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Effect of coconut biodiesel blended fuels on engine performance and emission characteristics

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Abstract

Alternative fuels have received much attention due to the depletion of world petroleum reserves and increased environmental concerns. Thus processed form of vegetable oil (Biodiesel) offers attractive alternative fuels to compression ignition engines. The present work investigates the engine performance parameters and emissions characteristics for direct injection diesel engine using coconut biodiesel blends without any engine modifications. A total of three fuel samples, such as DF (100% diesel fuel), CB5 (5% coconut biodiesel and 95% DF), and CB15 (15% CB and 85% DF) respectively are used. Engine performance test has been 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, engine emission tests have been carried out at 2200 rpm at 100% and 80% throttle position. As results of investigations, there has been a decrease in torque and brake power, while increase in specific fuel consumption has been observed for biodiesel blended fuels over the entire speed range compared to net diesel fuel. In case of engine exhaust gas emissions, lower HC, CO and, higher CO_2 and NO_x emissions have been found for biodiesel blended fuels compared to diesel fuel. Moreover, reduction in sound level for both biodiesel blended fuels has been observed when compared to diesel fuel. Therefore, it can be concluded that CB5 and CB15 can be used in diesel engines without any engine modifications and have beneficial effects both in terms of emission reductions and alternative petroleum diesel fuel.

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Keywords: Engine performance; emission; coconut biodiesel; sound level.

1. Introduction

The fossil fuel demand is continuously increasing world over resulting in rapid depletion of fossil fuel deposits [1]. According to the US department of energy, the world's oil supply will reach its maximum production and midpoint of depletion sometime around the year 2020 [2]. In several studies, it has been experimentally investigated that the human health hazards are associated with exposure to diesel exhaust emissions [3-6]. Therefore, limited fossil fuels and intensified environment pollution, it has become a global issue to develop such clean fuel, which is technically feasible, domestically available and environmentally acceptable [7]. Generally, recommended biodiesel for use as a substitute for petroleum-based diesel is produced from vegetable oil or animal fats by transesterification process. Biodiesel is an oxygenated, renewable, biodegradable and environmentally friendly bio-fuel with low emission profile [8]. According to experimental results conducted by various researchers around the world, it has been reported that biodiesel fuelled engine produced marginal loss

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in engine torque and power, and increase in bsfc as compared to diesel fuel. Besides that, 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) [9-13, 7].

According to the study [12] conducted on a six cylinders direct injection diesel engine, it has been reported that the increase of biodiesel percentage in the blend involves a slight decrease of both power and torque over the entire speed range. In particular, with pure biodiesel there was a reduction by about 3% maximum power and about 5% of maximum torque. Moreover, with pure biodiesel, the maximum torque was found to have reached at higher engine speed. Similar results were investigated by Aydin and Bayindir [14] using cottonseed oil methyl ester (CSOME). However, a decrease of CO, NO_x and SO_2 emissions were observed in the same study. In another study [15], similar power and torque output with higher bsfc were recorded using waste cooking biodiesel when compare to diesel fuel, whereas in terms of exhaust emissions, lower CO and HC emissions were reported.

The main purpose of the present study is to determine the suitability of using CB5 and CB15 on CI engine without any major hardware modification and to compare the results of these blend fuels with diesel fuel in terms of engine performance, exhaust emission and sound level.

2. Experimental methods and materials

In this study, a one-cylinder, four-stroke diesel engine is selected and is mounted on a test-bed. Its major specifications are given in Table 1. The experimental setup with necessary instrumentation has been shown in Fig. 1. In order to supply the fuel to the test engine, two fuel tanks, one for diesel fuel and another for blend fuels were used. 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 essential fuel properties can be found in Table 2. The engine was initially fuelled with diesel fuel to provide the baseline data and then, it was fuelled with biodiesel blend fuels. Before stopping the test engine after each test with biodiesel blend fuels, the engine was switched on diesel fuel until all the biodiesel based blend is purged from the fuel lines, injection pump and injector to avoid clogging when the engine is cooling down.

