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Performance Evaluation Of Rubber Seed Oil Biodiesel

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A B S T R A C T

In this study the engine performance evaluation of synthesized and characterized rubber seed oil biodiesel was carried out at varying engine speeds and different biodiesel blend levels using a four-cylinder, four-stroke Gardner diesel engine rated at 55.93 KW and 435Nm. The engine was operated on pure rubber seed oil biodiesel, biodiesel blends B10, B20, B30 and B40 with baseline diesel fuel as control. Experimental results showed that the brake torque decreased with increasing engine speed and biodiesel blend percentage while the power produced from the biodiesel blends was less than that produced from the diesel fuel. The power produced decreased as the biodiesel blend concentration increases. The maximum power for the biodiesel blended fuels are 55.14kW, 54 31kW, 54.48kW, 53.15kW, 51.17kW and 48.52kW corresponding to B0, B10, B20, B30, B40 and B100 respectively. The break mean effective pressure increased slightly with increasing engine speed and then sharply decreases with increasing engine speed and biodiesel blend concentration. The brake specific fuel consumption and brake thermal efficiency increased with increasing engine speed and increasing biodiesel blend concentration. The results of this investigation can be used for partial replacement of diesel fuel using low concentration of biodiesel (maximum 30%) produced from rubber seed oil thereby reducing the dependence on petroleum- based diesel fuel.

1. Introduction

The rapidly depleting petroleum reserves, increasing demand for refined crude oil and the growing environmental concern has significantly reawakened the research interest in renewable fuel for compression ignition engines. Biodiesel is an alternative fuel produced from renewable lipid feedstocks and it occupies an important position among the substitutes to conventional diesel fuel which is produced from petroleum reserves. It is named biodiesel because it is derived from biological products and matches diesel in properties and performance. It is defined as the mono-alkyl esters of fatty acids derived from vegetable oil or animal fats (Knothe, 2001 and Van. Gerpen et al., 2004). Furthermore, the research on the production of biodiesel has greatly increased in recent years because of the need for an alternative fuel that is endowed with renewability, low toxicity and biodegradability. Its other admirable quality is that its energy content is similar to that of conventional fuels, so it can be used either on its own or mixed with conventional diesel fuel to form biodiesel blends. In addition, biodiesel can be pumped, stored and handled using the same facilities utilized for diesel fuel (Van Gerpen et al., 2004 and Robles –Medina et al., 2009).

A further assertion is that the risk of illness and life threatening diseases can be reduced using biodiesel blends (Joshi and Pegg, 2007). However, the blending of biodiesel has its own problems. Some of these problems are fuel freezing in cold weather, reduced energy density, and degradation of fuel under storage for prolonged periods. Above all, higher level biodiesel blends are often not recommended because they require special handling equipment and engine modification (Jain *et al.,* 2011). Hence,

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obtaining an optimum biodiesel blend to counter these problems is important. Biodiesel blends are indicated by a "B" with a number "XX" following the "B" that represents the percentage of biodiesel in a litre of fuel. For example, B20 means a biodiesel blend with 20% biodiesel and 80% diesel.

Diesel engines are a large and growing segment of the world's transportation fleet. Diesel engine parameter evaluated with biodiesel fuels in literature typically includes engine power, torque, brake specific fuel consumption, brake thermal efficiency and exhaust gas temperatures (Jahirul et al., 2013). Hansen et al. (2006) researched on diesel engine performance and nitrogen oxides (NOx) emissions from oxygenated biofuels and blends with diesel fuel. They noted that the brake torque loss was 9.% in biodiesel at 1900rpm as the results of differences in heating value (13.3%), density and viscosity. Research findings from these studies confirm that the lower heating value of biodiesel is not the only factor which influences engine power and torque. Other biodiesel fuel properties including viscosity, density and lubricity have significant effects on engine output power and torque. Dorado et al. (2003) experimentally analyzed transesterized waste oil on a 3 – cylinder, 4-stroke, water-cooled and direct injection diesel engine. They reported a slight increase in brake specific fuel consumption. Carraretto et al. (2004) carried out experimental analysis and energetic evaluations of biodiesel as alternative fuel. In their results they were able to overcome the power loss of biodiesel engine by optimizing biodiesel combustion through reducing injection advance. It is therefore evident that power and torque developed in biodiesel engines is not only dependent on feedstock and fuel properties, but also on the engine type and operating conditions, such as engine speed, load, injection timing and injection pressure (Jahirul et al., 2013). Similar relationships have been found in the literature for other performance parameters such as brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature and combustion characteristics (Aydin and Bayindir, 2010; Murillo et al. 2007). From the literature review, more investigations are required in order to understand the diesel engine performance. Hence, in this study, the performance evaluation of diesel engine using biodiesel blends is conducted on a compression ignition engine by varying the biodiesel blends and the engine operating conditions such as speed.

