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Effect of Higher Alcohols Addition on Performance and Emission Characteristics of Single Cylinder Diesel Engine by using Diesel/Waste Plastic Oil Blends

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Abstract:** Usage of fossil fuel in conventional engine leads to two major problems, one is the environmental pollution and the other is its availability. Hence it is necessary to find a feasible another source to replace fossil diesel. Waste plastic oil is one such alternative and has dual advantage, its usage as fuel for engine and it reduces the pollution due to plastic waste as it takes almost decades for plastics to decompose. In this present study the extraction and characterization of waste plastic oil (WPO) obtained by pyrolysis has been discussed and later set out to investigate the effects of adding a renewable oxygenated component in the form of 1-hexanol and 1-octanol. Three ternary blends for 1-hexanol and 1-octanol were strategically prepared as D50-WPO40-H10, D50-WPO30-H20, D50-WPO20-H30 and D50-WPO40-O10, D50-WPO30-O20, D50-WPO20-O30 respectively with an objective to replace the usage of diesel by 50%. The performance, combustion and emission characteristics of these blends were analyzed for both alcohols separately in comparison with neat diesel and WPO operation. Experimental results indicated that, n-hexanol addition presented lower smoke and NOX emissions and higher HC emissions when compared to diesel. Addition of 20% n-octanol with ULSD/WPO blend reduced HC and CO emissions favourably when compared to both WPO and ULSD. Brake thermal efficiency (BTE) of the engine decreased with increasing higher alcohols fraction in the blends. But D50-W40-H10 blend shows better BTE and fuel consumption when compared to both WPO and diesel. This blend also enjoys lower peak pressure and presented lower smoke and CO emissions when compared to ULSD. Study revealed that addition of higher alcohols (by up to 20%) to ULSD/WPO blend could viable additive for diesel engines operating with WPO extracted from mixed waste plastic.

***Keywords:** Emission, Waste plastic oil, Hexanol, Octanol, Smoke, Diesel engine*

I. INTRODUCTION

In the contemporary society, growth in global energy demands is vast and extraction of energy from plastic is an attractive avenue to explore. The global production of plastics is increasing progressively due to its light weight characteristics and it is not affected by corrosion. However, plastics are non-biodegradable material and its disposal after usage is tedious task. On the other hand, the demand in cheap and environmentally friendly fuel for internal combustion engines is increasing to reduce the fossil fuels gradually. Waste plastics are obtained from petroleum products and hydrocarbons are recovered through thermo chemical process which can be re used as fuel. A high temperature, thermo chemical deposition is performed with the absence of oxygen. Catalysts like silica (SiO_2), alumina (Al_2O_3), silica-alumina, zeolites, FCC (Fluid catalytic cracking) catalyst and MCM-41 (Mobil Composition of Matter) are used to improve and influence the kinetics of thermal degradation to obtain waste plastic oil with high value product distribution. It is observed that soot emissions were generally on the higher side when the engine is operated with neat waste plastic oil or its blends. High soot emissions are usually attributed to the high aromatic content, high viscosity and low volatility of plastic oil. The percentage of aromatic compounds in WPO is usually high up to 55% which could result in the emission of toxic compounds both in the gaseous and particulate phases. Addition of oxygenated compounds like alcohols and esters can decrease fuel aromatics as well as fuel sulfur content in the blends. Attempts made to reduce the NO_X emissions usually employed exhaust gas recirculation (EGR) and retarded fuel injection that reduced the peak in-cylinder temperature which is chiefly responsible for thermal NO_X emissions. However, EGR and late injection both aggravated smoke emissions and also brought down fuel conversion efficiency and economy. Therefore, attempts were made to reduce smoke emissions by adding higher alcohols like n-hexanol and n-octanol with WPO. Addition of higher alcohols up to 15% with WPO was found to be beneficial with simultaneous reductions of

NO_X, smoke and CO emissions associated with an increase in brake thermal efficiency and un-affected fuel economy. But higher alcohols are not a naturally occurring biofuel and are currently produced by dehydration of ethanol which is derived from biomass feedstock. While addition of higher alcohols favourably decreased smoke emissions, it increased NO_X emissions.

Hence the use of an oxygenated bio-alcohol like n-hexanol and n-octanol could be beneficial to reduce harmful emissions from diesel engines fuelled with waste plastic oil or its blends. Studies have shown that reduction of smoke is strongly related to the oxygen-content of blends regardless of whether it is an ether or ester or alcohol. Adding n-hexanol and n-octanol has been used as one of the methods to improve diesel/biodiesel spray characteristics which can help the blends to burn efficiently. Further, its application as a bio-alcohol additive to WPO/diesel blends could be an advantageous strategy to improve the utilization of both a recycled component (WPO) and a renewable bio component (n-hexanol and n-octanol). Therefore, the present study attempts to substitute 50% by vol. of fossil diesel (D) with WPO (by up to 40% by vol.), n-hexanol (by up to 30% by vol.) and n-octanol (by up to 30% by vol.) by formulating three ternary blends of diesel /n hexanol / n-octanol/waste plastic oil. The effect of all these blends (D50-W40-H10, D50-W30-H20 and D50-W20-H30) and (D50-W40-O10, D50-W30-O20 and D50W20-O30) on performance and emissions of a DI diesel engine was then compared with both WPO and diesel for any improvements.

II. MATERIALS AND METHODS

n-hexanol (Analytical grade, CAS No: 108-93-0, Purity: 98%) and n-octanol (Analytical grade, CAS No: 111-87-5, Purity: 99%) is used as blend which are procured from a Merck Millipore, India. Ultra-low sulfur diesel (ULSD) is supplied by Shell petroleum, Chennai is used as fuel. WPO used in this study is extracted from mixed waste plastic using a laboratory scale pyrolysis unit. Mixed waste plastic is an assorted mix of PET (polyethylene terephthalate which includes water bottles, shampoo bottles and food containers), HDPE (high-density polyethylene which includes bottle caps, broken chairs, water pipes and engine oil containers), LDPE (low-density polyethylene which comprises plastic bags), PVC (polyvinyl chloride including broken pipes and containers), PP (polypropylene which includes ketchup bottles and stationery) and PS (polystyrene that includes disc cases and disposable food containers). Commercially available ZSM-5 (Zeolite Socony Mobil–5) heterogeneous catalyst is used for improving the reaction kinetics of the pyrolysis process.