The performance test was carried out at 100% load keeping throttle 100% wide open using Dynomax-2000 software. The test procedure was carried out through DYNOMAX 2000 data control system. Engine performance data were measured at "Step RPM Test" mode (between 1500 and 2400 rpm with intervals of 100 rpm). The emissions of different pollutants were measured at 2200 rpm at 100% and 80% throttle position. A portable BOSCH exhaust gas analyzer (model ETT 0.08.36) was used to measure the hydrocarbon (HC) in part per million (ppm) whereas, carbon monoxide (CO) and carbon dioxide (CO_2) were measured in percentage volume (%vol). NO_x emission was measured using AVL 4000 (Make: Graz/Austria) gas analyzer. In order to measure the sound level at different loads, the measurements of engine noise were taken from five directions at 1 meter away from the test engine bed such as front, rear, left, right and top side. However, in this work, only front side was selected, which produced the highest level of the noise. In this regard, to measure the noise level, NI Sound Level Measurement System was adopted. Therefore, PCB 130 Series of Array Microphones (microphone model 130D20) was employed in this work.

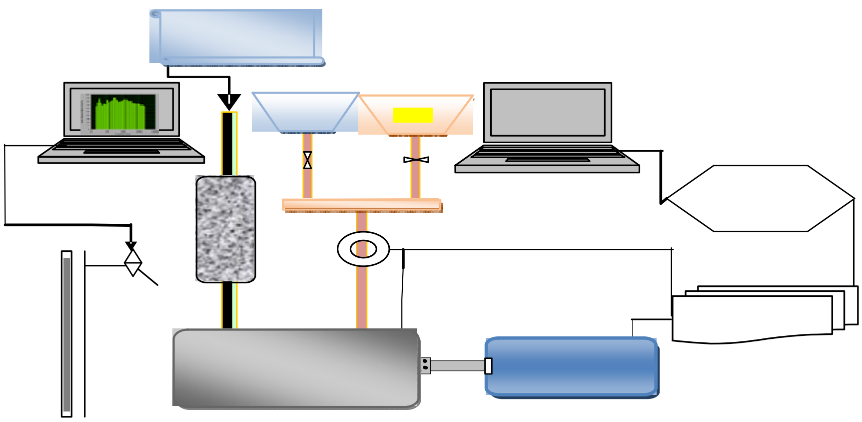

Fig. 1. Schematic diagram of experimental setup.

Table 1. Test engine technical specifications

Engine type		Four 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.	bTDC 17.0
Injection pressure	kg/cm^2	200

Table 2. Some of the important tested fuel properties

Parameters	CB5	CB15	DF
Kinematic viscosity @ 40 ^{0}C (cSt)	3.344	3.425	3.317
Heating value (MJ/kg)	45.407	44.838	45.547
Density @ 40 ^{0}C (gm/cm3)	0.823	0.825	0.822
Flash point (^{0}C)	83	86	78
Cetane number	51.5	53.4	51

3. Results and discussions

3.1. Engine performance analysis

3.1.1. Torque

Figure 2(a) presents the effects of coconut biodiesel addition (% by volume) and net diesel fuel on the engine torque with respect to the engine speed. Keeping in view the engine torque results with biodiesel blends, it can be observed that the trend of this parameter as a function of speed for both biodiesel blends is almost found to be similar to net diesel fuel. Initially, engine torque increases as the engine speed increases until it reaches a maximum value and then starts decreases with further increasing engine speed. The engine torque reduction after certain speed is found to be due to the two main factors. Firstly, it is the lowered volumetric efficiency of the engine due to the increase in the corresponding engine speed, and the second one is the augmentations in the mechanical losses [16]. For both biodiesel blends and diesel fuel, the maximum torque values were found at 2200 rpm of engine. However, net diesel fuel shows some higher torque values than biodiesel blends due to the fact that diesel fuel has higher heating value than biodiesel blends. The average torque reduction compared to net diesel fuel is found as 0.69% for CB5 and 2.58% for CB15 respectively.