2. Materials and method

The materials used were biodiesel, measuring cylinders (10ml and 1000ml), and diesel engine test bed. The performance evaluation of the biodiesel and blends with diesel were conducted using a diesel engine whose specification is as follows:

Engine type: Naturally aspirated four – cylinder Gardner model IL – 2 diesel engine.

Engine capacity: 5600cm^3

Bore 107.95mm

Stroke: 152.4mm

Maximum torque: 435Nm

Maximum power output: 55.93KW @ 2700rpm.

The engine was connected to an eddy current dynamometer. The test bed is equipped with fuel flow meter, digital manometer and digital tachometer. The fuel system was modified to take an extra fuel tank for the biodiesel fuel and blends. The fuel system has three valves which were connected to the diesel fuel tank, the extra tank and engine fuel pump. The engine was warmed up on diesel fuel at full throttle opening for 30 minutes to allow the engine oil pressure and cooling water temperature reach operating level. The valve to the extra fuel tank containing the fuel being tested was next opened. The engine was operated for 10 minutes to allow the test fuel to completely fill the fuel line. The engine was now operated at full throttle opening and load increased gradually until the speed reduces to the minimum at which the engine will just run smoothly. For each load value, the speed was measured as well as the temperature, exhaust emissions, smoke opacity and sound pressure level. The procedure was repeated for B100 and all the blends.

2.1 Experimental Setup

The experimental setup is shown in Figure

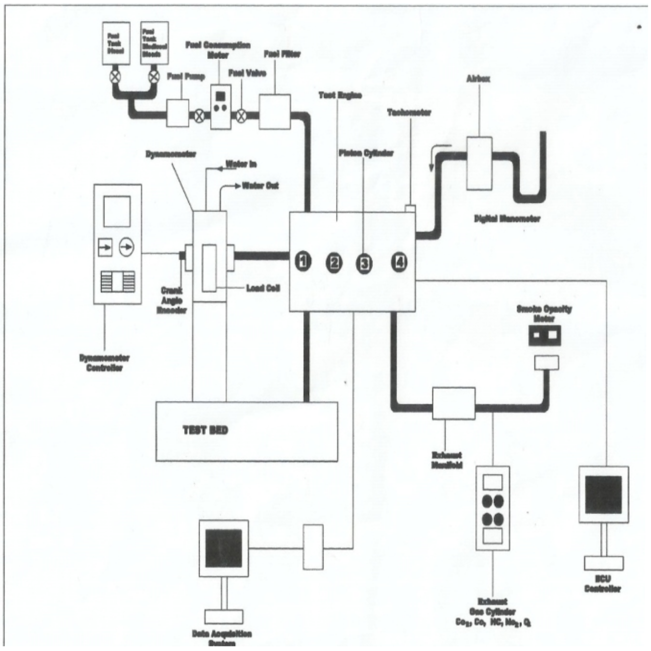

Figure 1. Schematic arrangement of experimental set – up

3. Results and discussion

3.1 Brake torque

The variation of the performance parameters with speed were investigated and the results obtained are as follows. Figure 2 shows the variation of torque with speed for biodiesel, diesel and blends.

