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Combustion, Performance and Emission analysis of Tire Pyrolysis Oil – Diesel Blends in a Single Cylinder Direct Injection Compression Ignition Engine.

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ABSTRACT

Reduction in fossil fuel and petroleum derivatives urged the researchers to identify a possible and sustainable alternative fuel. The environmental pollution due to solid waste also emerged as a major crisis in many developed and developing countries. Pyrolysis of solid waste tire bridged the gap between the above crises by producing an alternative fuel to petroleum diesel which can be used in internal combustion engine. A tire pyrolysis reactor was developed to produce TPO with a batch efficiency of 65% to 70%. The TPO was analyzed using GC/MS and FTIR techniques to understand its usability in CI engine. The TPO blends at 5%, 10% and 30% ratios were used in a CI engine and its combustion, performance and emission analysis were carried out. The in-cylinder pressure and rate of heat release showed a decreasing trend with addition of TPO. The performance parameters like BSEC and BTE exhibited a marginal reduction with a significant increase in UBHC emission at high loads.

Keywords: Combustion, Performance, Emission, TPO, Pyrolysis.

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INTRODUCTION

Depletion of fossil fuels and fuel resources seek the researchers to find an alternate fuel source which could be effectively utilized for internal combustion engine. On other hand solid waste management and the disposal of waste tires marginally increased day by day and cause serious damage to our environment. An automobile tire consists of non-degradable elements such as different form of rubber composition, steel wires, carbon black and other inorganic materials, which was extremely difficult to dispose causing land and air pollution. It was estimated that nearly 20 tons of waste automobile tires have been generated yearly in whole India. In order to bridge the gap between the solid waste management and the internal combustion engines, pyrolysis process has been implemented referring to the decomposition of inorganic materials at the elevated temperatures between 250^{o}C-750^{o}C in the absence of oxygen or in the presence of any other inert gases. This was capable to produce an output in the form of solid char, liquids and the gaseous state [1,4].

A review was made to analyze the feasibility of recovering oil from used tire by pyrolysis process. It revealed that, pyrolysis oil yielded solid, liquid and gas fractions between temperatures of 250^{o}C and 550^{o}C by thermogravimetric analysis. It was also found that apart from the above mentioned products, the TPO contained a significant quantity of complex organic substances with aromatic compounds [20]. A pilot scale anger reactor was used to produce tire pyrolysis oil and was blended with straight diesel to test the performance and emission characteristics. It was noticed that brake thermal efficiency and brake specific energy consumption were significantly decreased with the addition of TPO blends. The period of combustion was also found to be elongated than normal diesel combustion. NO_x emission was found to be higher in TPO blends on comparison with diesel fuel [11]. Distilled tire pyrolysis oil blended with diesel was employed in a single cylinder diesel engine to evaluate their performance, combustion and emission parameters. The variation in BTE, BSEC, in-cylinder pressure, exhaust gas temperature and emission were analyzed in detail [16].

In the present analysis a static bed batch type pyrolysis reactor was designed and developed with an overall dimension of 400cm X200cm X460cm and feeding capacity of 8 kg per cycle. The heating of the reactor was achieved with the help of 3 Koyos heating element which could withstand the maximum temperature of 700^{o}C. The heating rate is achieved at 15^{o}C per min yielding the gaseous and liquid output at 550^{o}C. The reaction time and reaction temperature was directly proportional to each other. The yield of the solid char, liquids and gaseous were in the ratio of 40%, 50% and 10% and these were analyzed in detail. Tire pyrolysis oil was standardized by physio-chemical properties, Gas chromatography/ mass spectrometry techniques, Fourier transform infra-red analysis and elemental analysis. It was found that the calorific value of tire pyrolysis oil was very much similar to straight diesel and it can be readily used in internal combustion engines without any prior modifications [17-19].

Pyrolysis process was very much compatible in the recovery of oil from waste automobile tire and the elemental analysis shows that oil was more appropriate fuel for the direct use as well as diesel blending in internal combustion engines. In this study, three different blends of tire pyrolysis oil was prepared in the ratio of 5%, 10% and 30% were compared with the straight diesel fuel. Combustion, performance and emission parameters for these blends were analyzed and compared with diesel.

