INVESTIGATION OF THE PERFORMANCE, COMBUSTION PARAMETERS, AND EMISSIONS ANALYSIS ON DI ENGINE USING TWO STAGED DISTILLED WASTE PLASTIC OIL-DIESEL BLENDS

by

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Waste plastic oil and tyre oil are alternative supplements for Diesel engines and also they can decrease the use of fossil fuels. This study focused on experimentations with Diesel engine using blends of two different categorized distilled waste plastic oil and desulphurized tyre and plastic oil. Initially, crude waste plastic oil was obtained through pyrolysis reactor. After extraction, it was distilled into two different forms of waste plastic oils. The properties of extracted oils were evaluated and compared with those of diesel standard fuel. From investigations, it became clear that the brake thermal efficiency and specific fuel consumption of first stage distilled blends were closer to diesel values than the other samples. In respect of emission, the increased NO, CO, and unburnt HC were recorded with increase in the blending ratio. The diesel emitted about 2354 ppm of NO_x, 0.136 vol.% of CO, and 59 ppm of unburnt HC while rich blends of distilled oils produced 2440 ppm of NO_x, 0.162 vol.% of CO, and 64 ppm of unburnt HC. Based on the results, upto 30 vol.% of distilled waste plastic oil blends could be used in Diesel engine without modification. Beyond 30 vol.% of blends, unstable combustion occurred and engine vibration increased during higher loads.

Key words: *waste plastic oil, tyre pyrolysis oil, distillation, DI engine*

Introduction

The use of Diesel engine is increasing gradually due to advancements and enlargement in fields like transport, farming, construction, and industrial sectors. Because of larger applications, huge shortage may occur in future for crude oil [1]. Several issues are being faced related to utilization of automotive engine due to depletion of crude oil resources, frequent hike in prices and pollutions aspects [2]. These worrisome scenarios have led to research on alternative fuels for automotive engines. Subsequently, investigations were carried out on various alternatives such as biofuels, synthetic fuels, fuels from wastes, *etc*. for minimizing the use of fossil fuels [3]. It has been reported that many alternative produce noxious emissions with several pollutants which are classified as regulated (NO_x, CO, HC, particulate matter) and unregulated (formaldehyde, benzene, toluene, xylene (BTX), aldehydes, SO_2, CO_2, methane, *etc*.) [4, 5]. These pollutants also produce adverse effects on humans which include heart disorders, nervous system damages, forming of carboxy-hemoglobin, irritation in respiratory tract,

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drowsiness, eye irritation, and coughing [5-8]. Moreover, it has been assured that waste plastic oil (WPO) is one of the potentially suitable sources for Diesel engines [9]. The plastics are inexhaustible energy sources and they are continuously used in many sectors such as automotive, agriculture, house hold, and packing sectors [10-12]. Many plastics are being used commercially which include polyethylene (PE), polypropylene (PP), polyethylene teraphlate (PET), polyvinyl chloride (PVC) and poly stirene (PS). The PE and PP are used mostly in the packing industry. Along with rapid growth of plastic utilization, the disposal of plastic wastes is another issue which is directly connected with environmental pollutions [13]. Owing to its non-degradable nature, the environmental pollution increases every day. Pollution assumes such alarming proportion that most of the governments in and around the world have started advising the people to minimize the use of plastic materials. On the other hand, some of the recycling techniques are being used to convert the waste plastics into useful materials. The techniques are pyrolysis (both thermally, and catalytically), coprocessing, fluidized cracking and gasification. Pyrolysis is one of the promising approaches to separate the solid waste into gas, liquid and char. The pyro-gas can be used for heat generation, pyro-oil (complex mixtures of paraffins, olefins, and aromatic compounds) is used as fuel or addition to petroleum products. The solid char consists of carbon block and minerals which are utilized to make many chemicals [14, 15]. The conversion rate and the quality of pyrolysis oil depend on its functional parameters such as residence time, reaction temperature, reactor design, reaction pressure and catalysts [14, 16, 17]. Use of waste plastic oil (WPO) with diesel blends in DI engine led to increase in the various compositions of emission such as NO_x, unburnt HC, CO, and smoke. Also the brake thermal efficiency (BTE) got increased with WPO operations more than diesel [18, 19]. Addition of oxygenates to WPO resulted in the reduction of emissions of NO_x, CO, and smoke [20]. Similar to the WPO extraction, the fuel oil from tyre has been used as alternative supplement for IC engines [21, 22]. The study was done with tyre pyrolysis oil (TPO) with diesel blends on DI engine which resulted in increased thermal efficiency and emissions compared with diesel operations. The emission consisted of more NO_x, HC, and CO concentration. But distilled tyre pyrolysis oil (DTPO) with diesel in various blends on DI engine was found to reduce emissions and increase thermal efficiency better than raw TPO blends [23].

