Plastic Pyrolysis Oil as Alternate Fuel in Diesel Engine: A Review

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Abstract— Increasing use of plastics has resulted in increase of plastic waste enormously. One of the methods of disposal is converting waste to oil through pyrolysis process (Plastic Pyrolysis Oil). Use of Plastic Pyrolysis Oil as an alternate fuel in diesel engine has been studied by various researchers. The present paper provides a review on effects of using (a) Blends of Plastic Pyrolysis Oil & Diesel (b) Diethyl Ester (DEE) as additive to Plastic Pyrolysis Oil (c) Jetropha Methyl Ester (JME) as additive to Plastic Pyrolysis Oil, in diesel engine. Results on brake thermal efficiency, specific fuel consumption, cylinder peak pressure and emissions are provided.

Key words: Plastic Pyrolysis Oil, Waste Plastic Oil blended with Diethyl Ester (WD), Waste Plastic Oil Blended with Jethropha Methl Ester (PJ)

I. Introduction

Plastics have become an integrated part in our daily lives. Usage and demand of plastics have shown increase in recent years. With increasing use of plastics, plastic waste disposal has also increased. As per reports of Central Pollution Control Board, production of plastic waste in country is estimated to be 15342 tonnes, out of which 9205 tonnes is recycled while 6137 tonnes is uncollected and littered [1]. The uncollected plastic waste results in great damage to land as well as marine creatures. According to journal Science Advances, India is estimated to dump 0.12 million tonnes of plastic waste to ocean and is ranked at 12th position in list of such countries[2].

Among various methods for plastic waste disposal, one of the methods is plastic pyrolysis process. The method involves heating of plastic waste in absence of oxygen in temperature range of 300-500^0 C for short interval of time. The gases so produced are condensed in order to obtain liquid which is referred as plastic pyrolysis oil. As plastics are basically hydrocarbon compounds, plastic pyrolysis oil have properties similar to diesel. Hence various researches have been done to assess results of using plastic pyrolysis oil as alternate fuel in diesel engine.

The present paper provides details of results on brake thermal efficiency, brake specific fuel consumption, cylinder peak pressure and emissions using (a) Blend of Plastic Pyrolysis oil and Diesel [3] (b) Di-ethyl Ester as additive to blend of plastic pyrolysis oil and diesel [4] (c) Jetropha Methyl Ester as additive to blend of plastic pyrolysis oil and diesel [5].

II. Test Conditions

The test conditions are as follows:

A. *Blend of Plastic Pyrolysis Oil & Diesel [3]*

Four-cylinder, direct injection, turbocharged engine tested with blend percentage of 25%, 50%, 75%, 90% and 100% (v/v%) and load of 25%, 50%, 75% and 100%

B. *Di-ethyl Ester as Additive to Blend of Plastic Pyrolysis Oil and Diesel [4]*

Single cylinder, direct injection diesel engine tested with diesel, WPO (waste plastic pyrolysis oil), WD05 (waste plastic pyrolysis oil blended with 5% diethyl ether), WD10 (waste plastic pyrolysis oil blended with 10% diethyl ether) and load of 20%, 40%, 60%, 80% and 100%.

C. *Jetropha Methyl Ester (JME) as Additive to Blend of Plastic Pyrolysis Oil and Diesel [5]*

Single cylinder, direct injection diesel engine tested with diesel, waste plastic oil (WPO), WPO mixed with 10% & 20% Jetropha Methyl Ester (PJ10 & PJ20) and load of 25%, 50%, 75% & 100%.

