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Performance and Emission Characteristics of a Direct Injection Diesel Engine Using Biodiesel Produced From Waste Cooking Oil

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Abstract: The increasing vehicular population causing consumption of petroleum fuels at a faster rate and causes increase in the danger of petroleum fuels depletion and the remarkable increase in high crude oil prices. The increasing consumption of petroleum products has been a matter of great concern for the country for the financial growth as well as environmental pollution abatement. The situation offers us a challenge as well as opportunity to look for substitutes of fossil fuels by utilizing waste cooking oil for both economic and environmental benefits to the country. In the present experimental study, biodiesel produced from waste cooking oil (WCO) has been selected. It has been tested on single cylinder, four stroke, water cooled, direct injection diesel engine for the performance and emissions using fuel samples containing different blends of WCO biodiesel (0%, 10%, 20%, 30%, 40%, 50%, 75% and 100%) and conventional diesel. Engine performance and exhaust emission characteristics have been measured and analyzed. The highest brake thermal efficiency has been found to be 27.67% and lowest brake specific fuel consumption of 0.305 kg/kw hr has been found with B20 blend. It is also found that emissions of carbon monoxide and un-burnt hydrocarbon reduce as load increases for all the blends of biodiesel tested on the engine up to 80% of maximum engine load (i.e. 88.98 N or 20 lbs.) beyond that, these emissions further increase. It has been found that nitrogen oxides emission increases as the engine load increases on the engine up to 80% of maximum engine load beyond that it further decreases. This may be due to the presence of oxygen available in bio-fuel. Biodiesel prepared from waste cooking oil also reduces liquid waste. Hence biodiesel from waste cooking oil can be used as potential alternative fuel in future.

Keywords: Alternative fuels, Biodiesel, Blends, Diesel engine, Emissions, Performance, Waste cooking oil.

1. Introduction

Biodiesel is an alternative for petroleum based fuels derived from vegetable oils, animal fats and used waste cooking oil (WCOs). Due to petroleum crisis in India, we are in search of proper alternative replacement of petroleum fuel. Use of WCO in diesel engines is an attempt towards it. Waste cooking oils are oils and fats that have been used for cooking or frying in the hotels, canteens, food processing industry, fast food centre and at a consumer level in household work. It can be originated from vegetable oils. It can be further collected and recycled for other uses. The quality of WCOs as a raw material is very critical for its transformation to bio-diesel and further its utilization in engine as fuel due to its ill effect in all stages. There is an urgent need to find alternative fuels due to scarcity of fossil fuels. Many investigators have attempted to replace diesel with a substitute such as bio-diesels produced from WCOs.

2. Literature Review

Heywood [1] has reviewed the future options for fuels for automotive engines. It has been suggested in this review that the impacts of fuel on engines depend on different phases and time frame. The period from 1980-1990 is completely dominated by fuels from natural petroleum and uses of alternative fuels will only be in token quantities. From 1990-2010, the dominance of fuels produced from natural petroleum and increase of contribution of alternative fuels continue. From 2010-2030, amounts of fuels from natural petroleum and alternative fuels become comparable. After 2030, alternative fuel will dominate.

Agrawal [2] has discussed the applications of biodiesel as fuel for internal combustion engine and has reviewed the production, characterization and current status of vegetable oil and biodiesel as well as the experimental research work carried out in various countries. Onion and Bondo [3] have surveyed worldwide activities related to oxygenate fuels for diesel engines. Ilkilic et al [4] have experimented with biodiesel produced from safflower in diesel engines and have concluded that the use of safflower oil biodiesel has beneficial effects both in terms of emission reductions and alternative petroleum diesel fuel. Lin et al. [5] have carried out experimental investigation of the performance and emission of a heavy duty diesel engine fueled with waste cooking oil biodiesel (WCOB), ultra low sulfur diesel

(ULSD) blends. It is concluded from the experimental results that ULSD /WCOB blends give lower PM, HC and CO emissions.