A. Waste Plastic Oil Extraction By Pyrolysis

The schematic of the waste plastic pyrolysis extraction unit is shown in Fig. 1. The mixed waste plastic is intended to cut into small pieces with the size of 1–1.5 cm^2 roughly. The small pieces are then washed with water to remove the foreign particles and it is desiccated. After that, it is mixed with 10% by wt. of coal and 1% by wt. of ZSM-5 catalyst and fed into a 4-laboratory scale batch reactor. The mixture then undergoes pyrolysis in an inert nitrogen atmosphere in the absence of oxygen with the temperature constantly maintained at the range of 450–500ºC at atmospheric pressure using a PID controller. The process is allowed to continue for 4–5 hr and the plastic vapour emanating from the reactor is passed through a double walled condenser which uses water as a coolant. The condensate (waste plastic oil) is collected in a separate tank.

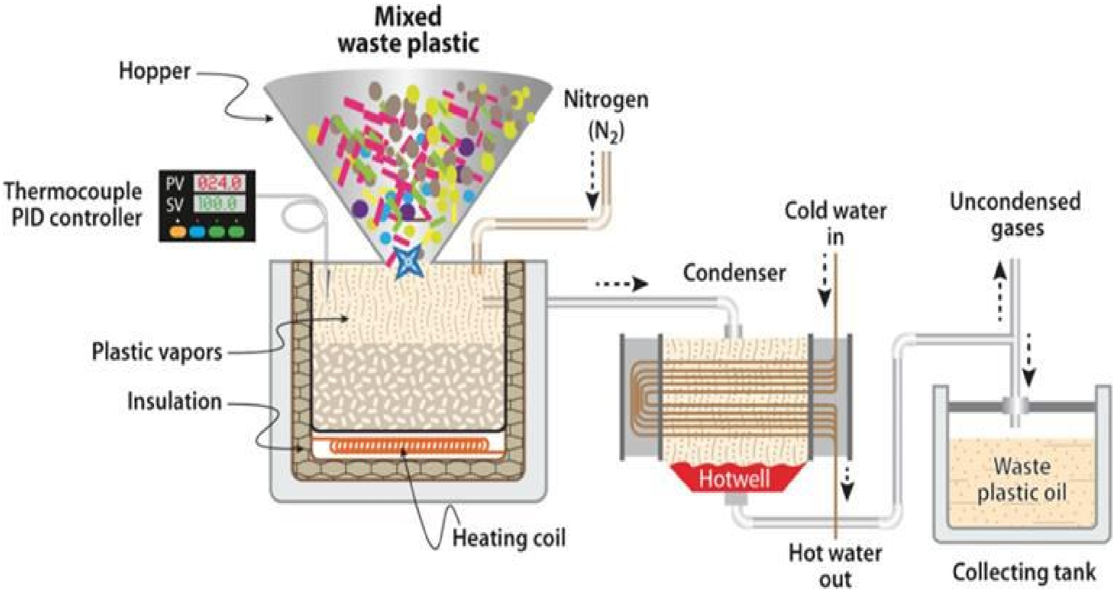


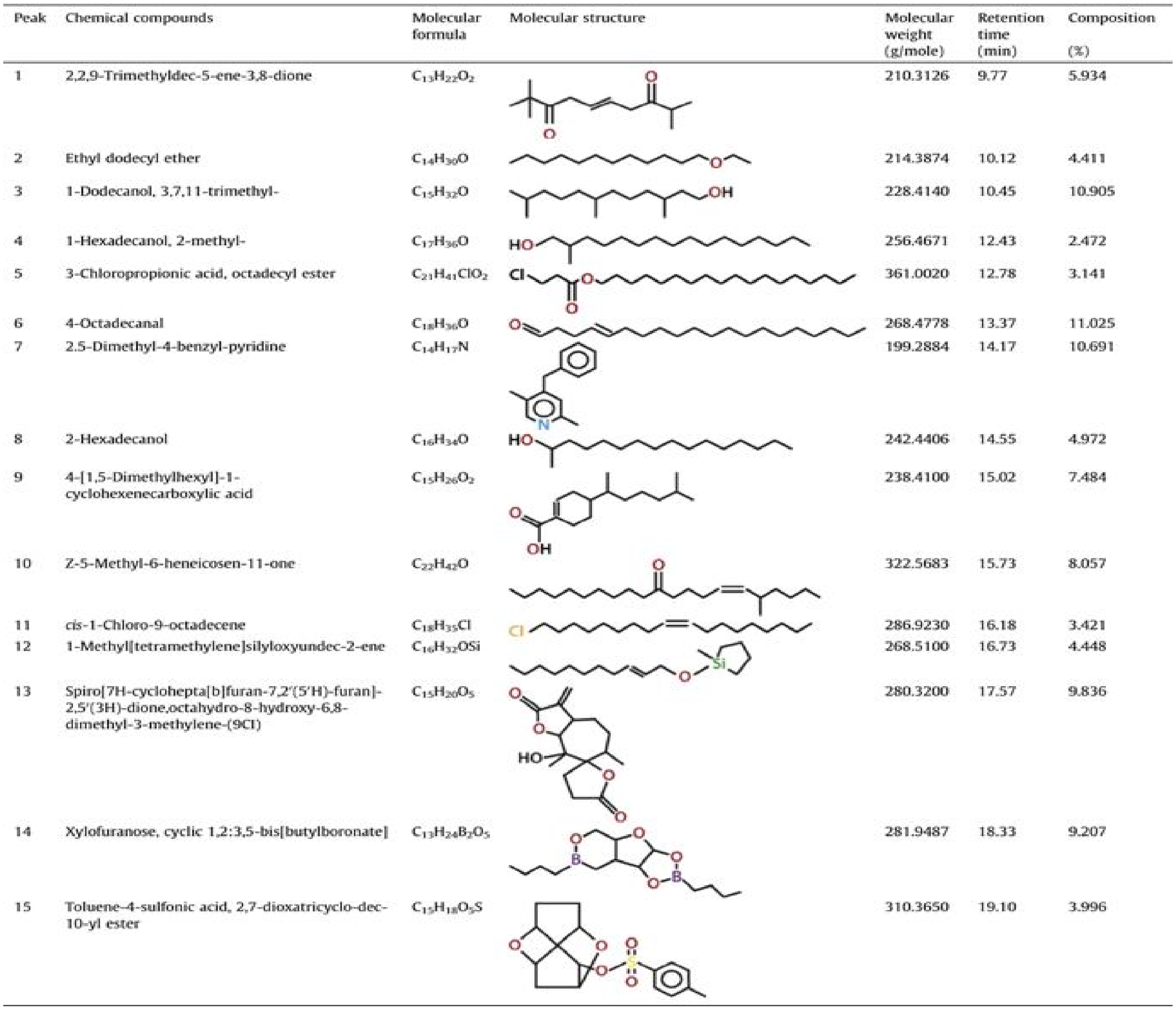
Fig.1. Schematic diagram of the waste plastic pyrolysis oil extraction unit.