III. Results on Brake Thermal Efficiency (BTE)

The results of brake thermal efficiency for three cases are shown in figures 1, 2 & 3. For blend of PPO (plastic pyrolysis oil) and diesel, brake thermal efficiency showed reduction. Lower BTE shown indicates that the engine operates less efficiently when PPO is used regardless of the blending ratio. The lower BTE of PPO blends can be explained by the existence of a high amount of aromatics contained in PPO, because the aromatic bonds require more energy to break thermal efficiency do not deteriorate much further with increased blending ratio and the efficiency is only marginally lower than that of diesel at medium load. These results suggest some potential working conditions for effectively utilizing this fuel (Fig 1)

Using Diethly ester (DEE) as additive results in increase of BTE at higher loads. The brake thermal efficiency at high loads for diesel and waste plastic pyrolysis oil is 28% and 27.75%, whereas for WD05 and WD10 is 27.51% and 29.12%. The thermal efficiency is higher for WD10. The addition of DEE increased the BTE. The presence of oxygen in the DEE helps in the complete combustion of the fuel raising the BTE (fig 2).

The variation in the brake thermal efficiency with engine load for diesel; waste plastic oil and waste plastic oil-JME blends is shown in Fig. 3. The BTE for diesel is highest among all fuels at full load. BTE of PJ10 & PJ20 are higher than WPO. As the Engine load increases the heat generated in the cylinder increases, and hence, the thermal efficiency increases. The thermal efficiency of the waste plastic oil is lower than that of diesel at full load, this may be due to the fact that at full load, the EGT and the heat release rate are marginally higher for waste plastic oil compared to diesel

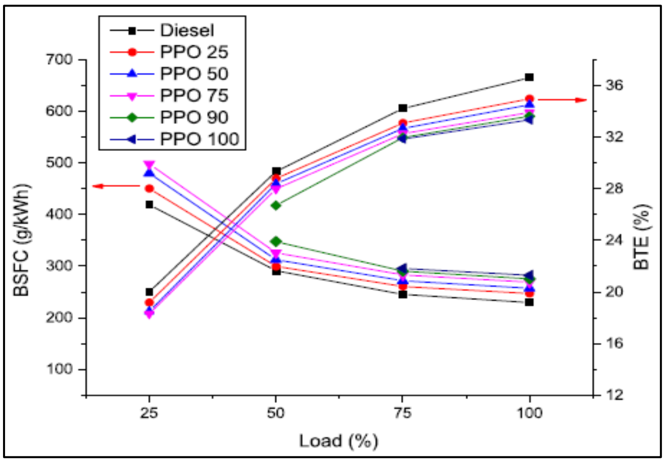

Fig. 1: Variation of BTE & BSFC in blends of PPO & Diesel [3]

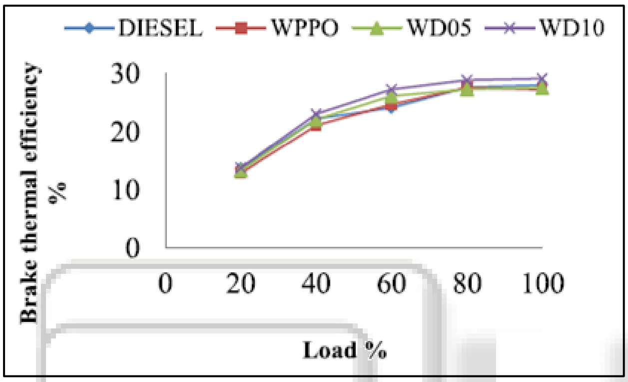

Fig. 2: Variation of BTE with DEE additive [4]

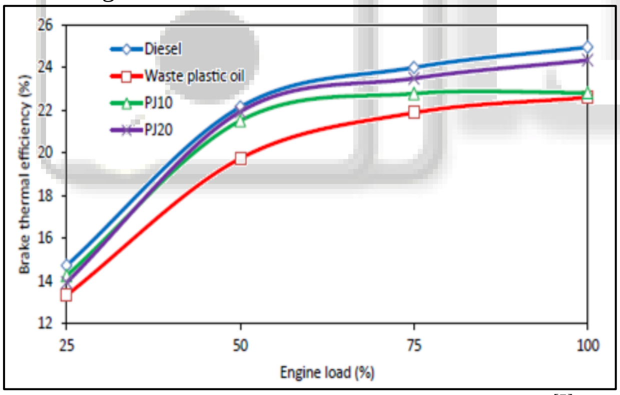

Fig. 3: Variation of BTE with JME additive [5]

IV. RESULTS ON BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)

Without any additives, blend of PPO and diesel resulted in considerable increase in BSFC at all operational conditions, even with the lowest blending ratio (figure 1). This can be partly attributed to the lower heating value of PPO fuel. Another reason could be that the higher combustion temperature of PPO results in high heat transfer losses. Similar to BTE, BSFC do not deteriorate much further with increased blending ratio and the efficiency is only marginally lower than that of diesel at medium load.

