



Research Paper

Application of blend fuels (*Jatropha curcas* biodiesel) in an indirect ignition diesel engine

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ABSTRACT

The use of fossil fuels for internal combustion engines features a number of negative effects such as inferior air quality, negative effects on human health, and global warming. In this study, blended biofuels (*Jatropha curcas* biodiesel) and pure ultra-low-sulfur diesel (petrodiesel) fuels were used to power a turbocharged diesel engine, in which a series of engine performance and exhaust emissions tests were performed. The results indicated that the emissions of hydrocarbon, carbon monoxide, carbon dioxide and smoke were reduced by 12.5%, 30.43%, 22.41% and 7.54%, respectively. However, the fuel consumption, oxygen and exhaust gas temperature were increased by 7.97%, 4.16% and 3.8%, respectively. No evident difference was exhibited in the emission of nitrogen oxides. The engine exhaust emissions for *J. curcas* biodiesel blends were lower than those for pure petrodiesel fuel because of the presence of O₂ in the molecular structure of the *J. curcas* biodiesel.

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INTRODUCTION

With the number of vehicles projected to show continued growth over the next three decades, the demand for fossil fuels is expected to increase by three times today, which will aggravate global air pollution problems. In recent years, many countries are beginning to get concerned about the negative impact of diesel machinery on the environment. Therefore, they have enacted various legislations to reduce vehicle exhaust emissions (Dwivedi et al., 2006; Demirbas, 2009). In addition to lowering engine exhaust emissions, biofuel development and use increase employment opportunities, improve a region's economic conditions, enhances energy security, increases foreign exchange reserves, decreases dependence on oil imports, and has a minimal negative effect on global warming. Because biofuels feature the advantages of renewability and ability to enhance exhaust emission quality, they have become a much preferred replacement of conventional fuels, especially for public transport. Hence, it is necessary to look for alternative fuels which can be produced from resources locally available within the country such as alcohol, biodiesel, vegetable oils, etc (Gokalp et al., 2011;

Hamamci et al., 2011).

The burning of fossil fuels leads to increased air pollution, acid rain, and carbon dioxide in the Earth's atmosphere, which are substances harmful to human health. Biodiesel is an alternative fuel that is environmentally friendly and renewable. When used to diesel engines, the latter facilitates equal or superior engine performance. Biodiesel is an oxygenated and sulfur-free fuel that contains 10% oxygen. These conditions allow biodiesel fuels to facilitate relatively more complete combustion and reduce a considerable amount of diesel engine exhaust emissions (Issariyakul et al., 2007; Lin et al., 2006). Biodiesel fuel quality is a key factor determining whether it can be successfully used to replace petrodiesel fuels in diesel engines. Biodiesel, defined as "the mono alkyl ester," is a long-chain fatty acid derived from lipids of renewable raw materials. The physical and chemical properties of biodiesel fuel have been shown to be similar and compatible with those of petrodiesel fuels. Biodiesel can be used as a replacement of fuel or as an additive to petrodiesel. Biodiesel flash point is reduced and its cetane number is

improved after esterification. Even low-concentration biodiesel can be used as a cetane improver. Biodiesel possesses a heating value which approximates that of petrodiesel. The main advantage of using biodiesel is that it is biodegradable, produces fewer harmful emissions, and can be used to power existing internal combustion engines without requiring engine modifications (Ghobadian et al., 2009; Syed et al., 2009).

Biodiesel can be produced from vegetable oils, edible and inedible oils, recycled vegetable oils, and animal fats. However, the use of edible oils to produce biodiesel is not an ideal option because it requires that ingredients from which edible oils are extracted from be used, which creates competition between food and fuel (Ong et al., 2011). Moreover, because the cost of raw materials used to make biodiesel accounts for approximately 65%–80% of total production cost, to reduce cost, one should consider using inedible oils and/or recycled edible oil to make biodiesel (Kalam et al., 2011). Non-edible oils such as *Jatropha curcas*, *Calophyllum inophyllum*, *Ficus elastica*, rubber seed, mahua, *Azadirachta indica*, silk cotton tree and tall oil microalgae whose potential availability can easily be found and these are very economical compared to edible oils. *J. curcas*-derived biodiesel is an immediate and sustainable form of biodiesel and outperforms most other fuels in terms of its ability to reduce greenhouse gas emissions (Liaquata et al., 2011; Altiparmak et al., 2007).