The present study focused on the extraction of fuel oil from the mixed waste plastics (60 wt.% of PE and 40 wt.% of PP). After extraction, it was processed with distillation unit on two different stages, and then was blended with diesel in various blending ratios. Also the oil from waste tyre scraps was extracted through pyrolysis and it was processed through desulphurization to remove carbon particles and other impurities. The blends of distilled WPO and mixed desulphurized tyre oil with plastic oil were tested for performance, combustion, and emission analysis on DI engine. The results were compared with the samples and diesel standard values. This is an attempt to mix the two different waste oils together and analyze the engine parameters. Because the tyre oil had higher value of carbon and sulphur content significantly, desulphurized tyre oil was mixed with WPO to reduce the impact of carbon particles and sulphur content.

Materials and methods

The WPO preparation

The house hold plastic wastes were collected and all other foreign materials were removed to restrict the unwanted reactions. About 60 wt.% of PE and 40 wt.% of PP were mixed together and filled in fixed bed reactor. The reactor made of mild steel has dimension of 160 mm diameter and 300 mm height. The Cu coil was wound with a capacity of 2.5 kW and connected with PID controller. The K-type thermocouples were fixed in the reactor for measuring temperature. Also mild steel horizontal counter flow condenser was attached to the reactor. The optimized reaction temperature was fixed between 360 °C and 450 °C with atmosphere pressure conditions. The schematic diagram of pyrolysis set-up is given in fig. 1. After obtaining oil from tyre pyrolyis, it was purified with desulphurization techniques to remove the carbon, sulphur and impurities [22]. The 8 vol.% of sulphuric acid was mixed with raw mixed T & WPO and stirred with magnetic stirrer for 15 minutes and then the mixture was kept for 45 hours. There were two layers formed in which the first-layer consisted of light oil and the second-layer consisted of heavy oil with impurities. The quantity of first-layer measured about 85 vol.% . Another purification process was done by distillation process through distillation column for WPO. Five litres of raw WPO was filled into fractional column and heated upto 500 °C. The fractions were separated in two stages, first stage between 140 °C and 210 °C, and second stage between 210 °C and 340 °C. The spiral type condenser was used and vacuum pump was fitted with the column to suck the vapor of two fractions. The measured fractions were about 45 vol.% at first stage, 35 vol.% at second stage and non condensable volatile gas about 4-5 vol.%. The remaining volume stayed back in the column as heavy oil.

Using the mentioned fuels, namely WPO, deT&PO, D1WPO, and D2WPO, the samples were prepared for engine testing which were named as WPO10, WPO30, deT&PO10, deT&PO30, D1WPO10, D1WPO30, D2WPO10, and D2WPO30. The WPO10 indicates 10 vol.% of WPO and 90 vol.% of diesel and the other mentioned samples have similar meanings. The basic fuel properties of raw samples and mentioned blends are given in tab. 1.

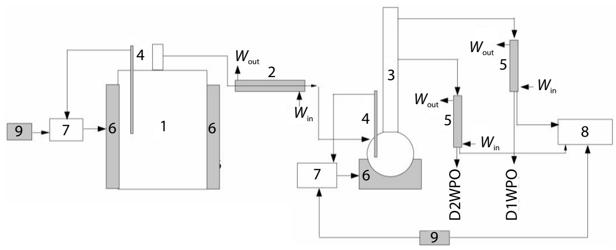

Figure 1. Pyrolysis reactor with distillation set-up;
1 – pyrolysis reactor, 2 – counter flow condenser, 3 – distillation column, 4 – thermocouple, 5 – spiral condenser, 6 – heater, 7 – PID controller, 8 – vacuum pump with controller, 9 – power supply

