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Short Term Tests on Performance Evaluation of Water-washed and Dry-washed Biodiesel from Used Cooking Oil

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Abstract—In this study, biodiesel from used cooking oil was produced as purified by washing with water (water wash) and amberlite (dry wash). The work presents the results of short term tests on performance characteristics of diesel engine using both biodiesel-fuel samples. In this investigation, the water wash biodiesel and dry wash biodiesel and diesel were compared for performance using a four-cylinder diesel engine. The torque, brake power, specific fuel consumption and brake thermal efficiency were analyzed. The tests showed that in all cases, dry wash biodiesel performed marginally poorer compared to water wash biodiesel. Except for brake thermal efficiency, diesel fuel had better engine performance characteristics compared to the biodiesel-fuel samples. According to these results, dry washing of biodiesel has a marginal effect on engine performance.

***Keywords*—**Biodiesel, engine performance, used cooking oil, water wash, dry wash.

I. INTRODUCTION

INCREASE in energy demand, high price of crude oil, global warming due to greenhouse gases, environmental pollution and fast diminishing supply of fossil fuels are the main important problem leading to search for alternative sources of energy. Among the alternatives capable of substituting fossil fuels; wind, solar and bioenergy have been widely studied. Presently, about 86% of the energy being spent globally and almost 100% of energy desired in the transportation division is provided by non-renewable fossil fuels, petroleum [1].

Biodiesel has considered a very complement and/or substitute for diesel which is a by-product of petroleum. This is due to the fact that it is a biofuel with characteristics similar to conventional diesel fuel. Biodiesel has been described as mono-alkyl esters of long chain fatty acids with vegetable oil or animal fat origin [2]. However, due to recent production of biodiesel from algae, biodiesel may be described as any fuel based on renewable raw materials and it is suitable for use in diesel engines. Biodiesel is biodegradable, non-hazardous and has low emission profiles when compared with diesel [3].

Transesterification is the most common way to produce biodiesel using alcohol in the presence of catalyst. The glycerol formed after transesterification is separated by settling or centrifuging. Unpurified biodiesel has numerous impurities such as free glycerol, soap, metals, methanol, free fatty acids (FFA), catalyst, water and glycerides (mono, di, and triglycerides). The effect of every impurity can be different in the fuel properties and engine performance. Therefore, there is the need for biodiesel to undergo purification. One of the most widely purification methods in use is washing. Biodiesel washing methods have been classified into wet and dry washing [4]. Washing provides valuable insight into the quality and completeness of transesterification - any soap, un-reacted oil, and unused catalyst present will make themselves known. In wet washing, a fine water mist is sprayed over the biodiesel and as the water settles to the base of the wash container, the impurities are collectively removed. If water is used, the wash water will be extremely soapy or the biodiesel and water will become suspended together in an emulsion. Dry washing methods allow for a strong affinity for polar compounds. Dry washing eliminates the need for wet washing as it reduces fresh water usage, disposal costs and significantly reduces overall operating cost.

The connection between the impurities and their properties such as corrosion due to the existence of FFA, water or methanol and deposits in the injectors due to traces of glycerides or catalysts has been explained by [5]. Since the diesel engines are not particularly made for biodiesel fuel to run them, the study of biodiesel is not complete until it is tested in a diesel engine. However, it appears that no studies have been carried out to investigate the effect of the type of washing on the performance of biodiesel in diesel engines. Therefore, the objective of this work is to attempt to study the effect of water-washing and drying-washing methods on some engine performance characteristics.

II. MATERIALS AND METHODS

A. Materials

The raw material employed for biodiesel production was used cooking oil collected from the campus cafeteria of Vaal University of Technology, Vanderbijlpark, South Africa. The

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used cooking oil had FFA value of less than 2%. Hence, a one-step transesterification method was used in biodiesel production. Amberlite resin was supplied by Bioman energy, South Africa. Chemicals were purchased from Labchem (Pty) Ltd, South Africa.

