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Application of blend fuels in a diesel engine

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Abstract

Experimental study has been carried out to analyze engine performance and emissions characteristics for diesel engine using different blend fuels without any engine modifications. A total of four fuel samples, such as DF (100% diesel fuel), JB5 (5% jatropha biodiesel and 95% DF), JB10 (10% JB and 90% DF) and J5W5 (5% JB, 5% waste cooking oil and 90% DF) respectively were used in this study. Engine performance test was carried out at 100% load keeping throttle 100% wide open with variable speeds of 1500 to 2400 rpm at an interval of 100 rpm. Whereas, emission tests were carried out at 2300 rpm at 100% and 80% throttle position. As results of investigations, the average torque reduction compared to DF for JB5, JB10 and J5W5 was found as 0.63%, 1.63% and 1.44% and average power reduction was found as 0.67%, 1.66% and 1.54% respectively. Average increase in bsfc compared to DF was observed as 0.54%, 1.0% JB10 and 1.14% for JB5, JB10 and J5W5 respectively. In case of engine exhaust gas emissions, compared to DF average reduction in HC for JB5, JB10 and J5W5 at 2300 rpm and 100% throttle position found as 8.96%, 11.25% and 12.50%, whereas, at 2300 and 80% throttle position, reduction was as 16.28%, 30.23% and 31.98% respectively. Average reduction in CO at 2300 rpm and 100% throttle position for JB5, JB10 and J5W5 was found as 17.26%, 25.92% and 26.87%, whereas, at 80% throttle position, reduction was observed as 20.70%, 33.24% and 35.57%. Similarly, the reduction in CO_2 compared to DF for JB5, JB10 and J5W5 at 2300 rpm and 100% throttle position was as 12.10%, 20.51% and 24.91%, whereas, at 80% throttle position, reductions was observed as 5.98%, 10.38% and 18.49% respectively. However, some NO_x emissions were increased for all blend fuels compared to DF. In case of noise emission, sound level for all blend fuels was reduced compared to DF. It can be concluded that JB5, JB10 and J5W5 can be used in diesel engines without any engine modifications However, W5B5 produced some better results when compared to JB10.

Kewords: Engine performance; exhaust emission; jatropha biodiesel; waste cooking oil

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1. Introduction

Unlimited use of the fossil fuels has led to global environmental degradation and health hazards. Reduction in engine emissions becomes a major task in engine development due to the increasing concern of environmental protection and more stringent emission norms. In addition to this more efforts are needed to reduce dependence on the petroleum fuels as it is obtained from limited reserves [1]. It has been reported by the US department of energy that the world's oil supply will reach its maximum production and midpoint of depletion sometime around the year 2020 [2]. Legislations have been passed in many countries, requiring diesel to contain a minimum percentage of biofuels. The Czech Republic proved to be the best, which insisted on 100% biofuel use for transportation [3]. The attractive characteristics of biodiesel include higher cetane number, non-toxic emissions, bio-degradability, absence of sulphur and aromatic compounds and excellent lubricity [4]. Biodiesel is the fuel that can be produced from straight vegetable oils, edible and non-edible, recycled waste vegetable oils, and animal fat [5].

To evaluate the engine performance of different biodiesel blends, several experimental studies have been carried out around the world. Generally a slight power loss, reduction in torque and increased brake specific fuel consumption (bsfc) were observed in case of biodiesel fuelled engines. Besides it reduces the emissions of carbon monoxide (CO), hydrocarbon (HC), sulfur dioxide (SO_2), polycyclic aromatic hydrocarbons (PAH), nitric polycyclic aromatic hydrocarbons (nPAH) and particulate matter (PM). However, a majority of research results have indicated an increase in nitrogen oxides (NOx) [6,8]. According to the study [7] conducted on six cylinders DI diesel engine, increase of biodiesel percentage in the blend involves a slight decrease of both power and torque. In particular, with pure biodiesel there was a reduction by about 3% maximum power and about 5% of maximum torque. Similar results were reported by Aydin and Bayindir [9] using cottonseed oil methyl ester (CSOME). However, a decrease of CO, NO_x and SO_2 emissions were observed in the same study. In many countries, the use of edible oil to produce biodiesel is not feasible due to a big gap in the demand and supply of such oils for dietary consumption. Therefore, it should be concentrated on the inedible oils such as Jatropha curcas, M. indica, Ficus elastica, Azardirachta indica, Calophyllum inophyllum, neem, P. pinnata, rubber seed, mahua, silk cotton tree and tall oil microalgae whose potential availability can easily be found and these are very economical comparable to edible oils [10]. The cost of feedstocks accounts about 60–80% of the total cost of biodiesel production. Therefore, the problem of high feedstock cost can also be mitigated by the selection of non-edible vegetable oil for the production of biodiesel [11].