Table 1. Properties of various fuel samples

	Testing methods	Diesel	WPO	T&PO	deT&PO	D1WPO	D2WPO
Density, [kgm^{-3}]	IS 1448 P 32	832	1080	1070	1015	1160	1110
Kinematic viscosity, [CST]	IS1448P25	3.05	1.87	2.16	1.72	Not detected	Not detected
Net calorific value, [kJkg^{-1}]	Bomb colorimeter	42342.3	39712.5	39218.64	38410.43	44610.87	42604.89
Flash point, [°C]	IS 1448 P 69	50	41	43	50	<30	34
Fire point, [°C]	IS 1448 P 69	56	45	45	55	<30	38
Acid value	IS 1448 P2	0.5	2.79	4.3	7.62	1.78	3.56
Sulphur content, [%]	IS 1448 P 33	0.045	0.35	0.55	0.14	0.13	0.08
Cetane number	IS 15607 : 2005	55	50	52	48	42	37

The WPO properties

From tab. 1, it is clear that the density of all virgin oils is higher than that of diesel, mainly distilled products such as D1WPO and D2WPO. As regards kinematic viscosity, all the samples have lower values than diesel. Particularly, D1WPO, D2WPO, and their blends were reported too low compared with diesel. Lower viscosity leads to leakages in fuel systems and earlier delivery from the injector. This may lead to unstable combustion process due to insufficient fuel delivery. The net calorific value of various virgin WPO was lower than that of standard diesel. The flash and the fire points of distilled WPO were lower than those of diesel and other raw oils. The acid value of all oil samples was higher than that of diesel.

Experimentation

The schematic diagram of engine testing set-up is shown in fig. 2. The eddy current dynamometer was used for providing various loads. Two different flow sensors were used to measure the fuel, and air-flow to engine. The pressure transducer was fitted on the engine cylinder and the injector to measure the engine pressure and injection pressure. For the measuring of cylinder pressure, the piezoelectric sensor was mounted at cylinder where thermal stresses were low and the heat release rate (HRR) was measured using cylinder pressure by engine software. The K-type thermocouples were fixed at various places such as exhaust gas outlet, water inlet and outlet, *etc*. Two rotometers were used to measure the water-flow into both engine and calorimeter. The AVL gas analyzer was used to measure the CO, HC, CO_2, O_2, and NO emissions.

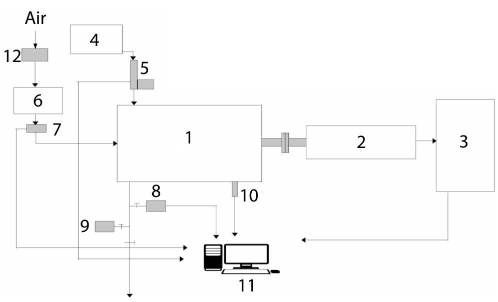

Figure 2. Schematic diagram of engine set-up with loading system; *1 – DI engine, 2 – dynamometer, 3 – control panel, 4 – fuel tank, 5 – fuel flow sensor, 6 – filter unit, 7 – air flow sensor, 8 – exaust gas analyzer, 9 – smoke meter, 10 – pressure transducer, 11 – computer, 12 – air box*

Also AVL smoke meter was used to measure the opacity of smoke. The engine was operated using diesel after every sample was tested which could flush out and avoid the dominance of previous samples. The entire tests were carried out with 1500 rpm. The specifications of the DI engine are given in tab. 2.

The maximum percentage of uncertainty of experiment was obtained by eq. (1) referred in [19].

$$U = \sqrt{\sum_{i=1}^{n} X_i^2} \tag{1}$$

where U is the total uncertainty and x is individual uncertainty of various factors which are given in tab. 3. The total uncertainty percentage was obtained as ±1.99.

Results and discussion

Performance

Brake thermal efficiency

Thermal energy of any fuel is indicated by BTE when it used in engine. Variations in BTE with brake power for different WPO and their blends are shown in fig. 3. During full loading condition, the BTE of diesel, WPO10, WPO30, D1WPO10, D1WPO30, D2WPO10, D2WPO30, deT&PO10, and deT&PO30 were recorded about 35.07, 33.55, 31.22, 35.45,