MATERIALS AND METHODS

Waste automobile tire was collected from the local tire vendor in Chennai and the tire has the composition of rubber, carbon black, metal and sulphur. The pretreatment process on waste tire has been done before the beginning of pyrolysis process. The steel wires from the tire beads were carefully taken out with the help of screwing machines and then the cutting machines were employed to cut the small pieces in the form of 3cm X 3cm. In order to remove the impurities from the waste tire, it was fully soaked in the hot water for 2 hrs to ensure that the waste tire was fully free from all types of impurities which would not affect the pyrolysis process at any cost. The static bed batch type pyrolysis reactor was designed by using Catia V5 software with an overall dimension of 400cm X 200cm X 460cm as shown in Figure 1. The reactor consists of two cylinders namely outer cylinder and inner cylinder, conical top, exhaust pipe and receiver chamber. The whole reactor was fabricated using Stainless steel grade 317A. The three Koyos made heating coil was employed for the heating purposes. They were placed around the inside cylinder vertically and the third one placed horizontally under the inside cylinder. The elemental analysis performed on the TPO oil could be seen from Table 1 where the carbon content was highest sowing 81.3% followed by hydrogen of 6.76%,Nitrogen 0.23%,sulphur 1.92%.

Table 1: Elemental analysis of TPO

Elements	Ratio proportions (wt %)
Carbon	81.28
Hydrogen	6.76
Nitrogen	0.23
Sulphur	1.92
Oxygen	7.37
Ashes (Inorganic)	2.44

Table 2. Physio-chemical properties of TPO-Diesel Blends

Properties	Units	Testing Methods	TPO 5	TPO 10	TPO 30
Density @ 15°c	kg/m3	IS:1448 P:16	829	834	850
Kinematic viscosity, @ 40°c	Cst	IS:1448 P:25	2.48	2.58	2.72
Flash point	°c	IS:1448 P:20	44	46	38
Fire point	°c	IS:1448 P:20	58	60	50
Gross Calorific value	kJ/kg	IS:1448 P:6	42,911	42,584	41,890
Sulphur content	%	IS:1448 P:33	0.10	0.28	0.31
Carbon residue	%	IS:1448 P:122	0.02	0.06	0.02
Ash content	%	IS:1448 P:126	0.08	0.03	0.02
Cetane Index		IS:1448 P:9	51	50	44
Distillation Range	°c	IS:1448 P:18			
Initial Boiling Point	°c	IS:1448 P:18	102	120	126
10 ml. recovery @	°c	IS:1448 P:18	176	170	180
20 ml. recovery @	°c	IS:1448 P:18	200	200	205
30 ml. recovery @	°c	IS:1448 P:18	234	220	226
40 ml. recovery @	°c	IS:1448 P:18	258	250	252
50 ml. recovery @	°c	IS:1448 P:18	280	270	276
60 ml. recovery @	°c	IS:1448 P:18	296	296	300
70 ml. recovery @	°c	IS:1448 P:18	312	316	318
80 ml. recovery @	°c	IS:1448 P:18	340	338	340
90 ml. recovery @	°c	IS:1448 P:18	354	352	354
95 ml. recovery @	°c	IS:1448 P:18	360	358	360
98 ml. recovery @	°c	IS:1448 P:18	366	366	368

Figure 1: Tire Pyrolysis Reactor

Oxygen content and ash content was found to be 7.37% and 2.44% respectively. The physio chemical properties of the TPO diesel blends were also determined as seen from Table 2 and the density and viscosity increased with increase of TPO percentage. The flash point and fire point reduced with increasing blends[2,3,8-13]. The calorific value and cetane index also reduced with increasing blends. Increase in sulphur content and reduction in ash content was notic3ed for the increasing blends.

EXPERIMENTATION

The experimental work was carried out in the Kirloskar DM 10 single cylinder four stroke direct injection compression ignition engine shown in the Figure 2 and the schematic layout can be referred from the Figure 3. The engine has the cubic capacity of 948 cc the bore and stroke of the engine were 102mm and 118mm respectively producing the maximum output of 7.5 kW at 1500 rpm. The combustion parameters such as In-Cylinder pressure and Net heat release were found by Kistler made charge amplifier and cathode ray oscilloscope. Crypton 290 five gas analyzer was employed to analyze the emission parameters such as unburnt hydrocarbons, oxides of nitrogen, carbon monoxide and particulate matter. The test engine was allowed to run with diesel fuel primarily for 30 minutes and the time taken for 10 cc fuel consumption was recorded. The process was repeated eight times to avoid uncertainties in the experiment and the average values were plotted graphically. The procedure was again repeated for all blends to TPO as shown.

