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Analysis of Performance and Emission Parameters of A DI Diesel Engine Powered by Waste Oil Blends.

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ABSTRACT

Large quantities of oil that are used for cooking purposes (WCO), insulation in electrical transformers and other purposes (WTO) are being misused and wasted after they reach a stage of incompetence. This oil can be renewed by converting it into biodiesels, which in turn, could be used to power diesel engines. In the following research, Waste Transformer Oil (WTO) was blended with Waste Cooking Oil methyl esters in the ratio 50:50 by volume. This blend was then mixed with diesel in three proportions – B10 (10% Waste oil blend + 90% diesel), B20 (20% Waste oil blend + 80% diesel) and B30 (30% Waste oil blend + 70% diesel). These blends were tested in a DI diesel engine and their performance and emission characteristics were determined. Experimental results showed a decrease in emissions and increases in performance were observed for B20 fuel.

Keywords: waste cooking oil, Waste Transformer oil, Emission, performance, diesel engine

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INTRODUCTION

Conventional fossil fuels, at the current rate of usage, are estimated to last only for another century. Developed countries are burning fuel at an alarming rate and hence, fuel reserves are nearing extinction. The emissions produced by the combustion of fuels have led to adverse and harmful effects on the environment. Thus, the exploration for alternative fuels to reduce such effects has become imperative.

Waste Transformer Oil (WTO) has a huge potential as an alternative fuel due to its easy availability at cheaper rates. Transformer Oil is usually a mineral oil obtained by fractional distillation of crude petroleum. It consists of either naphthenic, paraffinic, aliphatic, aromatic hydrocarbons or certain proportions of two or more of these hydrocarbons. There are several grades of Waste Transformer oil available depending on the period of usage and several other factors. Waste transformer oil, after its usage, is generally disposed into vacant lands affecting the soil greatly. Moreover, large volumes of WTO from several transformers installed throughout the country are being wasted. Hence, Waste Transformer Oil after refining can be effectively utilized to power CI engines.

Waste Cooking Oil is such oil which can be effectively reutilized. Unlike Transformer Oil, WCO is a bio-oil and is renewable. WCO is obtained from its plant seeds and it comprises mainly of triglycerides in its structural formula. G.Venkateswarlu et al [1] used isopropyl alcohol as an ignition improver and WTO as a fuel in a twin cylinder water cooled diesel engine and found that 10% isopropyl alcohol with B40 WTO gave the highest efficiency. Shubham Singh et al [2] conducted tests on waste transformer oil by blending it with four different proportions with diesel .The results showed that 20% blend lowered the CO, HC, and NOx emissions. Prasanna Raj et al [3] used WTO as fuel in a diesel engine and studied the influence of injection timing on performance and emissions. It was observed that for an injection timing of 20°bTDC, NOx, HC, and CO emissions decreased while BTE and smoke increased. Prasanna Raj Yadav et al [4] adopted catalytic cracking process to treat WTO by waste fly ash resulting in increase in BTE and peak heat release rate (PHRR) for 50% blend. Md.Nurun Nabi et al [5] revealed that various properties such as density, kinematic viscosity, cetane number, calorific value, flash and fire points of WTO were almost similar to those of diesel fuel. Six test fuels were prepared using used transformer oil with diesel by Pritinika Behera et al [6] who tested them in a4.4kW, air cooled, direct injection diesel engine to find that CO, HC, and NOx emissions were higher than diesel, whereas smoke reduced. Ritinika Behera et al [7] used a combination of Used Transformer Oil and acetylene, at full load condition. Smoke reduced by 13.7%. Saidulu et al [8] performed experiments using blends of WTO with diesel to find a rise in BTE and NO_x for B10 blends while decrease in CO and HC compared w to diesel fuel. Vipin Mohta et al [9] used WTO B30 and found an increase in thermal efficiency and less emission of CO and HC for B30 blend. S.Prasanna Raj Yadav et al [10] varied piston bowl geometry and used WTO as fuel in diesel engine to discover that toroidal geometry gave better result. Loai Nasrat et al [11] suggested that the electrical, physical, chemical, and thermal properties of used transformer oil could be improved by using activated Bentonite. The performance and emission characteristics of waste cooking oils such as waste palm oil and waste coconut oil were analyzed by M.A. Kalam et al [12] and their finding was that there was a reduction in brake power and increase in NOx emission. Mevlut Sureyya Kocak et al [13] tested the methyl esters of WCO, hazelnut oil and canola oil in a turbocharged diesel engine and found that the emissions were significantly reduced compared to diesel. Zahoor Ullah et al [14] used an-ionic liquid – butyl methyl imidazolium hydrogensulfate (BMIMHSO4) as catalyst in a two stage transesterification process and found a high yield of Waste Cooking Oil methyl esters and low fatty acids could be obtained when 5 wt% BMIMHSO4, methanol: oil ratio 15:1, 60 min reaction time, at 160 °C, and agitation speed of 600 rpm were used. Meyappan Venkatesan [15] investigated the performance and emissions of Jatropha oil methyl esters at three injection pressures (180, 200, and 220 bar) and two injection timings (27° btdc and 31° btdc) and stated that 220 bar pressure and 31° bTDC injection timing produced better performance amongst others under consideration. Lei Zhu et al [16] compared the combustion characteristics of Euro V diesel fuel, biodiesel, and ethanol–biodiesel blends and concluded that the engine performance improved with 5% ethanol in biodiesel.