Balat and Balat [6] have reviewed critically about biodiesel as a vehicular fuel. It is concluded that the viscosity of vegetable oil can be reduced by different ways such as dilution with hydrocarbons, emulsification, pyrolysis and transesterification. The major economic factor to consider for input costs of biodiesel production is the feedstock, which is about 80% of the total operating cost. Other expenditure includes labour charges and cost of catalyst etc. Utlu et al. [7] have experimentally investigated the performance and emissions of turbocharged direct injection diesel engine using biodiesel (waste frying oil methyl ester WFOME) as fuel. It has been found that specific fuel consumption of WFOME is increased to 14.34%, emission values are decreased to 17.14% and 1.45% for Carbon Monoxide (CO) and Nitrogen oxides (NO_x) respectively. Smoke intensity is increased in average 22.46% for the utilization of WFOME compared to diesel fuel.

Wu et al. [8] have experimentally investigated the performance and emissions on a Cummins ISBe6 Euro III diesel engine using five methyl esters with different sources such as cottonseed methyl ester (CME), soybean methyl ester (SME), rapeseed methyl ester (RME), palm oil methyl ester (PME) and waste cooking oil methyl ester (WME). It has been found that the use of different methyl esters results in large PM reductions ranging from 53% to 69%, which includes the dry soot (DS) reduction ranging from 79% to 83%. Different biodiesels increase NOx emission by 10% to 23% on average. All biodiesels produce less HC and CO than diesel fuel. Haldar et al. [9] have experimentally investigated the performance and emissions characteristics of non-edible straight vegetable oils of Putranjiva, Jatropha and Karanja after Degumming (which is a economical chemical process that is done by concentrated phosphoric acid) to find out the most suitable alternative diesel. Degumming process has been applied to the above-mentioned non-edible oils to remove the impurities for the improvement of viscosity, cetane number and better combustion in the diesel engine. Blends of diesel and degummed non-edible vegetable oils (10%, 20%, 30% and 40%) have been used in a Ricardo variable compression engine, the best results of performance and emissions have been found using 20% non-edible oil of Jatropha at high loads and 45^{o} crank angle before Top dead centre (TDC) injection timing.

Enweremadu et al. [10] have reviewed and analyzed the engine performance, combustion and emissions characteristics of used cooking oil (UCO) biodiesel on diesel engine and have found that biodiesel derived from used cooking oil is a cheap green liquid fuel available because of the primary ingredient being a post-consumer waste product UCO biodiesel. When used in diesel engines, it has shown an impressive engine performance, combustion and emission characteristics same as biodiesel produced from fresh vegetable oil which has been widely acknowledged as an alternative to petroleum diesel. However, the products formed during frying, such as free fatty acid and some polymerized triglycerides, can affect the transesterification reaction and the biodiesel properties. Singh et al. [11] have carried out the performance analysis of diesel engine using the biodiesel which was produced from used mustard oil and diesel blends. It has been found that dual fuel with a blend of 8% biodiesel yielded good efficiency in the diesel engines without the need for making any modifications in the engine.

Ghobadian et al. [12] have studied with artificial neural network (ANN) modeling of a diesel engine using waste cooking biodiesel fuel to predict the brake power, torque, specific fuel consumption and exhaust emissions of the engine. In order to acquire data for training and testing the proposed ANN, a two cylinders, four-stroke diesel engine has been fuelled with waste vegetable cooking biodiesel and diesel fuel blends and operated at different engine speeds. The properties of biodiesel produced from waste vegetable oil has been measured based on ASTM standards. The experimental results revealed that blends of waste vegetable oil methyl ester with diesel fuel provide better engine performance and improved emission characteristics. It has been observed that the ANN model can predict the engine performance and exhaust emissions quite well with correlation coefficient (R) of 0.9487, 0.999, 0.929 and 0.999 for the engine torque, Specific fuel combustion (SFC), CO and Hydrocarbon (HC) emissions, respectively.

3. Experimental Method

3.1 Blends Preparation:

In order to evaluate biodiesel as Compression Ignition Engine Fuel, various blends of waste cooking biodiesel (WB) and conventional diesel have been prepared by mixing different amount of biodiesel and diesel. The properties of blends have been measured (Table 1). The blends were designated by “WB”. For example, WB20 indicates that it contains 20% of waste cooking biodiesel and remaining 80% is diesel. For finding the optimum ratio, the blends WB10, WB20, WB30, WB40, WB50, WB75 and WB100 were prepared. Experiments have been conducted with WB0 (Pure diesel) and WB100 (Pure biodiesel) also.

