Performance, combustion and emission characteristics of B20 fish biodiesel blended with waste plastic oil on a diesel engine

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Abstract. Depletion of fossil fuels and environmental pollution are major challenges in the present world. Main pollution sources are the Plastic waste and automotive emissions. The present work deals with usage of the oil obtained from waste plastic blended with Fish Biodiesel. In order to carry out the study on plastic wastes, pyrolysis process was used. Pyrolysis runs without oxygen and in high temperature of about 250-300 °C. Fish Biodiesel was obtained from waste fish leftovers and transesterification was used to obtain Fish Oil Methyl Ester (FOME). B20FOME is obtained by blending 20% FOMEwith 80% Diesel. The 10% of fuel obtained from waste plastic is blended withB20FOME to obtain B20FOME10WPO. For conducting the various experiments,10HP single cylinder 4 stroke direct injection water-cooled diesel engine is employed. The engine is made to run at 1500rpm and the load is varied gradually from 0-100%. The BTE of biodiesel blend and bio diesel blend with plastic oil was increased by 3.82% and 10.02% respectively than that of diesel. UBHC and CO emissions were found to be lower than that of diesel. Whereas NOx emission and smoke opacity were observed to be marginally higher than that of diesel. The performance, emission and combustion characteristics are observed. It reveals that fuel properties are comparable with petroleum products. Converting waste plasticsinto fuel hold great promise for both the environmental and economic scenarios.

1. Introduction

A steep increase of transportation vehicles in the world has led to lavish usage of petroleum fuels. Countries' economy is suffered due to heavy usage of fossil fuels. At present, the government has a tough challenge on their hands to overcome the import of crude petroleum from the other petroleum oil producing countries. On the other hand the environmental pollution from the transportation vehicles has a big problem of climate change and acid rain. Hence governments in the world have been focusing on the utilization of renewable energy sources. The Exhaust gas emissions from diesel engine have become serious problem to the researchers. Hence there is a need for finding the solution for reduction of emission from the automobile engines. Now a days, fuels of bio-origin, such as alcohol, vegetable oils, biomass, biogas, biodiesels, etc. Are becoming important because of their renewable and environmental friendly nature. Some of these fuels can be used directly, while others need some sort of modification before they are used as substitute to conventional fuels. Biodiesel is a cost effective, environmental friendly, renewable alternative to conventional fuels [1]. Application of biodiesel, as a fuel in transportation vehicles, has nowadays become common in almost all oil importing nations. [2]. The principal advantage of biodiesel is that it reduces or suppresses the formation of CO, HC and PM emissions during the combustion process due to its low aromatic content and the presence of oxygen-containing compounds. The abbreviations and symbols are shown in Table 1.

A primary type of such biodiesel is fish oil obtained as a by-product in fish processing industries [22]. Crude marine fish oil can be extracted from the discarded parts of marine fish like viscera, fins, eyes and tails etc. known as soap stock.[3] Plastics are widely used in many day to day applications such as clothing, house-hold appliances, automotive-products and in aerospace. The treatment of waste plastics becomes an unavoidable and imminent issue. Hence there is an urgent need to effectively recycle plastic waste. The results showed that the waste plastic oil when mixed with heavy oils reduces the viscosity significantly and improves the engine performance [4]. Similar to petroleum derived cracking products, the fractions from plastics processing contains appreciable quantities of aromatics and unsaturated hydrocarbons [5]. The properties of the fuels are shown in Table 2.

Table 1. Abbreviations and symbols used

BP	Brake Power
BTDC	Before Top Dead Centre
BTE	Brake Thermal Efficiency
HRR	Heat Release Rate
B20	20% biodiesel + 80% Diesel
FOME	Fish Oil Methyl Ester
EGT	Exhaust Gas Temperature
UBHC	Unburnt Hydrocarbon
NOx	Oxides of Nitrogen
ppm	Parts per million
LPH	Litres per hour
WPO	Waste Plastic Oil
B20FOME	20% Fish Oil Methyl Ester + 80 % Diesel
B20FOME10WPO	10% Waste Plastic Oil + 90% B20FOME

Table 2. Properties of fuel.