In this study, the waste transformer oil and waste cooking were blended at 50:50 proportion. These blends were blended with diesel fuel at different proportions and tested in a constant speed, DI diesel engine to improve the emission and the performance of the engine full load condition.

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Nomenclature:

WTO	–	Waste Transformer Oil
WCO	–	Waste Cooking Oil
B10	–	10% of Waste Blend with 90% of petro diesel
B20	-	20% of Waste Blend with 90% of petro diesel
B30	–	30% of Waste Blend with 90% of petro diesel
CO	-	Carbon mono Oxide
HC	-	Hydrocarbon
CO_2	-	Carbon-di-Oxide
NOx	-	Oxides of Nitrogen
BSFC	-	Break Specific Fuel Consumption
BTE	-	Break Thermal Efficiency

MATERIALS AND METHODS

WTO was collected from the concerned authorities. The oil was filtered using a sieve to remove fine impurities. WCO was collected from the Sathyabama University central cooling facility, Chennai, India. WCO was transesterified initially to obtain its methyl esters. WTO and WCO methyl esters were blended in the ratio 50:50 by volume. Three test fuels i.e.) B10, B20, and B30 were prepared. These test fuels were tested in the DI diesel engine and performance was assessed. Emissions were recorded using an AVL 5 gas analyzer.

Transesterification of Waste Cooking Oil:

Transesterification is a traditional method which is employed to reduce the viscosity of raw oil. Initially, Free Fatty Acid (FFA) test was done to determine the number of stages of transesterification required. As the FFA content of WCO was considerably low, single stage transesterification process was opted. One litre of WCO was preheated to a temperature of 60°C to remove any moisture present in the oil. Simultaneously, 5gms of sodium hydroxide (NaOH) catalyst was added to 200 ml of methanol and stirred thoroughly until NaOH dissolved completely in methanol. The resulting solution was poured into the preheated oil in the mantle and stirred with the help of a magnetic stirrer. The mixture was maintained at 60°C for about 3 hours. A shell-tube condenser was introduced at the top of the mantle to prevent the methanol vapors from escaping into the atmosphere. After completion of the reaction, the mixture was poured into a separator funnel and allowed to settle down for 24 hours. The glycerol which settled at the bottom was drained out, thereby removing the soap content of the oil. The biodiesel obtained was now washed with equal amount of wash water to neutralize the acids which might be present. Finally, the oil was heated again to remove any moisture carried from washing cycle. The WCO and its methyl esters are shown in Fig.1 and Fig.2 respectively.

Fig.1 Waste Cooking Oil

Fig.2 Waste Cooking Oil Methyl esters

The waste transformer oil was collected and filtered using a seive to remove the impurities from the raw oil as shown in Fig.3. The 50% filtered WTO was blended with 50% of WTO methyl esters as shown in Fig.4.