Table 1: Properties of Diesel & WCO Bio-diesel

Blend	Density (Kg/m^3)	Kinematic Viscosity (mm^2/sec) at 40 °C	Flash Point (°C)	Calorific value (MJ/kg)
WB0	815	2.75	50	43.35
WB100	876	4.2	160	39.769

3.2 Experimental set-up:

The study has been carried out in the laboratory on a diesel engine. The schematic diagram of test engine set-up is shown in figure 1.

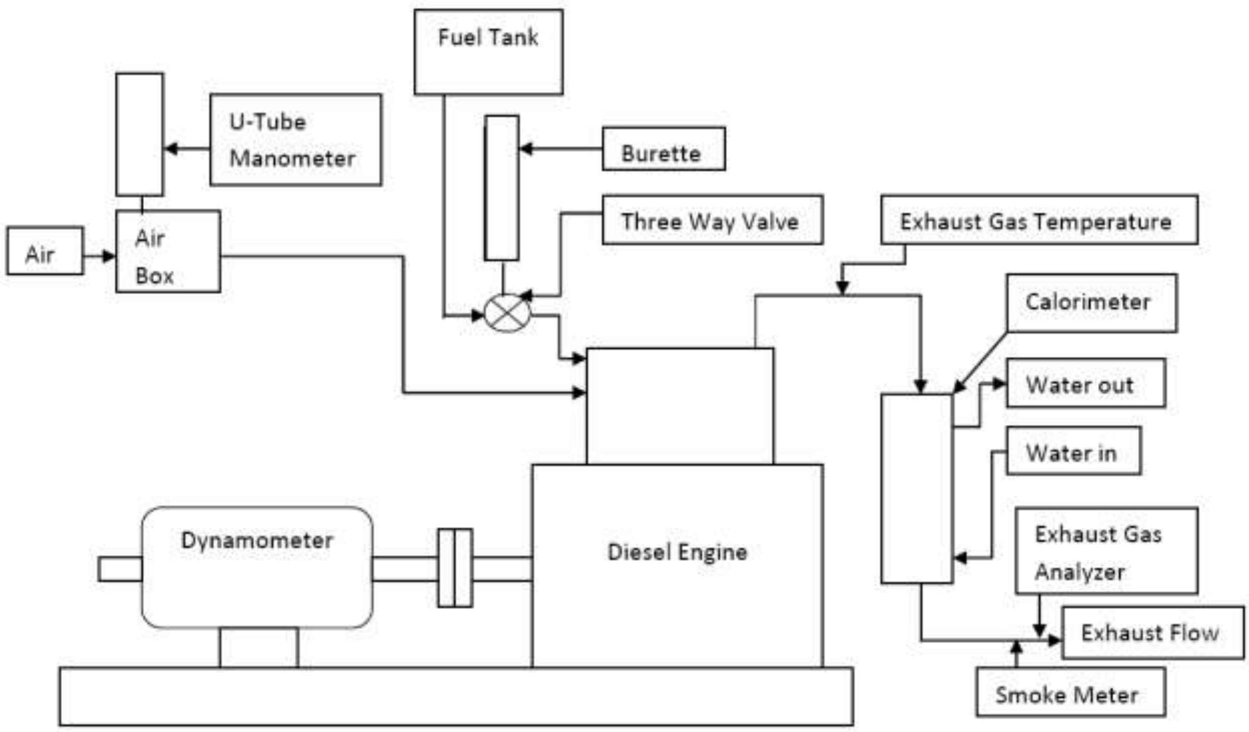

Figure 1: Schematic Diagram of Test Engine Set-up

The specifications of test engine are given in table 2.

Table 2: Specification of Diesel engine

S No	Parameter	Details
1	Make	Kirloskar
2	Model	1M 11x11
3	Engine type	Single cylinder, vertical, constant speed diesel engine
4	Bore and stroke	110mm x110mm
5	Swept Volume	1045.8 cc
6	Compression Ratio	16.5:1
7	Rated power	7.46 KW (10 BHP) at 1500 rpm
8	Engine cooling	Water cooled

4. Experimental Procedure

The experiments have been conducted on the diesel engine. The engine has been then tested from no load to full load at the interval of 10% of rated load. For varying the load, hydraulic dynamometer has been used. For which the given arm length of 0.535 m, 88.97 N is full load at rated power of 7.46 KW and rated speed of 1500 rpm. The engine at the above mentioned loads has been tested with pure diesel, 10%, 20%, 30%, 40%, 50%, 75% blends of WCO biodiesel with diesel and 100% WCO biodiesel. Measurement of exhaust gas emissions and smoke opacity has been done using Indus five gas analyzer-model PEA205 and Netel's smoke meter-model NPM-SM-111B respectively.