Figure 2: Pictorial View of Test Engine

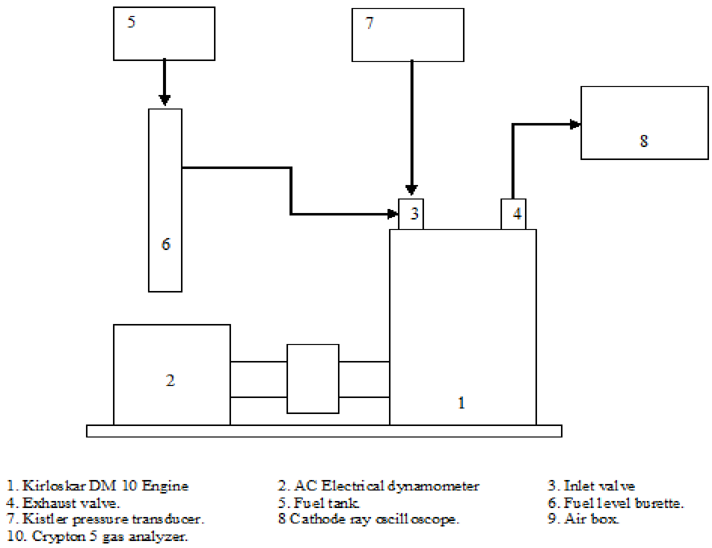

Figure 3: Schematic Diagram of Experimental Setup

RESULTS AND DISCUSSION

Variation in Combustion parameters

The effect of TPO blended diesel on In-cylinder pressure at full load condition is shown in Figure (4). It can be seen that, with increase in TPO blends in diesel, the in-cylinder pressure gradually reduces at all loads. During low load condition, the peak pressure for diesel was found to be 40 bar whereas TPO blends exhibited 3% to 4% decrease in the in-cylinder pressure.

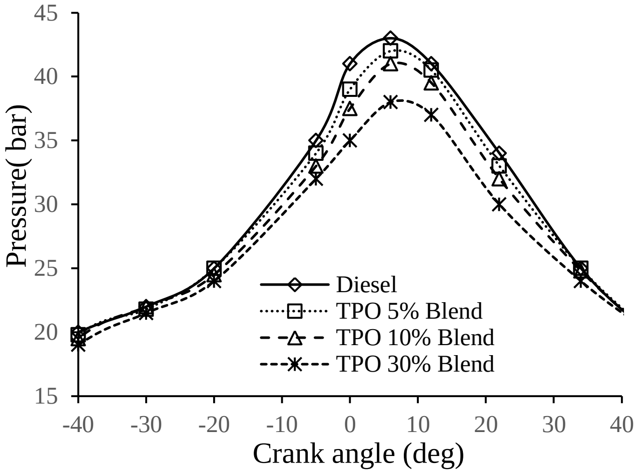

Figure 4: Variation in In-Cylinder pressure for Diesel and TPO blends at full load condition

The part load condition also exhibited a marginal reduction in in-cylinder pressure with increase in TPO blends. At full load condition, the peak in-cylinder pressure for diesel, TPO5%, TPO10% and TPO 30% blends were found to be 43 bar, 42 bar, 41 bar and 39 bar respectively. This significant reduction in cylinder pressure may be due to shortened premixed combustion phase which also affects the diffusive combustion phase and poor atomization of air-fuel mixture in the combustion chamber at high loads.

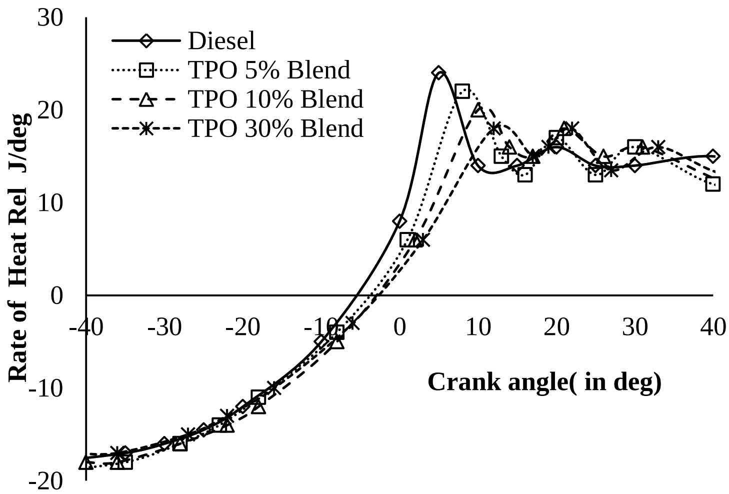

Figure 5: Variation in Heat Release rate for Diesel and TPO blends at full load condition