B. Biodiesel Production and Testing

To produce biodiesel on laboratory scale, the used cooking oil was filtered to eliminate bits of food remains and heated up to 60°C for 15 minutes to remove water. 70 grams of oil was measured in a beaker. 30 grams of methanol was measured in another beaker. 1 gram of KOH was dissolved in the 30grams of methanol. The beaker containing oil was put on a heating mantle and kept constant at 60°C while stirring at 300 rpm.

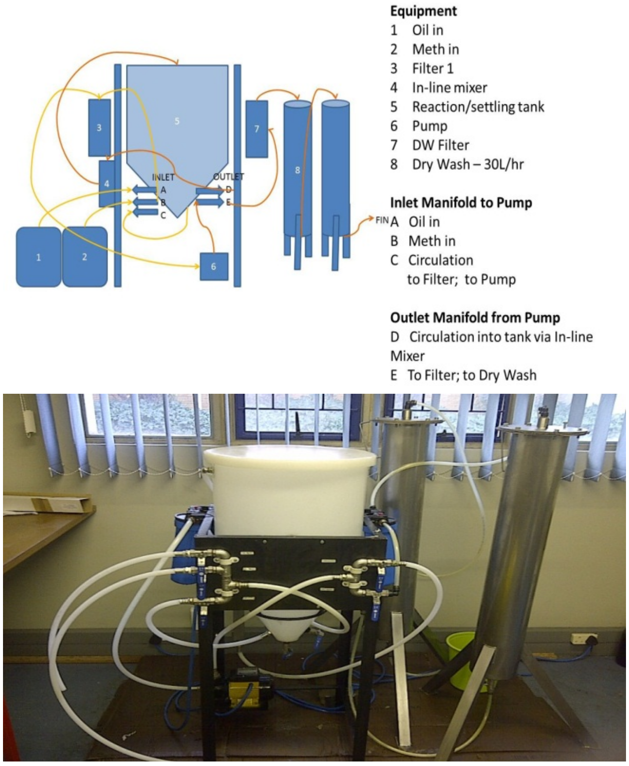

Fig. 1 Schematic and photographic images of the biodiesel plant

The methanol and KOH mixture was then added. The whole mixture was allowed to heat and stir for 1hour. A mixture of glycerol and biodiesel was formed. The mixture was put in a separating funnel and left overnight to settle. The glycerol was drained of the bottom of the separating funnel leaving biodiesel. The biodiesel was washed with water and boiled to remove the water left in it. A 27/3 test was performed to confirm biodiesel was produced. The 27/3 test involves putting 27ml of methanol in a cylinder and adding 3ml of biodiesel to it. After shaking, biodiesel dissolves in the methanol while oil will not dissolve. The laboratory specimen was up-scaled using a 50-litre capacity biodiesel pilot plant (see Fig. 1). One batch of the biodiesel was dry- washed using Amberlite BD10DRY (dry resin) powder while another batch was washed with distilled water and heated to a temperature of 75°C and left for 1 hour to permit evaporation of trapped water and excess methanol.

TABLE I
PROPERTIES OF THE BIODIESEL FUEL SAMPLES

Property	Biodiesel Fuel Sample	
	B100W	B100D
Density at 15 °C, kg/m^3	864	864
Kinematic viscosity at 40 °C, mm^2/s	4.473	4.515
Flash point, °C	155	160
Oxidation stability, hr	3.584	1.65
Acid value, mgKOH	1.18	0.77
Cold Filter Plugging Point, °C	-12	-10
Cloud point, °C	0	-2
Pour point, °C	-12	-8
Lower heating value, kJ/kg	36727	36727

The physical and chemical properties of the test fuel samples were determined experimentally according to ASTM procedure (see Table I). The fuel properties are kinematic viscosity, density, flash point, cloud point, pour point, cold filter plugging point, oxidation stability, acid value and calorific value. B100W stands for water-washed biodiesel while B100D is used represent dry-washed biodiesel.