B. Characterization of Waste Plastic Oil

The characterization of WPO is performed in the Sophisticated Analytical Instrument Facility (SAIF) in the Indian Institute of Technology, Madras. Gas chromatography/Mass Spectrometry (GC/MS) facility (MS Make: Jeol, Model: AccuTOF GCV, Mass range: 10–2000 amu with mass resolution of 6000 and GC Make: Agilent, Model: 7890 with FID detector and head space injector) is used to analyze the chemical compounds present in the WPO extracted. The sample oil is injected, and the spectra are compared with the NIST mass spectral library. The major chemical compounds present in WPO and their percentage composition are listed in Table 1. It can be seen that the WPO extracted consists of 15 compounds, of which 39% are aromatic compounds. Since one of the objectives is to replace fossil diesel by 50%, only the proportions of WPO and n-hexanol/n-octanol are varied. All blends are found to be stable without any phase separation after 2 months of observation at room temperature.

TABLE I

Major Chemical Compounds In Waste Plastic Oil And Their Compositions



Peak	Chemical compounds	Molecular formula	Molecular structure	Molecular weight (g/mole)	Retention time (min)	Composition (%)
1	2,2,9-Trimethyldec-5-ene-3,8-dione	$C_{13}H_{22}O_2$		210.3126	9.77	5.934
2	Ethyl dodecyl ether	$C_{14}H_{30}O$		214.3874	10.12	4.411
3	1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$		228.4140	10.45	10.905
4	1-Hexadecanol, 2-methyl-	$C_{17}H_{36}O$		256.4671	12.43	2.472
5	3-Chloropropionic acid, octadecyl ester	$C_{21}H_{41}ClO_2$		361.0020	12.78	3.141
6	4-Octadecanal	$C_{18}H_{36}O$		268.4778	13.37	11.025
7	2,5-Dimethyl-4-benzyl-pyridine	$C_{14}H_{17}N$		199.2884	14.17	10.691
8	2-Hexadecanol	$C_{16}H_{34}O$		242.4406	14.55	4.972
9	4-[1,5-Dimethylhexyl]-1-cyclohexenecarboxylic acid	$C_{15}H_{26}O_2$		238.4100	15.02	7.484
10	Z-5-Methyl-6-heneicosen-11-one	$C_{22}H_{42}O$		322.5683	15.73	8.057
11	*cis*-1-Chloro-9-octadecene	$C_{18}H_{35}Cl$		286.9230	16.18	3.421
12	1-Methyl[tetramethylene]silyloxyundec-2-ene	$C_{16}H_{32}OSi$		268.5100	16.73	4.448
13	Spiro[7H-cyclohepta[b]furan-7,2′(5′H)-furan]-2,5′(3H)-dione,octahydro-8-hydroxy-6,8-dimethyl-3-methylene-(9CI)	$C_{15}H_{20}O_5$		280.3200	17.57	9.836
14	Xylofuranose, cyclic 1,2:3,5-bis[butylboronate]	$C_{13}H_{24}B_2O_5$		281.9487	18.33	9.207
15	Toluene-4-sulfonic acid, 2,7-dioxatricyclo-dec-10-yl ester	$C_{15}H_{18}O_5S$		310.3650	19.10	3.996

The properties of the test fuels are estimated using American Society for Testing and Materials (ASTM) methods in the Polymeric Materials Research Laboratory at Alagappa College, Tamil Nadu and are presented in Table 2. Since the facility to determine cetane number of the test fuels using ASTM D613 method is not available with this laboratory, the cetane indices of the test fuels are estimated by using the four variable equation as specified by ASTM D4737 using the test fuel's density (estimated by ASTM D4052) and T10, T50 and T90 distillation points (estimated by ASTM D86).