Table 2. Diesel engine specification

Product	Single-cylinder, 4-stroke, water cooled, diesel (computerized)
Engine	Make Kirloskar, Model TV1, Type single-cylinder, 4-stroke diesel, water cooled, power 5.2 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cm^3, compresion ratio 17.5.
In-cylinder	Stroke length 110 mm, bore diameter 87.5 and 661 cm^3
Dynamometer	Type eddy current, water cooled, propeller shaft with universal joints
Air box	M S fabricated with orifice meter and manometer
Fuel tank	Capacity 15 L with glass fuel metering column
Calorimeter	Type pipe in pipe
Piezo sensor	Combustion: range 350 bar, diesel line: range 350 bar with low noise cable
Crank angle sensor	Resolution 1°, speed 5500 rpm with TDC pulse
Data acquisition device	NI USB-6210, 16-bit, 250 kS/s
Piezo powering unit	Model AX-409.
Temperature sensor	Type RTD, PT100 and Thermocouple, K-Type
Temperature transmitter	Type two wire, input RTD PT100, range 0-100 °C, I/P Thermocouple, range 0-1200 °C, O/P 4-20 mA
Load indicator	Digital, range 0-50 Kg, supply 230VAC
Load sensor load cell	Type strain gauge, range 0-50 kg
Fuel-flow transmitter	DP transmitter, range 0-500 mm WC
Air-flow transmitter	Pressure transmitter, range (–) 250 mm WC Software *Enginesoft* engine performance analysis software
Rotameter	Engine cooling 40-400 LPH; calorimeter 25-250 LPH
Exhaust gas analyzer	Make: AVL, range O_2: 0-22 vol%, CO:0-10 vol.%, CO_2: 0-20 vol.%, HC: 0-20000ppm, NO_x: 0-5000 ppm.

Table 3. Equipment with uncertainties

Instrument	Uncertainty in %	S. No.	Instrument	Uncertainty in %
Pressure transducer	±1	6	Fuel-flow sensor	±0.5
Crank angle encoder	±0.2	7	Air-flow sensor	±0.5
Load cell (Strain gauge)	±0.2	8	AVL di-gas analyzer CO_2	±1
Speed sensor	±0.1	9	CO, HC, O_2, NO_x, AVL smoke meter	±0.3,±0.1,±0.15, ±0.5,±1, respectively
Thermocouple K-type	±0.15			

36.38, 34.6, 36.47, 32.01, and 32.1%, respectively. At 25% of loads, it was 19.77, 18.59, 17.91, 20.63, 21.53, 21.11, 22.18, 21.65, and 19.61%, respectively. The BTE of both raw WPO and deT&PO blends were lower than that of diesel, whereas distilled WPO blends were found to have higher than diesel. Lower BTE is mairly due to higher exhaust gas temperature and higher density with raw WPO, and deT&PO blends compared with diesel. But due to lower viscosity, the D1WPO and D2WPO blends produced better atomization which led to higher BTE than diesel. Also high concentration of alcohol and aliphatic iodo and chloro compounds in distilled WPO is shown in fig. 2. The BTE increased with increase of blending proportions for all the sample blends. Moreover, restarting problem occurred when the blends of distilled WPO were

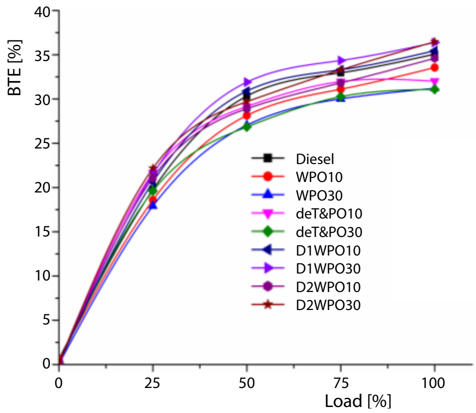

Figure 3. The BTE with various samples

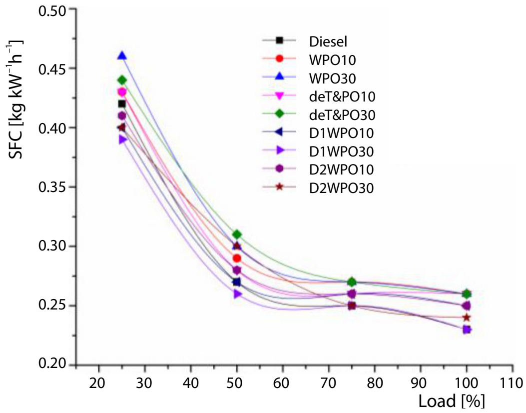

Figure 4. The SFC with different samples

increased beyond 50 vol.%. This was due to higher density and lower viscosity which led to leakages in fuel system and narrow down flame structure. The narrowing and dipper flame structure caused the improper mixing of fuel and air.

