COMPARATIVE STUDY OF PERFORMANCE AND EMISSION CHARACTERISTICS OF A DIESEL ENGINE FUELED BY CASTOR BIODIESEL

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Abstract: *Biodiesel is playing an important role in recent years as an alternative fuel for diesel engines. Biodiesel derived from castor oil gives comparable performance and emission characteristics. In this research paper, a comparative study has been done between castor biodiesel blends and diesel fuels. Castor biodiesel was prepared from castor oil by Transesterification process. Diesel- biodiesel blends of 5, 10, 15 and 20% was prepared. Biodiesel blends were tested in a four stroke, single cylinder, diesel engine at a constant speed of 1500 rpm and variable loads. Experimental results of biodiesel blends compared with diesel fuel show that biodiesel provided insignificant increase in fuel consumption, specific fuel consumption, exhaust gas temperature, NO_x, CO_2 and oxygen concentrations about diesel fuel. Castor biodiesel blends resulted insignificant decrease in thermal efficiency, volumetric efficiency, air- fuel ratio, CO and HC emissions about diesel fuel. Castor biodiesel blends can be used up to 20% with diesel fuel without any engine modifications.*

Keywords: *Castor Biodiesel- Diesel Engine-Engine Performance- Emissions- B20*

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1. INTRODUCTION

Fuel blends of 5%, 20% and 35% for castor diesel -biodiesel blends were studied at different engine loads. Specific fuel consumption and the exhaust emissions concentrations of carbon dioxide, carbon monoxide and hydrocarbons were measured. The engine was kept with its original settings for diesel oil operation. The results showed increased fuel consumption with higher biodiesel concentration in the fuel. At lower loads, CO emission was increased by nearly 40% when fuel blend containing 35% of castor biodiesel was used compared with diesel fuel. At higher loads, using of biodiesel blends containing 20% of castor biodiesel increased HC emissions by 16% compared with diesel fuel. CO_2 concentration did not change significantly. The results demonstrate that optimization of fuel injection system is required for proper engine operation with biodiesel. Biodiesel is found to burn more efficiently than diesel. The emission of carbon monoxide, hydrocarbons and oxides of nitrogen were decreased by 58, 63 and 12 percent, respectively, in comparison with diesel fuel [1, 2].

Castor oil was converted to biodiesel and blended by 5%, 10%, 15% and 20% by volume with diesel fuel. This fuel was used on a single cylinder, four stroke diesel engine. The blended fuel gave lower emissions of CO but resulted in higher values of CO_2 and NO_x. Engine output power and thermal efficiency for blended biodiesel fuel were lower than diesel fuel because of lower heating value of blended fuel. Higher engine exhaust gas temperatures were obtained with blended fuel in comparison with that of diesel fuel [3].Engine performance and emission analysis were performed using diesel and castor biodiesel blends of 2, 5 and 10% in a diesel engine at different loads. Thermal efficiency and specific fuel consumptions with 10% Castor biodiesel were close to diesel fuel. CO and HC emissions were lower compared to diesel fuel. However NOx emission was higher for Castor biodiesel blends. Specific fuel consumption for Castor biodiesel blends increased due to lower calorific value and higher viscosity. Diesel- biodiesel blend of 10% yields the best result in terms of performance and emission [4]. Major problems associated with vegetable oils are higher viscosities and lower heating. Castor biodiesel and their blends with diesel fuel are used as alternative fuels in diesel engines. Thermal efficiency and volumetric efficiency are slightly decreased, specific fuel consumption and exhaust gas temperature increased compared to diesel fuel for all biodiesel blends. Engine output power of the engine was almost same for all the loads [5].

Castor biodiesel was used in a four stroke, single cylinder diesel engine and experiments were carried out at a rated speed of 1500 rpm at different engine loads. Vegetable oils cause problems during operation in diesel engines. These problems are attributed to high viscosity and low volatility. Transesterification is an effective method of reducing vegetable oil viscosity and eliminating operational and durability problems. Engine performance was investigated with different blends of biodiesel and was compared with diesel fuel. Exhaust gas temperature increased with increasing biodiesel concentration [6, 7].

Performance tests are compared with different blends of castor biodiesel with diesel fuel. Blend B80 has highest thermal efficiency and lowest specific fuel consumption. Blend B80 shows the overall optimum performance when used in diesel engine [8]. Castor biodiesel blends wereprepared by blending biodiesel with different volumes of diesel fuel. Castor biodiesel blends of 5, 10, 15, 20 and 30% were studied. Biodiesel fuel was evaluated in terms of its physical and chemical characteristics such as flash point, viscosity, density and calorific value. Results showed that biodiesel has similar properties with diesel fuel [9].