5. Results & Discussion

Figure 2 shows the variation of BTE (brake thermal efficiency) and engine load for diesel and diesel- WCO biodiesel blends. It is observed that as the load increases, BTE increases for all the fuel samples tested including diesel up to 80 % of rated engine load. This may be due to increase in power developed with increase in load associated with less increase in energy input. The maximum value of efficiency has been found for WB20 fuel sample as 27.67% which is 2.52 % higher than diesel for 80% of rated engine load. After mixing biodiesel in diesel oil, the brake thermal efficiency of the engine improves as biodiesel provides better lubricity to the fuel resulting in lower loss of power in fuel pump. The oxygen molecules available in esters enhance the combustion quality. As the WCO biodiesel content increases in the fuel sample, BTE increases up to WB20 blend, beyond this blend, it further reduces for all the loads. It may be due to larger concentration of biodiesel (above WB20), in the blend which tends to reduce the net calorific value of the mixture leading to increase in fuel consumption as compared to WB0-WB20 fuel samples.

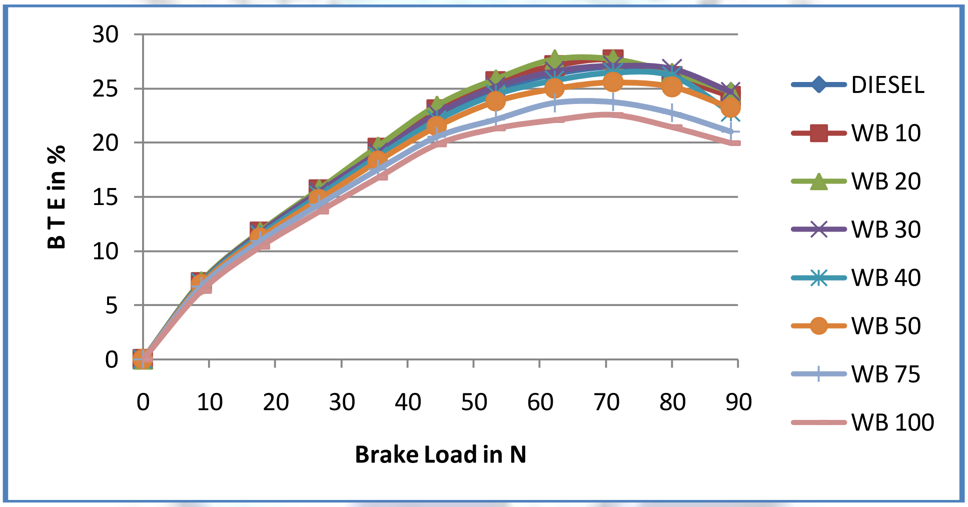

Figure 2: Variation of brake thermal efficiency with engine load for the different blends of WCO biodiesel and conventional diesel

The fuel samples WB10, WB20 and WB30 perform better than diesel. WB100 blend is not observed to be better for any load as compared to diesel, this may be due to high viscosity and improper mixing of fuel.

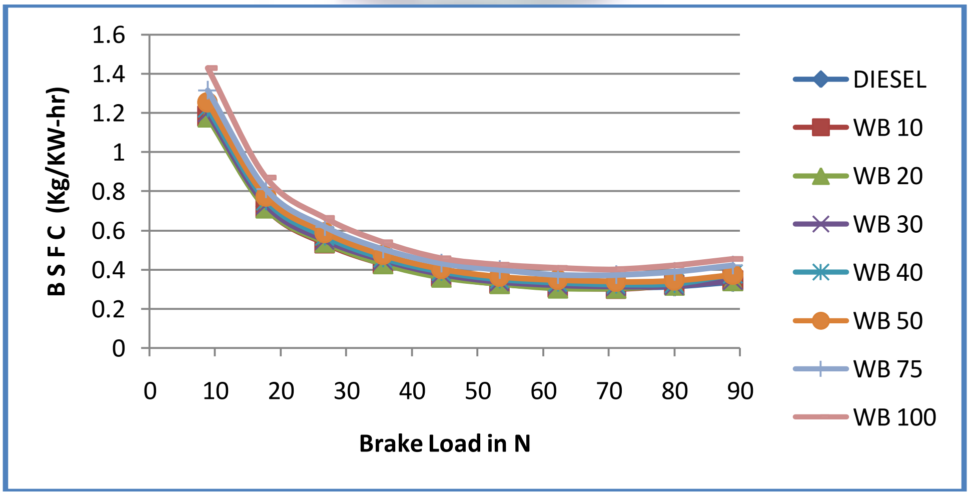

Figure 3: Variation of brake specific fuel consumption with engine load for the different blends of WCO biodiesel and conventional diesel