Fig.3 Waste Transformer Oil

Fig.4 50% WTO + 50% WCME

TABLE 1: Comparison of properties of WTO, WCME, and Petro Diesel

S.NO	PROPERTY	Diesel	BIS Biodiesel	WTO	WCME
1.	Kinematic Viscosity at 40 ° C cst	2 – 4.5	2.5 - 6	8.2468	3.916
2.	Density at 15 ° C kg / m^3	820 - 845	860 - 900	0.865	0.875
3.	Flash Point °C min	35	262	161	182
4.	Calorific Value kJ/kg	42,000		18,352	32,693

The calorific value of WTO was found to be very less in comparison with petro diesel. The densities of WTO and WCME were the same and the flash and fire points were higher. From this comparative study, 50% WTO + 50% WCME blend (abbreviated as 50WT50WC) was chosen to be the most appropriate blend. Even though the blend containing 10%WTO + 90%WCME had the highest calorific value, 50WT50WC blend was chosen for maximum utilization of WTO. The various properties of WTO, WCME, and diesel are given in Table.1. The WTO and the WCO were blended at different proportions and the calorific value of the resultant fuel was found.

EXPERIMENTAL SET-UP:

The engine considered for this experiment was a 4 stroke, single cylinder diesel engine. The specifications of the test engine used for this experiment are given in Table.2. The engine was allowed to run for 15 minutes for adulteration at a constant speed of 1500 rpm. Loads on the engine were provided by using an eddy current dynamometer. The load on the engine was gradually increased from 0% to 100% at intervals of 25%. The emissions of CO, HC, CO_2, O_2, and NOx were monitored by using the AVL DI GAS Analyzer. Smoke emission was measured with the help of AVL smoke meter. A manometer was utilized for flow rate measurements. The details of various measuring instruments used are given in Table.3. Three different blends considered in this study were B10 (10% 50WT50WC + 90% diesel), B20 (20% 50WT50WC + 80% diesel), and B30 (30% 50WTWC + 70% diesel). The photographic view of the engine set-up is shown in Fig.5.

Fig.5: Photograph of the Experimental Setup

TABLE 2: Specifications of the test engine

Type	4 Stroke, Single Cylinder Vertical Air Cooled Diesel Engine
Combustion	Direct Injection
Rated Power	4.4 Kw
Rated Speed	1500 rpm
Compression Ratio	17.5: 1
Fuel injection pressure	200 bar
Dynamometer	Eddy current

TABLE 3: Details of Measuring Systems

Pressure Transducer	AVL PRESSURE TRANSDCER GH14D/AH01
Software Version V 2.5	AVL INDICOM MOBILE Software
Data Analyzer from Engine	AVL PIEZO CHARGE AMPLIFIER
Smoke meter	AVL 415 SMOKE METER
5 Gas Analyzer (NO_x, HC, CO, CO_2, O_2)	AVL DI GAS 444 Analyzer

The engine was allowed to run till it reached steady state at no load condition. The fuels were tested by varying the load in steps of 25% up to 100%. The emissions and performance were recorded at full load condition and at the constant speed of 1500 rpm. The experiment was repeated thrice and the average of the results was taken.

RESULTS AND DISCUSSION

BRAKE SPECIFIC FUEL CONSUMPTION

The variation of BSFC for waste oil blends and diesel fuel is shown in Fig.4.1. It can be observed that as the load increases, BSFC decreases for all the blends. At full load condition, there are only marginal decreases in BSFC for waste oil blends when compared to diesel. The reduction in BSFC for B20 and B10 blends are 11.04% and 6.25% respectively compared with PD at full load conditions. This may be due to higher temperatures developed in the combustion chamber for waste oil blends leading to a lower consumption of fuel. Another factor which causes fuel consumption reduction may be the higher density of waste oil blend compared with diesel.