Addition of DEE reduces BSFC compared to neat plastic oil. Pure diesel fuel has the BSFC of 0.560 kg/kW h at 20% load and 0.276 kg/kWh at full load. For WPPO, the value is 0.616 kg/kW h at 20% and 0.292 kg/kWh at full load. The BSFC for WD05 is 0.605 kg/kW h at 20% and 0.294 kg/kWh at full load. The BSFC for WD10 is 0.591 kg/kW h at 20% and 0.301 kg/kWh at full load (figure 4). At high speeds of the engine, the differences between BSFC values of fuel blends become smaller, due to the short combustion period in spite of the increased fuel amount. By excess oxygen and fast burning ethanol molecules, combustion temperature increases. All these factors affect combustion in a better way. As a result of this, BSFC values of WD blends become closer to pure diesel fuel BSFC at high engine speeds. The BSFC in case of blends was higher compared to diesel in the entire load range, due to its lower heating value, greater density and hence higher bulk modulus.

With JME blends, the variation in brake specific fuel consumption with load for different fuels shows decline with an increase in load. The BSFC in case of blends was higher compared to diesel in the entire load range, due to its lower heating value and hence higher bulk modulus. The higher bulk modulus results in more discharge of fuel for the same displacement of the plunger in injection pump, thereby resulting increase in BSFC. This is attributed to the combined effect of viscosity and lower heating values of waste plastic oil-JME which requires larger fuel consumption in order to release same energy as that of diesel.

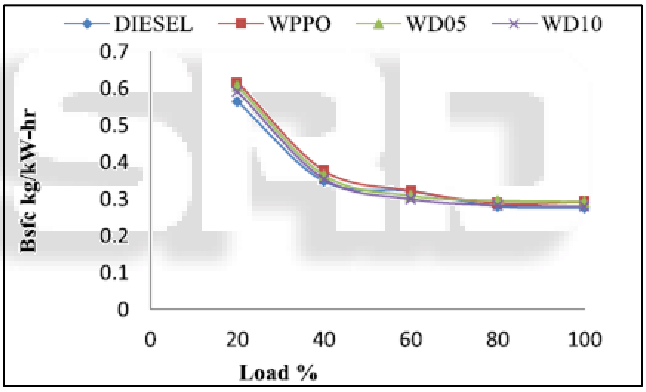

Fig. 4: Variation of BSFC with DEE additive [4]

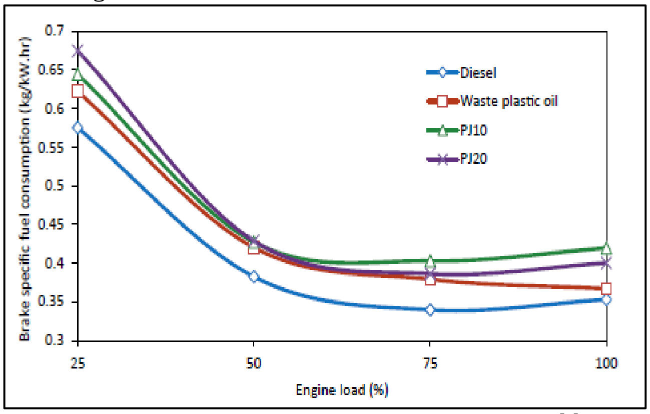

Fig. 5: Variation of BSFC with JME additive [5]