In Malaysia, biodiesel production is mainly palm oil based though it has taken some initiative to introduce jatropha production in mass level. Jatropha is also getting importance for a yield factor of 1.2 tons/ha with about 0.8 kg/m^2 production of seeds per year. Jatropha is a potential second generation biodiesel feedstock, though it still requires more research and development [12]. It has been also reported that among the vegetable oils, jatropha oil exhibits very good properties. It is a non-edible oil, its calorific value and cetane number are higher compared to many others. The jatropha plant can grow almost anywhere, even on gravely, sandy and saline soils. Its water requirement is very low [13]. Based on the studies available, jatropha oil is seems to be as one of the best substitutes to fossil diesel supply. In case of using waste cooking oil in diesel engines, it is found to be an alternative way of reducing the disposal of waste cooking oil and for abatement of the fuel crisis as well. Waste edible oil (WEO) can not be discharged into drains or sewers due to blockages and odour or vermin problems and may also pollute watercourse. It is also a prohibited substance and will cause problems if it is dumped in municipal solid waste landfill and municipal sewage treatment plants. Being cheap and easily available, waste cooking oil seems like a good substitute for diesel, but its high viscosity is a major drawback. To overcome this problem, a small percentage, like 5%, can be blended and tested for engine compatibility [14].

Keeping in view the above facts, the main objective of the present study is to determine the suitability of using biodiesel derived from non-edible oil such as jatopha oil along with the use of WCO to investigate the effect of jatropha biodiesel addition (5% and 10% in volume) and JB + WCO (5% +5% in vol.) with conventional diesel fuel, on performance and emission characteristics of a DI diesel engine.

2. Experimental setup and experiments

The present study is conducted on an engine installed in the heat engine laboratory of Mechanical Engineering Department at University of Malaya. The essential fuel properties are given in the Table 1. The experimental setup is shown in Fig. 1. A one-cylinder, four-stroke diesel engine is selected and is mounted on a test-bed. Its major specifications are shown in Table 2. Two fuel tanks, one for DF and another for blend fuels were used for supplying the fuels to the test engine. The engine is coupled to an eddy current dynamometer. It can be operated at a maximum power of 20 kW at 2450 to 10000 rpm. The engine was first fuelled with DF to determine the baseline parameters and then, it was fuelled with blend fuels. In order to calculate mean values, each test was repeated three times.

Engine performance parameters have been measured are engine torque, brake power, and brake specific fuel consumption (bsfc). In this regard, test procedure was carried out to run a single cylinder diesel engine through DYNOMAX 2000 data control system. In order to carry out the performance test, engine was run at 100% load keeping throttle 100% wide open. Engine test conditions were monitored by Dynomax-2000 software. All engine performance data were measured at "Step RPM Test" mode (between 1500 and 2400 rpm with intervals of 100 rpm conditions). To examine the emission characteristics, a portable BOSCH exhaust gas analyzer (model ETT 0.08.36) was used to measure the concentration of exhaust gases of the test engine such as hydrocarbon (HC) in part per million (ppm) while carbon monoxide (CO) and carbon dioxide (CO_2) in percentage volume (%vol). While NO_X emission was measured using AVL 4000 (Make: Graz/Austria) gas analyzer. The emissions of different pollutants were measured at 2300 rpm at 100% and 80% throttle position. To measure the noise level, NI Sound Level Measurement System was adopted. In this regard, the PCB 130 Series of Array Microphones (microphone model 130D20) was employed. Because of limited conditions, the measurement of engine noise was carried on the engine test bed in engine testing laboratory. Sound level was measured at different brake mean effective pressure (bmep) such as 0.98, 1.48, 1.97, 2.46 and 2.95 bar respectively. Sound level was taken from five directions at 1 meter away from the test engine bed such as front, rear, left, right and top side. However, only front side was selected for this study, which produced the highest level of noise.