Property	**Straight Diesel**	**Pure Plastic Oil**	**Fish Oil (B100FOME)**	**Fish Biodiesel (B20FOME)**	**WPO-Biodiesel Blend (B20FOME10WPO)**
Density (kg/m3)	850	835	873	854.6	852.64

Kinematic Viscosity (at 40 °C)	2	2.52	4.97	2.594	2.5866
Calorific Value (kJ/kg)	42000	44340	40839	41767.8	42025.02
Flash Point (°C)	50	42	152	70.4	67.56
Cetane Index	55	51	57	55.4	54.96

A mixture of biodiesel and plastic fuel provides an innovative product blend for usage in CI engine to give an optimum emission as well as considerable efficiency [6]. The study involves preparing the blend of B20FOME with 10% waste plastic oil (WPO) and testing it along with B20FOME and conventional Diesel on a direct injection 4-stroke CI diesel engine and analysing Performance, Emission and Combustion parameters of each fuel. On comparing the stated characteristics of the fuels it was evident that B20FOME10WPO resulted in best performance and reduced emission. This new blend can be used as a fuel for diesel engine as it has two significant advantages, firstly, the process of converting waste plastic into value added fuels tackles problem of waste plastic disposal. Secondly renewable fuels like Fish oil and plastic oil can partially eliminate the limited diesel.

2. Transesterification

The use of straight vegetable oil in compression ignition engine results in choking, carbon deposition, vaporization and clogging of fuel injector in the combustion chamber. This can be minimized by reducing the viscosity of the oil by pyrolysis, transesterification and thermal cracking. Out of these three, transesterification is widely used [7]. Transesterification is the conversion of one ester into another, i.e. a glyceride ester into alkyl ester, in case of biodiesel where a methanol replaces the glycerine. The Biodiesel molecule is smaller and less complex. Biodiesel has lower viscosity than raw oils and fats, because the transesterification process shortens the carbon length of the fatty acid molecules in the oil. Transesterification converts the triple chain triglycerides to three single chain methyl ester molecules with glycerine as a by-product, but the chain lengths of the fatty acids themselves remain same. The catalyst breaks the bond holding the fatty acid chains into glycerine, the fatty acid chains then bonds with the methanol. Transesterification process occurs in three stages. First, one fatty acid chain breaks off the triglyceride molecule and bonds with methanol to form methyl ester molecule, leaving a diglyceride molecule (two chains of fatty acids bound by glycerine). Then a fatty acid chain breaks off the diglyceride molecule and bonds with methanol to form another methyl ester molecule, leaving a mono glyceride molecule. Finally the mono glycerides are converted to methyl esters. Figure. 1 shows a schematic representation of the Transesterification process [8]. After transesterification, the kinematic viscosity was reduced from 14 times to 2.48 times that of diesel. Similar reduction in density was also observed. However, the calorific value of Fish oil was found to be 40839 KJ/kg which is less than calorific value of diesel (42000 KJ/kg) and plastic oil (44340KJ/Kg).

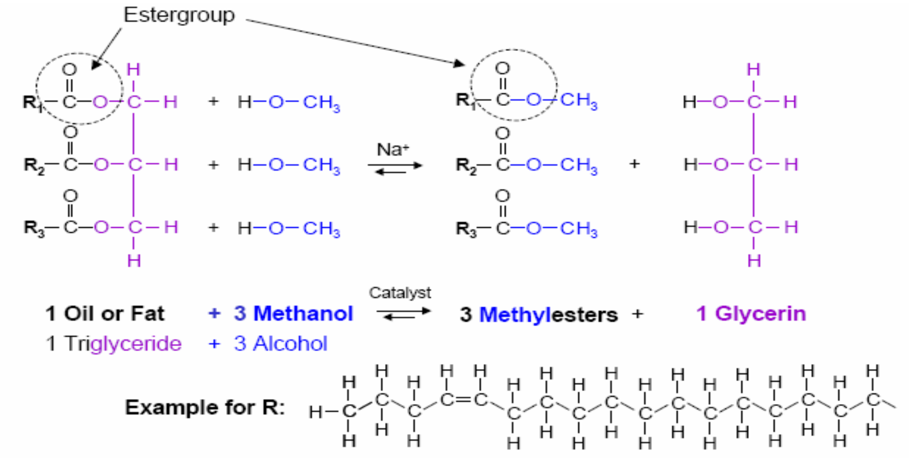

Figure Error! No text of specified style in document.**1.** Mechanism of Transesterification process[20].