Specific fuel consumption

The SFC is a measure of conversion of thermal shaft power by combusting fuel per cycle, by the engine. Normally, the specific fuel consumption (SFC) is correlated with density, viscosity and calorific value of fuel. Larger viscosity can affect the vaporization and atomization of fuel mixture which could lead to incomplete combustion. Lower density and higher calorific value indicate the higher energy content presence in the fuel which injects lesser fuel during cycle operations. Generally, SFC increases with increase of loads because quantity of fuel injected to engine is increased to compensate increasing loads. Figure 4 shows the comparative perception of SFC between various categories of WPO blends and diesel values. The SFC with diesel recorded about 0.42 kg/kWh at lower loads and 0.23 kg/kWh at full loads. As regards raw WPO blends, SFC increased with blending proportions and loads. This was because of the lower calorific value of raw WPO given in tab. 1. Also the deT&PO blends gave almost similar values of raw WPO values. But SFC with D1WPO10 was observed to be 0.40 kg/kWh at lower loads and 0.25 kg/kWh at full loads. These values were slightly lower than that of diesel. This was due to higher density and calorific values of D1WPO compared with diesel. Also, increasing the ratio of D1WPO in blends led to decrease in the SFC further which is shown in fig. 4. The SFC of D2WPO10 was nearly identical with diesel values. From these SFC values, it was concluded that the engine consumed lesser fuel when distilled WPO was used.

Combustion parameters

Pressure variation in cylinder

The variations of cylinder pressure for various WPO blends and diesel at full load are shown in fig. 5. From the experiment, it was observed that higher cylinder pressure was obtained with all the WPO than diesel fuel. Also, it increased with increase of blending proportions. The cylinder peak pressures for diesel, WPO10, WPO30, D1WPO10, D1WPO30, D2WPO10, and D2WPO30 were observed to be 66.28, 67.35, 70.88, 67.26, 70.95, 68.39, and 72 bar at 100% of load. Also, it was obvious that the cylinder pressure increased with increase of loads.

From this investigation, it became clear that the maximum peak pressure (obtained from engine software) was noticed with D1WPO and D2WPO blends compared with raw WPO. Also larger fluctuation was found with cylinder pressure curve especially with all WPO blends. This was mainly because of the ignition delay caused by lower cetane number of the fuel, combustion abnormality and fuel non-homogeneity. Normally, late ignition leads to late combustion which causes the premixed burning. This was the main reason for the higher HRR rate shown in fig. 6.