Jatropha oil is a branched triglyceride-type inedible vegetable oil and a potential alternative of petrodiesel fuels. It features properties similar to those of petrodiesel; when diesel engines, *Jatropha* oil reduces their exhaust emissions. Because the number of vegetable oils that can be used to make biodiesel is remarkably high, finding specific energy crops that are sustainable and feature high oil content and productivity is crucial. For countries facing food crises such as India and African countries, *J. curcas* oil is a favorable biodiesel option because it is inedible and thereby eliminates the potential conflict between food and energy. Concerning *J. curcas*, it is widely distributed in the tropical and subtropical regions of Africa, India, and Southeast Asia. *J. curcas* can grow favorably even under large-scale, adverse soil conditions such as sandy soil, soil with high mineral content, and soil with poor water drainage properties. *J. curcas* has an advantage over other forms of inedible oils in that it is drought-tolerant and can be grown in abandoned agricultural land. Therefore, considerable attention is being paid to the development potential of *J. curcas*-derived biodiesel. For example, *J. curcas* oil is safer than petrodiesel during storage, loading and unloading, and transport (Usta, 2005; Pal et al., 2010; MacLean and Lave, 2003; Silitonga et al., 2011).

Chauhan et al. (2010) investigated the feasibility of using biodiesels to diesel engines and assessed diesel engine performance and exhaust emission characteristics for different fuel types. Experiment results showed that diesel engines powered by biodiesels performed slightly lower

than those powered by biodiesel. Suryawanshi and Deshpande (2004) performed diesel engine tests using blended biodiesels and pure petrodiesel, in which the results showed that the former significantly reduced smoke emissions regardless of load condition. The reason was that blended biodiesels were oxygenated, which reduced aerosol produced from incomplete combustion. Buyukkaya (2010) discovered that compared with pure petrodiesel, which created a smoke emission of 60%, the use of blended fuel B70 reduced smoke emissions to 45%. However, compared with petrodiesel, the use of blended fuels B5, B20, B70, and B100 increased brake specific fuel consumption by 2.5%, 3%, 5.5%, and 7.5%, respectively. Banapurmath et al. (2008) analyzed the effect of biodiesel on diesel engine emissions, in which the results showed that compared with diesel engines powered by petrodiesel, those powered by biodiesel blended fuels generated greater diesel engine smoke, HC, and CO emissions. However, diesel engines powered by biodiesel blended fuels produced less NO_x emissions. Agarwal (2007) showed that an increase in the ratio of biodiesel in petrodiesel increased CO₂, and HC emissions but decreased smoke emissions. Reddy et al. (2000) produced simple structured biodiesel by using the transesterification process and achieved reduced smoke emissions. In addition, they reported that smoke concentration was reduced when injection pressure increased to over 200 bar, and that biodiesel produced high CO₂ concentration and low CO and O₂ concentrations. Because such biofuels contain oxygen and renewable biological resources, they have the potential of reducing engine exhaust emissions. In consideration of the aforementioned information, the objectives of this study were to ensure that fuels used as biodiesel were inedible oils, determine the applicability of *J. curcas* oil, and analyze the effect of adding *J. curcas*-derived biodiesel to conventional petrodiesel on engine performance and exhaust emissions.

EXPERIMENTAL PROCEDURE

Different types of fuels (that is, pure petrodiesel fuel and *J. curcas* fuel blends) were tested. A *J. curcas* biodiesel-petrodiesel fuel blend is referred to as JXX, with XX referring to the proportion of *J. curcas* biodiesel. For example, J20 refers to a fuel blended with 20% of *J. curcas* biodiesel and 80% of petrodiesel. A series of *J. curcas* biodiesel-petrodiesel fuel blends with different concentrations were investigated. Each of the tested fuel blend was mixed by a mechanical mixer for 30 minutes, with none of the fuel blends exhibiting phase separation phenomena.

We compared the influences of biodiesel-petrodiesel fuel blends on the exhaust gases emitted from a diesel engine (Figure 1), in which a water-cooled 4-stroke direct injection gasoline engine (engine speed: 750–3000 rpm) was used



Figure 1: Experimental set-up of the diesel engine testing system.

Table 1: Test engine specifications.

Item	Specifications
Engine	Diesel engine
Engine Category	Four strokes, water-cooled Engine Type
Bore x stroke	83 x 92 mm
Displacement	1991 cc
Cylinders	In-line 4 Cylinder
Compression Ratio	17.7 : 1
Fuel System	Common Rail (Direct Injection)
Injection Pressure	1500 bar max
Nozzle	Hole
Air Intake System	Turbocharged with inter cooler Emission Control System
	DOC, PCV, EGR

for the experiment. The engine specifications are shown in Table 1. The essential fuel properties are given in Table 2. To examine the properties of the exhaust gases emitted from the diesel engine, a portable SINCRO exhaust gas analyzer (model EGA2001C) was employed to test the emitted exhaust gases such as HC and NO_x in part per million (ppm); CO, CO₂, O₂ and Smoke in percentage volume (%vol) and exhaust gas temperature (°C). The test conditions were those defined by the ISO standard for defining air conditions for testing emission characteristics. The fuel temperature was maintained at 40°C, relative humidity was maintained between 50% and 55%, and the mean ambient temperature in the laboratory was maintained at approximately 23-25°C.