3.1.2. Brake power

Figure 2(b) illustrates the variations in the brake power for net diesel fuel and biodiesel blends as a function of the engine speed. It can be observed that brake power of the engine increases with increasing engine speed until 2200 rpm and then starts to decrease due to the effect of higher frictional force. The engine brake power for biodiesel blends was found to be lower than obtained for net diesel fuel. The lower brake power for CB5 and CB15 can be due to their respective lower heating values. The average power reduction compared to diesel fuel over the entire speed range is found as 0.66% for CB5 and 2.61% for CB10% respectively.

3.1.3. Brake specific fuel consumption

Figure 2(c) presents the brake specific fuel consumption (bsfc) for net diesel fuel and biodiesel blends as a function of engine speed. Good engine performance in terms of fuel economy is reflected by the bsfc parameter. For the biodiesel blends, heating value is found slightly higher than that for diesel fuel. This may be attributed to the lower heating value and higher density of the blends. It is also known that biodiesel contains oxygen content, which results in the lower heating value [17]. Thus for the same energy output from the engine, it requires larger mass fuel flow, which increases bsfc to compensate the reduced chemical energy in the fuel [18,19]. The average increase in bsfc compared to diesel fuel is found as 0.53% for CB5 and 2.11% for CB15 respectively.

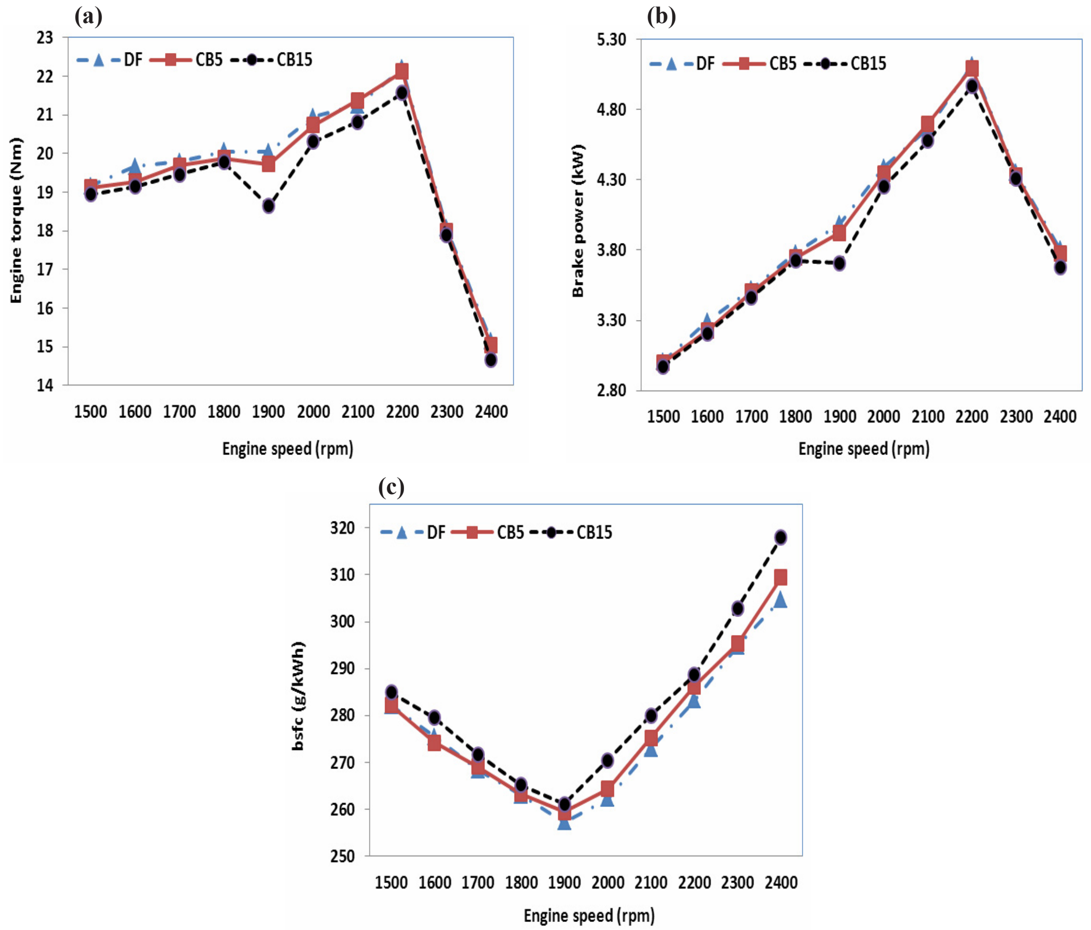

Fig. 2. Engine performance analysis.

3.2. Exhaust emission analysis

3.2.1. Exhaust gas temperature