C. Engine Test Setup

The engine used for the performance tests is a Mercedes Benz OM 364A, four-cylinder, four-stroke direct-ignition turbocharged industrial diesel engine. The engine specifications are shown in Table II. The maximum power output of the engine is 87 KW at 2600 rev/min. A 265 KW output Froude eddy current dynamometer was used. The experimental test setup is shown in Fig. 2.

TABLE II
SPECIFICATIONS OF MERCEDES BENZ OM 364A ENGINE

Engine specifications	
Model	Vertical, in-line with exhaust gas turbocharger
Number of cylinders	4
Cylinder bore	97.5 mm
Piston stroke	133 mm
Connecting rod length	230 mm
Total piston displacement	3972 cm^2
Compression (dead) space per cylinder	64 cm^2
Compression ratio	16.5:1
Cut-off ratio	3.75
Crank angle for fuel injection	164^0
Automotive rating	87 kW at 2600 rpm
Engine gross approximate weight	415 kg

D. Test Engine and Procedure

The engine used for the performance tests is a Mercedes Benz OM 364A, four-cylinder, four-stroke direct-ignition turbocharged industrial diesel engine. The engine specifications are shown in Table II. The maximum power output of the engine is 87 KW at 2600 rev/min. A 265 KW output Froude eddy current dynamometer was used. The experimental test setup is shown in Fig. 2. To get the base line data of the engine, first the experiment was performed with diesel and followed by the biodiesel fuel samples. The engine runs to a temperature between 80^{0}C-90^{0}C warm-up periods prior to data collection. The experiment was repeated for particular fuel at different speeds. The parameters measured include fuel flow, power, torque, different temperatures and pressures, etc.

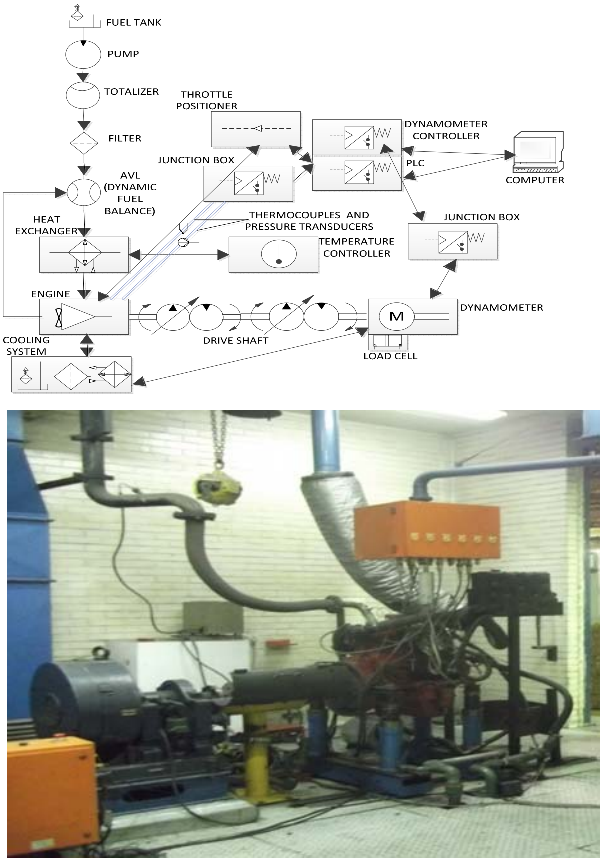

Fig. 2 Schematic and photographic images of the test cell setup

III. Results and Discussion

A. Properties of the Biodiesel Fuel Samples

Table I summarizes the properties of the water-washed and dry-washed biodiesel fuel samples. The table shows that while density and calorific value are the same for both fuel samples, there are marginal differences between the other properties of water-washed and dry-washed biodiesels.