Table 1. Fuel properties

Parameters	JB5	JB10	J5W5	DF
Kinematic viscosity @ 40^0C (mm^2/s)	3.32	3.45	3.89	-
Heating value (MJ/kg)	45407	45114	45178	45547.5
Density @ 40^0C (gm/cm^3)	0.830	0.832	0.833	0.8272
Flash point (K)	350	356	358	345
Cetane number		49	48.5	-

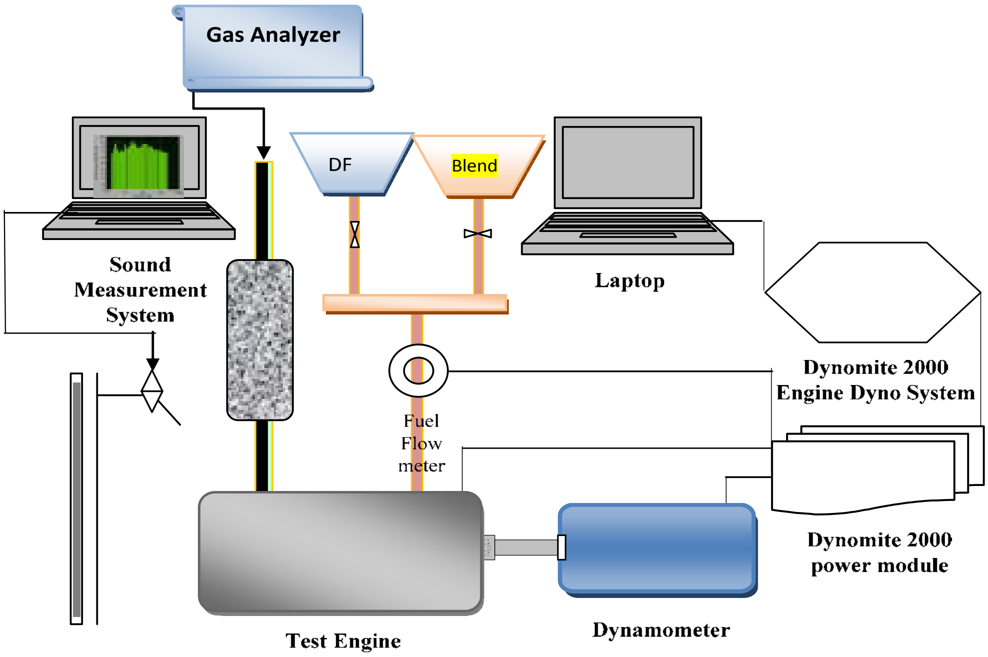

Fig. 1. Schematic diagram of test engine and setup

Table 2. Specifications of the test engine

Engine type		4 – stroke DI diesel engine
Number of cylinders		One
Aspiration		Natural aspiration
Cylinder bore x stroke	mm	92 x 96
Displacement	L	0.638
Compression ratio		17.7
Max. engine speed	rpm	2400
Max. power	kW	7.7
Injection timing	deg.	bDTC 17.0
Injection pressure	kg/cm^2	200

3. Results and discussions

3.1. Engine performance results

3.1.1. Engine torque

The effects of jatropha biodiesel and waste cooking oil addition (% in volume) on the engine torque with respect to the engine speed are shown in Fig. 2(a). Considering torque performance with all blend fuels tested, it can be said that the trend of these parameters as a function of speed is almost similar to net DF. Torque initially increases with increasing of engine speed until it reaches a maximum value and then decreases with further increasing engine speed. There are two main factors due to which the torques of the engine decreased. The first one is considered to be the lowered volumetric efficiency of the engine due to the increase in the corresponding engine speed. The second one is thought to be the augmentations in the mechanical losses [15]. The maximum torque values were observed at 2200 rpm of engine, for all test fuel samples. However, the torque of the engine fuelled with DF is higher than that of blend fuels. The reason for the reduction of torque with blends can be attributed to the lower heating value of the fuel. Over the entire speed range, the average torque reduction compared to DF is found as 0.63% for JB5, 1.63% for JB10 and 1.44% for J5W5. However, it can be seen that J5W5 produced better results.