V. RESULTS ON CYLINDER PRESSURE

Results of cylinder pressure with diesel-PPO blends is shown in figure 6. The results suggest that low blending ratio (PPO 25) makes negligible effect on peak pressure regardless the engine operational conditions, but higher blending ratios in general elevated the peak pressure except at relatively low engine load. It is believed that this attributes to the combined effect of lower cetane number and lower viscosity of PPO fuel in comparison with diesel. The lower viscosity of PPO will likely improve the spray atomization and evaporation, which will increase the portion of premixed combustion. The lower cetane number results in delayed combustion which further enlarges the premixed combustion portion. Therefore at low engine load, when PPO blends were used, the peak pressure occurred after TDC with lower values due to the prolonged combustion delay. But at high engine load, the higher portion of premixed combustion resulted in more violent combustion and higher peak pressure.

The variation of cylinder pressure at maximum load at an injection pressure of 215 bar with crank angle for Diesel, WPPO, WD05 and WD10, are shown in fig. 7. The higher cetane number of DEE shortens ignition delay period when added to fuel. It can be observed that with increasing percentage of DEE in the blend, the start of combustion occurs later (the pressure rise due to combustion starts later), while the maximum pressure falls and occurs later. The start of combustion is delayed as a consequence of synergy of the lower dynamic injection timing and increased ignition delay. In a CI engine, the peak pressure depends on the combustion rate in the initial stages, which is influenced by the amount of fuel taking part in the uncontrolled combustion phase that is governed by the delay period. It is also affected by the fuel mixture preparation during the delay period.

Similar results are obtained using JME as additive. The variation of cylinder pressure with crank angle for diesel, waste plastic oil, PJ10 and PJ20 at maximum load is shown in fig. 8. The higher cetane number of JME shortens the ignition delay period when added to waste plastic oil. It is noted that the peak pressures of 63.82, 68.05, 67.09 and 64.62 bar were recorded for standard diesel, waste plastic oil, PJ10 and PJ20 respectively. It is observed from the figure that the peak cylinder pressure is decreased with the increase of JME addition in the waste plastic oil.

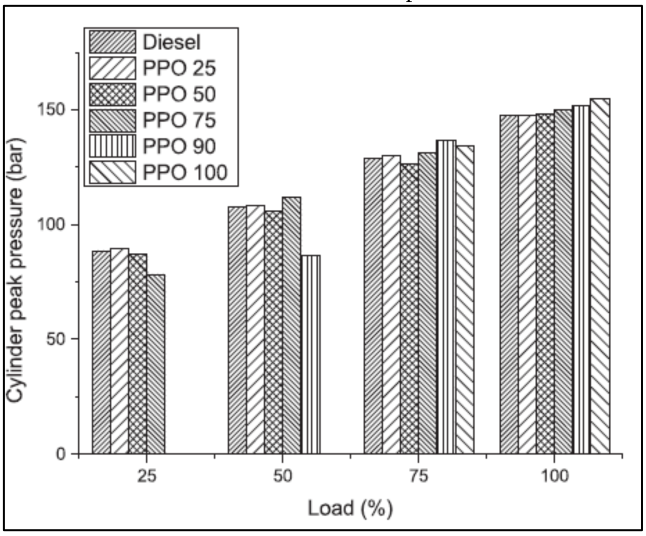

Fig. 6: Variation of Cylinder Pressure with Load [3]

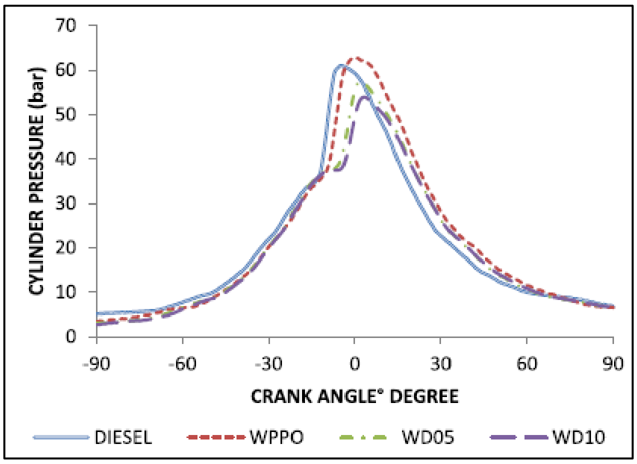

Fig. 7: Variation on cylinder pressure for DEE additive [4]

