% load, PM emission decreases as compared to pure diesel fuel except in B5. It may be the result of lower viscosity and more advancing of injection time in B5 than the other blend fuels.



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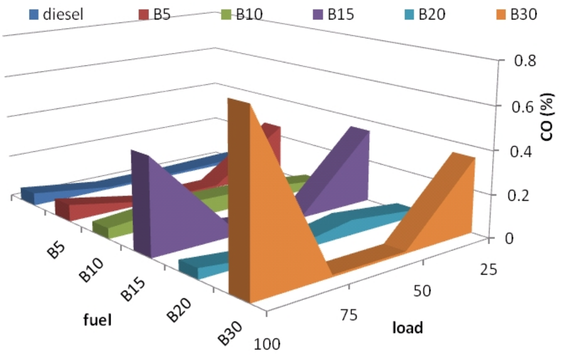

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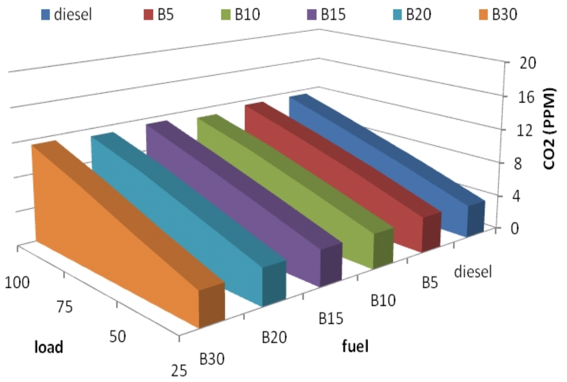

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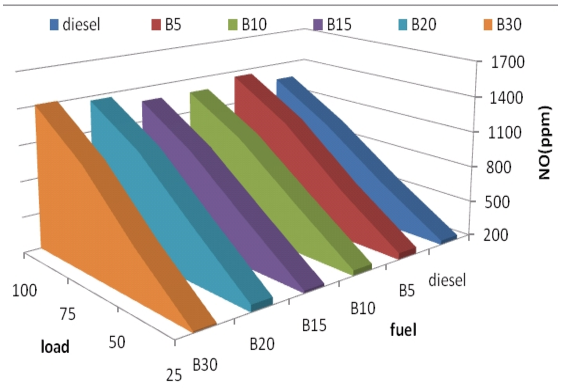

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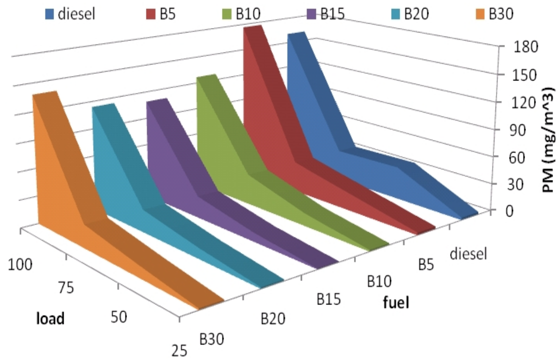

(e)

Figure 2. Variations of the HC emissions (a), the CO emissions (b), the CO_2 emissions (c), the NO_x emissions (d), the soot emissions (e)

4. CONCLUSION

Biodiesel, derived from vegetable oil, is recommended for use as a substitute for petroleum-based diesel mainly because biodiesel is a renewable, domestic resource with an environmentally friendly emission profile and is readily biodegradable. Performance and emissions of a diesel engine fuelled with 5, 10, 15, 20, 30 % (by volume) Castor oil and pure diesel fuel separately was experimentally investigated at various loads. The engine tests results indicate B10 and B15 fuel blends at full load operation are proposed in terms of performance efficiency and environmentally friendly emissions for using as fuel in diesel engine. B15 and B20 at full load operation give the best brake specific fuel consumptions (BSFC) of engine. Maximum decreasing of PM emission is 73.2% and observed in B15 at 50% load. At these conditions, NO_x increases 4%. At B30 and 25% load condition, PM and NO_x emissions decreases almost 37 and 9% respectively, while at the same time CO and UHC increase. The experimental results proved that Castor oil biodiesel can partially be substituted by the diesel fuel without any modifications in diesel engine.

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Experimental Study of the Effect of Castor Oil Biodiesel Fuel on Performance and Emissions of Turbocharged DI Diesel

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چکیده

در کار ارائه شده، آزمون‌های تجربی بر روی یک موتور کشاورزی نیمه‌سنگین (MT4.244) کارخانه موتورسازاندر بارهای مختلف به منظور ارزیابی عملکرد و آلایندگی در حالت سوخت مخلوط دیزل و بیودیزل (Castor oil) با نسبت‌های حجمی 30 , 10,15,20 ,5% انجام شده است. نتایج نشان می‌دهند که بیشترین کاهش دوده در حالت دو سوخته 73.2% در بار 50% و در سوختB15 مشاهده می شود. همچنین، بیشترین افزایش در BSFC و NO به ترتیب 10.7و 15.6% در سوختB30 و B20 در بار 50% مشاهده می‌شوند. نتایج نشان می‌دهند که در B15 و در بار 50% ، NO و PM به ترتیب 6 و 64% کاهش و BSFC1.5% افزایش می‌یابد.

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