3.1.2. Engine brake power

The variation in the brake power of the test engine as a function of the engine speed for DF, JB5, JB10 and J5W5 are presented in Fig. 2(b). It can be seen that brake power increases with increasing engine speed until 2200 rpm and then power starts to decrease due to the effect of higher frictional force. The engine brake power for DF was found higher than those obtained for blends. The lower brake power by JB5, JB10 and J5W5 as compared to DF is mainly due to their respective lower heating values. Average power reduction over the entire speed range compared to DF for JB5, JB10 and J5W5 found as 0.67%, 1.66% and 1.54% respectively. However, it can be seen that J5W5 produced little lower reduction when compared to JB10.

3.1.3. Brake specific fuel consumption

Fig. 2(c) shows the brake specific fuel consumption (bsfc) for DF and blend fuels as a function of engine speed at various mixing ratios. The bsfc is a parameter that reflects how good the engine performance is. The bsfc for the tested fuels is found slightly higher than that for DF. These increased fuel consumptions for blend fuels are because they contain oxygen content in the fuels, which result in the lower heating value. The lower heating values and higher densities of those fuels require larger mass fuel flows for the same energy output from the engine, leading to the increase of the brake specific fuel consumption to compensate the reduced chemical energy in the fuel. However, it has been observed that at some lower engine speeds for blend fuels, the bsfc values were lower than that of DF. The reason for lower fuel consumption for blend fuels may be because of the improved combustion due to the inherently oxygen containing [6]. Over the entire speed range, the average increase in bsfc compared to DF is found as 0.54% for JB5, 1.0% for JB10 and 1.14% for J5W5.