The rate of heat release compared with cylinder crank angle for diesel, TPO5%, TPO10% and TPO30% blend ratios at full load condition is shown in Figure (5). The ROHR on comparison with in-cylinder pressure shows a similar trend of heat release (i.e.) the ROHR was gradually reduced with the increase in TPO blends and diesel. At full load condition, the maximum rate of heat release for diesel, TPO5%, TPO10% and TPO30% blend ratios was found to be 24 J/CAD, 22 J/CAD, 20 J/CAD and 19 J/CAD respectively. As the rate of heat release directly relates the engine performance and work output, is can be noticed that, an increase TPO blend, reduces the ROHR and engine performance gradually. A similar trend was also seen during low and part load operations with TPO-diesel blends. This may be due to reduction in the calorific value of the fuel with a sharp increase in density and kinematic viscosity of the fuel with increase in TPO blends [6].

Variation in Performance parameters

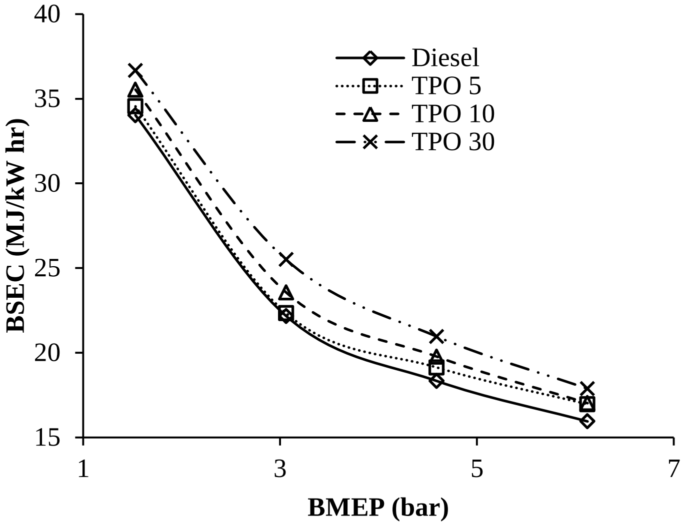

Figure 6: Variation of Brake Mean Effective Pressure with Brake Specific Energy Consumption

BSEC was found to be the more reliable factor in performance parameters due to the calorific value and density of the TPO fuels are slightly differ from the Diesel. For diesel BSEC varies from 34.02 MJ/kW hr at low load condition to 15.94 MJ/kW hr at full load condition, whereas for TPO 5 it varies from 34.54 MJ/kW hr at load condition and in full load it steeps down to 16.95 MJ/kW hr. For TPO 10 the BSEC Curve falls from 35.53 MJ/kW hr to18 MJ/kW hr from low load to high load condition. TPO 30 shows the greatest value when compared to all blends and diesel BSEC varies from 36.65 MJ/kW hr at low load condition to 17.87 MJ/kW hr at full load conditions and these inferences can be clearly seen from Figure 6. It can be clearly seen that the BSEC is higher when the concentration of TPO blends ratio is more. This is due to the blends with low calorific value when compared to diesel due to this nature engine will consume more power [5,7].