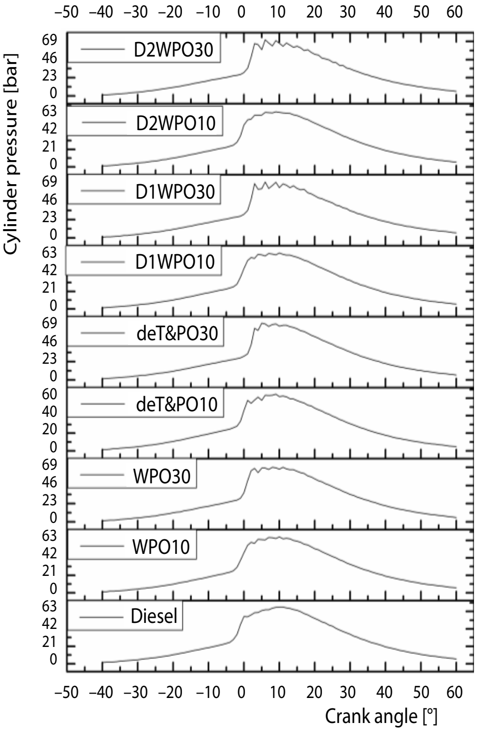

Figure 5. Cylinder pressure at 100% load

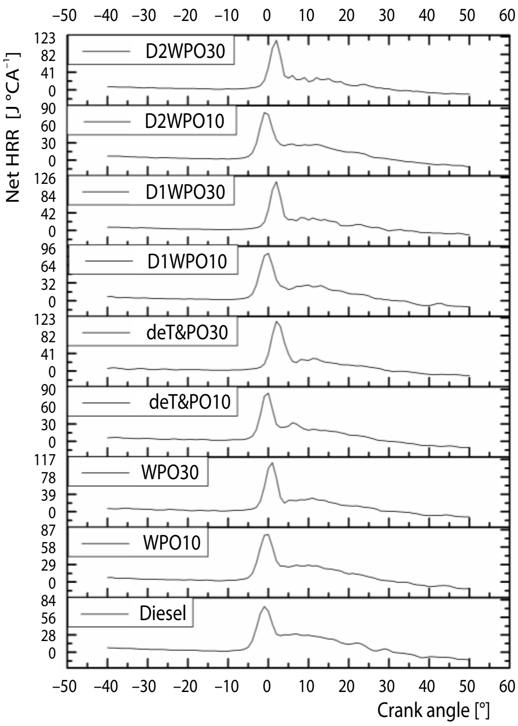

Figure 6. Net HRR at 100% load

Heat release rate

Figure 6 shows the net HRR for all the blends at full engine loads. It was observed that the ignition delay with all the blends of WPO was longer than diesel. This was due to rapid premixed burning carried out after diffusive combustion which released the higher rate of heat. The heat release due to premixed combustion influenced the increase of both cylinder pressure and peak pressure [24]. The maximum net HRR for diesel, WPO10, WPO30, D1WPO10, D1WPO30, D2WPO10, and D2WPO30 were reported to be 73.51, 79.14, 110.08, 85.17, 115.46, 79.08, and 114.30 J/CA at 100% load. The curves of HRR for diesel and lean blends (WPO10, deT&PO10, D1WPO10, and D2WPO10) are shorter and broader which indicate lower heat release and longer combustion duration. But in case of rich blends (WPO30, deT&PO30, D1WPO30, and D2WPO30), curves are sharper and leaner which indicate the higher heat release and shorter combustion duration. Also, the high aromatic content with WPO has greater adiabatic flame temperature which results in high HRR. Another reason for higher HRR is more oxygen content in WPO and tyre oil which improves the volatile combustion that leads to higher HRR [25, 26].

Emissions

Figure 7 shows the NO_x variations with different loads among various WPO blends. The NO_x in emission with different samples such as diesel, WPO10, WPO30, D1WPO10, D1WPO30, D2WPO10, D2WPO30, deT&PO10, and deT&PO30 was recorded as 2354, 2375, 2541, 2365, 2480, 2369, 2482, 2380, and 2529 ppm, respectively, at 100% load, whereas 445, 495, 672, 449, 565, 451, 578, 451, and 584, respectively, at 25% of load. This investigation revealed that the NO_x increased with increasing loads for all the WPO blending proportions. Also, formation of NO_x strongly influenced the ignition delay which caused lower cetane number of fuel and non-homogeneity of fuel mixture. Due to this delayed ignition, the NO_x formation was promoted in two different ways, first one was late combustion which released higher heat resulting in a higher NO_x in emission. On the other hand, the premixed combustion was engaged which also was the other reason to increase NO_x formation. Normally, all the WPO have larger aromatic contents which cause higher heat release during premixed combustion to form more NO_x in emissions.