RESULTS AND DISCUSSION

Blend stability Fuel blend stability tests were conducted to

evaluate whether phase separation of the fuel blends occurred. The test was performed using 0%, 2%, 5%, 10%, 20%, 50% and 100% *J. curcas* biodiesel by weight in petrodiesel fuel. The blended fuels were maintained in a temperature controlled atmosphere at 28–30°C, and stability was tested every 2h for the first 24h and every day thereafter for 2 months. During the experiment, no precipitation or turbidity of the fuel blends was observed, indicating that the stability and blend ability of these two types of fuels were excellent (Figure 2).

Engine performance test

For a second stage of testing, we compared the influences of *J. curcas* biodiesel (5%, 10%, 20%, 50% and 100%) fuel blends and pure petrodiesel fuels on engine performance and exhaust gas emissions. The type of testing engine used was a four-stroke diesel engine. The engine speed, fuel

Table 2: Base fuel properties.

Property	Petrodiesel	Jatropha curcas biodiesel
Density at 15°C (kg/m ³)	840	875
Viscosity (40°C, Cst)	2.62	4.60
Flash point (°C)	88	165
Sulphur content(%)	0.01	<0.01
Water content(mg/kg)	50.2	500
Cetane number	52.3	54



Figure 2: The sedimentation of biodiesel in petro-diesel of pure petro-diesel (left), 2% biodiesel, 5% biodiesel, 10% biodiesel, 20% biodiesel, 50% biodiesel and 100% biodiesel (right).

contents and fuel properties will affect emission exhaust from engine. Carbon monoxide (CO) is formed when the fuel gas temperature cools and the progression to CO₂ is not complete. This happens when the gas front approaches the relatively cool cylinder liner and combustion slows or stops. It also happens in the crevice volume that is between the outer diameter of the piston and the cylinder wall, where the gas front is extinguished. The other source of carbon monoxide is when the engine is operated on too rich fuel air ratio and there is full oxygen for complete combustion (Gokalp et al., 2011).

The CO emissions for various types of fuel at 750-3000 rpm is shown in Figure 3. The measured CO emissions (2000 rpm) of J5, J10, J20, J50 and J100 fuels were 0.084%, 0.080%, 0.071, 0.065 and 0.060% lower than that of the pure petrodiesel. The pure petrodiesel fuel had the highest carbon content, and therefore exhausted the highest CO concentration compared to the other biodiesel blends fuel. J100 had the lowest CO emission, followed by J50, J20, J10, and J5. CO is a toxic combustion product resulting from incomplete combustion of hydrocarbons. In presence of

sufficient oxygen, CO is converted into CO₂. Biodiesel is an oxygenated fuel that leads to more complete combustion; hence CO emissions reduce in the exhaust. In another study, it was reported that blend fuels have some higher cetane number, which results in the lower possibility of formation of rich fuel zone and thus reduces CO emissions (Ghobadian et al., 2009; Syed et al., 2009).

A comparison of the unburned HC emissions of various fuels at 750-3000 rpm is shown in Figure 4. The HC emission at 2000 rpm was 32.0, 31.3, 30, 29.4, 28.5 and 28 ppm for pure petrodiesel (J0), J5, J10, J20, J50 and J100, respectively. It can be seen that the lowest level of HC was produced from J100, followed by J50, J20, J10, and J5. Increasing *J. curcas* biodiesel concentration in blends has a beneficial effect in reducing HC emissions (Figure 4). The reduction in HC is mainly the result of complete combustion of *J. curcas* biodiesel blends within the combustion period as confirmed by combustion characteristics such as net heat release rate and mass burn fraction that can be found elsewhere (Liaquata et al., 2011). The HC species during *J. curcas* biodiesel fuel oxidize better than pure petrodiesel