Figure 3(a) presents exhaust gas temperature at 2200 rpm at 100% and 80% throttle position for diesel fuel and biodiesel blends. In order to indicate the cylinder combustion temperature, engine exhaust temperature has been considered as one of the important parameters. Therefore, it is a good parameter in analyzing the exhaust emissions especially for NO_x. The increase in exhaust gas temperature compared to diesel fuel at 2200 rpm and at 100% throttle position was observed as 2.22% for CB5 and 3.33% for CB15 whereas, at 80% throttle position, increase was found as 3.62 for CB5 and 5.96% for CB15 respectively.

3.2.2. Carbon monoxide (CO) emission

CO emissions at 2200 rpm, at 100% and 80% throttle position are presented in Fig. 3(b). CO is one of the compounds formed during the intermediate stages of fuels and is formed mainly due to incomplete combustion of fuels. If combustion proceeds to completion, CO is converted to CO_2. If the combustion is incomplete due to shortage of air or low gas temperature, CO will be formed. In case of biodiesel blends, CO emissions were lower than that of diesel fuel, due to some extra oxygen contents, which convert CO to CO_2 and resulted in complete combustion of the fuel [20]. In another study, it has been reported that higher cetane munber of biodiesel blends; results in the lower possibility of formation of rich fuel zone and thus reduces CO emissions [21]. Average reduction in CO at 2200 rpm and 100% throttle position was found as; 13.38% for CB5 and 21.51% for CB15, whereas, at 80% throttle position, reduction in CO was found as 5.98% for CB5 and 16.03% for CB15 respectively.