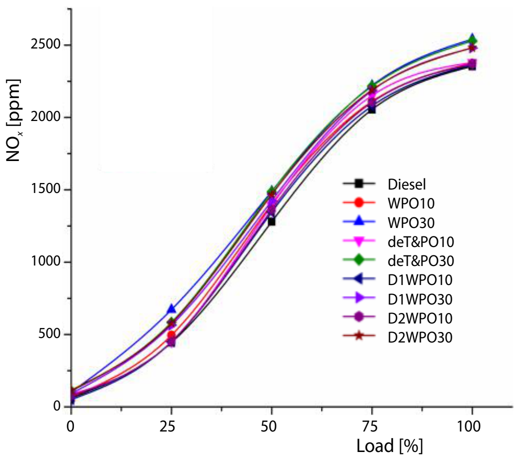

Figure 7. The NO_x with different loads

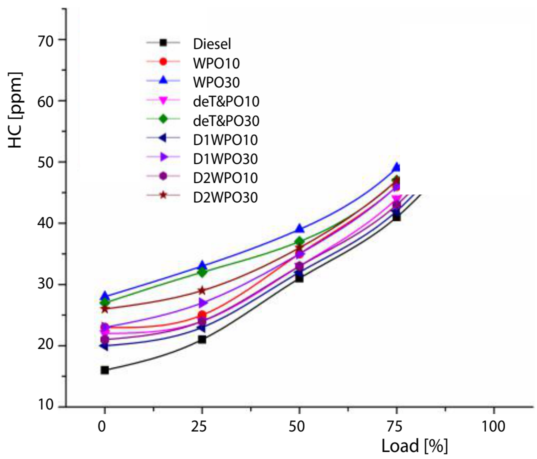

Figure 8. The HC with different loads

Hydrocarbon

Due to incomplete combustion, the organic fuel molecules are exhausted in the emission. The HC is in the gaseous state as well as solidstate (particle matter) in emission which produces adverse effects on human health particularly respiratory system [27, 28]. Figure 8 shows the unburnt HC variations with different samples. It is noticed that HC concentration increases with loads, because of the presence of some insufficient oxygen that causes the rich mixture to burn. The diesel emits the HC about 18 ppm at lower load and 59 ppm at full load, whereas WPO10 and WPO30 produce about 64 ppm and 69 ppm at full load. The HC emission with deT&PO 10 and deT&30 are a little lower than raw WPO blends about 63 ppm and 66 ppm at full load. This is due to desulphurization and more oxygen present in tyre oil. For distilled WPO blends, it also increased with increase of its blending ratio. Emissions of D1WPO10 and D1WPO30 were found to be 61 ppm and 64 ppm at full load. Another distilled product D2WPO10 and D2WPO30 emitted 62 ppm and 64 ppm at full load. Normally, most of alternative fuel blends produce higher HC emission because of non homogeneity fuel and unsaturated HC present in the fuel.

Carbon monoxide

Generally, CO is toxic and considered under regulated emissions. The CO in emission indicates the incomplete combustion and it must be reduced by converting CO into CO_2 when it reacts under 1200 °C. The CO emission is mainly due to shortage of oxygen, poor mixture and poor air entrainment. In fig. 9, it is clear that CO emission increases in the case of all the WPO operations. At minimum load (25%), CO is higher than medium loads such as 50% and 75%, but lower than maximum load. This is because of lower cylinder temperature that causes increase in CO contents, but during medium loads (50 and 75%) fuel air mixture is lean which helps to complete the combustion. During maximum loading condition, the rich mixture is provided to compensate the loading which results in higher CO emission. At lower load, D1WPO10 and D1WPO30 give 0.059 vol.% and 0.09 vol.% which are lower than the other WPO samples. But it is higher than diesel about 0.038 vol.%. The maximum CO is found with WPO30 which is about 0.119 vol.% at lower loads. During higher loads, diesel produces 0.146 vol.% which is higher than D1WPO10 about 0.139 vol.% but lower than D1WPO30 about 0.162 vol.%.