Table 3. Specification of OROTECH Exhaust Gas Analyser

Measurement Parameters	Range	Resolution
Carbon Monoxide (CO)	0-10% vol.	0.001% vol.
Hydrocarbon (HC)	0-9999% ppm vol.	1.0 ppm vol.
Oxides of Nitrogen (NOx)	0-5000 ppm vol.	1.0 ppm vol.

Table 4. Specification of AVL437C Smoke Meter

Measurement Parameters	Range	Resolution
Opacity	0-99.9%	0.1%
Linearity	±0.1 m^{-1}	
Repeatability	±0.1 m^{-1}	
Response time- Physical	< 0.4 seconds	
Response time- Electrical	< 1 millisecond	
Warm up time at Atm. Conditions	< 7 minutes	
Engine RPM	400-9990 RPM	10 RPM
Engine Oil Temperature	0-150°C	1°C
Operating Temperature	5°C to 50°C	
Smoke measuring cell length	215mm (430mm folded length)	

2.1 Preparation of blend
B20FOME was prepared by mixing 20% by volume of biodiesel with 80% by volume of diesel in a beaker and stirring it for 15 minutes at constant room temperature. B20FOME10WPO was prepared by adding 100 ml of waste plastic oil to 1 litre of B20FOME biodiesel blend.

3. Experimental Setup
The setup consists of single cylinder, four-stroke Constant Speed Research engine connected to eddy current Dynamometer. Rotameters are provided for cooling water and calorimeter water flow measurement as shown in Figure. 2. The experiments were conducted at the designed injection timing of 23 degrees BTDC (230 was chosen as it is proven to have best performance and emission), constant speed of 1500 rpm and 17.5: 1 compression ratio. The setup has stand-alone panel box consisting of air box, twin fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and piezo powering unit. Rotameters are provided for cooling water and calorimeter water flow measurement. The engine works with programmable open ECU, throttle position sensor (TPS), fuel pump, ignition coil, fuel spray nozzle, trigger sensor etc. The engine was started by diesel fuel supply and it was allowed to get its steady state (for about 15 minutes). Water to engine cooling jacket was maintained at about 300LPH and water flow pressure was maintained between 1 to 1.5 bars throughout the experiments in order to just sustain constant flow across the engine and keeping the outlet at atmospheric pressure. The engine and dynamometer specifications are shown in Table 3 [9]. The experiments were conducted at no load, 25% of full load, 50% of full load, 75% of full load and full load conditions. The engine was next run with the B20FOME and then with B20FOME10WPO for the same above conditions and performance, combustion and emission tests were carried out as before.