B. Engine Performance

Fig. 3 shows the variation of torque with speed for diesel (D), water-washed biodiesel (B100W) and dry-washed biodiesel (B100D). The torque performance pattern of all the fuels is similar. With increase in engine speed, the torque reaches a maximum and then decreases with further increase in engine speed. The maximum torque values is about 333 Nm for diesel fuel at 1800 rev/min while the maximum of about 325 Nm and 323 Nm were recorded for B100W and B100D respectively at 1800 rev/min. This trend could be observed from 1000 rev/min to the maximum speed of 2800 rev/min. However, at higher speed the increase became more pronounced with B100W showing a higher value of torque 257 Nm compared to 246 Nm for B100D at maximum speed. It has been argued that fuel density directly affects fuel performance. The density of fuel affects the quality of atomization and combustion [6]. With both fuel samples having the same values of calorific value and density, a possible explanation for the differences in the torque especially at higher speed could be due to the differences in the kinematic viscosity. In diesel engine, higher viscosity leads to less accurate fuel injectors, and to poorer atomization, and hence lower torque for B100D.

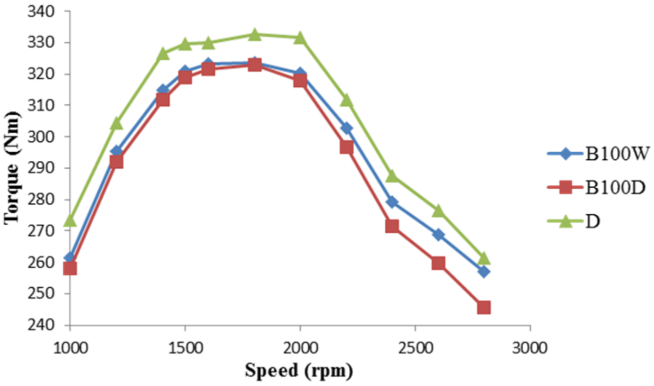

Fig. 3 Variation of torque with engine speed

The brake power variation with engine speed is presented in Fig. 4. As with torque, the brake power performance pattern of both biodiesel fuels is similar. The brake power increases at all engine speeds until it reaches a maximum value. The maximum brake power was obtained at 2800 rev/min with diesel performing slightly better than the biodiesel fuel samples. Except from 2000 rev/min, the brake power for B100W and B100D was almost the same. Diesel had the maximum brake power of 77 kW at maximum engine speed while the recorded values for B100W and B100D were 76 kW and 72 kW respectively. Heating value, lubricity and viscosity are some of the fuel properties known to have an important effect on engine power [7]. Higher viscosity results in power losses as it decreases combustion efficiency due to bad fuel injection atomization [8], [9]. With the same calorific value and density for the biodiesel samples, the kinematic viscosity differences might have caused the higher brake power shown by B100W.