Performance and emissions of diesel engine using blends of diesel fuel with 5, 10,15, 20, 30% by volume of castor biodiesel and diesel fuel were investigated at various loads. The maximum increase in specific fuel consumption and NO_x emission when compared to diesel fuel are 10.7 and 15.6% for B30 at half load, respectively. Blends B15 and B20 at full load operation gave the best specific fuel consumptions of diesel engine. NOx increases 4% about diesel fuel for B30 at 25% load condition [10]. Exhaust emissions and performance parameters of diesel engine using castor biodiesel and its blend with diesel from 0% to 40% by volume are investigated. The acid based catalyzed transesterification process was used to produce castor biodiesel. Diesel engine performance test indicated that the specific fuel consumption of biodiesel blend increased with the increase of blend percentage. Reduction in exhaust emissions and improvement in performance parameters made the blends of caster biodiesel up to 20%are suitable alternative fuels for diesel engine. Blend B20 can be selected due to its better combustion with lower percentages of CO and HC emissions compared to diesel fuel [11]. Effects of castor biodiesel blends have been examined on diesel engine performance and emissions. Engine performance parameters such as specific fuel consumption, thermal efficiency and exhaust emissions were analyzed. Volumetric blending ratios of biodiesel with diesel fuel of 5, 10, 15, 20 and 30% were used. Lower blends of biodiesel provide acceptable engine performance. Meanwhile, exhaust emissions are much decreased. B15 blend of castor biodiesel was the optimum blend of biodiesel-diesel blends [12].

Specific consumption increase for biodiesel blends of castor compared to diesel fuel. Using biodiesel blends from castor oil of B10 and B20 show satisfactory results compared to diesel fuel [13].Experimental tests were conducted on a four stroke, single cylinder, direct injection diesel engine with diesel and various blends of castor biodiesel. Performance parameters and emission tests are compared for various blends of castor biodiesel with diesel fuel. At blend B60, specific fuel consumption is lowest with highest exhaust gas temperature as compared to other biodiesel blends. B60 shows optimum performance for use in diesel engines [14].

2. BIODIESEL PRODUCTION

Transesterification is most commonly used to reduce the viscosity of vegetable oilskin this process, triglyceride reacts with three molecules of alcohol such as methanol in the presence of a catalyst such as potassium hydroxide producing a mixture of fatty acids, alkyl ester and glycerol. The process of removal of all the glycerol and the fatty acids from the vegetable oil is in the presence of a catalyst. Biodiesel properties are similar to diesel fuel. Properties of castor biodiesel such as density, viscosity, heating value and flash point were measured in Egyptian Research Petroleum Institute and are indicated in Table 1 [9, 11, 15].

Table 1. Properties of castor biodiesel, diesel fuel and their blends.

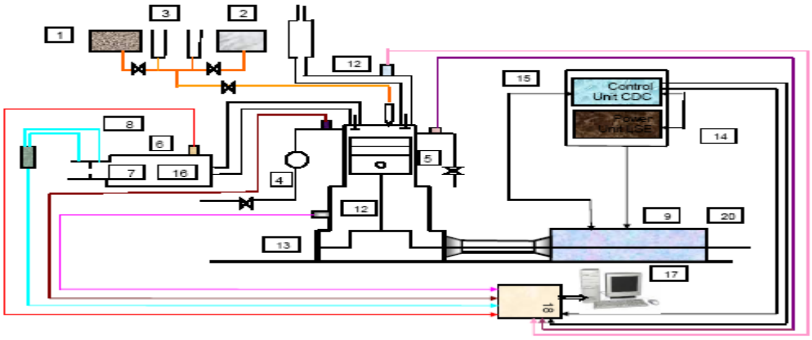
Properties	**Diesel**	**B20**	**B100**
Density (kg/m^3)	808	825	915
Kinematic Viscosity (mm^2/sec) at 40°C	3.05	4.9	12.5
Flash point	65	73	179
Heating value (MJ/kg)	42	41.25	38.6

3. EXPERIMENTAL SET UP AND INSTRUMENTATIONS

The present study was carried out to investigate the performance and emission characteristics of castor biodiesel blends with diesel fuel in diesel engine and compared to diesel fuel. The test engine is a Kirloskar make, single cylinder, four stroke, water cooled, direct injection, AV1 model diesel engine. Its specifications are given in Table2. The engine was connected to an eddy current dynamometer to measure the power output and speed. The engine was equipped to measure fuel consumption, engine speed and exhaust gas temperature. The engine receives air through an air box fitted with an orifice for measuring the air consumption. A pressure differential meter is used to measure the difference in pressure between the two sides of the orifice. Fuel consumption rate was determined using a glass burette and stop watch. The engine speed was measured using a digital tachometer. MRU DELTA 1600-V gas analyzer was used for measuring the exhaust gas emission concentrations of CO, HC, CO_2, O_2 and NO_x. A data acquisition card (National Instrument 6210) is used to acquire data to be fed to personal computer. The schematic diagram of experimental set up and test rig is shown in Fig.1. The engine was warmed up before taking all readings. When the engine reached its stable condition, the experiments were started and measurements recorded. The engine was then operated with blends of diesel and castor biodiesel (B5, B10, B15 and B20). For every operating condition, the engine speed was checked and maintained constant at 1500 rpm. The performance parameters and exhaust gas emissions investigated were fuel consumption, specific fuel consumption, thermal efficiency, exhaust gas temperature, volumetric efficiency, air- fuel ratio, carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), unburned hydrocarbons (HC) and oxygen (O_2) concentrations.

Table 2. Test Engine Specifications.