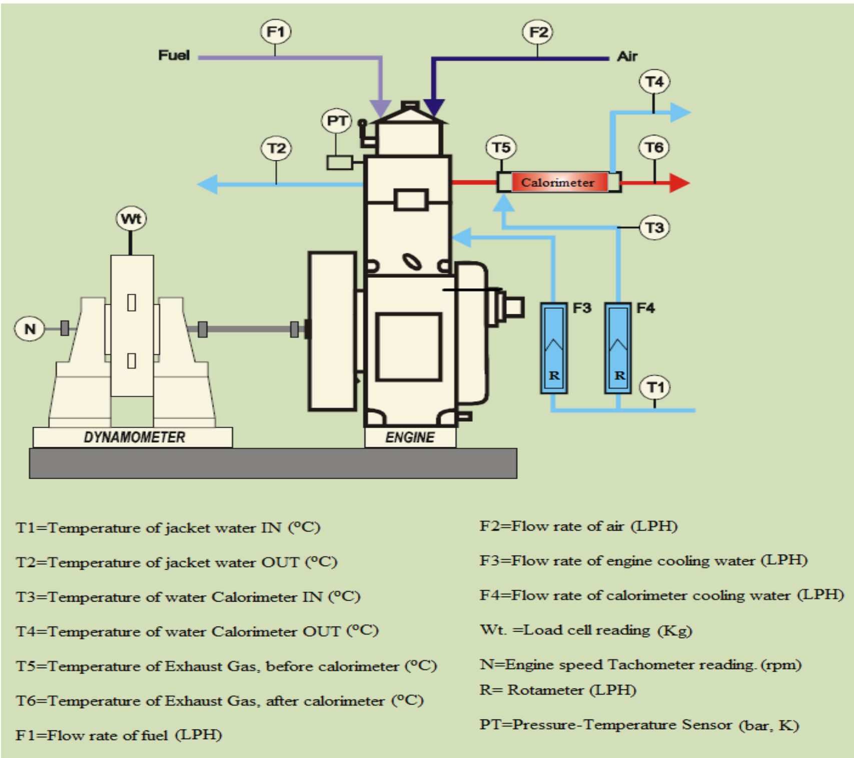

Figure Error! No text of specified style in document.**2.** Experimental Setup [21].

Table 5. Engine and Dynamometer specification

FOUR STROKE SINGLE CYLINDER DIESEL ENGINE TEST RIG	
Make	Kirloskar
Capacity	3.5KW
Compression ratio	17.5:1
Cylinder bore	80mm
Stroke	110mm
Cylinder capacity	661cc
Cooling	Water cooling
Loading	Eddy current Dynamometer
Speed	1500rpm

4. Results and Discussion

4.1 Performance Characteristics

4.1.1 Brake Thermal Efficiency

The variation of Brake Thermal Efficiency (BTE) with load for tested fuels is shown in Figure.3. For all fuels the general trend is that BTE improved with increase in load, this was due to reduction in heat loss and increase in power with increase in load. It is observed that among the fuels the B20FOME10WPO showed maximum BTE with 34.48% at full load, while B20FOME showed 32.54% and Diesel showed 31.34%. Thus B20FOME10WPO showed an increase in BTE with respect to Diesel by 9.8 %. The main reason is due to the finer spray formed with plastic blend in the combustion chamber leading to a more uniform fuel-air mixture during combustion. an effective combustion by making use of the rich oxygen content within the ester (FOME) and plastic molecules leading to higher pressure[10,11].

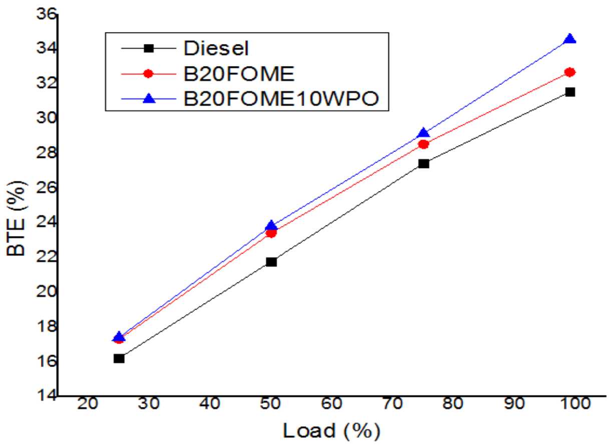

Figure 3. Variation of BTE with load

4.2 Combustion Characteristics

4.2.1 Heat Release Rate

Figure 4. shows the variation of Heat Release Rate (HRR) with various crank angles for the fuels. Both B20FOME and B20FOME10WPO show a marginal increase in HRR compared to Diesel. Diesel

at full load is chosen as a baseline for comparison of combustion characteristics. The maximum HRR was shown by B20FOME10WPO at 36.486\kJ/0CA whereas B20FOME and Diesel showed at35.986kJ/0CA and 35.872kJ/0CA respectively. At full load B20FOME and B20FOME10WPO showed slightly greater HRR than Diesel by 0.32%, and 1.72% respectively. Owing to more oxygen molecules present in the molecular structure of B20FOME10WPO than B20FOME and diesel, it showed a marginal increase in its HRR [12, 13]. Higher HRR of Plastic Blend is also attributed to a higher peak pressure due to a premixed combustion and higher Peak Pressure.