The variation of BSFC with brake load for different blends of fuels is presented in figure 3. It is observed that BSFC decreases with increase in the engine load for all the blends of fuel tested on the engine till 80% of the rated load, beyond that it further increases. This may be due to the fact that as engine load increases, the brake power increases for better utilization of injected fuel. The increase in brake power is more as compared to the increase in fuel consumption resulting in lower BSFC. Using lower percentage of biodiesel in diesel blends (up to WB20), the BSFC of the engine is lower than that of diesel for all loads. In case of WB30-WB100 blends, the BSFC is found to be higher than that of diesel. It is observed that a larger amount of biodiesel is supplied to the engine compared to that of conventional diesel.
Figure 4 shows the variation of exhaust gas temperature (EGT) with brake load for different blends of bio-diesel and conventional diesel in the test engine. It is observed that EGT of WCO biodiesel is found to be lower than the conventional diesel. The EGT of diesel at rated load is 515^{o}C where as for WCO biodiesel, it is 492^{o}C. It is also observed that EGT increases with the increases in engine load for the fuel samples tested. Although, EGT of WB20 has been found higher than diesel. The maximun EGT has been found as 525^{o}C for WB20 at 100 % rated load. As the biodiesel content increases in fuel sample, EGT reduces. It may be due to the reducing trend of calorific value of fuel samples. The high EGT enhances the oxidation of un-burnt hydrocarbon in tail pipe.

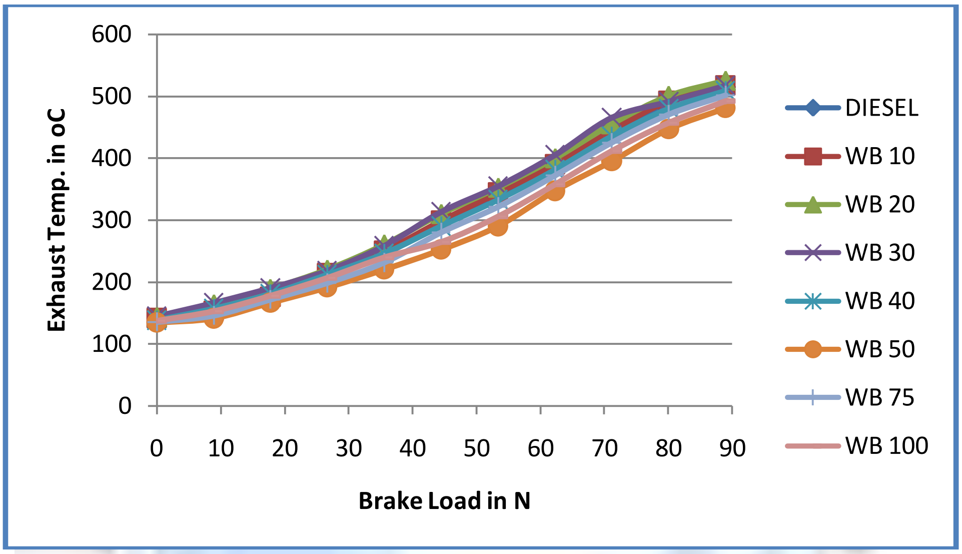

Figure 4: Variation of exhaust gas temperature with engine load for the different blends of WCO biodiesel and conventional diesel