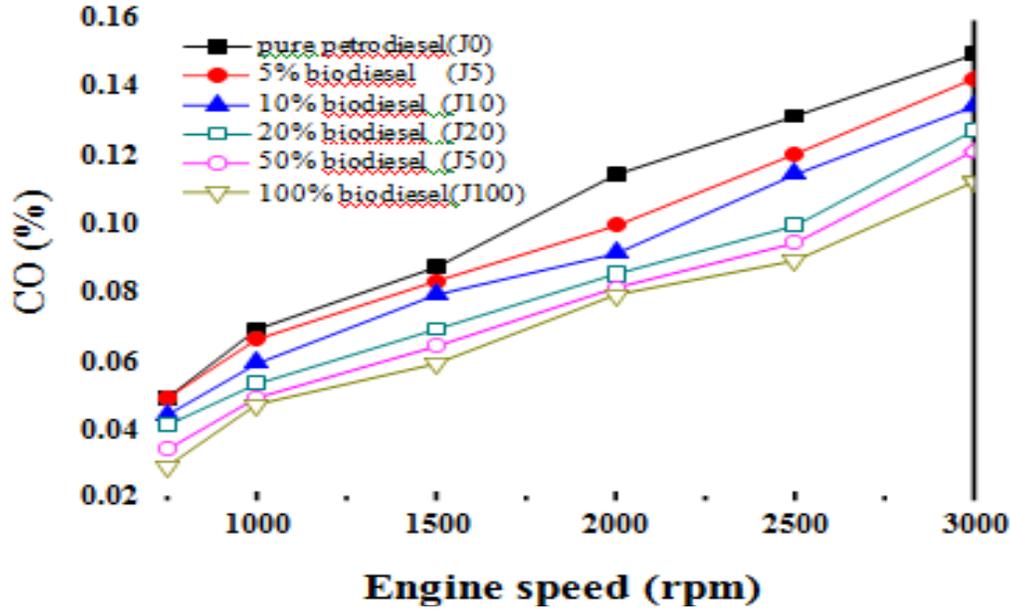


Figure 3: CO exhaust emissions for various types of fuels.

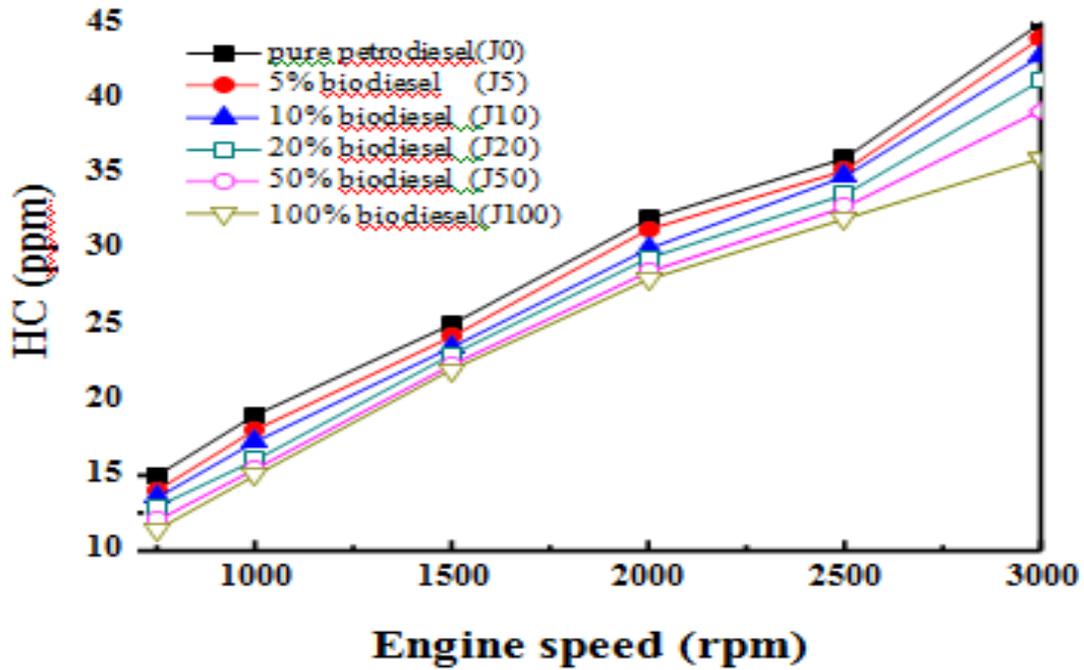


Figure 4: HC exhaust emissions for various types of fuel.

fuel. This is due to the higher heat release rate and higher cylinder pressure at the expansion stroke as compared to pure petrodiesel. On average, a 14.28% reduction in HC was obtained with *J. curcas* biodiesel in comparison to pure petrodiesel fuel. Because HC and CO undermines the overall effect of the ozone layer, biofuels can be added to petroleum fuels to substantially decrease the emissions of HC and CO. Moreover, fuel with a higher cetane index has a

superior compression ignition quality in diesel engines and thus better combustion characteristics.