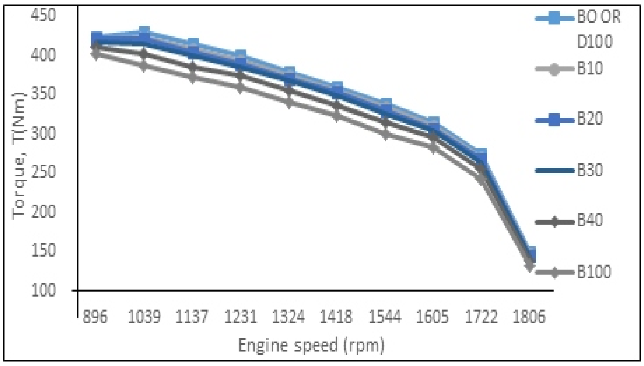

Figure 2: Variation of brake torque with engine speed at different biodiesel blend ratio.

The obtained results shows that the brake torque decreases with increasing engine speed. The trend between the brake torque and the engine speed is an inverse proportion trend. For instance at engine speed of 1800 rpm, the percentage reduction in brake torque of the biodiesel blended fuels compared to the diesel fuel are 1.33, 2.67, 4.00, 7.33 and 11.33% for B10, B20, B30, B40 and B100 respectively. From the Figure it was observed that the pure diesel fuel had the highest brake torque. The brake torque decreased with increasing biodiesel blend percentage in all test conditions. The highest decrement in brake torque occurred at the maximum speed of 1800 rpm with 11.33% reduction in brake torque when using pure biodiesel as engine fuel. In other words, the pea`k brake torque values for the different biodiesel blends were lower than the baseline diesel fuel by 1.32%, 2.37%, 3.16%, 6.33% and 10.00% for B10, B20, B30, B40 and B100 respectively at the engine speed of 1300 rpm. The brake decreased because the engine was unable to inject a fuel charge of air at higher speed. Again, the slight reduction in brake torque could be related to the lower heating value of biodiesel and diesel – biodiesel blends. However, there was a marginal difference in the torque values between the pure diesel fuel and the biodiesel blended fuels showing a similar trend in engine performance. Similar results were reported by other researchers (Liaquat *et al.,* 2013). Furthermore, the engine torque reduction with increasing engine speed could be attributed to the lowered volumetric efficiency of the engine due to the increase in the corresponding engine speed and the augmentations in the mechanical losses (Ilkir and Ayden, 2011 and Liaquat *et al.,* 2013). The higher viscosity of biodiesel, which might affect the engine brake effective power and engine torque especially in full-load conditions, increased 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. The higher viscosity reducing the back flow across the piston clearance of the injection pump could be responsible for this decrement (Buyukkaya, 2010). Other reasons which could be used to explain the reduction in torque output are the increase in pumping work and the decrease in combustion work which could be the result of lower combustion temperatures and decrement in air-fuel ratio.

3.2 Brake power

The variation of engine power with speed for the biodiesel, blends and diesel are shown in Figure 3.

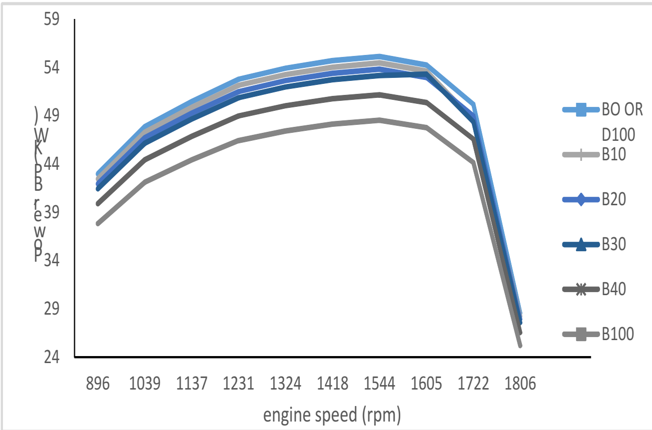

Figure 3. Variation of brake power with engine speed at different biodiesel blend level