Engine parameters	**Specifications**
Type	Kirloskar
Number of cylinders	Single
Cycle	Four stroke
Cooling	Water
Cylinder diameter (mm)	85
Piston stroke (mm)	110
Compression ratio	17.5:1
Governing speed	1500 rpm
Rated power (HP)	6.5



1- Diesel Tank	2- Biodiesel Tank
3- Burette	4- Inlet water temperature sensor
5- Outlet water temperature sensor	6- Intake air temperature sensor
7- Orifice	8- pressure differential sensor
9- Dynomemeter	10- Power unit
11- Exhaust temperature sensor	12- Oil temperature sensor
13- Diesel engine	14- power unit
15- Control unit	16- Air tank
17- Personal computer	18- Data acquisition card

Fig.1. Schematic Diagram of a diesel Test Engine fueled with Diesel and Biodiesel Blends

4. RESULTS AND DISCUSSION

4.1 Fuel Consumption

The variation of fuel consumption with brake power is shown in Fig.2. It is observed that as the load increases, fuel consumption increases for all the fuels. This variation increases from lower loads to higher loads due to the increase in injected fuel with the increase in output power. As percentage of biodiesel increases, the fuel consumption tends to increase because of lower heating value of biodiesel. At full load, the maximum increase in fuel consumption for blend B20 in comparison with diesel fuel was about2.6 %. Above results are confirmed with these references [6, 15].

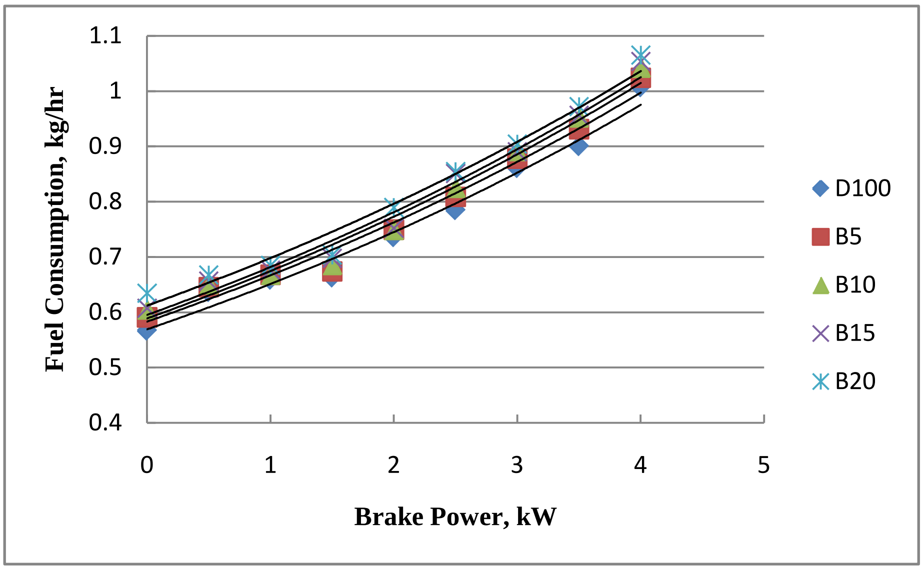


Fig.2. Variation of Fuel Consumption with Brake Power for Biodiesel Blends

4.2 Specific Fuel Consumption

Figure 3 shows the variation of specific fuel consumption with brake power. Specific fuel consumption increased with increase in load. Specific fuel consumption of diesel engine depended on the relationship among fuel density, viscosity and lower heating value. Increase of biodiesel percentage in biodiesel blends were needed to produce the same amount of power output due to its lower heating value compared with diesel fuel. Specific fuel consumption was higher in biodiesel compared to diesel fuel because of less ignition delay time and higher cetane number. At full load, the highest value of specific fuel consumption for blend B20 in comparison with diesel fuel was about 2.2 %. These results are confirmed by references [16, 17,18, 19].

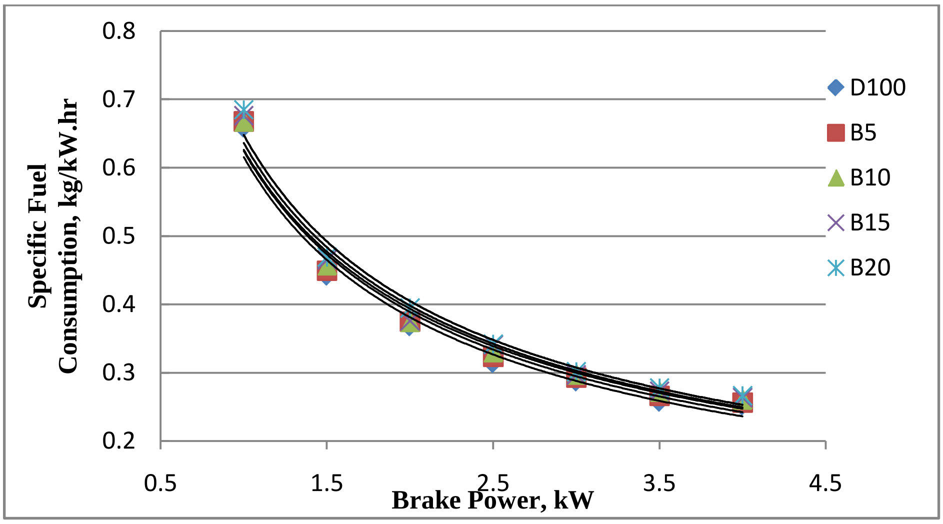


Fig.3. Variation of Specific Fuel Consumption with Brake Power for Biodiesel Blends