CO₂ is an essential parameter indicating the combustion property of a fuel. A comparison of the CO₂ emissions of various fuels at 750-3000 rpm is shown in Figure 5. The experimental results revealed that J0 emitted the largest amount of CO₂. The CO₂ emission for all types of fuel was found at 2000 rpm: 2.32%, 2.15%, 2.10%, 1.97%, 1.92%

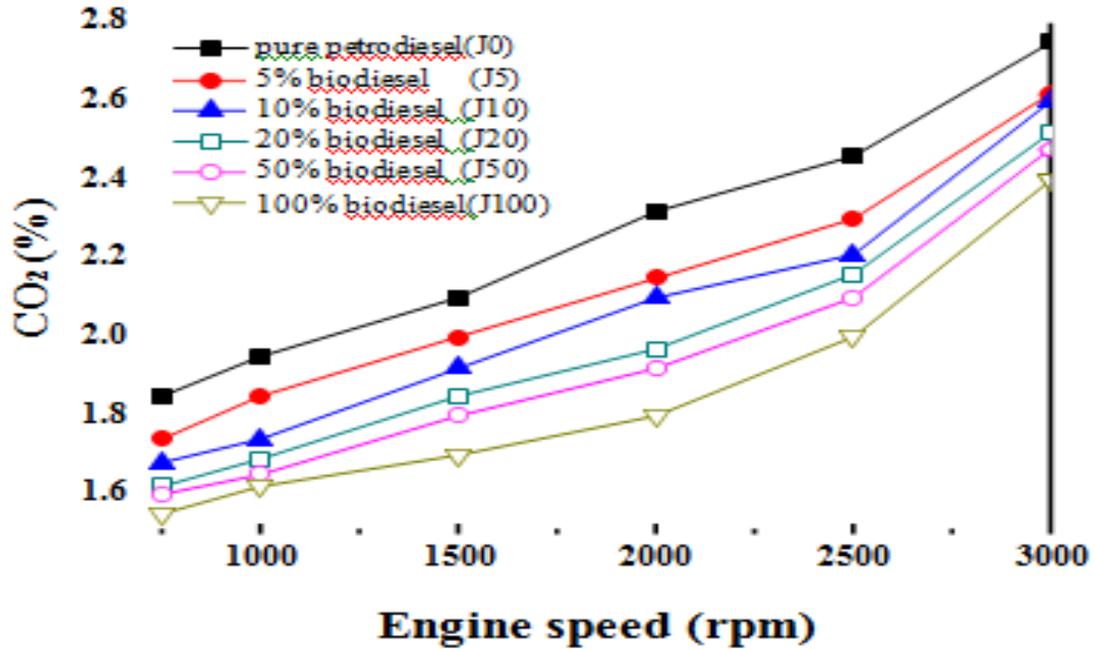


Figure 5: CO₂ exhaust emissions for various types of fuel.

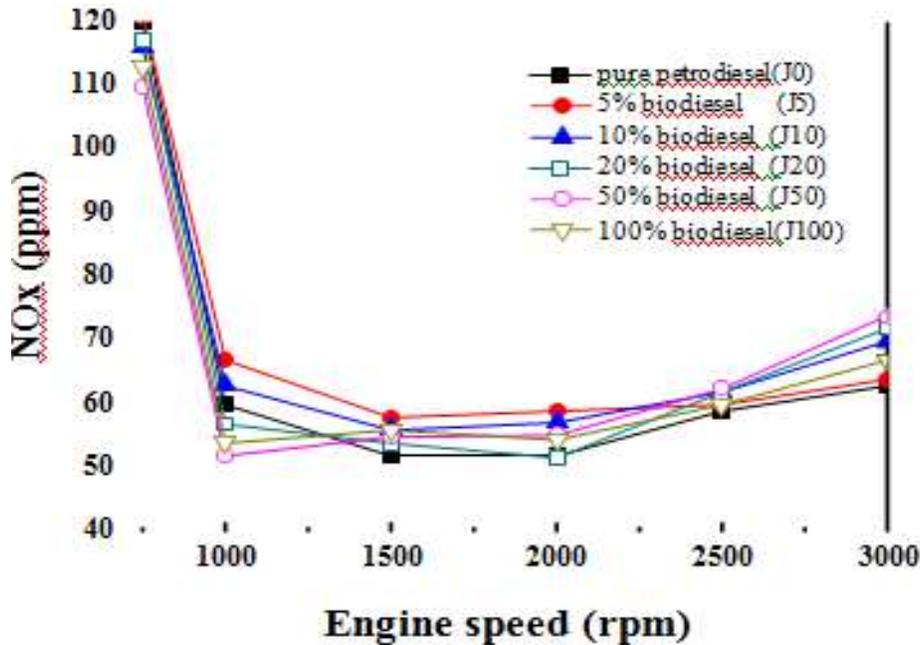


Figure 6: NO_x emissions for various types of fuel.