From the Figure 3 it was observed that less power was derived from the biodiesel blend fuels compared to the baseline diesel fuel. There was a slight difference between the biodiesel blend fuels compared to neat diesel fuel. This difference gradually increased with increasing biodiesel blend ratio. In addition to that, there was a close similarity between the biodiesel blended fuels and the diesel fuel at low engine speed but this similarity gap gradually widens at higher engine speed and differences between the biodiesel blended fuels and the diesel fuel become conspicuous. The maximum brake power for the biodiesel blended fuels are 55.14KW, 54.31KW, 54.48KW, 53.15KW, 51.17KW and 48.52KW corresponding to B0, B10, B20, B30, B40 and B100 respectively. At 1800 rpm the reduction in brake power of the biodiesel blended fuels compared to neat diesel fuel are 1.02%, 2.35%, 3.54%, 7.07% and 11.80% corresponding to B10, B20, B30, B40 and B100 respectively.

The decreasing trend in power output obtained for each of the biodiesel blended fuel could be related to the combustion temperature of the fuel. Moreover, the heating value of the fuel affects the power output of the engine. The lower energy level of the biodiesel blended fuels lead to the decrement in the obtained power output when it is used in compression ignition engines without any modification. On the contrary, some researchers (Liaquat *et al.,* 2011) observed that the brake power increases with increasing engine speed until 3000rpm and then power starts to drop due to the effect of higher frictional force. The pure diesel fuel had the highest brake power while the biodiesel blends had a brake power relatively higher than that of pure biodiesel fuel. In other words, the pure biodiesel fuel had the lowest brake power. At 1300 rpm, the pure diesel fuel B0 had the highest brake power of 53.90kW, while the biodiesel blends had a brake power relatively higher than that of pure biodiesel fuel B100 which was 47.43kW. The biodiesel blend B10, B20, B30 and B40 had the brake power of 53.25kW respectively at 1800 rpm while B0, B10, B20, B30, B40 and B100 had the lowest brake power of 28.57kW, 28.23kW, 27.90kW, 27.56kW, 26.55kW and 25.20kW in that order. Similar results were obtained by other researchers. For instance, Knothe *et al.,* (2004) reported that the higher power output shown by diesel-biodiesel blends is related to the lower viscosity profile of the tested neat biodiesel. High fuel viscosity led to a reduction in fuel injection efficiency and atomization and could have a negative impact on fuel injection and combustion resulting in power losses in engines. As the biodiesel blend concentration increases, the adsorption layer on metal surface in relative motion to one another (such as injection system, pistons, rings and sleeves) become more lubricated thereby reducing metal to metal contacts and start to deteriorate in frictional horse power to produce more power and brake mean effective pressure in the engine(Ejilah and Asere,2008). There is a marginal increasing trend in engine power output until a maximum peak was attained and the power output decreased quickly with increasing engine speed. It was generally observed that the power decreased with increasing biodiesel blend concentration in all the tested fuel samples. This was due to the effect of higher frictional force.

3.3 Brake mean effective pressure

Figure 4 shows the effect of engine speed variation on brake mean effective pressure at varying biodiesel blend concentrations.

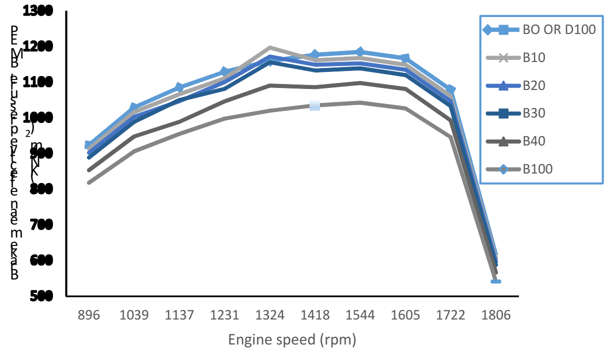

Figure 4. Effect of engine speed variation on brake mean effective pressure at different biodiesel blend level .