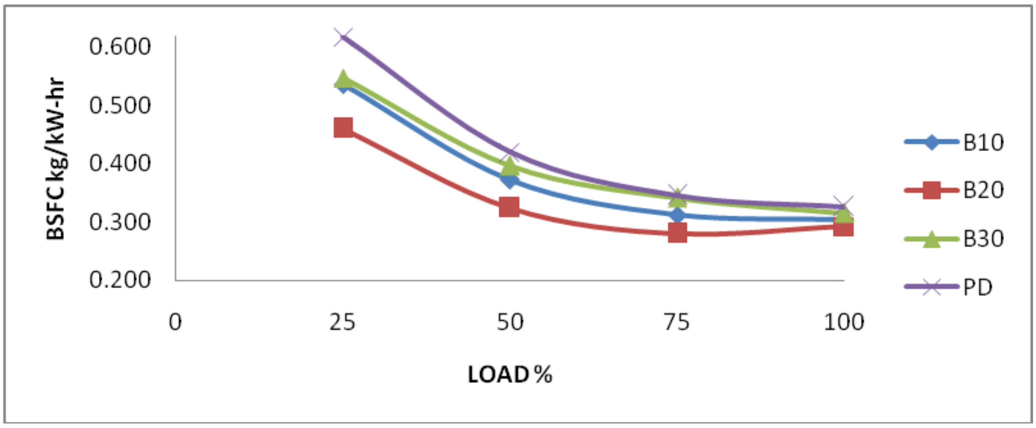

Fig 4.1: Variation of BSFC with respect to load

BRAKE THERMAL EFFICIENCY:

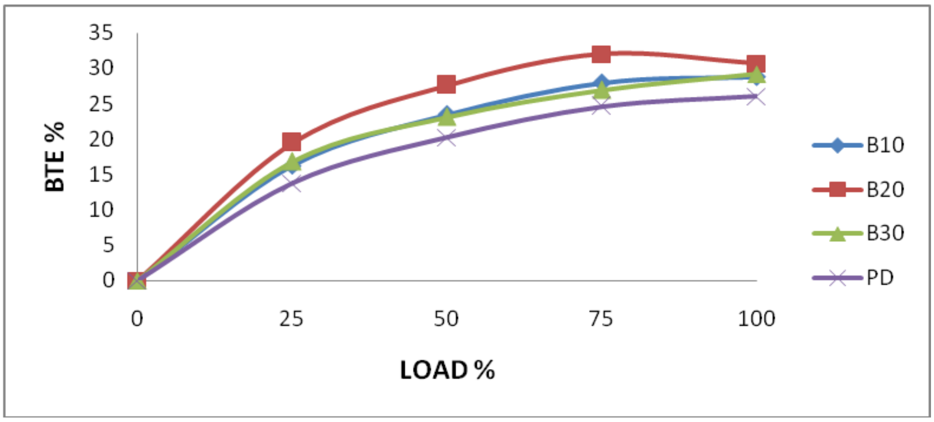

Fig 4.2: Variation of BTE with respect to load

Fig.4.2 shows the variation of Brake Thermal Efficiency (BTE) with respect to load. It can be seen that at full load, Brake Thermal efficiency is higher than that of pure diesel for all three blends of 50WT50WC. BTE is higher by 17.71% for B20, by 11.02% for B30, and by10.94% for B10 compared with PD. Brake Thermal efficiency increases due to the higher oxygen content in the fuel, when compared to diesel fuel.

CARBON MONOXIDE (CO):