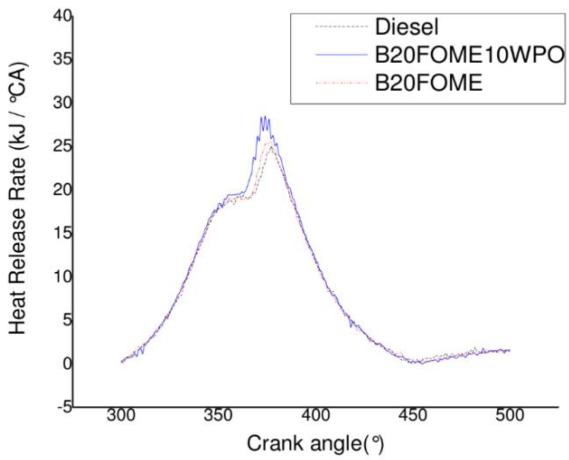

Figure 4. Variation of Heat Release Rate with Load

4.2.2 Peak Cylinder Pressure

The comparison of peak cylinder pressure with load has been shown in Figure. 5. The peak pressure increases steadily with the load. It is seen from the Figure that the peak pressure of B20FOME10WPO is higher than that of diesel at all loading conditions. The maximum Peak Pressure was shown by B20FOME10WPO at 65.52 bar whereas B20FOME and Diesel showed at 64.93 bar and 63.62 bar respectively. At full load B20FOME10WPO and B20FOME showed a greater Peak Pressure than Diesel by 2.98% and 2.06%, respectively. At full load condition the B20FOME10WPO blend shows an increase in peak pressure due to its higher ignition delay which arises due to premixed combustion as it has higher viscosity it takes more time to mix with air and get ignited than other fuels. Thus the combustion is more abrupt so peak pressure is higher and concentrated at a smaller Crank Angle Range. The other reason could be that it contains more Oxygen content than diesel leading to a more complete combustion [14].

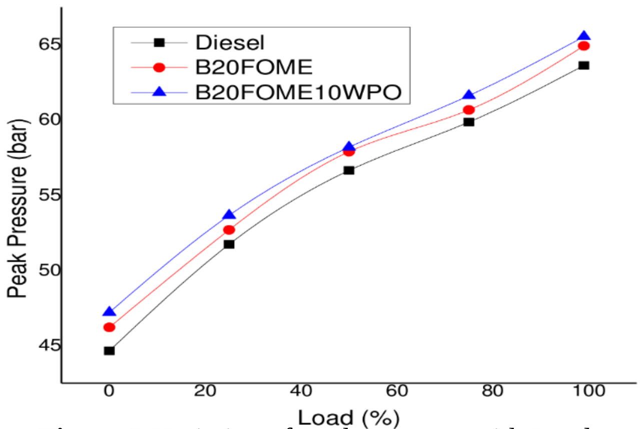

Figure 5. Variation of Peak Pressure with Load

4.3 Emission Characteristics

4.3.1 Exhaust Gas Temperature

The Figure.6 depicts the variation of EGT with load for all the fuels tested. It was observed that EGT increases with increase in load for all the fuels, because of more amount of fuel being consumed. It can be seen that B20FOME10WPO shows slight increase in EGT as that of other fuels. This is due to higher HRR and poor volatility which leads to late burning that causes increase in temperature [15]. It may also be due to a higher Oxygen content in the plastic fuel so burning gets more complete. At the full load B20FOME10WPO showed the highest EGT at 360.790C whereas B20FOME and Diesel showed 340.262 0 C and 340.8850C respectively. 20FOME and Diesel showed similar values. This is due to nearly same quantity of both fuels being consumed per hour. Since heat loss to the exhaust on percentage basis was approximately constant throughout the load range, therefore same quantity of fuel consumed implies same heat was rejected resulting in marginal variation in EGT for Diesel and B20FOME.