The variation of BTE at all loads can be referred from Figure 7. Brake thermal efficiency of diesel fuel has been found 10.58% at low load condition and it goes up to 22.50% at full load conditions. For TPO blends the BTE was found very lower values when it compared with diesel. This is due to less calorific value of TPO when compared to diesel; it has been found that the calorific value for TPO was 42,800 kJ/kg whereas for diesel it was found 43,817 kJ/kg

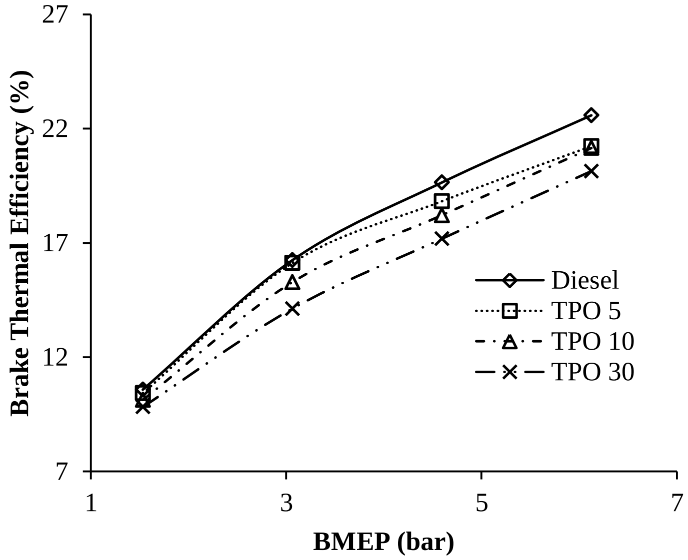

Figure 7: Variation of Brake Mean Effective Pressure with Brake Thermal Efficiency

For TPO 5 the BTE varies from 10.42% from low load to 21.23% at high load conditions. For TPO 10 BTE varies from 10.13% from low load conditions to 21.15%. TPO 30 shows very much lower values than any other blends for low load condition it found at 9.82% and goes up to 20.14% at full load conditions [14,15].

Variation in Emission parameters

The variation of UBHC emission for Diesel, TPO5%, TPO10% and TPO30% blend ratios at low, part and full load conditions are shown in Figure (8).

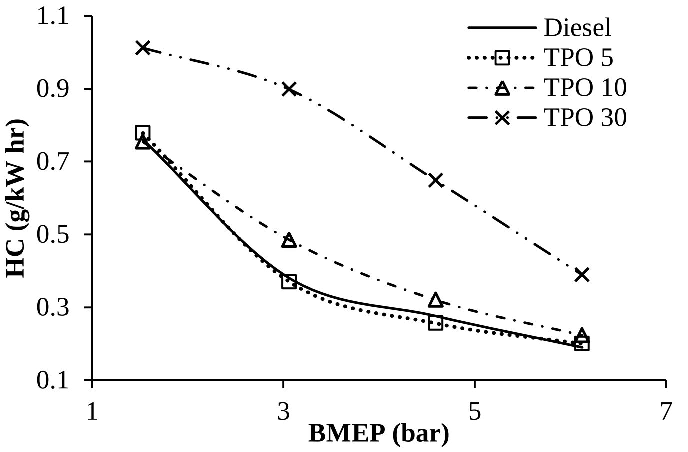

Figure 8: Variation of Brake Mean Effective Pressure with Hydro carbons emission

Hydro carbons emissions decrease with increase in brake mean effective pressure. HC varies from 0.76 g/kW h at low load condition 0.19 g/kWh at full load condition for diesel. And it varies from 0.778 g/kW h to 0.2 g/kW h for TPO 5 blend and it steeps down from 0.754 g/kW h to 0.223 g/kW h for TPO 10 blend. For TPO 30 blend the HC emission varies from 1.012 g/kW h to 0.389 g/kW h which shows the large amount of hydro carbon emissions found for the higher TPO blend ratio. This may be due to the fact that fuel spray does not inject and atomize properly due to the density of TPO. Usually HC emissions were formed due to the improper combustion at high temperature.

NO_x usually occurs in Diesel engines due to the high temperature which available in cylinder, NO_x contains both NO and NO_2within it. NO_x emissions increase when the blend ratio is higher and this is due to the rich mixture of fuel as seen from Figure 9. NO_x varies from 2.34 g/kW hr at low load condition to 1.326 g/kW hr at full load conditions. With the higher TPO blends, the amount NO_x was gradually increased. For TPO 5 NO_x varies from 2.867 g/kW hr at low load to 1.485 g/kW hr at full load. For TPO 10,NO_x varies from 3.02 g/kW hr in low load condition and it falls down to 2.386 g/kW hr in full load conditions. Whereas for TPO 30 at low load the NO_x value was 4.389 g/kW hr and at full load it was found to be 2.482 g/kW hr [18,21].