TABLE II
Properties Of Test Fuels

Properties	Test method	ULSD	WPO	H	D50W40H10	D50W30H20	D50W20H30
LHV (MJ/kg)	ASTM D240	42.5	40.35	39.1	41.3	41.175	41.05
ν at 30°C (mm^2/s)	ASTM D445	2.72	2.16	5.32	2.756	3.072	3.388
ρ (kg/m3)	ASTM D4052	838	813	821.8	826.38	827.26	828.14
CCI	ASTM D4737	54	51	23	49.7	46.9	44.1
Flash point (°C)	ASTM D93	70	38	59	56.1	58.2	60.3

LHV – low heating value; ν – kinematic viscosity; ρ – density; CCI – calculated cetane index; WPO – waste plastic oil;
H – 1-hexanol; ULSD – ultra low sulphur diesel

Properties	Test method	ULSD	WPO	O	D50W40O10	D50W30O20	D50W20O30
LHV (MJ/kg)	ASTM D240	42.5	40.35	52.94	42.684	43.943	45.202
ν at 30°C (mm2/s)	ASTM D445	2.72	2.16	5.51	2.775	3.11	3.445
ρ (kg/m^3)	ASTM D4052	838	813	827	826.9	828.3	829.7
CCI	ASTM D4737	54	51	39	51.3	50.1	48.9
Flash point (°C)	ASTM D93	70	38	81	58.3	62.6	66.9

LHV – low heating value; ν – kinematic viscosity; ρ – density; CCI – calculated cetane index; WPO – waste plastic oil;
O – 1-octanol; ULSD – ultra low sulphur diesel

III.EXPERIMENTAL INVESTIGATION

A. Test Engine and Facilities

Tests are conducted in a 1-cylinder, constant-speed, 4-stroke, DI diesel engine which is widely used in Indian agricultural sector for pumping water to irrigate fields. The schematic layout of experimental setup is shown in Fig. 2.

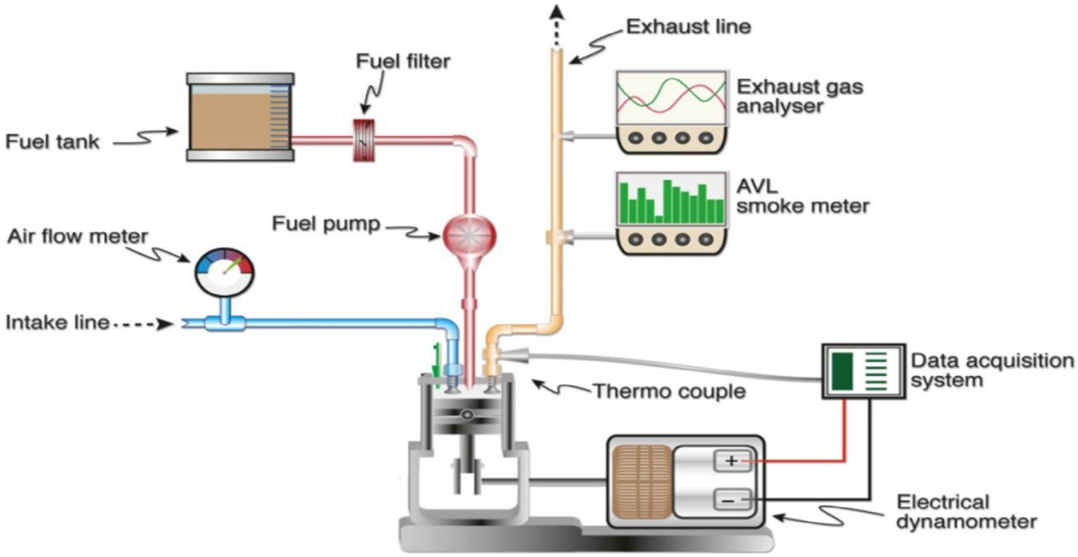


Fig. 2. Schematic diagram of experimental setup

B. Test Procedure

Engine tests are conducted at four load conditions at the brake mean effective pressures (BMEP) of 1.55, 3.1, 4.65 and 6.2 bar which correspond to 25, 50, 75 and 100% of the rated load respectively. All the trials are carried out in the same day at almost same ambient atmospheric conditions. The engine is operated at its standard injection timing of 23°CA bTDC and standard injection pressure of 21 MPa during the investigation. The lubricating oil temperature is kept between 85 and 90°C. Initially, the engine was run with diesel fuel and the reference readings are taken. The engine is always run for some time to allow for stabilization before recording the data. Before each refuelling with test blends, the engine is run to consume the fuel that stayed in the fuel supply system during the previous trial. Each test is repeated three times and the results are averaged. This is done to ensure that the obtained results are repeatable within the experimental uncertainties.

IV. RESULTS AND DISCUSSION

The performance, combustion and emission characteristics of the engine fuelled with D-W-H and D-W-O ternary blends are discussed with reference to baseline engine fuelled with fossil diesel (ULSD) and WPO operating under naturally aspirated conditions.

A. Performance analysis

The variation of BSFC and BTE with respect to engine load for all test fuels for D-W-H blends is shown in Fig. 3. It can be observed that addition of 10% of 1-hexanol to the ULSD/WPO blends improved BTE. Increase in 1-hexanol fraction in the blend, increases the density of the blends which may reduce the spray atomization and lower fuel vaporization which resulted in decreased efficiency. D50-W40-H10 and D50-W30-H20 delivered better performance than WPO and ULSD. There seen a general decrease in BSFC as the BMEP escalates and lowest for D50-W40-H10 blend at all loads. This may due to shorter ignition delay period when compared to other blends. There seen an increase in viscosity with increase of 1-hexanol fraction in the blend which results significant increase in BSFC. BSFC increases with increase in 1-hexanol in the blend since a greater number of blends are required to produce the same amount of power by the engine due to less energy content of 1-hexanol when compared to diesel.