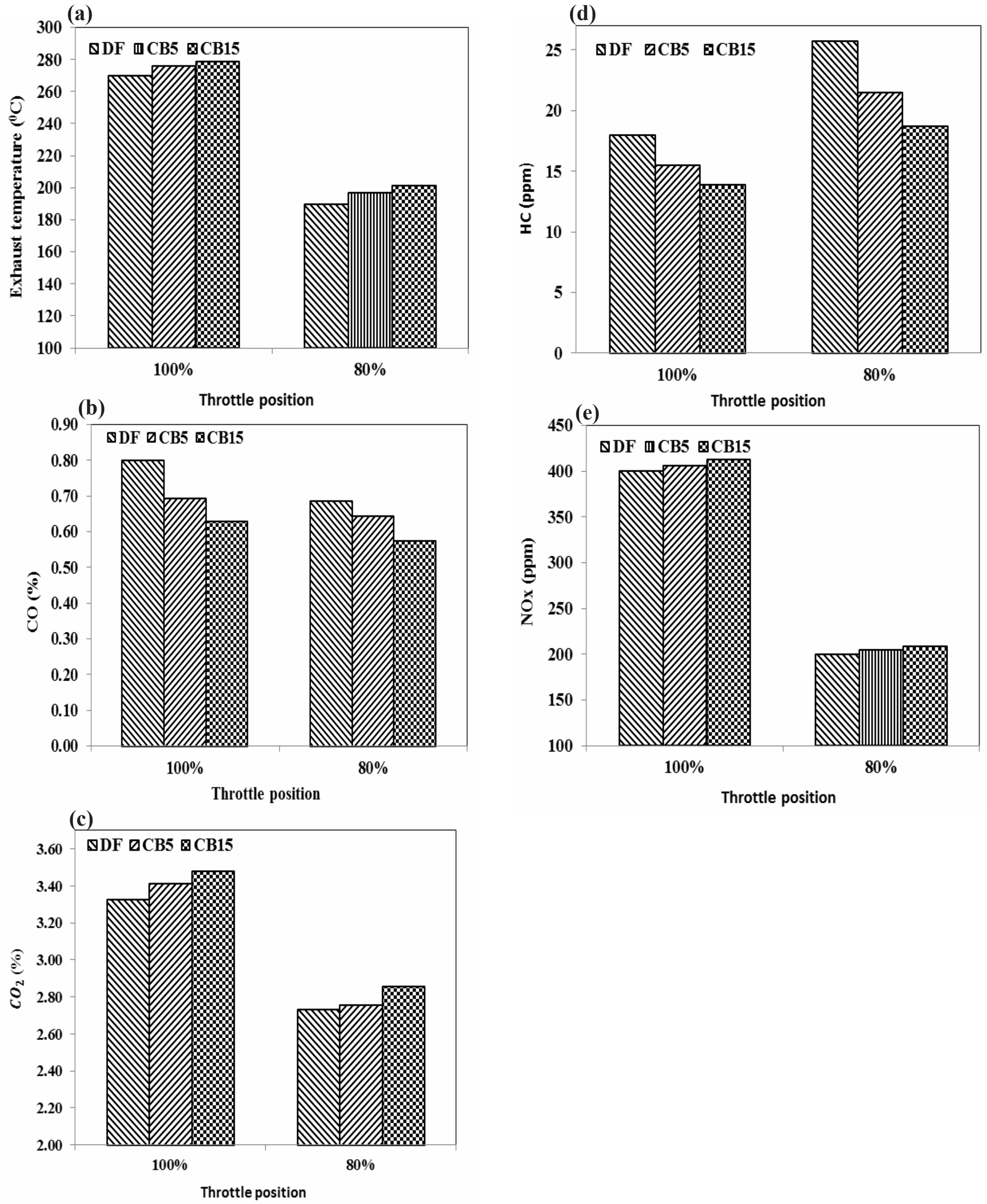

Fig. 3. Engine exhaust emission analysis.

3.2.3. Carbon dioxide (CO_2) emission

Figure 3(c) illustrates the carbon dioxide (CO_2) emissions for diesel fuel and biodiesel blends at 2200 rpm at 100% and 80% throttle position. It can be noted that the CO_2 emissions for biodiesel blends increased compared to diesel fuel. This may be attributed to the oxygen content in biodiesel which reacts with unburned carbon atoms during the combustion and increases the formation of CO_2. More amount of CO_2 in exhaust emission indicates the complete combustion of fuel [22]. Compared to diesel fuel, CO_2 for biodiesel blends at 2200 rpm and at 100% throttle position, was increased as 2.54% for CB5 and 4.64% for CB15 respectively. Whereas, at 2200 rpm at 80% throttle position, CO_2 compared to diesel fuel was increased as 0.79% and 4.56% respectively.

3.2.4. Hydrocarbon (HC) emission

HC emissions for diesel fuel and biodiesel blends at 2200 rpm at 100% and 80% throttle position are shown in Fig. 3(d). it has been reported that the oxygenated compounds available in the blends improve the fuel oxidation and thus it reduces HC emissions [23]. 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. Furthermore, higher cetane number of biodiesel blends reduces the combustion delay, and such a reduction has also been related to decreases in HC emissions [24-26]. Compared to diesel fuel, reduction in HC at 2200 rpm and 100% throttle position was found as 13.89% for CB5 and 22.88% for CB15 respectively, whereas, at 80% throttle position, HC emission reduction was found as 16.58% CB5 and 27.19% for CB15 respectively.