4.3 Thermal Efficiency

The variation of the thermal efficiency with load for diesel- biodiesel blends was shown in Fig.4.Thermal efficiency was having tendency to increase with increase in engine load due to reduction in heat loss and increase of output power. Thermal efficiencies for diesel-biodiesel blends from B5 to B20were very close to that of diesel fuel. At full load, the maximum decrease in thermal efficiency for B20 about diesel fuelwas4 %. We can observe that thermal efficiencies for diesel- biodiesel blends were lower than diesel fuel due to poor combustion, problems in atomization, low volatility, high viscosity and density. The above results are in agreement with the results reported by other researchers [16, 19].

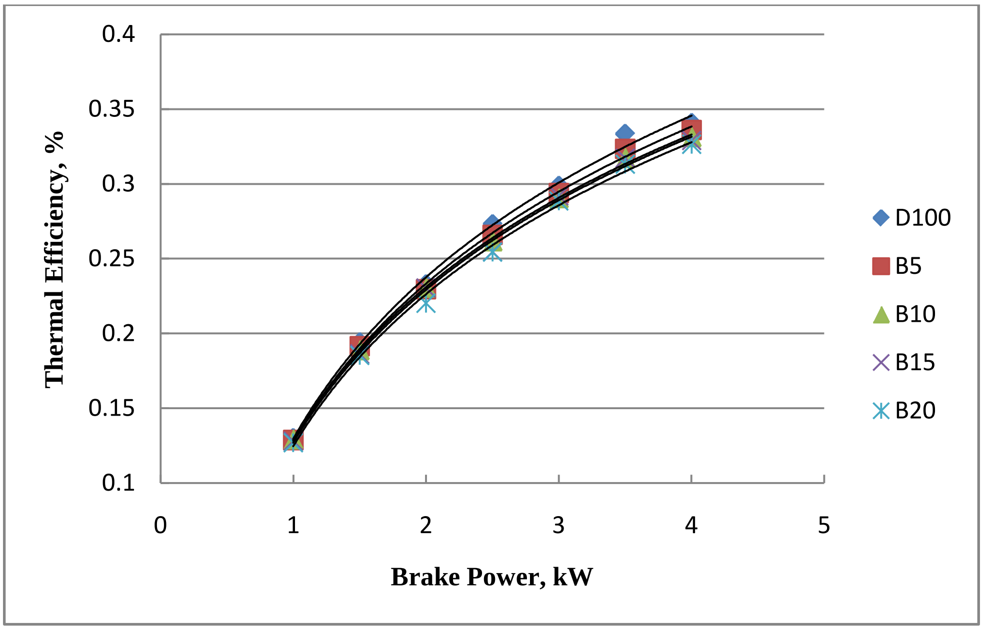


Fig.4. Variation of Thermal Efficiency with Brake Power for Biodiesel Blends

4.4 Exhaust Gas Temperature

The variation of exhaust gas temperature with brake power was shown in Fig.5. Exhaust gas temperature was an indication of conversion of heat into work, which happens inside the cylinder. Exhaust gas temperature increased with increase in engine load for all diesel-biodiesel blends. As the biodiesel concentration in biodiesel blends increased, the exhaust gas temperature also increased. The higher exhaust gas temperature was 427 °C at higher engine load for B20 but for diesel fuel was 417 °C. This increase in the exhaust gas temperature may be due to the higher viscosity of castor biodiesel and the oxygen content. As the load increased, fuel-air ratio increased and hence the operating temperature increased which results in higher exhaust temperature. For biodiesel blends, the combustion was delayed due to higher physical delay period. As the combustion was delayed, injected biodiesel fuel molecules may not get enough time to burn completely before top dead centre, hence some fuel- air mixtures tend to burn during the early part of expansion, consequently afterburning occurs and hence increase in the exhaust gas temperature. These results are confirmed with these references [16, 17, 19].