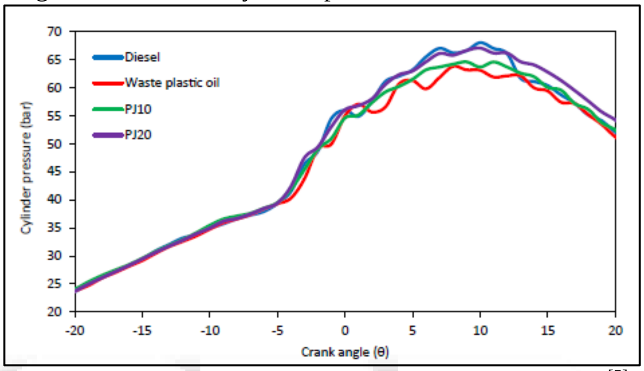

Fig. 8: Variation on cylinder pressure for JME additive [5]

VI. RESULTS ON NO_X EMISSIONS:

NOx emissions in diesel engines increase due to elevated temperatures and high oxygen availability. Without any additive, NOx emissions increase as the percentage of PPO increases (fig 9).This is due to the longer ignition delay which results in higher portion of premixed combustion, thus higher heat release rates and higher in-cylinder temperatures. Another reason that may affect the NOx emissions is the higher nitrogen content in the fuel that promotes the NOx formation by fuel mechanism.

Using DEE as additive, NOx emissions were found to be reduced. Since DEE is a cetane improver and any increase in cetane number decreases NOx emission (fig 10). DEE has high oxygen content and high heat of evaporation. It is easy to ignite the fuel-air mixture and it yields shorter combustion duration. By addition of DEE, heat release decreases in the stage of diffusion controlled combustion, thereby leading to lower NOx emissions.

NOx emissions increased gradually with increasing JME content in the blends. This is obviously due to the increased oxygen content in the blends as a result of JME addition. The NOx values for diesel vary from 251 ppm at 25% load and 668 ppm at full load. For waste plastic oil, it varies from 266 ppm at 25% load and 685 ppm at full load. . For PJ10 and PJ20, it varies from 302 to 292 ppm at 25% load and 694 ppm and 705 ppm at full load (fig. 11). The NOx formation is increasing as the load increases.

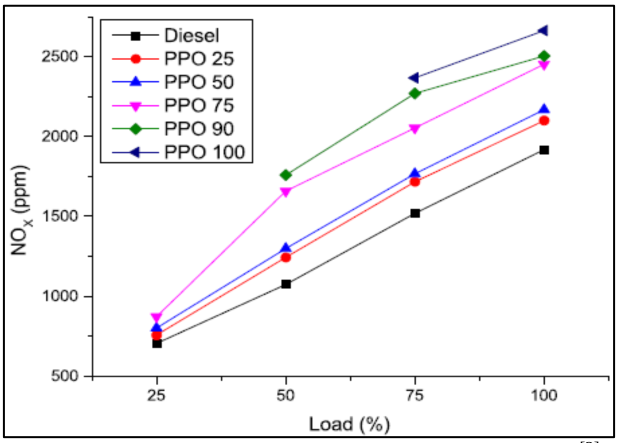

Fig. 9: Variation of NOx in blends of PPO & Diesel [3]