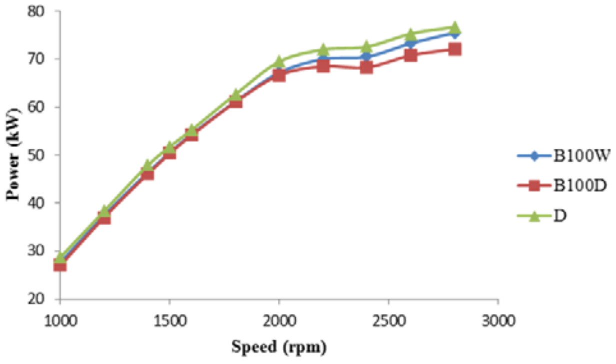

Fig. 4 Variation of brake power with engine speed

The variations of specific fuel consumption (SFC) with engine speed for the tested fuels are presented in Fig. 5. The SFC values of B100D and diesel decrease until 1400 rev/min while that of B100W decreases up to 1600 rev/min. There is a significant difference noted between the biodiesel fuels and diesel at 1000 rev/min and this decreased as the engine speed increased. Nevertheless, the SFC of all the fuels showed similar behaviour at all values of engine speed. The maximum SFC value of diesel at 2800 rev/min was 231 g/kWh, while for B100W and B100D; it was 242 g/kWh and 250 g/kWh, respectively. Lower heating value, higher density and higher viscosity have been identified to play primary role in engine fuel consumption for biodiesel [10]. As the density and calorific value of B100W and B100D are the same, higher value of kinematic viscosity for dry wash biodiesel might have caused higher specific fuel consumption when compared with water wash biodiesel.

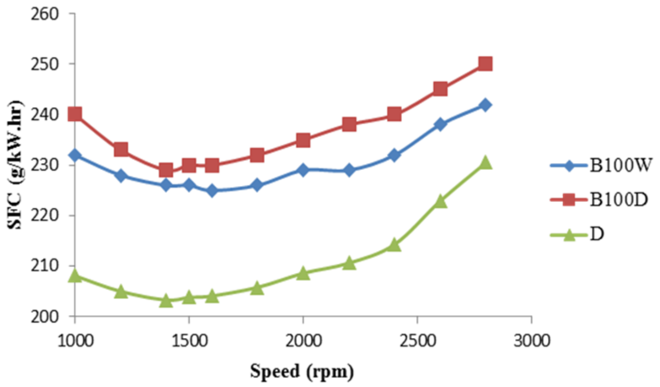

Fig. 5 Variation of specific fuel consumption with engine speed

Fig. 6 shows the brake thermal efficiency (BTE) of the engine fuelled with diesel, water washed biodiesel and dry washed biodiesel. The overall trends of the BTE characteristics of all the fuels are almost similar in nature. As seen in Fig. 6, the brake thermal efficiency of the engine fueled with B100W and B100D biodiesel fuels is higher than that of diesel. This behaviour has been observed in other tests and in some published works by [11]-[14]. The highest brake thermal efficiency was found at 1600 rpm for water-wash biodiesel with a value of 45.3%. The BTE values for B100W and B100D were 42.2% and 39.8% respectively, at maximum speed of 2800 rpm. The low BTE obtained for B100D was due to its higher value of SFC and viscosity compared to B100W since density and calorific value are the same.

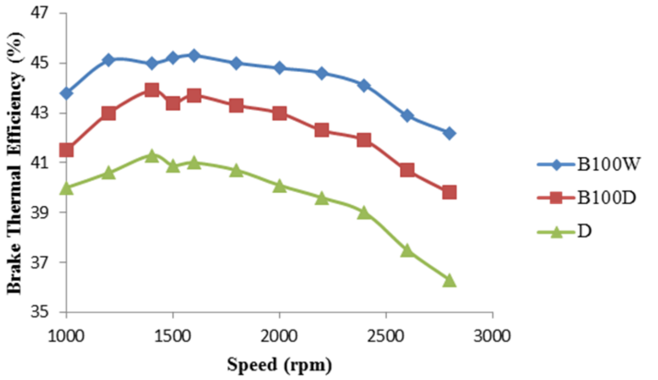

Fig. 6 Variation of brake thermal efficiency with engine

IV. CONCLUSION

In present work, short term tests were carried out to investigate the effect of water-washed and dry-washed biodiesel fuels on produced from used cooking oil will have on diesel engine performance. Results showed that except for heating values and densities of both biodiesel fuels which were the same, other properties tested were marginally different. Compared to water-washed biodiesel, a 5.26% power loss occurred with dry-washed biodiesel. The SFC value of water-washed biodiesel was 3.2% lower than that of dry-washed biodiesel. The difference in brake thermal efficiency between both biodiesel-fuel samples were marginally at 5.69%. Therefore considering the marginal differences in all the parameters tested, it is concluded that dry washing of biodiesel does not improve diesel engine performance characteristics.

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