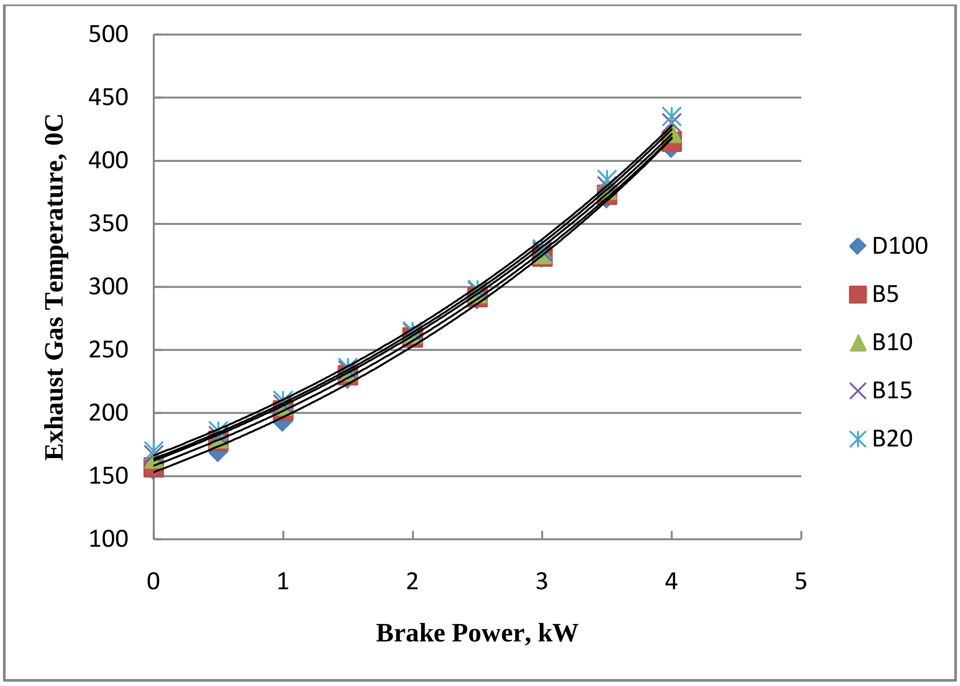


Fig.5. Variation of Exhaust Gas Temperature with BrakePower for Biodiesel Blends

4.5 Volumetric Efficiency

In Fig.6, variation of volumetric efficiency with engine load was shown. The volumetric efficiency increased with the increase in engine load. This was due to the less flow restrictions in the air filter and intake manifold. This led to increase in the amount of air enters the cylinder. It was seen that volumetric efficiencies were lower for diesel- biodiesel blends compared to diesel fuel. Volumetric efficiency decreased with the increase in biodiesel percentage in biodiesel blends because biodiesel fuel contains oxygen which decreases the amount of air needed for complete combustion. At full load, the maximum decrease in volumetric efficiency for B20 about diesel fuel is 8 %. The above results are in agreement with other researchers [16].

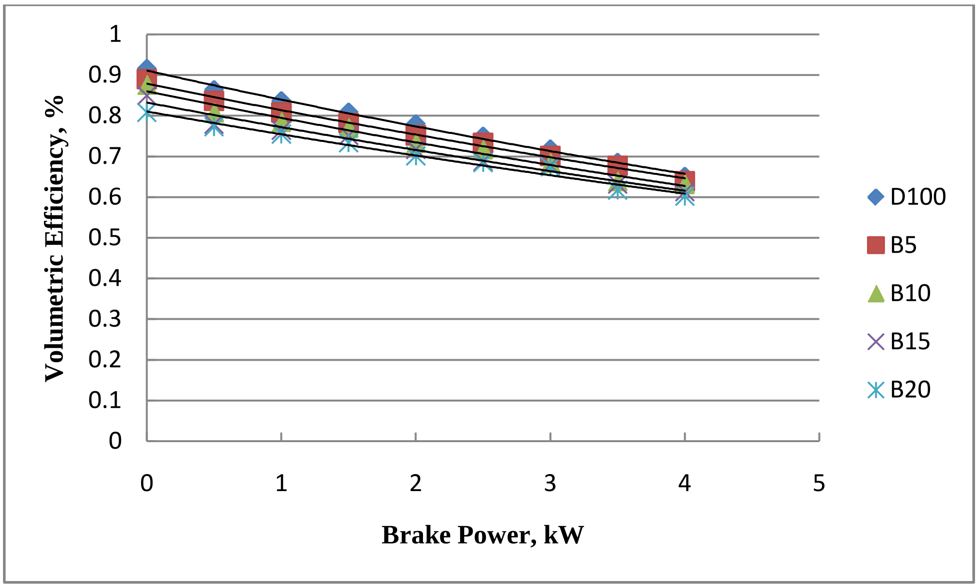


Fig.6. Variation of Volumetric Efficiency with BrakePower for Biodiesel Blends

4.6 Air- Fuel Ratio

The variation air-fuel ratio with load for diesel and biodiesel blends was shown in Fig.7. A richer mixture was needed at higher loads. Air- fuel ratio decreased with the increase in load due to the increase in mass of fuel. Fuel consumptions were higher for biodiesel blends compared to diesel fuel hence air-fuel ratio decreased. Air- fuel mixing process was affected by the problems appear in atomization of biodiesel due to its higher viscosity. At full load, the maximum decrease in air- fuel ratio for B20 about diesel fuel is 11 %. These results are confirmed with these references [16].