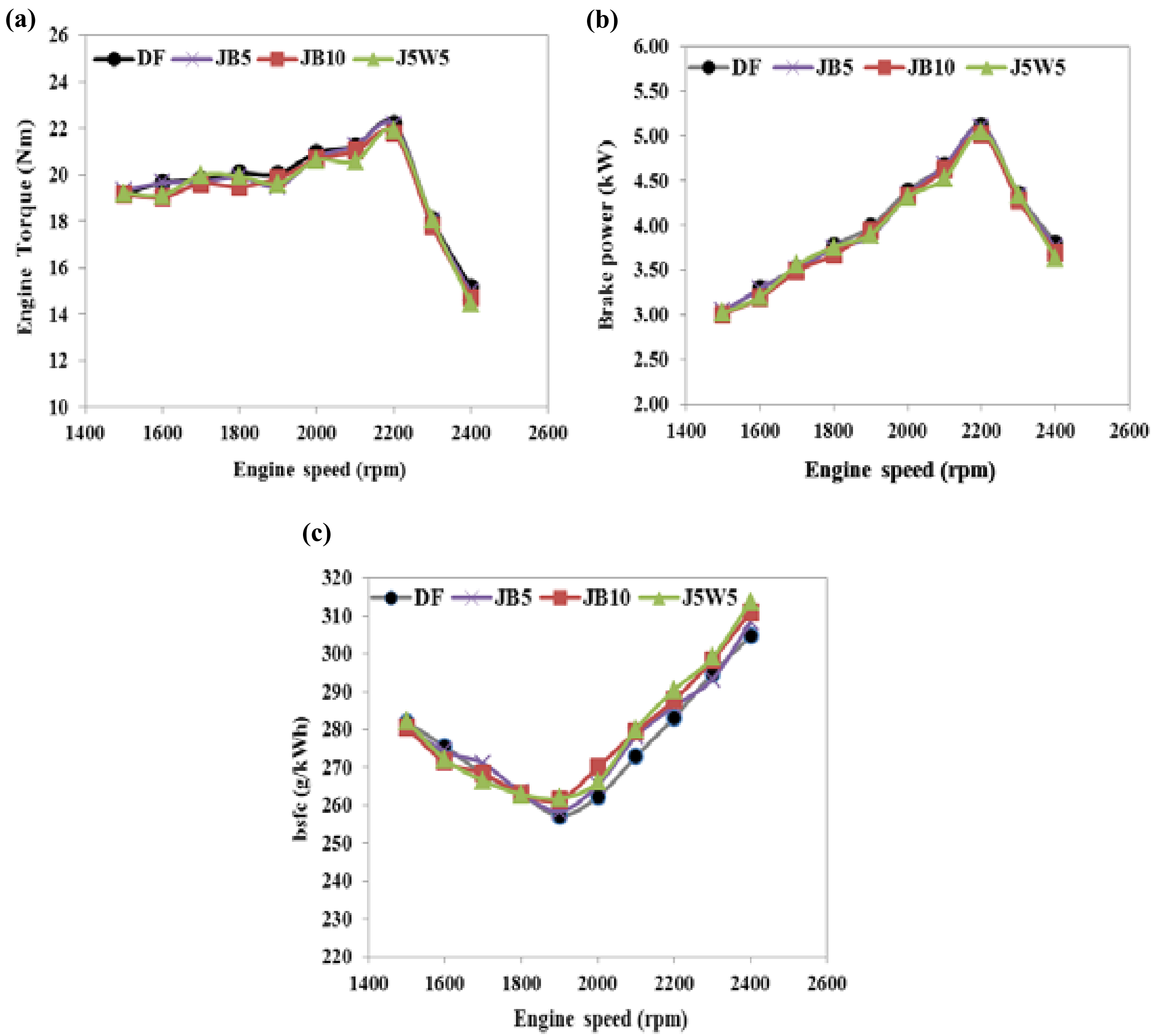

Fig. 2. Engine performance results

3.2. Engine Exhaust Emissions

3.2.1. Hydrocarbon (HC) Emission

The effects of jatropha biodiesel and waste cooking oil addition on the HC emissions at 2300 rpm under 100% and 80% throttle position are shown in Fig. 3(a). As reported by other authors, the oxygenated compounds available in the blends improve the fuel oxidation reducing HC emissions [16]. When the oxygen content of fuel blend is increased, it requires less oxygen for combustion. However, oxygen content of fuel is the main reason for more complete combustion and HC emission reduction. Another, higher cetane number of blends reduces the combustion delay, and such a reduction has also been related to decreases in HC emissions [17-18]. As shown in Fig. 3(a), average reduction in HC compared to DF for JB5, JB10 and J5W5 at 2300 rpm and 100% throttle position, found as 8.96%, 11.25% and 12.50%, whereas, at 80% throttle position, HC emission reduction found as 16.28%, 30.23% and 31.98% respectively. It can be observed that J5W5 shows some more reduction when compared to JB10.

3.2.2. Carbon monoxide (CO) emission

Fig. 3(b) shows the variations of CO emissions at 2300 rpm under 100% and 80% throttle position. CO is an intermediate combustion product and is formed mainly due to incomplete combustion of fuel. If combustion is complete, CO is converted to CO_2. If the combustion is incomplete due to shortage of air or due to low gas temperature, CO will be formed. For blend fuel mixtures CO emission was lower than that of DF, because blend fuels contain some extra oxygen in their molecule that resulted in complete combustion of the fuel and supplied the necessary oxygen to convert CO to CO_2. In another study, it has been reported that blend fuels have some higher cetane munber, which results in the lower possibility of formation of rich fuel zone and thus reduces CO emissions [19]. As compared to DF, average reduction in CO at 2300 rpm and 100% throttle position was found as; 17.26% for JB5, 25.92% for JB10 and 26.87% for J5W5, whereas, at 80% throttle position, reduction in CO was observed as 20.70% for JB5, 33.24% for JB10 and 35.57% for J5W5 respectively. However, it can be seen that, J5W5 shows more reduction when compared to JB10.

3.2.3. Carbon dioxide (CO_2) emission

The carbon dioxide (CO_2) emission for using DF and blend fuels at 2300 rpm under 100% and 80% throttle position is shown in Fig. 3(c). It can be seen that the CO_2 emission compared to DF decreased for all the blend fuels. This may be attributed to the fact that blend fuels have a lower elemental carbon to hydrogen ratio than DF. The burning of blend fuels with air will therefore form lower CO_2 emission than DF. As shown in Fig. 3(c), the reduction in CO_2 compared to DF at 2300 rpm and 100% throttle position was as; 12.10% for JB5, 20.51% for JB10 and 24.91% for J5W5, whereas, at 80% throttle position, reductions was observed as 5.98% for JB5, 10.38% for JB10 and 18.49% for J5W5 respectively. However, J5W5 produced more reduction compared to JB10.