3.2.5. Nitrogen oxide (NO_x) emission

Figure 3(e) presents NO_x emissions at 2200 rpm at 100% and 80% throttle position for diesel fuel and biodiesel blends. The NO_x emissions for blends are found higher than diesel fuel. It has been reported that formation of NOx emissions are strongly dependent upon the equivalence ratio, oxygen concentration and burned gas temperature. According to Beatrice et al. [27] and Song et al. [28] increased oxygen levels increase the maximum temperature during the combustion, and thus increase NOx formation. It is also agreed that in the production of NO_x, the fuel borne oxygen is more effective than the external oxygen supplied with the air [14]. The increase in NO_x compared to diesel fuel at 2200 rpm and at 100% throttle position was observed as 1.42% for CB5 and 3.19% for CB15 whereas, at 80% throttle position, increase was found as 2.44 for CB5 and 4.64% for CB15 respectively.

3. Noise emission

As noise effects are restricted to the time of its emission, therefore, noise emission is thought to be quite different from that of air pollutants or other climate gases [29]. The diesel engine produces much more noise than that produced by the spark ignition engine [30]. 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. It has been found that reduction in the ignition delay period results in reduction of the maximum pressure rise rate ($dp/d\Theta$), which leads to the smoother engine running [31]. Thus shorter ignition delay reports for biodiesel and blends have been investigated by many authors [32-34]. In our research work, sound level for diesel fuel and biodiesel blends was measured form five different directions (front, rear, left, right and top) around the test engine bed. However in this study as shown in Fig. 3, only front side has been selected which produced the highest level of the noise. Fig. 3 shows that the sound level for CB5 and CB15 is decreased as compared to diesel fuel and increased as the load (bmep) increased for each fuel sample. Lower sound level for biodiesel blends compared to diesel fuel may be attributed due to their higher viscosities 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 that, it was noted that engine noise emissions were reduced with the increase in fuel oxygen content in blend fuels due to improved combustion efficiency.

4. Conclusion

This work presented the experimental investigations in terms of engine performance and emissions of using diesel fuel as baseline and biodiesel blends such as CB5 and CB15 respectively. The experimental results of this research work can be summarized as follows.

Compared to diesel fuel, engine torque and brake power for biodiesel blends were decreased, mainly due to their respective lower heating values. The bsfc values for biodiesel blends were higher when compared to diesel fuel due to lower heating values and higher densities.

In case of engine exhaust gas emissions, HC and CO emissions were reduced whereas, CO_2 and NO_x emissions were increased for CB5 and CB15 when compared to diesel fuel at both engine operating conditions.

In comparison with the diesel fuel, biodiesel blends produced lower sound levels due to many factors including increase in oxygen content, reduction in the ignition delay, higher viscosity, lubricity etc.

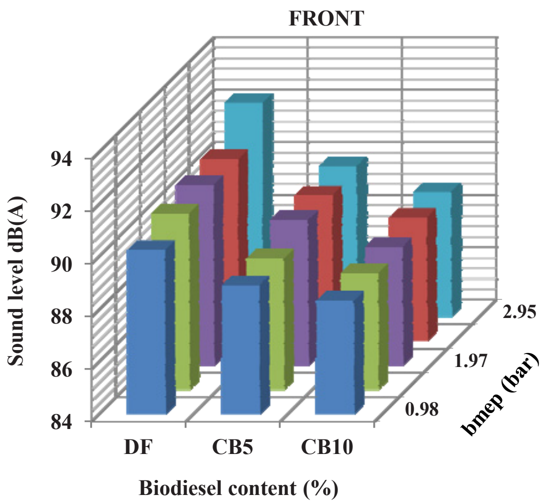

Fig. 4. Sound level at various loads for diesel fuel and biodiesel blends.

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