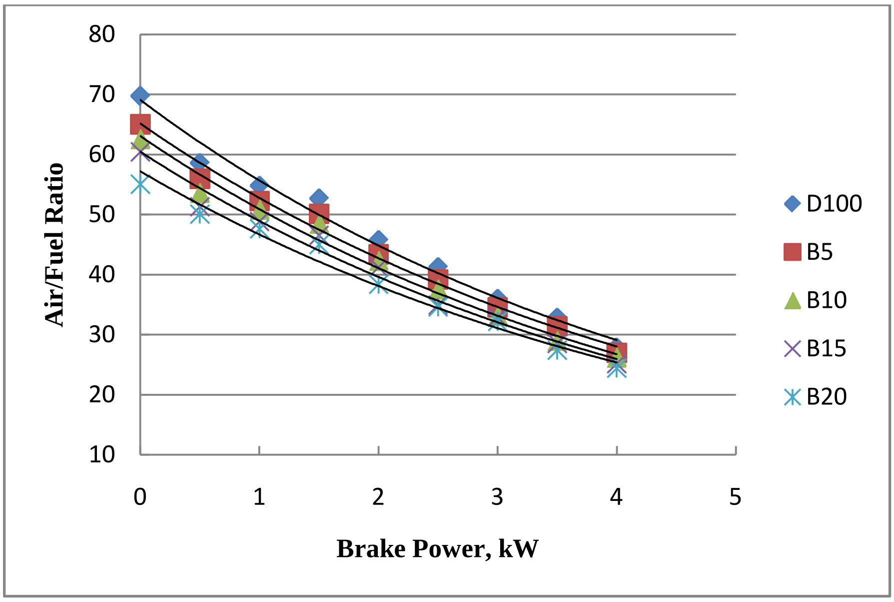


Fig.7. Variation of Air- Fuel Ratio with Brake Power for Biodiesel Blends

4.7 CO_2 Emission

Figure 8 shows the variation of CO_2 emissions with brake power for diesel and biodiesel blends. It is noted that carbon dioxide emission increased with increase in load because of higher fuel entry as the load increased. High values of CO_2 emissions for biodiesel blends compared to diesel fuel were due to the presence of more carbon atoms as well as higher oxygen content in biodiesel and this leads to complete combustion. B20 emit more carbon dioxide emission which indicated the more complete combustion of the fuel. The increase percentage of oxygen in diesel- biodiesel blends will promote increase in CO_2 emissions compared to diesel fuel. At full load, the values of CO_2 emissions for Diesel and B20 fuels were 5.3 and 6.7%, respectively. The above results are closer to the results reported by other researchers [16, 17, 18, 19].

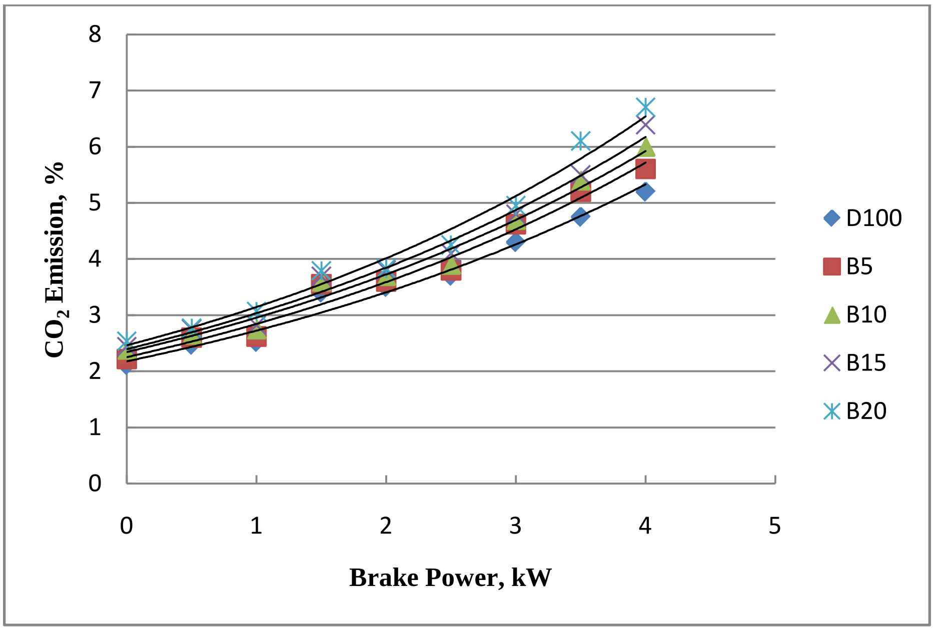


Fig.8. Variation of CO_2 Emission with Brake Power for Biodiesel Blends

4.8 NO_x Emission

Figure9 shows the variation of nitrogen oxides emissions with brake power. It is observed that NOx emission increased with increase in the load due to higher combustion temperature. At full load, B20 and diesel fuels gave 670 and 650 ppm emissions, respectively. It is observed that oxygenated fuel blends can result in increase in NOx emission. It was also observed that complete combustion causes higher combustion temperature which resulted in higher NOx formation. NO_x emission was a function of oxygen concentration, time and combustion temperature inside the combustion chamber.

Oxygen concentration in biodiesel blends caused the formation of NO_x. The increase of NO_x emission was due to the higher cetane number of biodiesel which will reduce the ignition delay. Higher NO_x emissions levels for biodiesel blends about diesel fuel due to higher heat release rate at the premix or slow combustion phase. The above results are confirmed with the results reported by other researchers [17, 18, 19].