and 1.8% for J0, J5, J10, J20, J50 and J100, respectively. The CO₂ emission increased with the increase in engine speed for these six fuels. The five kinds of biodiesel blends had lower CO₂ emission than pure petrodiesel. This is attributed to the fact that *J. curcas* biodiesel is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than petrodiesel fuel. The burning of biodiesel with air will

therefore form lower CO₂ emission than pure petrodiesel (Altiparmak et al., 2007; Usta, 2005).

The NO_x forms by oxidation of atmospheric nitrogen at sufficiently high temperatures. A comparison of the NO_x emissions of various fuels at 750-3000 rpm is shown in Figure 6. The comparatively higher NO_x emission index for engine speeds between 750 and 1000 rpm. Engine speed

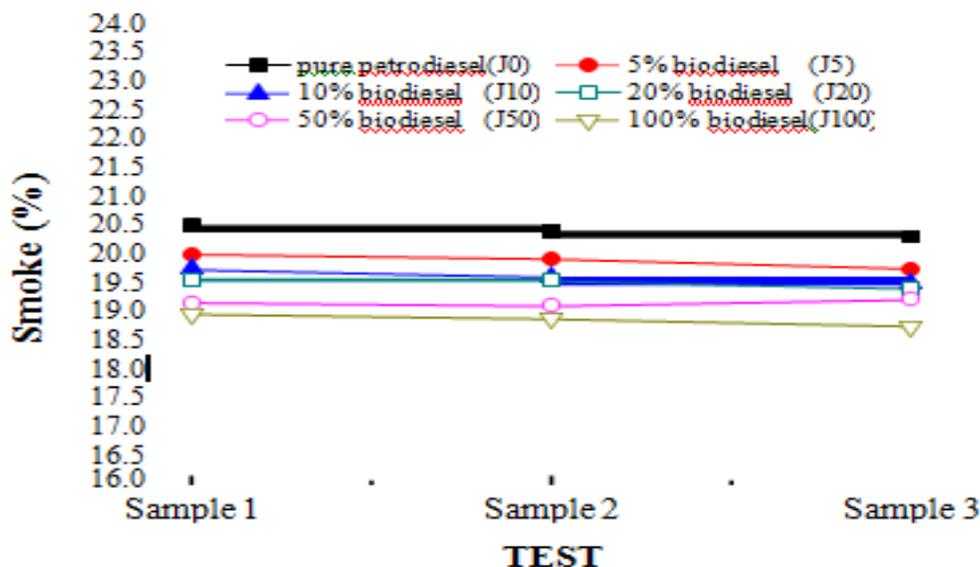


Figure 7: Smoke emissions for various types of fuel.

also affects NO_x emissions. Some authors Ghobadian et al. (2009), Syed et al. (2009), Ong et al. (2011) agreed that NO_x emissions reduced with an increase in engine speed. They analyzed that this trend was primarily due to the shorter residence time available for NO_x formation, which may be as the results of an increase both in the volumetric efficiency and flow velocity of the reactant mixture at higher engine speeds. This is probably because of the relatively higher oxygen content of biodiesel, which produced a higher NO_x formation, even at a lower burning gas temperature and a lower mass flow rate of intake air, under the operating condition of lower engine speeds (Usta, 2005).

There are several reported results of slight increase in NO_x emissions for biodiesel. It is quite obvious, that with biodiesel, due to improved combustion, the temperature in the combustion chamber can be expected to be higher and an higher amount of oxygen is also present, leading to formation of higher quantity of NO_x in biodiesel-fueled engines. However, biodiesel's lower sulfur content allows the use of NO_x control technologies that cannot be otherwise used with conventional diesel.

Hence biodiesel's fuel NO_x emissions can be effectively managed and eliminated by engine optimization. Pradeep and Sharma (2007) suggested that use of hot exhaust gas recirculation (EGR) for oxides of nitrogen control in diesel engine fuelled with *J. curcas* biodiesel can effectively reduced NO_x emission (Usta, 2005).