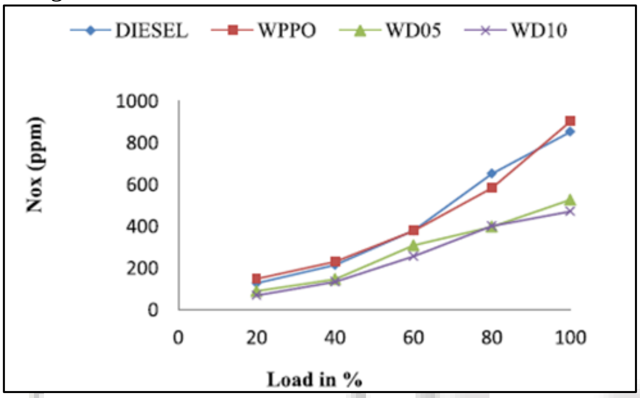

Fig. 10: Variation of NOx with DEE additive [4]

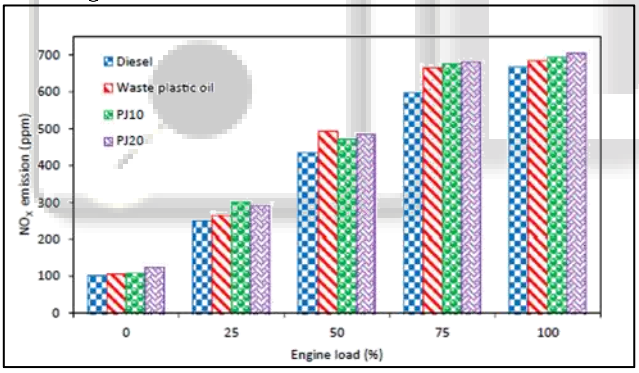

Fig. 11: Variation of NOx with JME additive [5]

VII. RESULTS ON CARBON MONOXIDE (CO) EMISSIONS

CO emissions are mainly formed by incomplete combustion and affected by the equivalence ratio and temperature. CO emissions decrease as the engine load increase regardless of the fuel. In general, higher PPO blending ratio results in higher CO emissions, due to lower cetane number of PPO. With low to medium blends and high loads, the rise is marginal. Figure 12 shows variation in CO emissions with load for various blends of PPO and diesel

Addition of DEE reduces CO emissions (compared to WPO) at full loads due to increased oxygen availability. For WPO, the amount of CO is increasing with the increment in the load. The reason for the increase in CO in case of WPO, is less in cylinder temperature. The decrease in CO at full load when the mixture is getting increased from WD05 to WD10 may be due to the availability of oxygen is more, when DEE is added to WPO.

Fig. 14 shows the trend of CO emission for diesel, plastic oil and plastic oil-Jatropha blends, with respect to engine load. Generally, CI engines operate with a lean mixture. Therefore, the CO emission is found to be lesser than that in the SI engines. The amount of CO emission from diesel varies from 0.03% at 25 percent load and 0.36% at full load. For plastic oil, it varies from 0.05% at 25 percent load and 0.26% at full load. For PJ10 and PJ20, the values are same 0.04% at 25 percent load and 0.17% and 0.13% at full load respectively. For all test fuels, the amount of CO is increasing with the increment in the load. The CO emission is lower for waste plastic oil- JME blends compared to that of diesel at full load, the reason for this may be the excess oxygen present in the JME is helpful for better combustion.

VIII. RESULTS ON HYDRO-CARBON (HC) EMISSIONS

The HC emissions in the exhaust are mainly due to the under mixing or over-leaning (bulk-quenching) zones and wall flame quenching. Unburnt hydrocarbon emissions for diesel are lower and increase with increase in blend percentage of PPO. The reason that PPO blends result in higher UHC emissions remains unrevealed, but it is believed that the higher aromatic contents may be responsible. Another possible reason is that the spray of PPO blends may have better chance to impinge the wall due to its higher density, lower viscosity and cetane number which results in longer ignition delay. Figure 15 shows variation in HC emissions in various blends of diesel & PPO.