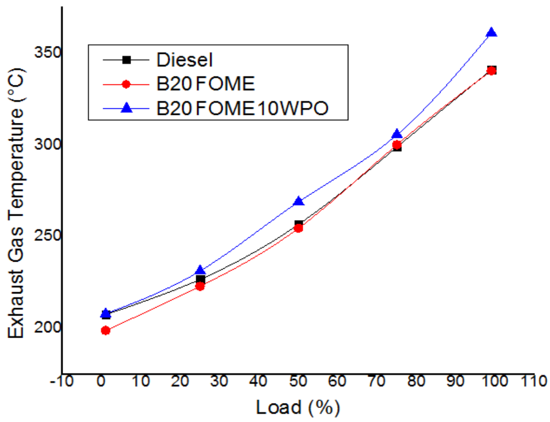

Figure 6. Variation of EGT with Load

4.3.2 Oxides of Nitrogen

Figure.7 depicts the variation of NOx with load for all tested fuels. The nitrogen oxides result from the oxidation of atmospheric oxygen at high temperature inside the cylinder of an engine rather than just resulting from a contaminant present in the fuel. It is observed from the figure that the amount of NOx increased with increase in the load for all fuels, it happens because, with increase in the load the temperature of the combustion chamber increases, as NOx formation is strongly temperature dependent phenomenon [16]. The figure indicates that NO x emissions were found at full load to be 1110ppm for B20FOME10WPO, 1080ppm for B20FOME and 1050ppm for Straight diesel. NOx emission of B20FOME appears to increase marginally as compared to that of diesel. The plastic blend shows increased NOx emission as compared to other fuels. The reason for this trend is higher HRR in case of plastic blend. Due to higher HRR, the temperature inside cylinder will also increase thereby NOx emission will be more [17].

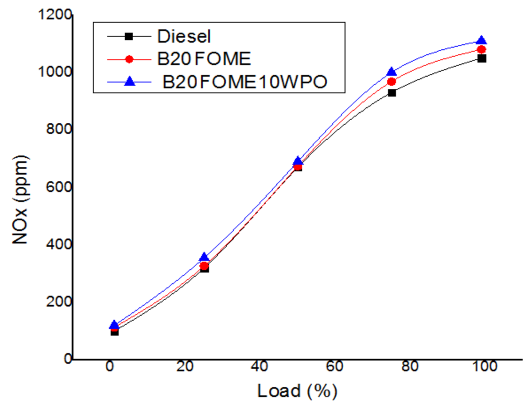

Figure 7. Variation of NOx with Load

4.3.3 Carbon Monoxide Emissions

The variation of CO with load is presented in the Figure. 9. The CO is a toxic by product of combustion of all hydrocarbons due to incomplete combustion. It is reduced by increasing the oxygen content of the fuel. From the Figure, it is found that the amount of CO at no load is higher than part load since no load corresponds to very lean mixture and equilibrium leads to CO formation. It decreased at part load (0-60% loading condition) and again increased at full load condition for all tested fuels. This is due to a richer air- fuel mixture needed for maximum power condition corresponding to full load condition. It is observed that CO emissions for biodiesel and plastic blends are lower than straight diesel. Presence of oxygen content in methyl esters and plastic blend leads to the further decrease in the CO emissions compared to that of B20FOME and straight diesel. Carbon monoxide emission is mainly due to the lack of oxygen, poor air entrainment, mixture preparation and incomplete combustion process [18]. CO emission decreases with increase in cylinder temperature as combustion tends to be more complete.\