Smoke opacity is a direct measure of smoke and soot. The amount of smoke emitted was correlated with the cooling effect of fuel and the air-fuel ratio. The amount of smoke emitted from J100 was the lowest compared with that of J0, J5, J10, J20, and J50 as shown in Figure 7. The ignition delay of J100 was shorter than that of J0 and thus smoke emission was reduced. This finding implied that the combustion of

J100 was more complete compared with that of J50, J20, J10, and J5. On average, the amount of smoke emitted by the J100 and J50 fuels was reduced by 7.54% and 6.07% respectively, when compared with that by pure petrodiesel fuels. Another positive effect of adding biodiesel to the petrodiesel fuel is the notable decrease in smoke emissions, not so apparent in the J5, J10 and J20 mixture but quite apparent in the J50 and J100 mixture. In all the phases of the cycle, the smoke emissions were similar to the diesel fuel decreased. The trend which smoke emissions of biodiesel will be reduced is due to lower aromatic and sulfur compounds and higher cetane number for biodiesel, but the more important factor is the higher oxygen content. It should be noted that, the advantage of no sulphur characteristics for biodiesel will disappear as the sulfur content in diesel becomes fewer and fewer (Pal et al., 2010; MacLean and Lave, 2003).

The O₂ emission of various fuels from the diesel engine is shown in Figure 8. At 2000 rpm, the O₂ concentration recorded was 17.79%, 18%, 18.22%, 18.34%, 18.43% and 18.53% for J0, J5, J10, J20, J50 and J100, respectively. It can be seen that the O₂ emission compared to pure petrodiesel increased for all the blend fuels. This may be attributed to the fact that blend fuels have a lower elemental carbon to hydrogen ratio than pure petrodiesel. The burning of blend fuels with air will therefore form higher O₂ emission than pure petrodiesel (Silitonga et al., 2011).

Figure 9 displays the temperature changes in the exhaust gases emitted from all of the tested fuels. The emitted exhaust gas temperature was the lowest in J0, followed by J5, J10, J20, J50 and J100. The temperature of exhaust gases emitted from biodiesel fuel blends ranged from 316°C to 328°C, and that from pure petrodiesel fuels was 316°C. This was possibly because the consumption of petrodiesel and biodiesel per hour differed in the biodiesel-petrodiesel fuel

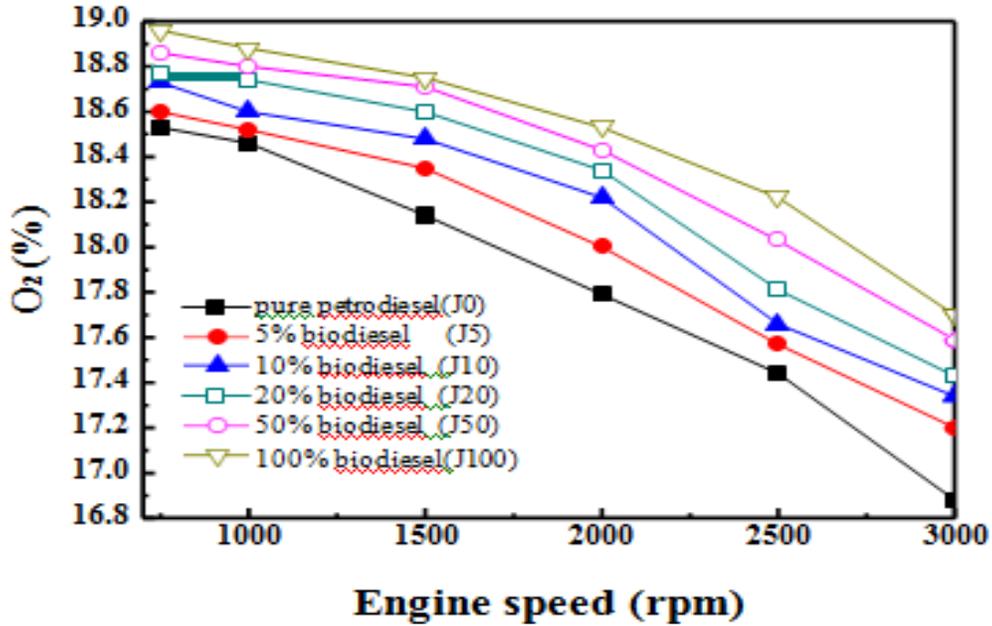


Figure 8: Oxygen emissions for various types of fuel.