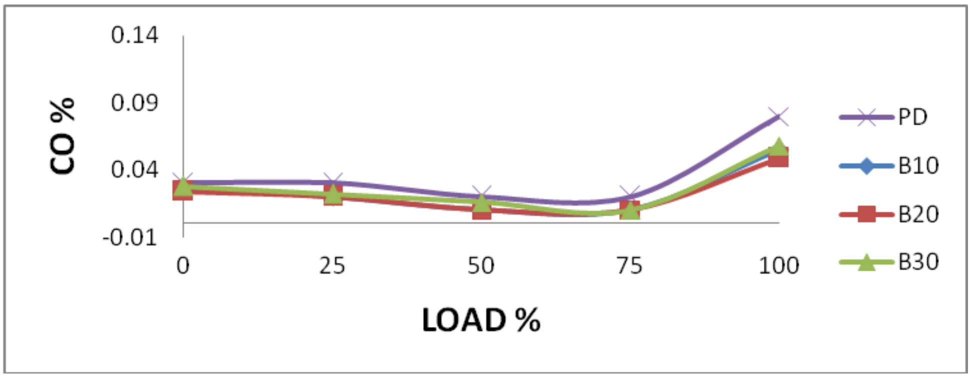

Fig 4.3: Variation of CO with respect to load

The use of biodiesel in C.I engines produced lower CO emissions. CO is produced mainly because of inadequate supply of oxygen for combustion. Hence, a decrease in CO emission indicates that better combustion has taken place. Fig.4.3 shows the variation of CO with respect to load for different proportions of waste oil blend with diesel. At full load condition, a significant decrease in CO emissions can be observed for all blends compared to pure diesel. B20 blend produced the lowest emission with 38.75% reduction compared with PD. CO decreased by 27.5% for B30 fuel compared with PD. This could be attributed to the higher oxygen content present in Waste Cooking Oil methyl esters. The oxygen present in these blends facilitated better burning of fuel ultimately resulting in better combustion and therefore reducing CO emissions.

HYDROCARBON:

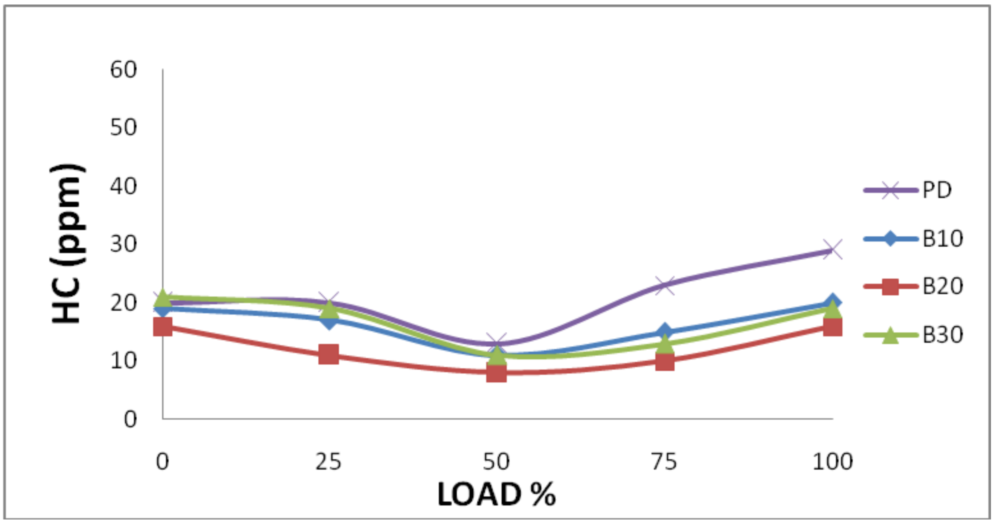

Fig 4.5: Variation of HC with respect to load

The emission curves of HC with respect to load for waste oil-diesel blends and pure diesel are shown in fig.4.5. The emission of HC is a measure of the unburned hydrocarbons which have escaped from the combustion chamber without undergoing combustion. Unburned hydrocarbons have decreased by 44.83% for B20 and 34.48% for B30 compared with PD at full load condition. HC emission could have decreased due to the higher cetane number of WCME. The higher cetane number resulted in reduced ignition delay and hence better combustion of waste oil-diesel blends. The ignition delay is shortened, due to the higher bulk modulus of waste oil blends. Higher bulk modulus means that they are less compressible compared to diesel.