From the Figure it was observed that the brake mean effective pressure (BMEP) increased gradually with increasing engine speed up to a maximum value and then sharply decreases with increasing engine speed up to a minimum value. Furthermore, it was observed that brake mean effective pressure decreased with increasing engine speed and biodiesel blend concentration (% vol/vol). A decrease in brake mean effective pressure would also result in a corresponding decreased in torque developed by the engine. As the percentage volume of biodiesel in fuel blends increased, the fatty acids methyl ester molecules were absorbed into their surface and become more lubricated thereby leading to a reduction in metal to metal contacts and a deterioration in frictional horse power to generate more power and brake mean effective pressure in the engine(Ejilah and Asere). At 1800 rpm, the reduction in brake mean effective pressure of the biodiesel blended fuels compared to the baseline diesel fuel are 1.46%, 2.93%, 4.39%, 7.97% and 12.03% for B10, B20, B30, B40 and B100 respectively. At 1300 rpm, the improvement in brake mean effective pressure of the biodiesel blended fuels compared to reference diesel fuel are 3.28% and 1.12% for B10 and B20 respectively while the reduction in brake mean effective pressure of the biodiesel blends compared to diesel fuel are 0.26%, 5.87% and 11.99% for B30, B40 and B100 respectively. At 900 rpm, the decrement in brake mean effective pressure of the biodiesel blends compared to diesel fuel are 1.19%, 2.38%, 3.79%, 7.68% and 11.49% for B10, B20, B30, B40 and B100 respectively. The decreasing trend in brake mean effective pressure observed here could be attributed to the effect of higher frictional force and combustion process in the combustion chamber of the diesel engine. These results agree with those obtained by other researchers in this field (Ejilah and Asere,2008., Liaquat *et al.,* 2013; and Dhaundiyal, 2014).

3.4 Brake specific fuel consumption

Figure 5 shows the effect of engine speed variation on brake specific fuel consumption at varying biodiesel blend concentration.

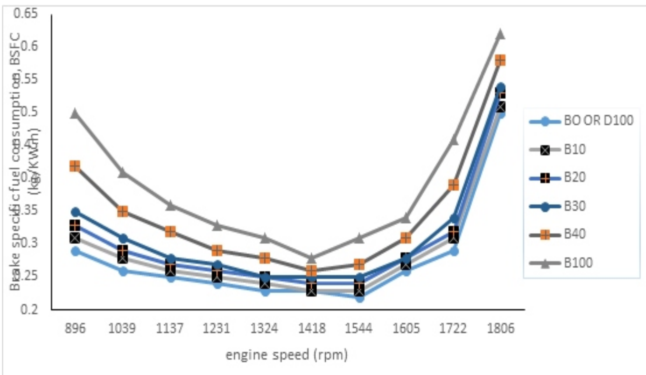

Figure 5. Effect of engine speed variation on BSFC at different biodiesel blend fraction.

From the Figure it was observed that the brake specific fuel consumption decreases with increasing engine speed and increasing biodiesel blend concentration in the fuel sample. The Figure shows that brake specific fuel consumption of biodiesel blended fuels trend is very similar to that of baseline diesel fuel because in the first part of the Figure all the tested fuel samples brake specific fuel consumption decreased with increasing engine speed whereas in the second part of the Figure it increased with increasing engine speed. The brake specific fuel consumption for benchmark diesel fuel is lower than that for biodiesel blends due to the higher value of energy content for diesel. A low values of specific fuel consumption are obviously desirable. The lowest brake specific fuel consumption of 0.22kg/kWh was recorded with the baseline diesel fuel at 1500 rpm while the pure biodiesel (B100) had the highest brake specific fuel consumption of 0.62kg/KWh at 1800 rpm. The highest brake specific fuel consumption of B100 shows that more fuel was consumed to generate the same power output. With respect to the baseline diesel fuel, the test fuel B10, B20, B30, B40 and B100 had higher brake specific fuel consumption by 2.00%, 6.00%, 8.00%, 16.00% and 24.00% respectively at 1800 rpm. The B10 and B20 biodiesel blends showed less increment of brake specific fuel consumption (2.00% and 6.00% respectively) at 1800 rpm. This shows that they have a higher fuel consumption efficiencies than those of the other biodiesel blended fuels at all the measured engine speed ranges. This fuel consumption behaviour could be attributed to their improved miscibility, better fuel atomization characteristics and combustion process. At 1300 rpm, the brake specific fuel consumption of the biodiesel blends B10, B20, B30, B40 and B100 were observed to be higher by 4.35%, 8.70%, 8.70%, 21.74% and 34.78% respectively than that of the diesel fuel. At 900 rpm, the brake specific fuel consumption of the biodiesel blends B10, B20, B30, B40 and B100 were observed to be higher by 6.90%, 13.79%, 20.69%, 44.83% and 72.41% respectively than that of the diesel fuel. These percentage differences in brake specific fuel consumption was higher at low engine speeds and gradually decreased as the engine speed increases. The produced power in low speeds was low and the bulk of the fuel was used to overcome the engine friction. The probable reason why brake specific fuel consumption was increased with increasing engine speed is that friction power increased with increasing engine speed (Najafi *et al.,* 2007).