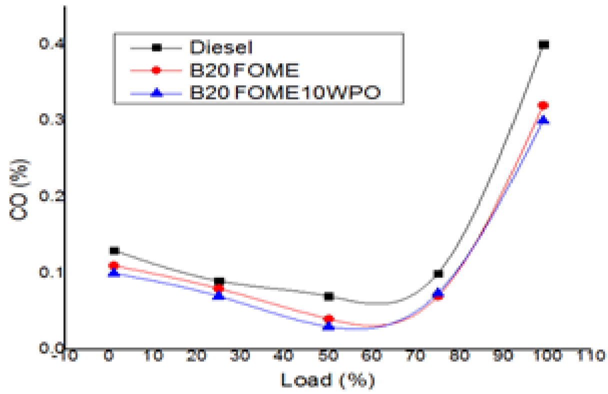

Figure 8. Variation of CO with Load

4.3.4 Unburnt Hydrocarbons (UBHC)

Figure. 8 shows the variation of UBHC with load. From the Figure it is observed that UBHC emissions for all blends are lower than the diesel. At full load B20FOME and B20FOME10WPO showed lesser UBHC emission than diesel by approximately 14.2 % and 24.1 % respectively. The biodiesel is comprised of animal fat and vegetable oil methyl esters i.e., there are hydrocarbon chains whose one end of the chain is oxygenated. The presence of oxygen in the biodiesel and plastic oil promotes more complete combustion that leads to lowering the hydrocarbon emissions.

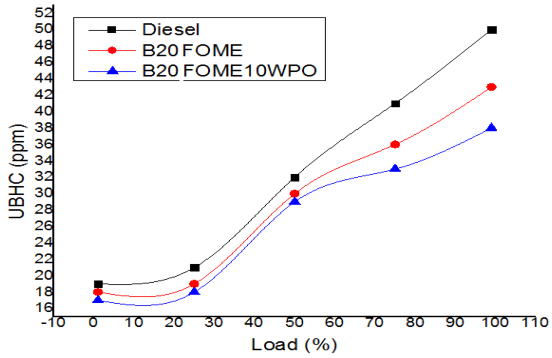

Figure 9. Variation of UBHC with Load

4.3.5 Smoke Opacity

Figure.10 shows the variation of opacity with load. The amount of smoke present in the exhaust gas gives the measure of particulate matter present in exhaust gas. It is observed that the smoke opacity of exhaust gas with increase in load for all fuels. This is due to more amount of fuel being consumed at full load so more soot particles are encountered in the exhaust. It can be noticed that the smoke for the blends is higher than the diesel; this is due to poor volatility and mixing of the fuel droplets with air because of higher viscosity of the blends. The molecules of biodiesel and plastic oil being heavier also attributes to the increase in smoke emissions [19].

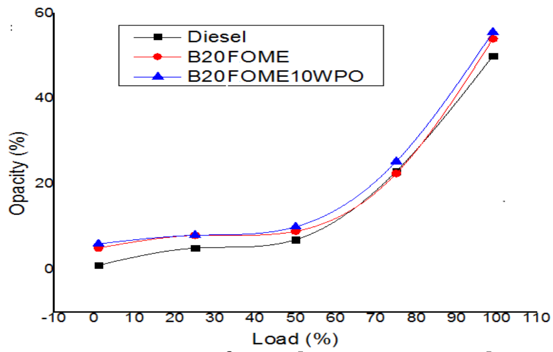

Figure 10. Variation of Smoke Opacity with Load

5. Conclusion

In this study engine tests were conducted with plastic oil and fish blends for no load to full load condition and the corresponding performance, combustion and emission characteristics were studied in comparison with Diesel fuel. All the tests were conducted under the same condition and repeated for three times to obtain consistent values. Waste plastic oil blended with biodiesel from Fish is determined to be suitable replacement to straight diesel. From the results, following features were noticed. Transesterification of the Fish oil leads to reduction in kinematic viscosity and density whereas the calorific value is increased. The B20FOME10WPO showed increased BTE with respect to diesel by 9.3% at full load. The cylinder pressure was found to be maximum for B20FOME10WPO. The oxygen content in B20FOME10WPO helps in the premixed combustion phase to progress in a better way which leads to better combustion. For B20FOME10WPO the emission of HC, CO decreases as compared to diesel signifying a near complete and an efficient combustion. It shows a slight increase in Smoke Opacity and NOx as compared to diesel. Thus these factors strongly support the fact that Plastic oil blended with Fish oil and diesel can be a promising fuel for diesel engines in future as they have good efficiency and reduced emissions. Using renewable and eco-friendly fuels like waste plastic oil and Fish oil, a significant percentage of the limited diesel can thus be eliminated. It also provides a novel method to recycle plastic.

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