NITROGEN OXIDES

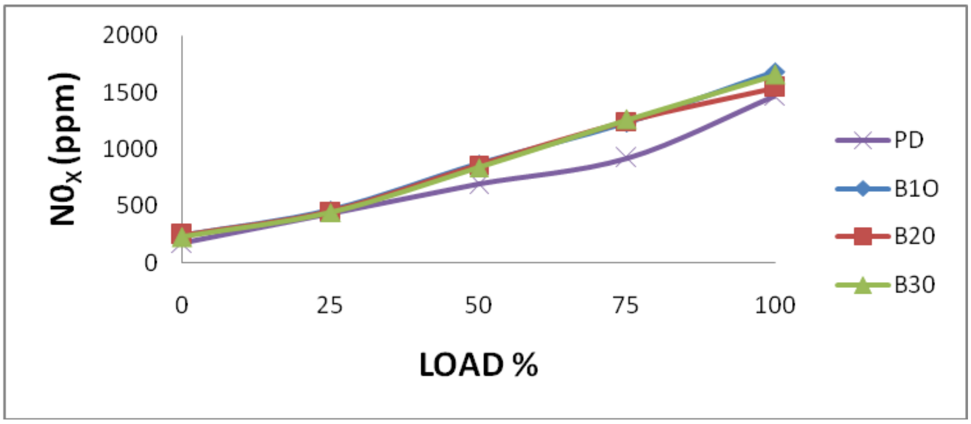

Fig 4.6: Variation of NOx with respect to load

The variation of NOx with respect to load is shown in fig.4.6. The oxidation of nitrogen present in the atmospheric air is the primary reason for NOx formation. Any nitrogen content which may be present in the fuel also contributes to NOx formation. It can be seen that NOx increases proportionally with respect to load. At full load, B10 and B30 blends show an increase of 14.63% and 12.72% respectively in NOx emission compared to PD, whereas B20 blend produces a marginal increase in NOx emission compared to PD. Generally, higher temperatures favour NOx formation. Shorter ignition delay for these blends favour the development of higher temperature in the combustion chamber.

SMOKE:

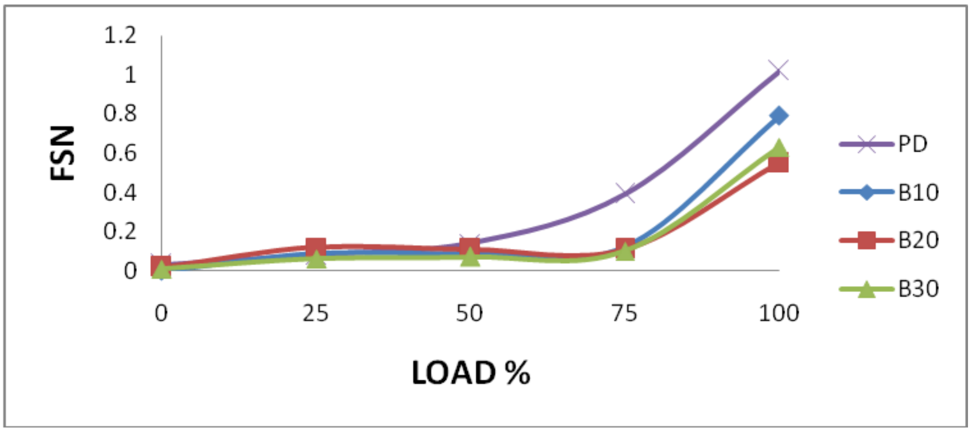

Fig 4.7: Variation of smoke with respect to load

Fig.4.7 shows the variations in smoke emission at various loads for waste oil biodiesel blends and pure diesel. At 100% load, we witness a decrease of 46.07% in smoke emission in comparison to PD for B20 blend, whereas B30 blend shows 38.23% decrease in smoke compared to PD. The reason for reduction in smoke level could possibly be an effect of better combustion characteristics of Waste Cooking oil methyl esters. The higher residence time and shortened ignition delay favour the oxidation of soot and hence decrease smoke emissions. Biodiesel generally possesses very low or no sulphur content and thus produces lower smoke emissions compared to diesel.

CONCLUSION

In this research, a blend of 50% waste cooking oil methyl esters and 50% waste transformer oil was used in different proportions with diesel and the performance and emission characteristics of these blends were determined. From a thorough analysis of the results obtained, it could be concluded that B20 blend (20% Waste oil blend + 80% diesel) was the most optimal blend amongst the different blends considered. It produced the lowest emissions and gave the highest performance in comparison with other blends. The decrease percentage for emissions of various exhaust gases for B20 was: i) 38.75% reduction in CO, ii) 44.83% reduction in HC and iii) 58.7% reduction in smoke. However, there was a marginal increase in NOx emission. As far as the performance parameters were concerned, 11.04% decrease in BSFC and 17.71% increase in BTE were recorded. Thus, it could be stated that the use of B20 blend as replacement for diesel, would improve both performance and emission characteristics. However, further studies should lead us to solution for finding out ways to reduce NOx emissions.

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