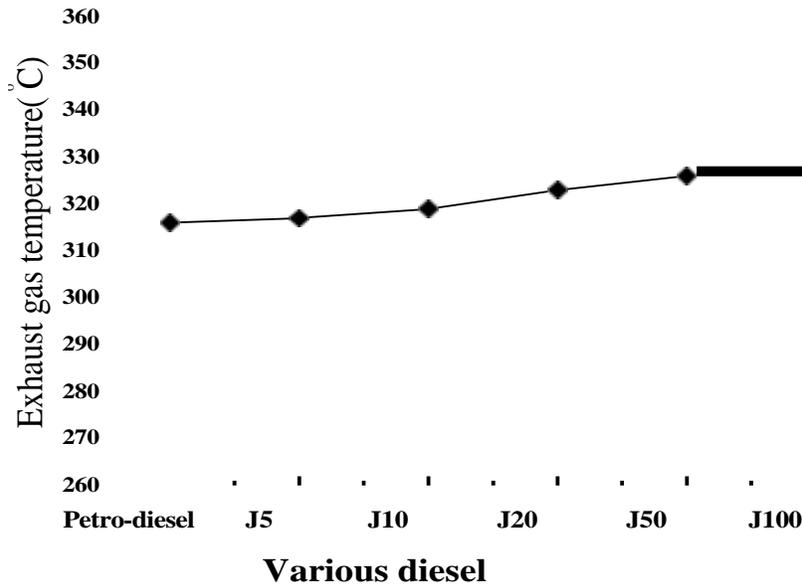


Figure 9: Exhaust gas temperature for various types of fuel.

blend. In addition, there were no obvious variances in the exhaust gas temperatures among the biodiesel fuels. The results revealed that the fuel consumption was the lowest in J0, followed by J5, J10, J20, J50 and J100. A fuel with high oxygen content also generated a low heating value, which possibly caused a large amount of power dissipation and elevated fuel consumption (Figure 10). An increase in biodiesel fuel consumption, due to low heating value, high density and viscosity of biodiesel, has been found, but this trend will be weakened as the proportion of biodiesel

reduces in the blend.

CONCLUSION

The following conclusions were derived based on the above analysis: The use of *J. curcas* biodiesel as an additive to pure petrodiesel fuel improved diesel engine performance and reduced exhaust gas emission. The results indicated that the emissions of hydrocarbon, carbon monoxide, carbon

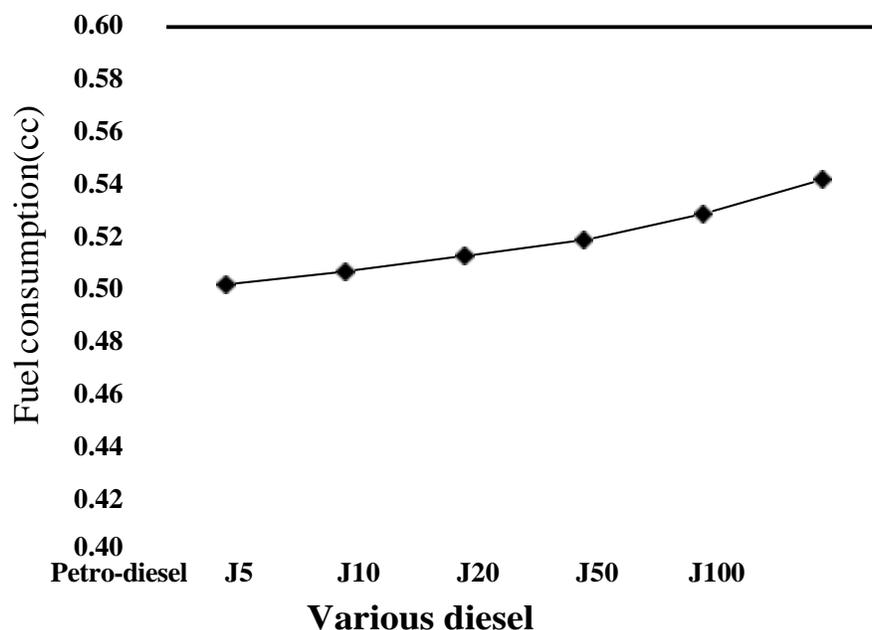


Figure 10: The changes of the fuel consumption of the tested fuels.

dioxide and smoke were reduced by 12.5%, 30.43%, 22.41% and 7.54%, respectively. However, the fuel consumption, oxygen and exhaust gas temperature were increased by 7.97%, 4.16% and 3.8%, respectively. No evident difference was exhibited in the emission of nitrogen oxides. A biodiesel fuel with a high octane number can undergo a high compression ratio and prevent engine knocking, thus enabling the engine to effectively and economically generate additional power.

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