3.2.4. Nitrogen oxide (NO_x) emission

Fig. 3(d) shows the variations of NO_x emissions at 2300 rpm under 100% and 80% throttle position using different fuels samples. The NOx emissions with blend fuels are found little higher than that with DF. It has been reported that formation of NOx emissions are strongly dependent upon the equivalence ratio, oxygen concentration and burned gas temperature. The oxygen content of blend fuels was the main reason for higher NOx emissions [20]. During the of combustion process, the oxygen in the blend fuels can react easily with nitrogen. It is also agreed that in the production of NOx, the fuel borne oxygen is more effective than the external oxygen supplied with the air [9]. In Fig. 3(d), it is determined that percentage of biofuel addition resulted in higher NO_x emissions. The increase in NO_x compared to DF at 2300 rpm and 100% throttle position was as 4% for JB5, 6.25% for JB10 and 8% for J5W5 whereas, at 80% throttle position, increase was found as 9.5% for JB5, 17.0% for JB10 and 20.0% for J5W5 respectively.

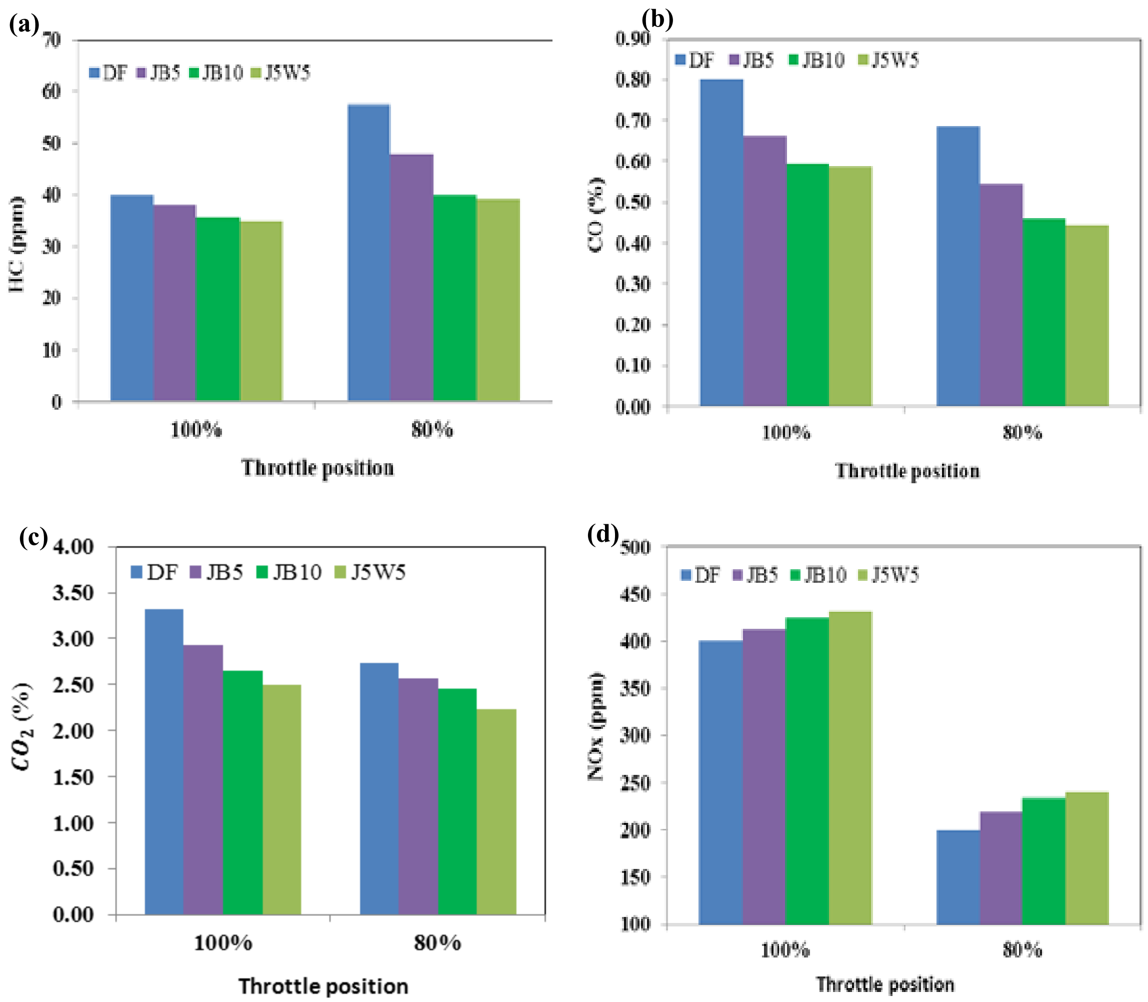

Fig. 3. Engine exhaust emission results

3.3. Noise Emission

The noise emission is different from that of air pollutants or other climate gases, as noise effects are restricted to the time of emission. The combustion noise is associated with the maximum pressure rise rate produced in the cylinder. Thus, higher pressure rise rate produces higher combustion noise and vice versa. The maximum pressure rise rate (dp/dΘ) can be decreased with the reduction in the ignition delay period so the engine will be running more smoothly [21]. Shorter ignition delay reports for biodiesel and blends have been investigated by many authors [22-23].The sound level at different directions using different blend fuels and DF in the engine showed that among all the directions (front, rear, left right and top), only front side from each fuel sample produced the highest level of the sound. Therefore in Fig. 4, only front side has been selected. Generally, Fig. 4 shows that the sound level for all blend fuels is decreased when compared to DF and increased as the load (bmep) increased for each fuel sample tested. Lower sound level compared to DF may be