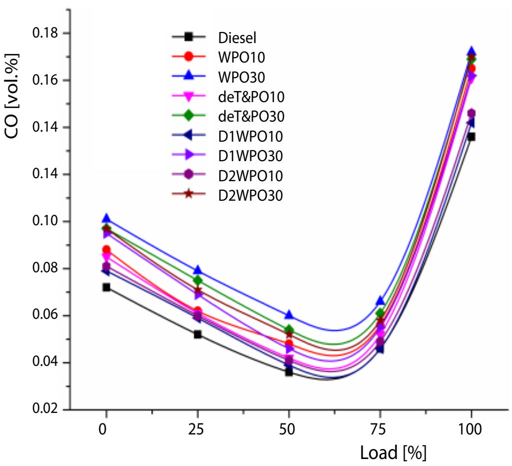

Figure 9. The CO with different loads

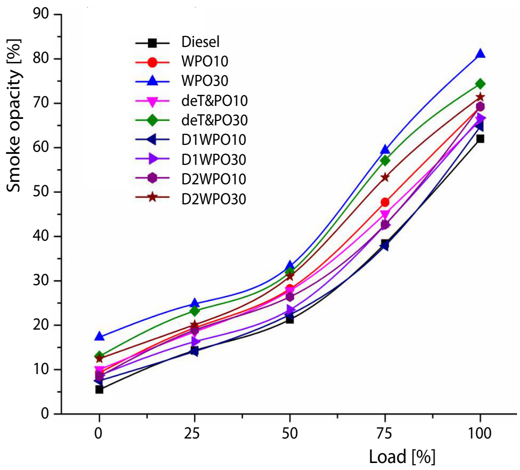

Figure 10. Smoke opacity with different loads

Smoke opacity

Opacity is nothing but percentage of emitted light blocked by smoke, particularly which can measure the intensity of smoke exhausted from the engine. The smoke intensity increased gradually with loads, because of insufficient oxygen being supplied during rich mixture combustion shown in fig. 10. Also, it was observed that smoke opacity of diesel was 14.3 % at low load and 62% at full load. But in the case of WPO10, it was 19.4% and 69.2% for low and full load, respectively. There was slight reduction in smoke intensity with deT&PO blend compared with raw WPO blends. As regards D1WPO10 and D1WPO30, smoke intensity was noted to be very close to diesel values. It was recorded about 14.1% at low load and 64.8% at full load and 16.3% at low load and 66.3% at full load. This was due to higher combustion temperature and flame propagation [29]. Also D2WPO blends were reported to have higher opacity than D1WPO blends and lower than raw WPO and deTandPO blends. The higher opacity with higher blends was due to delayed combustion, shortage of oxygen, saturated HC presence, non homogeneity of fuels and lower cylinder temperature.

Conclusions

From these experimental investigations, it was evident that the engine could run with WPO and distilled WPO blends upto 30 vol.%. Beyond 50 vol.%, it was found that more engine vibration and higher emissions were generated. This implies that modification is needed with fuel system of engine while increasing the blend ratio beyond 50 vol.%. Rich blends of raw WPO affect the fuel filters severely due to the presence of impurities, whereas it is less severe with desulphurized T&PO blends. Also, rich blends of desulphurized fuel can not be used in Diesel engine for a long term due to higher acid value which leads to corrosion and particle deposits. But the distilled WPO can be used as an alternative supplement upto 30 vol.% without modification in engine.

- All the WPO blends have longer ignition delay, HRR rate and cylinder pressuure due to lower cetane number and non-homogeneity of fuel mixture.
- A higher BTE is obtained with D1WPO blends than diesel, both D2WPO blends and raw WPO blends. This is because of higher energy content and calorific value.
- Better SFC is found with distilled WPO blends. The reason is higher calorific value with distilled WPO than virgin WPO.
- Beyond 30 vol.% blends of WPO and DWPO would not be preferable for long term use due to much HRR and more volatile combustion which may have catastrophic effects on the engine.
- In respect of emissions, all the WPO blends have more significance with negative impacts on environments. Because the emission of NO_x, HC, and CO are found higher than diesel. This is mainly due to delayed combustion, poor mixture, lower cylinder temperature, and unsaturated HC.
- Intensity of smoke is found higher with WPO, and deT&PO blends because of delayed combustion and insufficient oxygen. But D1WPO blends produce lower intensity smoke than other WPO samples. In thickly populated cities, the high intensity smoke affects the natural light severely.

Nomenclature

DI	– direct injection
DWPO	– distilled waste plastic oil
D1WPO	– first product of WPO during distillation
D1WPO10	– 10 vol.% of D1WPO and 90 vol.% of diesel
D1WPO30	– 30 vol.% of D1WPO and 70 vol.% of diesel
D2WPO	– second product of WPO during distillation
D2WPO10	– 10 vol.% of D2WPO and 900 vol.% of diesel
D2WPO30	– 30 vol.% of D2WPO and 70 vol.% of diesel
deT&PO	– desulphurized tire and plastic oil (30 vol.% and 70 vol.%)
deT&PO10	– 10 vol.% of T&PO and 90 vol.% of diesel
deT&Po30	– 30 vol.% of T&PO and 70 vol.% of diesel
IC	– internal combustion
PE	– polyethylene
PET	– polyethylene tarapthlate
PP	– polypropylene
PS	– poly stirene
PVC	– polyvinyl chloride
TPO	– tire pyrolysis oil
WPO	– waste plastic oil
WPO10	– 10 vol.% of WPO and 90 vol.% of diesel
WPO30	– 30 vol.% of WPO and 70 vol.% of diesel

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