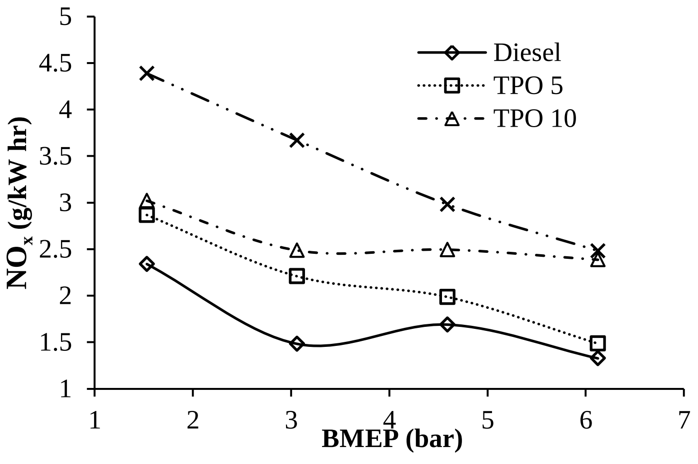

Figure 9: Variation of Brake Mean Effective Pressure with Oxides of Nitrogen Emission

Carbon monoxide emissions are usually toxic and more dangerous and hazardous gases for environment and hence it should be controlled. For diesel at low load condition CO was found 0.089 g/kW hr to 0.485 g/kW hr. For TPO 5 it varies from 0.14 g/kW hr at low load conditions to 0.984 g/kW hr at full load conditions. For TPO 10 it varies from 0.12 g/kW hr at low load to 0.847 g/kW hr at full load. For TPO 30, at low load it was found 0.23 g/kW hr but at higher loads, it reached a very high value and was found to be 2.06 g/kW hr and these can be referred from Figure 10. This is due to the high amount of blend ratio. From the elemental analysis it has been proved that the TPO has the carbon content of 81.28% in it [18].

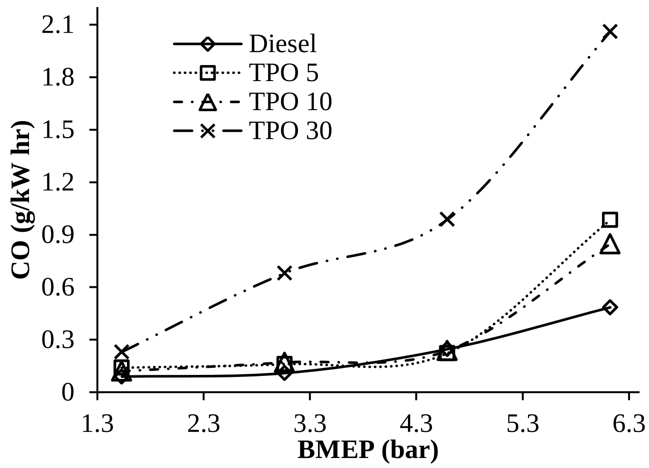

Figure 10: Variation of Brake Mean Effective Pressure with Carbon monoxide Emissions

CONCLUSION

In this study, the experimental investigations were carried out with Straight Diesel and Tire Pyrolysis Oil extracted from waste tire by means of thermal Pyrolysis process. TPO was blended with diesel in three different proportions and combustion, performance and emission for TPO blends and diesel were experimentally investigated in single cylinder compression ignition engines under different loads. The peak in cylinder pressure was high for diesel of about 43 bar and it reduced gradually with the TPO blends. The ROHR was noted high for diesel of 24 J/CAD and it also decreased with TPO blends. BSEC increases when the TPO blend ratio increases, the largest BSEC ratio was found at 36.65 MJ/kW hr at low load and 17.57 MJ/kW hr at high load conditions for TPO 30. BTE for all TPO blend at all loads are lower when compared to diesel this due to the lower calorific value of TPO.

Emission parameters such as HC, NO_x and CO has been found for TPO blends and diesel blends in all different engine loads and NO_x emissions decrease with increase in engine load for all TPO blends. NO_x emissions were found low in full load condition when compared to low loads. CO emission increase with increase in engine load for all TPO blends and for TPO 5 and TPO 10, the CO emissions are found similar to diesel at all loads. In the case of TPO 30 the CO emissions were high at all loads. This was due to the elemental composition of tire amount of carbon content present in a tire would be around 80%.

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