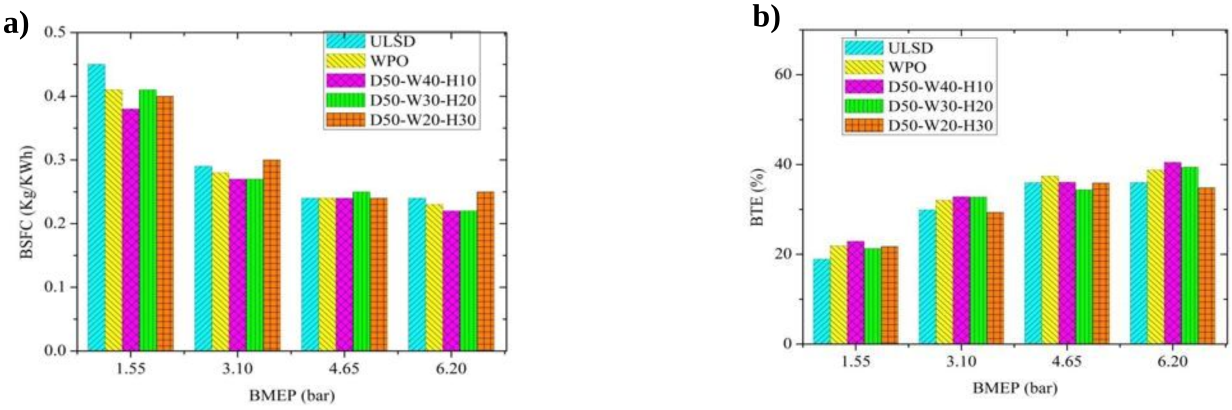


Fig. 3. Variation of BSFC and BTE with engine load for all test fuels for D-W-H ternary blends.

The variation of BTE and BSFC with all engine loads for D-W-O ternary blends are shown in Fig. 4. Addition of 1-octanol with ULSD/WPO blends shows a drop-in efficiency, since more energy is spent to breakdown the heavy hydrocarbon chains. BTE decreases with increase in viscosity and density of the ternary blends. Higher density predominates fuel atomization and mixing with air resulting poor combustion with reduced BTE. BTE of the blend D50-W40-O10 is found to be even better than ULSD. But D50-W40-H10 and D50-W30-H20 blends delivered that better performance than WPO, ULSD and other test fuels. From Fig. 4, there seen a general decrease in BSFC as the BMEP escalates and lowest for D50-W40-O10 blend at all loads this may due to shorter ignition delay period when compared to other blends. There seen an increase in viscosity with increase of 1-octanol fraction in the blend which results significant increase in BSFC. BSFC increases with increase in 1-octanol in the blend since a greater number of blends are required to produce the same amount of power by the engine due to less energy content of 1-octanol when compared to diesel. It is evident from the Fig. 4 that BSFC of WPO and D50-W30-O20/ D50-W20-O30 blends are almost equal to each other.

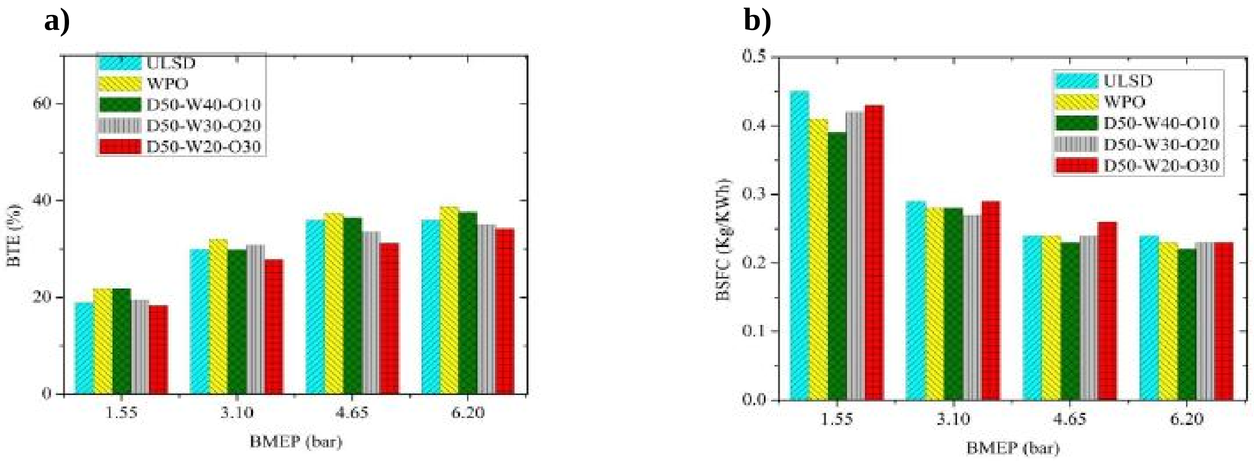


Fig. 4. Variation of BSFC and BTE with engine load for all test fuels for D-W-O ternary blends.

B. *Combustion analysis*

Combustion characteristics are analyzed based on in-cylinder pressure measurements. Heat release rates are deduced from the pressure data that is averaged over 100 cycles to minimize the effects of cycle-by-cycle variations. In this study, ignition delay is calculated as the difference between fuel injection timing and the timing at which 5% mass fraction of fuel is burnt. Combustion duration is taken as the difference between CA5 and the timing at which 90% mass fraction is burnt. Fig. 5 shows the variation of in-cylinder pressure and HRR vs crank angle for D-W-H ternary blends at rated speed of the engine.

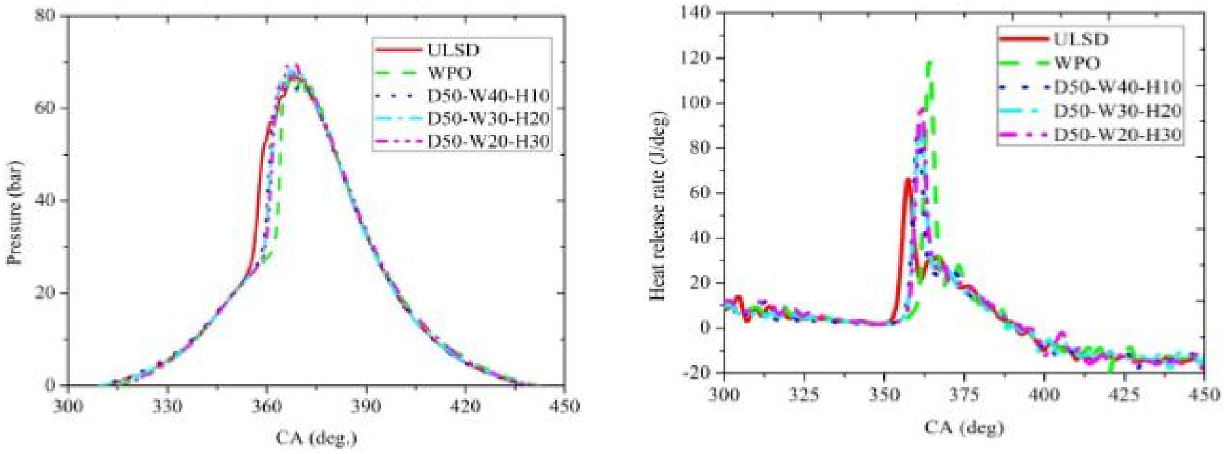


Fig. 5. Variation of in-cylinder pressure and HRR vs Crank angle at BMEP=6.2 bar and speed=1500 rpm for D-W-H ternary blends