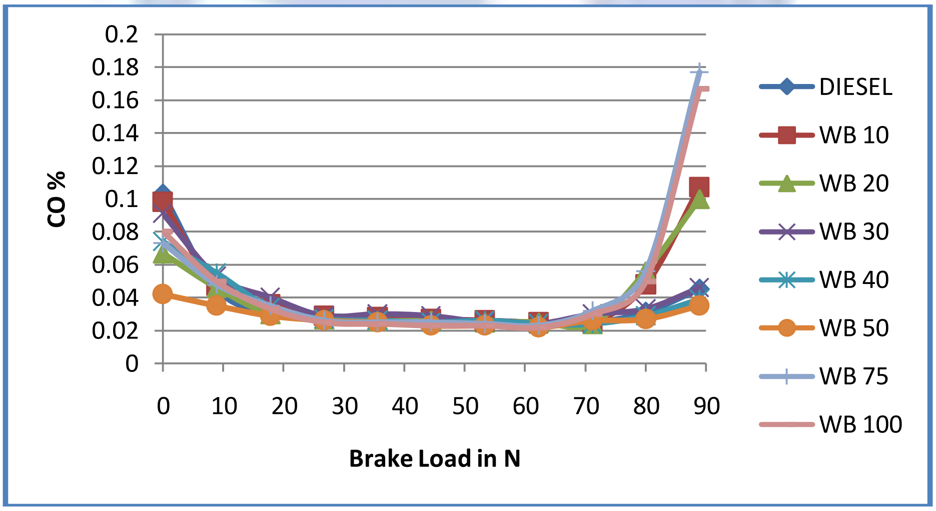

Figure 5: Variation of carbon monoxide with engine load for the different blends of WCO biodiesel and conventional diesel

Figure 5 shows the variation of carbon monoxide (CO) in exhaust gas with brake load for different blends of bio-diesel and conventional diesel in the test engine. It has been found that CO reduces in engine exhaust as load increases up to 80% of rated load for WB0-WB20 blends but for the other blends, it decreases up to 70% of rated load and after that it further increases. It may be due to improper combustion in higher range of load.

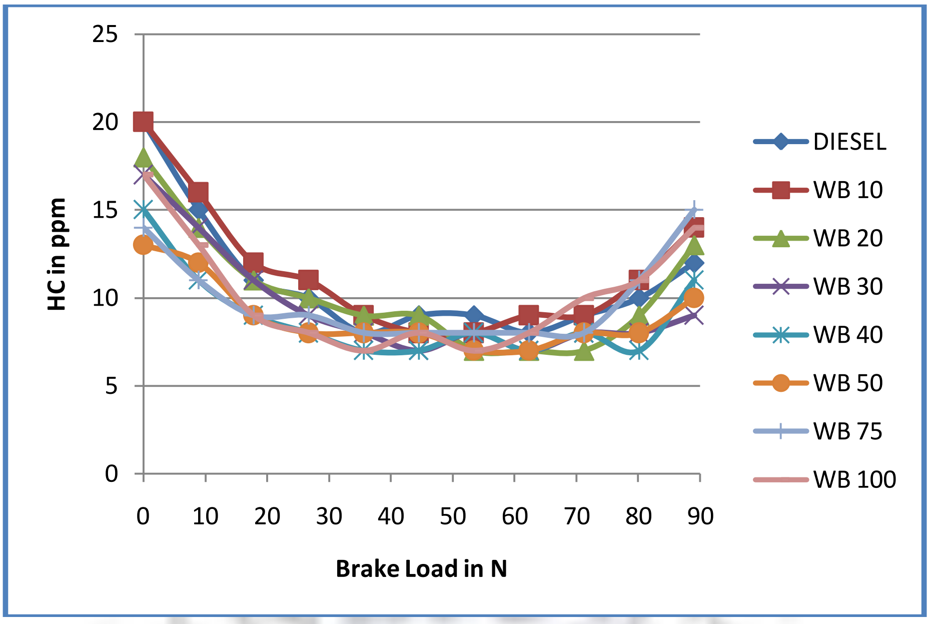

Figure 6: Variation of un-burnt hydrocarbon with brake load for the different blends of WCO biodiesel and conventional diesel

Figure 6 shows the variation of un-burnt hydrocarbon in exhaust gas with brake load for different blends of bio-diesel and conventional diesel in the test engine. It has been observed that for all the samples of fuel tested on engine, un-burnt hydrocarbon reduces with increase of load up to 60-70% of engine load, after that it further increases. It may be due to poor combustion at higher load.