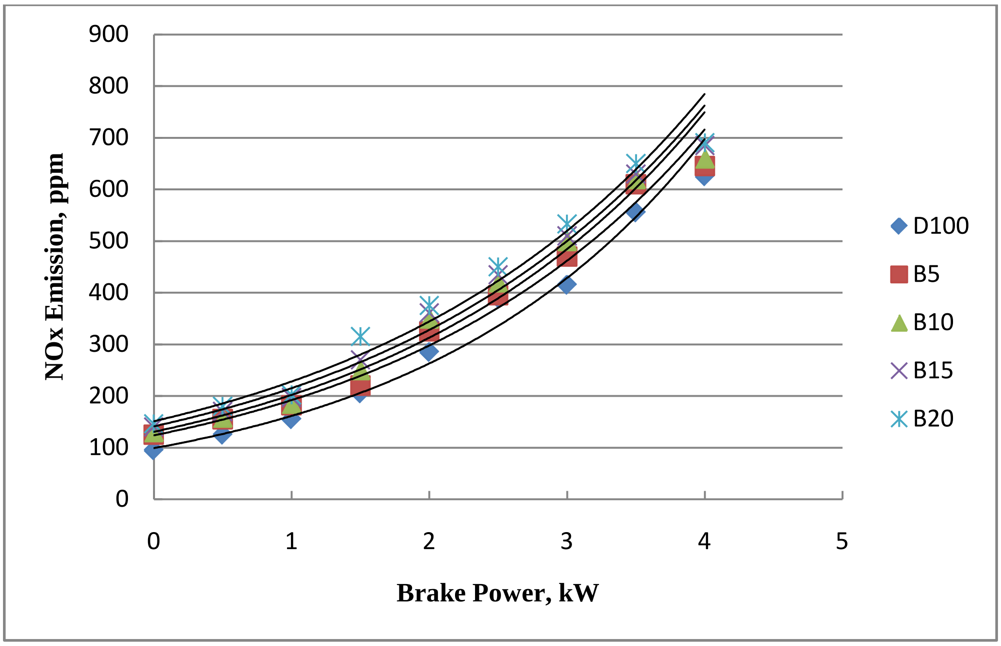


Fig.9. Variation of NO_x Emission with Brake Power for Biodiesel Blends

4.9 HC Emission

Figure9 shows the variation of hydrocarbon emissions with brake power. It is observed that hydrocarbon emissions of various fuels increased with the increase in load. At higher loads, when more fuel was injected into the engine cylinder, the availability of free oxygen was relatively less for the reaction, soHC emissions increase with the increase in load. Oxygen content in its molecular structure may be responsible for complete combustion and thus reducing the HC emissions in biodiesel blends. The decrease of HC emission is due to the higher cetane number of biodiesel which will reduce the ignition delay. Higher temperature of burned gases prevented condensation of the heaviest hydrocarbons in the sampling line, suggesting proper conditions for HC emission. At full load, the maximum decrease in HC emission for B20about diesel fuel is about 25 %.The above results are similar to the results reported by other researchers [16, 17, 18, 19].

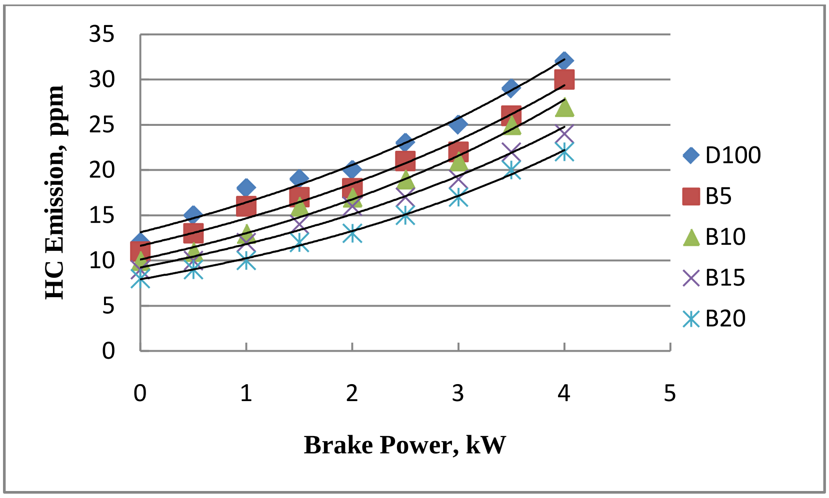


Fig.9. Variation of HC Emission with Brake Power for Biodiesel Blends

4.10 CO Emission

The variation of carbon monoxide with brake power is shown in Fig.10. At lower loads, CO emissions are found to be decreasing with increase in load for all fuels. At higher loads, CO emissions are found to be increasing with increase in load for all fuels. This was due to that air- fuel mixing ratio was affected by difficulty in atomization. At full load, CO emissions for diesel- biodiesel blends decreased when compared with diesel fuel. At full load, CO emission for B20blendwas about 18% lower than that of diesel fuel. It was also observed that CO emissions decreased for all diesel- biodiesel blends about diesel fuel due to the enrichment of oxygen produced from addition of biodiesel. The increase percentage of oxygen in diesel- biodiesel blends will promote further oxidation of CO and more complete combustion. This is a proof of CO_2 increase in biodiesel blends. The above results are agreed with the results reported by other researchers [17, 18, 19].