It can be noted that ignition delay period and peak heat release rates of WPO was higher than ULSD and other blends, since more energy and more time were spent to breakdown the heavy hydrocarbons (C_{13} to C_{22}) and the major aromatic compounds which comprises more than 39% of the WPO. It is evident from the results that there is significant increase in ignition delay and peak pressure and peak heat release rate, more than diesel, when addition of 1-hexanol with ULSD/WPO blends. D-W-H ternary blends has lower cetane number than ULSD and hence the blends experience delayed auto-ignition and longer ignition delay. Longer ignition delay results in more fuel to be burnt during the premixed combustion phase which in-turn leads to faster burning rates. Hence, gradual addition of 1-hexanol to ULSD/WPO blends causes gradual increase in peak cylinder pressure and peak HRR. But ignition delay and peak HRR of the D-W-H ternary blends were lower than WPO, because WPO contains more heavy hydrocarbons and aromatic compounds than the blends. Since more energy is spent to breakdown the heavy hydrocarbons and aromatic compounds. Hence the lower viscosity property of the WPO implies better spray characteristics and fuel atomization which enhances the combustion process.

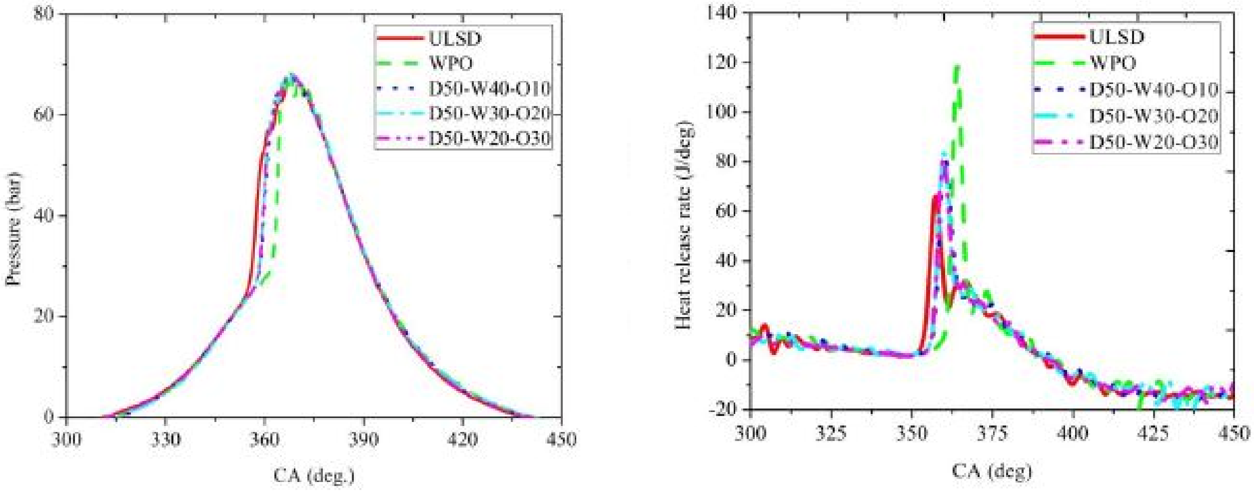


Fig. 6. Variation of in-cylinder pressure and HRR at BMEP=6.2 bar and speed=1500 rpm for D-W-O ternary blends

Fig. 6 shows the variation of pressure and HRR for D-W-O ternary blends in comparison with ULSD and WPO at rated power output of the engine. It can be seen that ignition delay of D-W-O ternary blends are slightly longer than ULSD. This is due to lower cetane number of 1-octanol than ULSD. Lower cetane number resists auto-ignition and prolongs the ignition delay. An increase in 1-octanol fraction in the blends lowers the cetane number and slightly extends the ignition delay. The increase in ignition delay causes more fuel to be burnt in the premixed combustion phase which increases the rate of pressure rise leading to a faster burning rate and shorter combustion duration with increased peak pressure and peak heat release rate. Hence, the addition of 1-octanol to ULSD/WPO blends causes a gradual increase in peak cylinder pressure and heat release as inferred from Table 2.

TABLE II
Combustion Parameters For All Test Fuels At BMEP = 6.2 BAR AND SPEED = 1500 RPM

Fuels	**Injection timing**	**Peak pressure P_{max}**	**Peak heat release rate HRR_{max}**
	°CA bTDC	Bar	J/°CA
ULSD	23	66.96	68.18
WPO	23	70.31	127.5
D50-W40-H10	23	65.65	93.68
D50-W30-H20	23	69.13	93.87
D50-W20-H30	23	71.15	101.35
D50-W40-O10	23	67.68	84.61
D50-W30-O20	23	68.43	87.62
D50-W20-O30	23	68.45	85.52

With respect to the different blending ratios, blends with higher 1-octanol fraction showed shorter combustion duration due to higher premixed combustion fraction caused by the longer ignition delay. From the analysis, it may be concluded that D50-W40-H10 shows the lowest peak pressure when compared with other test fuels (From Table. 2). It can be observed from Fig. 5 and Fig. 6 that the order ignition delay is (from shortest to longest): D-W-O ternary blends, D-W-H ternary blends, WPO. This order directly correlates to the decrease in ignition delays with increasing carbon chain length of all functional groups.