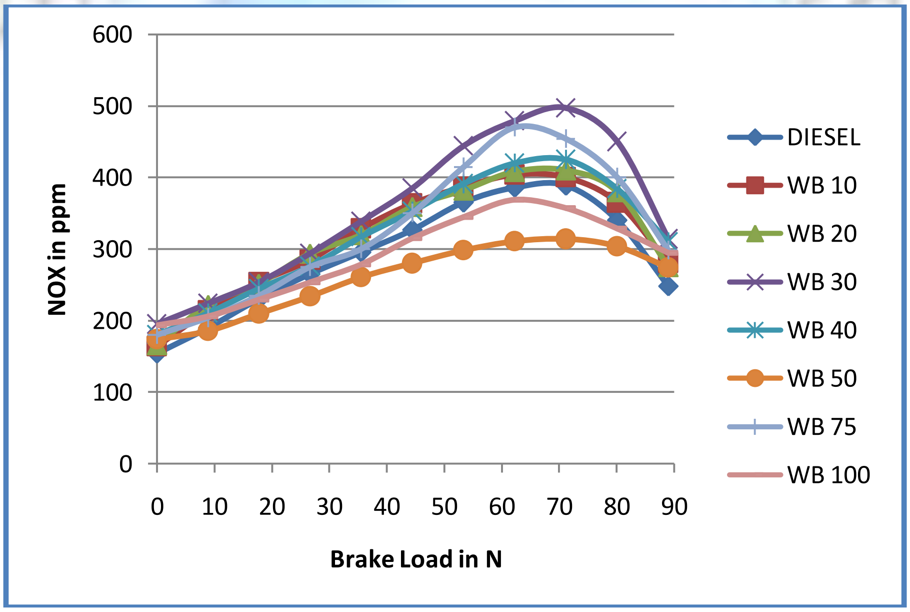

Figure 7: Variation of nitrogen oxides with engine load for the different blends of WCO biodiesel and conventional diesel

Figure 7 shows the variation of nitrogen oxides (NO_x) in exhaust gas with brake load for different blends of bio-diesel and conventional diesel in the test engine. It has been observed that as load increases, NO_x increases till 80% of rated load, beyond that it further reduces for most of the samples of fuel tested. It may be due to improper combustion at higher load. The maximum concentration of NO_x has been found 497ppm for WB30 blend at 80% of rated load. The NO_x emission increases as biodiesel content in the fuel increases for the samples WB0-WB30, beyond that it further reduces. It may be due to proper combustion of fuel samples having low percentage of biodiesel content.

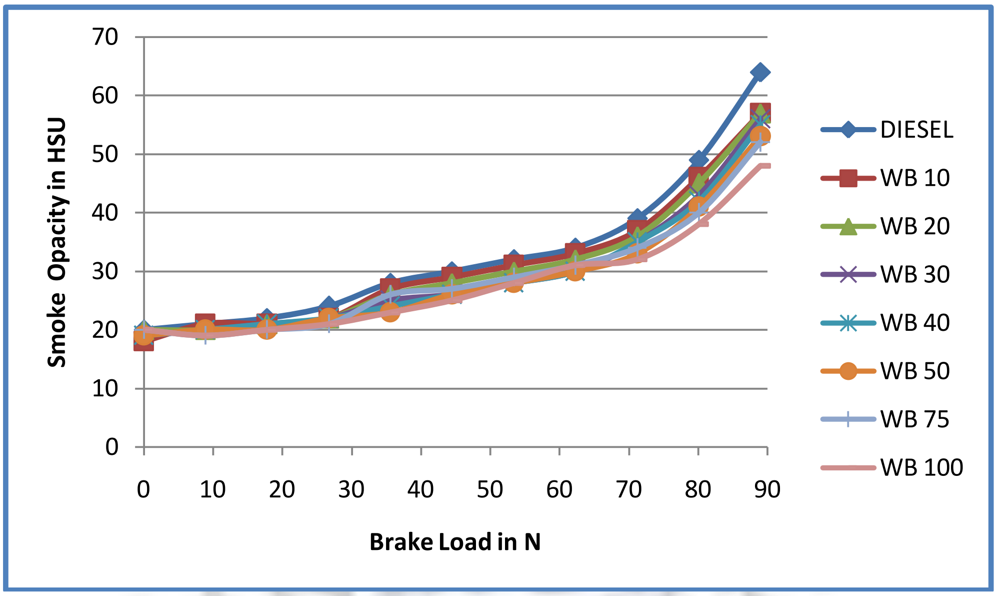

Figure 8: Variation of smoke percentage with engine load for the different blends of WCO biodiesel and conventional diesel

Figure 8 shows the variation of smoke percentage in exhaust gas with brake load for different blends of bio-diesel and conventional diesel in the test engine. It clearly shows that the smoke percentage increases as load increases for all the blends tested. It may be due to supply of more quantity of fuel and improper combustion of fuel at higher loads. The maximum smoke percentage in exhaust has been found to be 64% at full load for diesel fuel which is 10.94% higher than WB20 fuel sample. It may be due to the availability of oxygen molecules in biodiesel blended fuel which enhances combustion quality.