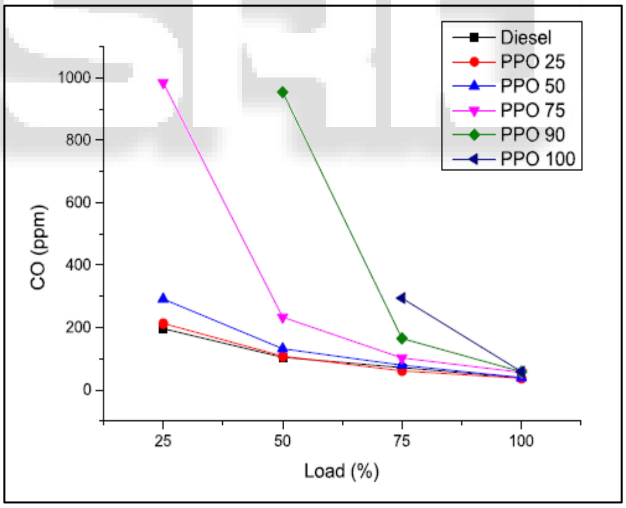

Fig. 12: Variation of CO in blends of PPO & Diesel [3]

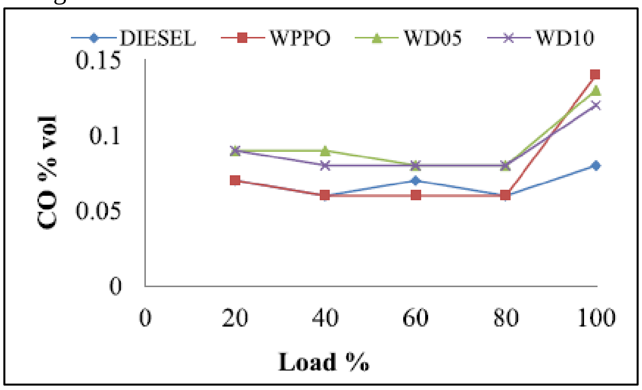

Fig. 13: Variation of CO with DEE additive [4]

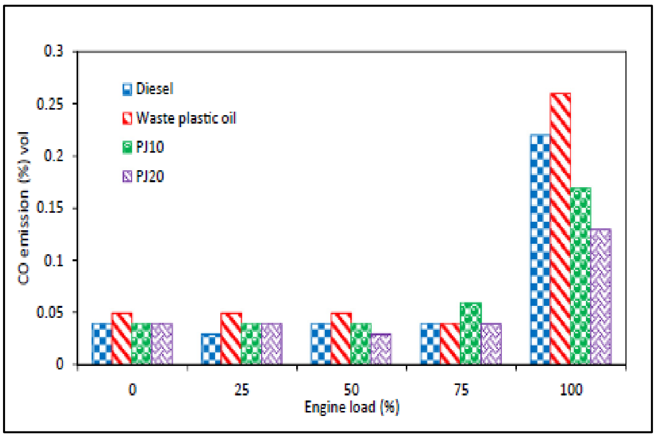

Fig. 14: Variation of CO with JME additive [5]

The addition of DEE with WPO increases the HC emissions than diesel. The reason behind increased unburnt hydrocarbon in waste plastic oil may be due to higher fumigation rate. The increase in HC emissions with the use of WD10 can be attributed to the leakage of the fuel through the injector nozzle due to the considerably low viscosity of the fuel. DEE additive has a low charge temperature and decreases combustion temperature due to its high heat of evaporation. Additionally, some of the DEE additive mixes with air during fuel injection and accumulates in the ring space between the piston and cylinder. Consequently, the combustion flame cannot effectively reach these spaces, thus yielding high HC emissions (figure 16).

The variation in the UHC emission with engine load for diesel; waste plastic oil and waste plastic oil-JME blends is shown in Fig. 17. For Diesel, it varies from 22 ppm at 25% load and 29 ppm at full load. For WPO the values are 34 ppm at 25% load and 48 ppm at full load. For PJ10 and PJ20, the values are 34 and 30 ppm, at 25% load and 38 ppm and 37 ppm at full load. The addition of JME with waste plastic oil decreases the HC emissions than waste plastic oil. The reason behind increased hydrocarbon in waste plastic oil may be due to higher fumigation rate.