C. Emission analysis

1. *NO_X emissions and smoke opacity* As per the extended Zeldovich mechanism, thermal NO_X is formed at high temperatures (>1600°C) inside the engine cylinder when molecular nitrogen and oxygen undergo dissociation into their atomic states participating in a series of reactions which are as follows: $N_2 + O \rightarrow NO + N$ and $N + O_2 \rightarrow NO + O$. The variations of NO_X emissions with different engine loads for the D-WH ternary blends are shown in Fig. 7 (a). It can be seen that NO_X emissions of WPO increases gradually with increase in engine loads. This is due to fact that ignition delay period of WPO is longer than other test fuels. The increase in ignition delay causes more fuel to be burnt in the premixed combustion phase which increases high flame temperature which results in high NO_X. NO_X emission decreases gradually with increasing the 1-hexanol content in the ULSD/WPO blends. Generally, 1-hexanol has high latent heat of vaporization. Due to this property, addition of 1-hexanol content in the blend decreases the flame temperature which leads to cooling effect with subsequent decrease in NO_X emission. Fig. 7 (b) shows the variation of smoke opacity with different engine loads. It can be noticed that the smoke level for waste plastic oil is lower than diesel. The reason for the reduced smoke is the availability of premixed and homogeneous charge inside the engine well before the commencement of combustion. Higher combustion temperature, extended duration of combustion and rapid flame propagation are the other reasons for reduced smoke. However, at higher load range due to non-availability of sufficient air and abnormal combustion there was a visible white smoke emission. Another reason for lower smoke may be better and complete combustion of fuel due to the oxygen present in the waste plastic oil. When 1-hexanol is added to the WPO/ULSD blends, there is a considerable decrease in smoke opacity due to the increase in fuel-bound oxygen in the blends (via 1-hexanol) that improved oxygen availability even in fuel rich zones. Low smoke emissions due to additional oxygen content of 1-hexanol could also be evidenced from the lean burning nature of the ternary blends as shown in Fig. 7 (b).

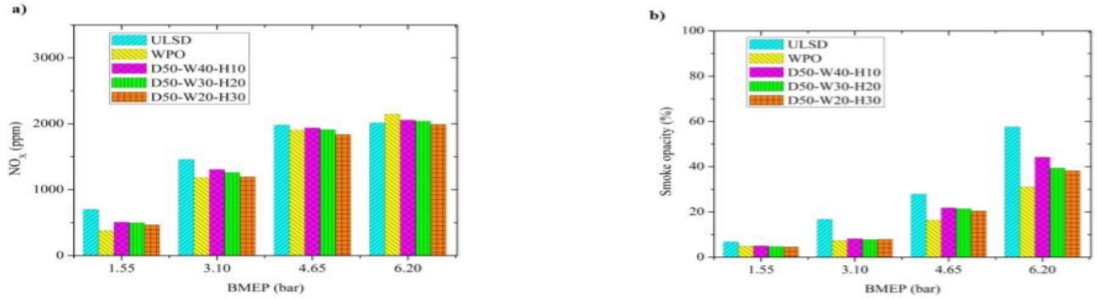


Fig. 7. Variation of (a) NOX emissions vs engine load and (b) smoke opacity vs engine load for D-W-H ternary blends

The variation of NO_X emissions for D-W-O ternary blends with different engine loads are shown in Fig. 8 (a). NO_X emission decreases gradually with increasing the 1-hexanol content in the ULSD/WPO blends. Generally, 1-octanol have high latent heat of vaporization. Due to this property, addition of 1-octanol content, up to 20 %, in the blend decreases the flame temperature which leads to cooling effect with subsequent decrease in NO_X emission. After addition of 30 % of 1-octanol content in the ULSD/WPO blends, NO_X emissions are slightly increased.

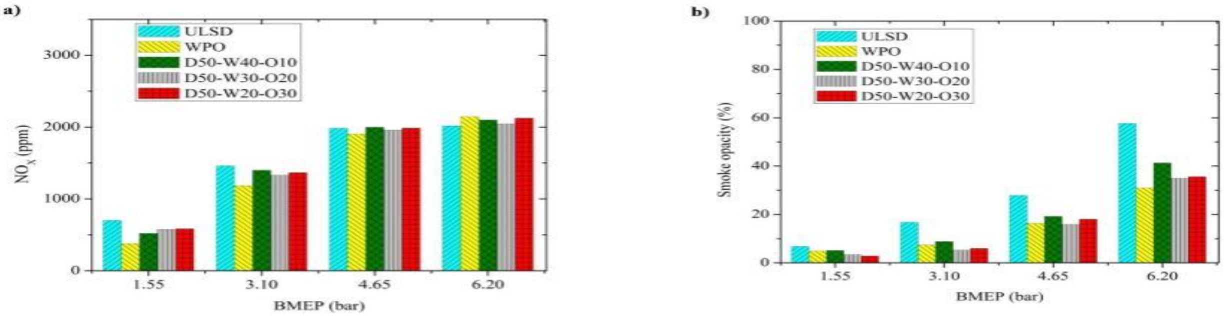


Fig. 8. Variation of (a) NOX emissions vs engine load (b) smoke opacity vs engine load for D-W-O ternary blends

Fig. 8 (b) shows the variation of smoke opacity with all engine loads for D-W-O ternary blends. When the addition of 1-octanol, up to 20%, with the WPO/ULSD blends, there is slight decrease in smoke opacity levels. After addition of 30% of octanol with the blends, smoke opacity levels are increased at medium and high loads.

V. CONCLUSION

Waste plastic oil (WPO) is extracted from mixed waste plastic by pyrolysis using ZSM-5 as a catalyst. The properties of WPO determined using ASTM methods are found to be closer to ULSD. With the aim to replace the fossil diesel partially by 50%, ternary blend is prepared with diesel/waste plastic oil/ 1-hexanol and the blend components is designated as D50-W40-H10, D50-W30-H20, D50-W20-H30. Test are conducted in a light duty direct injection diesel engine and following conclusions are made:

A. At all load conditions D50-W40-H10 shows higher brake thermal efficiency and lower BSFC, about 11% increase in BTE and 8% decrease in BSFC has been noted when compared sole diesel.