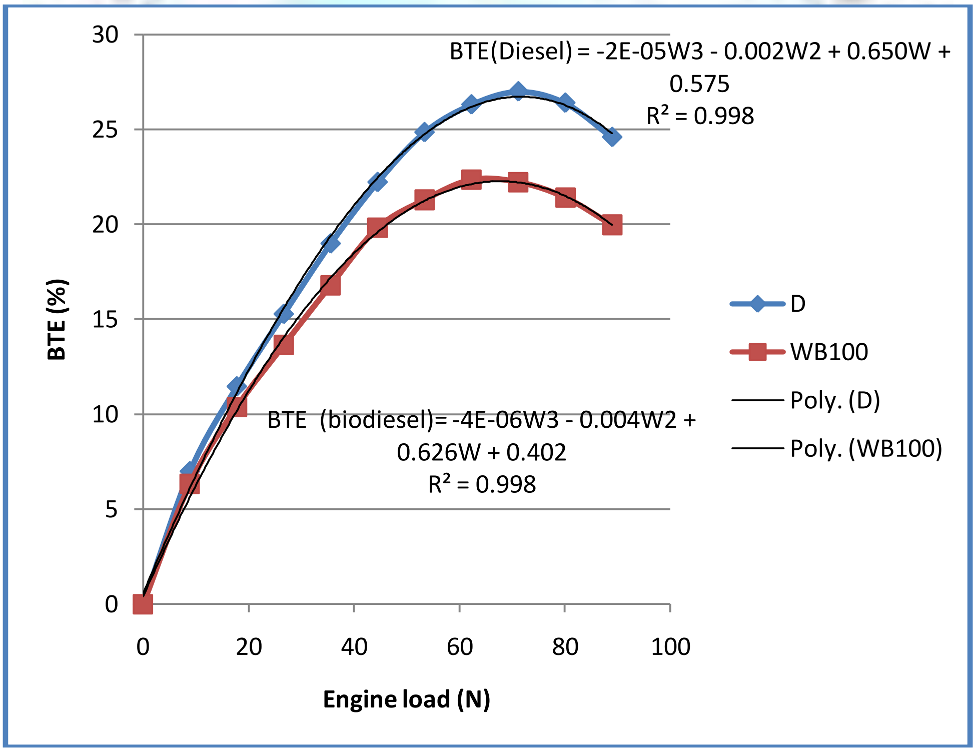

Figure 9: Trend of brake thermal efficiency-load curve for diesel and WCO biodiesel

The trend of brake thermal efficiency verses engine load curve for pure conventional diesel and pure WCO biodiesel is shown in figure 9. It clearly depicts that both the fuels are following almost similar pattern. It shows that the waste cooking oil biodiesel behaves nearly as diesel. Therefore WCO biodiesel can be adopted as alternative fuel for future requirement.

6. Conclusion

Alternate fuels for diesel engines have become increasingly important due to decreasing petroleum reserves and the environmental consequences of exhaust gases from petro-fuel. Thus WCO bio-diesel can be adopted as an alternative fuel for the existing diesel without any major modification in the system hardware. The trend of performance and emission characteristics of WCO bio-diesel demonstrated are in close agreement with the diesel oil making it a potential candidate for the application in diesel engine for partial replacement of diesel fuel. It is observed that blend of 10-20% WCO bio-diesel with conventional diesel is found to be the best proportion as far as brake thermal efficiency and brake specific fuel consumption is concerned. The emission characteristics of engine shows that the use of WCO bio-diesel is reducing harmful emissions from the exhaust such as un-burnt hydrocarbon, carbon monoxide and smoke. Nitrogen oxide emission is found to be little bit higher with some blends of bio-diesel for some range of brake power.

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