attributed due to some higher viscosities of blend fuels which produced lubricity and damping and thus resulted in decrease of sound level. Secondly, higher cetane number of blend fuels may decrease the ignition delay which causes the maximum pressure rise rate to decrease so the engine produced lower sound level. Besides, it was noted that engine noise emissions were reduced with the increase in fuel oxygen content in blend fuels due to improved combustion efficiency. Moreover, it can be also be observed that compared to all fuels samples J5W5 produced the lowest level of noise at all loads.

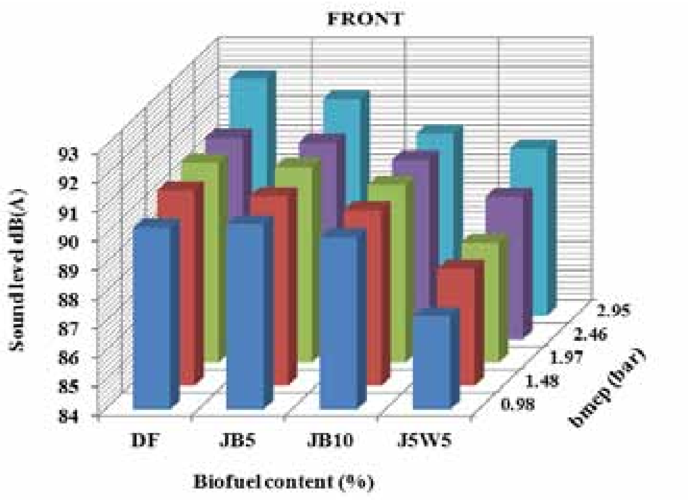

Fig. 4. Sound level for different fuel samples

4. Conclusion

In this work, the engine performance and emissions of using blend fuels such as JB5, JB10 and J5W5 were investigated and compared with diesel fuel:

Engine torque and brake power for blend fuels were decreased when compared to diesel fuel, mainly due to their respective lower heating values. However, J5W5 showed lower reduction compared to JB10. The bsfc values for blend fuels were higher than that of DF due to lower heating values and higher densities. It is also noted that at some lower engine speeds, the bsfc values for blend fuels were found lower than that of DF because of the improved combustion due to the inherently oxygen containing.

In case of engine exhaust gas emissions, reduction in HC, CO and CO_2 were found for JB5, JB10 and J5W5 when compared to DF at both engine operating conditions. Whereas, NO_x emission for all blend fuels was increased as compared to DF. However, J5W5 was found to be comparable with JB10 and produced better results except NO_x.

In comparison with the diesel fuel, blend fuels produced lower sound levels due to many factors including increase in oxygen content, reduction in the ignition delay, higher viscosity, lubricity etc. However, among all the blend fuels J5W5 produced the lowest level of sound.

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References

[1] Hulwanm DB, Joshi SV. Performance, emission and combustion characteristic of a multicylinder DI diesel engine running on diesel–ethanol–biodiesel blends of high ethanol content. *Applied Energy* 2011;**8 (12**):5042–55.