B. Analyzing combustion characteristics of the test fuels, D50-W40-H10 enjoys the lowest peak pressure about 2% decrease in peak pressure have been noted against neat diesel. Neat WPO oil shown highest heat release rate when compared to sole diesel about 46% increase in HRR have been noted, also while comparing with blends D50-W20-H30 shows highest peak HRR against diesel, about 33% increase in HRR have been reported.

C. At peak load condition, D50-W20-H30 shows the lowest emission of NO_X about 1.2% decrease in NO_X on comparing with diesel.

D. At peak load condition, D50-W20-H30 shows lower smoke emission among all blends about 34% lower than diesel and also WPO shows the lowest smoke emission.

With the aim to replace the fossil diesel partially by 50%, ternary blend is prepared with diesel/waste plastic oil/ 1-octanol and the blend components is designated as D50-W40-O10, D50-W30-O20, D50-W20-O30.Test are conducted in a light duty direct injection diesel engine and following conclusions are made

1) At all load conditions, D50-W40-O10 shows higher brake thermal efficiency and lower BSFC, about 4.5% increase in BTE and 8% decrease in BSFC has been noted when compared sole diesel. Analyzing combustion characteristics of the test fuels, diesel enjoys the lowest peak pressure while octanol blends have nearest peak pressure to diesel. Neat WPO oil shown highest heat release rate when compared to sole diesel about 46% increase in HRR have been noted, also while comparing with blends D50-W30-O20 shows highest peak HRR against diesel, about 23% increase in HRR have been reported.

2) At peak load condition, diesel shows the lowest emission of NOX. On comparing among blends D50-W30-O20 shows the lower emission which is 1.5% slightly increase on comparing with diesel.

3) At peak load condition, D50-W30-O20 shows lower smoke emission among all blends about 35% lower than diesel and also WPO shows the lowest smoke emission.

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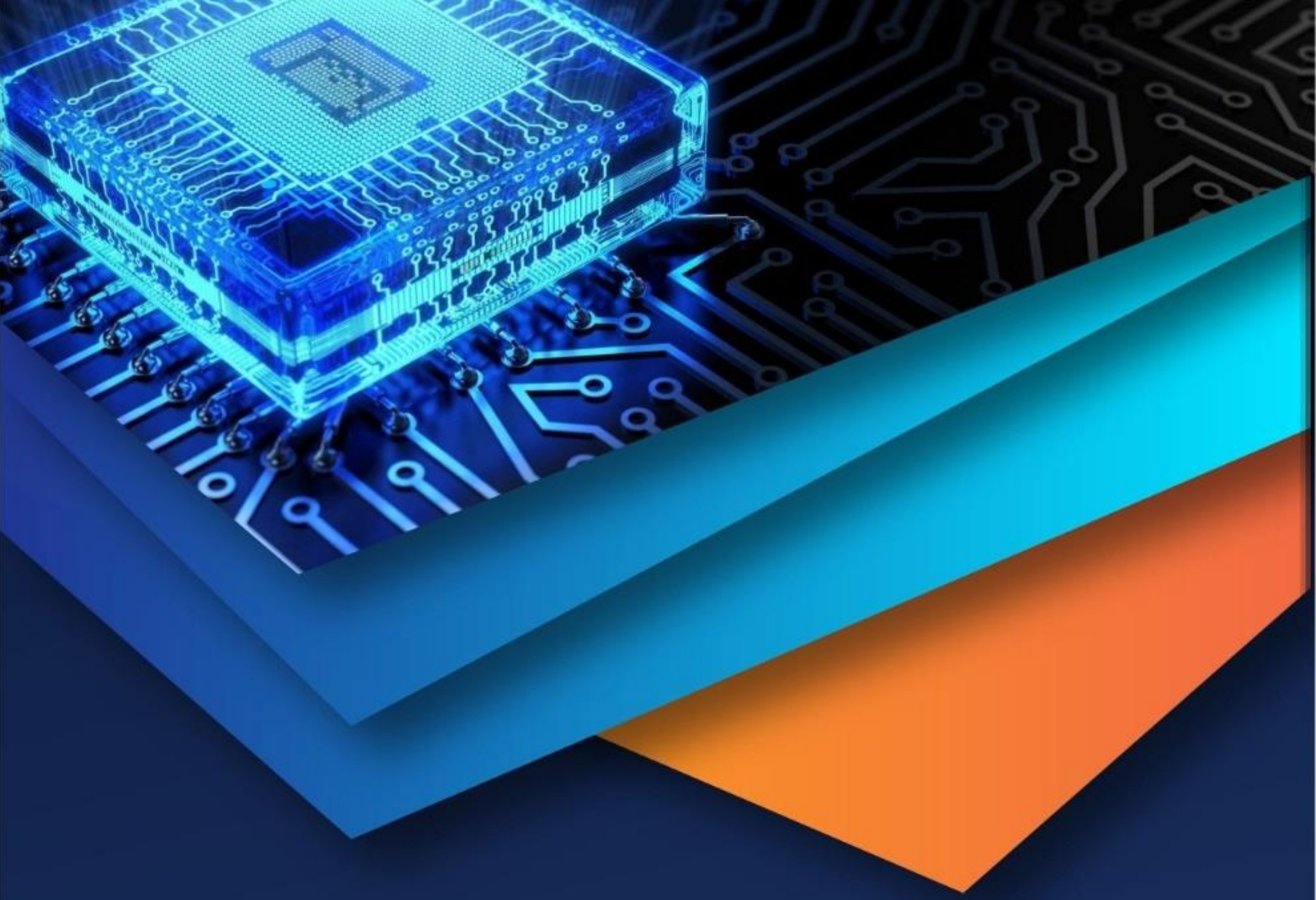

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