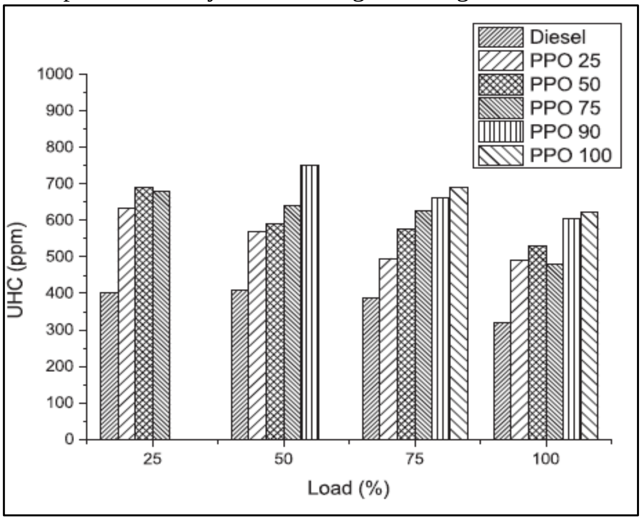

Fig. 15: Variation of HC in blends of PPO & Diesel [3]

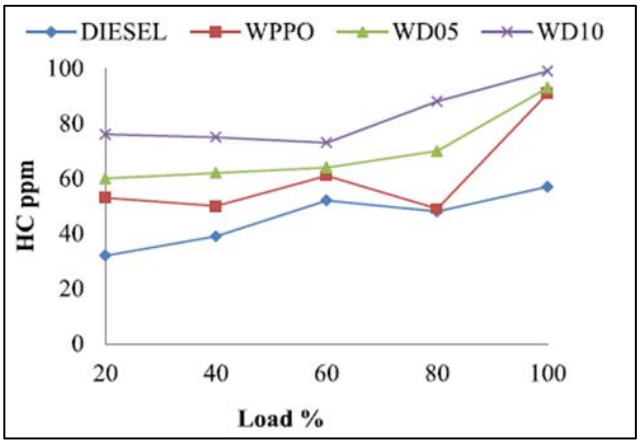

Fig. 16: Variation of HC with DEE additive [4]

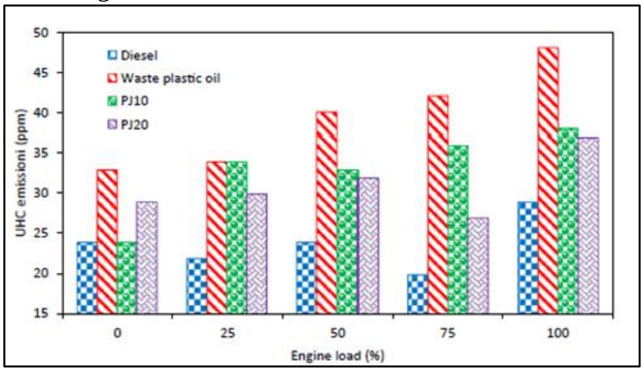

Fig. 17: Variation of HC with JME additive [5]

IX. Conclusions

- Compared to diesel, Brake Thermal Efficiency of engine reduces when operating with Plastic Pyrolysis Oil. Addition of DEE as well as JME improves efficiency. However it is lower than diesel.
- BSFC increases when engine is operated with blends of plastic pyrolysis oil and diesel. Addition of DEE reduces BSFC due to higher oxygen content, which enables complete combustion. Addition of JME increases BSFC.
- Cylinder peak pressure increases with use of plastic pyrolysis oil. Addition of DEE and JME reduces cylinder peak pressure.
- All emissions (NO_x, CO, HC) increase by increasing blending percent of plastic pyrolysis oil.
- Addition of DEE reduces NOx emissions, while JME addition results in increase of NOx emissions.
- CO emissions reduce by addition of DEE as well as JME.
- HC emissions increase by addition of DEE and reduce by addition of JME.

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