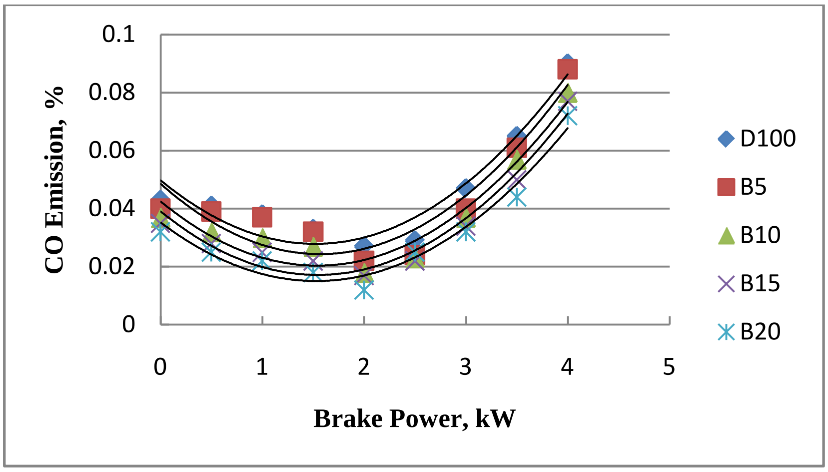


Fig.10. Variation of CO Emission with BrakePower for Biodiesel Blends

4.11 Oxygen Concentration

The variation of oxygen concentration with brake power was shown in Fig.11. The observed decrease in oxygen content in the exhaust with increase in load may be due to richer mixture being burnt in the engine cylinder. The higher cylinder temperature led to produce a larger portion of oxygen which reacts with nitrogen and carbon to form CO, NO_x and CO_2 at higher loads. Hence less oxygen was released to the atmosphere. It can also be observed that the oxygen emissions increased with increase in biodiesel percentage in diesel-biodiesel blends. Further, the increase in oxygen emission with increase in blend proportion may be due to the inherent oxygen present in biodiesel. It can be noted that the percentage of oxygen in the exhaust was maximum for biodiesel blends and it decreased for other biodiesel blends in the order B20, B15, B10, B5 and diesel fuel. The maximum increase of oxygen concentration for B20 in comparison with diesel fuel was about 10%.

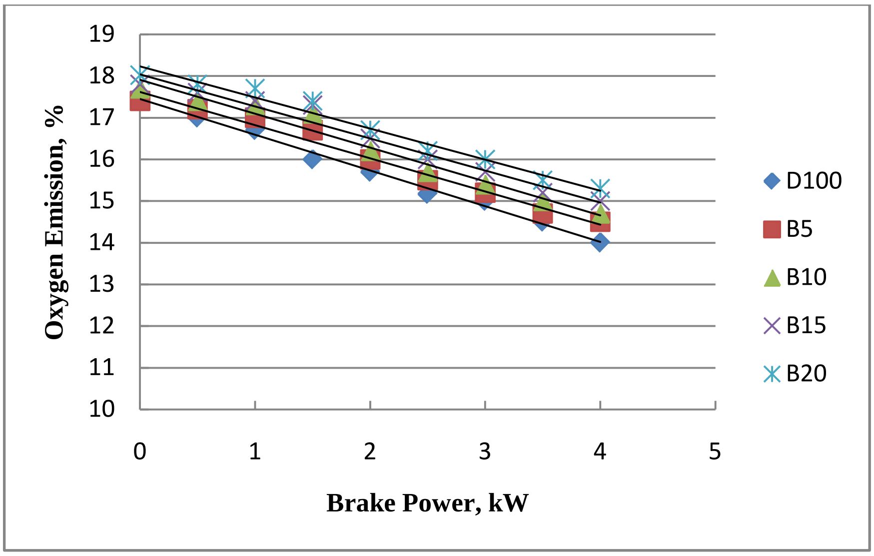


Fig.11. Variation of Oxygen Concentration with Brake Power for Biodiesel Blends

4. CONCLUSIONS

Castor biodiesel can be used as alternative fuel for diesel engines. Castor biodiesel blends of 5, 10, 15 and 20% were tested in a four stroke, single cylinder, diesel engine at a constant speed of 1500 rpm and variable loads. Experimental results of biodiesel blends compared with diesel fuel show that**:**

- Diesel- biodiesel blends show increase in fuel consumption due to the lower heating value of the biodiesel. B20 showed an increase of 2.6% in fuel consumption compared to diesel fuel.

- Biodiesel blend B20 showed insignificant decrease in engine thermal efficiency about 4% in comparison with diesel fuel, volumetric efficiency and air- fuel ratio for B20 had reductions of 8 and 11%, respectively compared to diesel fuel.
- The exhaust gas temperature increased insignificantly with the operation of biodiesel blends about diesel fuel. Biodiesel blend B20 and diesel fuels recorded about 427 and 417°C of exhaust gas temperatures.
- At full load, the values of CO_2 emissions for diesel and B20 fuels were 5.3 and 6.7%, NO_x emissions values were 670 and 650 ppm, respectively.
- At full load, the maximum decrease in HC emission for B20 about diesel fuel was about 25 %.
- The maximum increase of oxygen concentration for B20 in comparison with diesel fuel was about 10%.
- Using neat castor biodiesel in conventional diesel engine is not recommended.
- Castor biodiesel blends can be used up to 20% with diesel fuel without any engine modifications. Performance and emissions of a diesel engine using biodiesel blends up to 20% with diesel fuel were closer to diesel fuel.

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