[2] Jindal S, Nandwana BP, Rathore NS, Vashistha V. Experimental investigation of the effect of compression ratio and injection pressure in a direct injection diesel engine running on Jatropha methyl ester. *Appl Therm Eng 2010;* **30**: 442–8.

[3] Ganapathy T, Gakkhar RP, Murugesan K. Influence of injection timing on performance, combustion and emission characteristics of Jatropha biodiesel engine. *Appl Energ* 2011;**88(12**):4376–86.

[4] Anand K, Sharma RP, Mehta PS. Experimental investigations on combustion, performance and emissions characteristics of neat karanji biodiesel and its methanol blend in a diesel engine. *Biomass and Bioenergy* 2011;**35(1)**:533-41.

[5] Liaquat AM, Kalam MA, Masjuki HH, Jayed MH. Potential emissions reduction in road transport sector using biofuel in developing countries. *Atmos Environ* 2010;**44**:3869-77.

[6] Behçet R. Performance and emission study of waste anchovy fish biodiesel in a diesel engine. *Fuel Process Technol* 2011;**92**:1187-94.

[7] Machado Corrêa S, Arbilla G. Carbonyl emissions in diesel and biodiesel exhaust. *Atmos Environ* 2008;**42**:769-75.

[8] Aydin H, İlkılıç C. Effect of ethanol blending with biodiesel on engine performance and exhaust emissions in a CI engine. *Appl Therm Eng* 2010;**30**:1199-1204.

[9] Aydin H, Bayindir H. Performance and emission analysis of cottonseed oil methyl ester in a diesel engine. *Renew Energ* 2010;**35**:588-92.

[10] Demirbas A. Progress and recent trends in biodiesel fuels. *Energ Convers Manage* 2009;**50**:14-34.

[11] Varanda MG, Pinto G, Martins F. Life cycle analysis of biodiesel production. *Fuel Process Technol* 2011;*92*:1087–94.

[12] Jayed MH, Masjuki HH, Saidur R, Kalam MA, Jahirul MI. Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. *Renewable and Sustainable Energy Reviews* 2009;**13**: 2452-62.

[13] Senthil KM, Ramesh A, Nagalingam B. Use of hydrogen to enhance the performance of a vegetable oil fuelled compression ignition engine. International Journal of Hydrogen Energy 2003;28:1143-54.

[14] Kalam MA, Masjuki HH, Jayed MH, Liaquat AM. Emission and Performance Characteristics of an Indirect Ignition Diesel Engine Fuelled with Waste Cooking Oil. *Energy* 2011;**36**:397-402.

[15] İlkılıç C, Aydın H. Fuel production from waste vehicle tires by catalytic pyrolysis and its application in a diesel engine, *Fuel Procesg Technol* 2011;**92**:1129–35.

[16] Agarwal AK. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Progress in Energy and Combustion Science* 2007;**33**:233–71.

[17] Monyem A, Van Gerpen JH., Canakci M. The effect of timing and oxidation on emissions from biodiesel-fueled engines. *Trans ASAE* 2001;44:**35**–42.

[18] Lapuerta M, Armas O, Rodriguez-Fernandez J. Effect of biodiesel fuels on diesel engine emissions. *Prog Energy Combust Sci* 2008;198–223.

[19] Xue J, Grift TE, Hansen AC. Effect of biodiesel on engine performances and emissions. *Renewable and Sustainable Energy Reviews*. 2011;**15**:1098–1116.

[20] Karabektas M. The effects of turbocharger on the performance and exhaust emissions of a diesel engine fuelled with biodiesel. *Renew Energ* 2009;**34**:989–93.

[21] Mohamed SY, Selim, Salah B, Al-Omari, Abdullah AJ, Al-Aseery. Effects of Steam Injection to Dual Fuel Engine on Performance, Noise and Exhaust Emission. SAE Paper 2009-01-1831.

[22] Sahoo PK, Das LM. Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine. *Fuel* 2009;**88**:994–99.

[23] Rao GLN, Sampath S, Rajagopal K. Experimental Studies on the Combustion and Emission Characteristics of a Diesel Engine Fuelled with Used Cooking Oil Methyl Ester and its Diesel Blends. *Int J App Sci Eng Technol* 2008;**4**:64-70.