3.5 Brake thermal efficiency

Figure 6 shows the effect of engine speed variation on brake thermal efficiency at varying biodiesel blend rate.

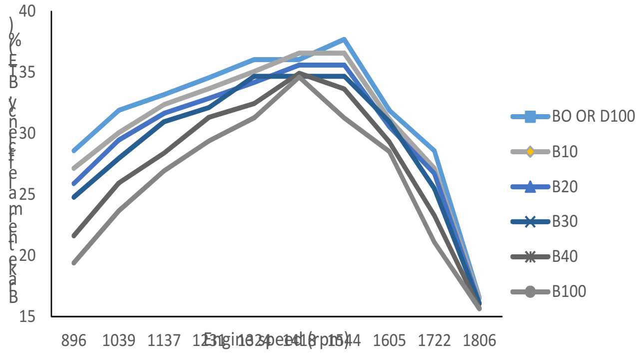

Figure 6. Effect of engine speed variation on brake thermal efficiency at different biodiesel blend ratio.

From the obtained results it was observed that the brake thermal efficiency increased with increasing engine speed up to 1500 rpm and after reaching the maximum value, it began to decrease with a further increase in engine speed. At 1500 rpm , the brake thermal efficiency values are 37.68%, 36.57%, 35.59%, 34.66%, 33.62% and 31.26% for diesel fuel (B0), B10, B20, B30, B40 and pure biodiesel (B100) respectively. In other words, the brake thermal efficiency of the engine is deteriorated with increasing concentration of the biodiesel mixtures. This deteriorated brake thermal efficiency could be explained with the increased lubricity of these biodiesel blends as compared to diesel fuel (Buyukkaya, 2010). It should be noted that the brake specific fuel consumption is inversely proportional to the brake thermal efficiency. From the Figure it was observed that brake thermal efficiency for the biodiesel blends is lower than that for the diesel fuels. That is, the efficiency for diesel fuel was higher than the brake thermal efficiency values for biodiesel and its blends due to the different number of carbon atoms for each fuel. Consequently, the higher density of biodiesel and its blends compared to diesel fuel is due to the fact that they contain more oxygen atoms thereby resulting in low fuel temperature of biodiesel and its blends. Therefore, the brake thermal efficiency is lower as the fuel temperature is low. The thermal efficiency is improved when the fuel temperature increases.

Conclusion

The results showed that the biodiesel blend B10 and B20 showed a reduction in brake torque of 1.33% and 2.67% compared to diesel whereas B30 and B40 show a reduction in brake torque of 4.00% and 7.33% compared to diesel at 1800 rpm. The biodiesel blends B10 and B20 give more power output of 54.31 kW and 54.48 kW than the other blends B30, B40 and B100. Also blend B10 and B20 give a higher brake thermal efficiency of 36.57% and 35.59% compared to 34.66%, 33.62% and 31.26% for B30, B40 and B100 respectively. The increment in brake specific fuel consumption at 1800 rpm compared to diesel for blend B10, B20, B30, B40 and B100 was 2.00%, 6.00%, 8.00%, 16.00% and 24.00% in that order. The overall engine performance parameters were in favour of the lower blends B10 and B20. Based on these observations, biodiesel blend B10 and B20 can be used to partially replace diesel fuel for running diesel engines without any adverse effect on engine performance.

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