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Evaluation of CI engine performance fuelled by Diesel-Polanga oil blends doped with iron oxide nanoparticles

M.Santhanamuthu[1], S.Chittibabu[2*], T.Tamizharasan[3] and T.P.Mani[4]

[1]Department of Chemical Engineering, Periyar Maniammai University, Vallam, Thanjavur- 613403, Tamilnadu, India

[2]Department of Biotechnology, Periyar Maniammai University, Vallam, Thanjavur-613403, Tamilnadu, India

[3]Department of Mechanical Engineering, TRP Engineering College, Irungalur – 621105, Tamilnadu, India

[4]Department of Mechanical Engineering, Periyar Maniammai University, Vallam, Thanjavur – 613403, Tamilnadu, India

*Corres. author :chittibabus@pmu.edu

Abstract: Experimental investigations on performance and emission characteristics of internal combustion engine fuelled by polanga oil diesel fuel blend were carried out in this research work. To enhance the engine performance, iron oxide nanoparticles were doped with polanga oil–diesel fuel blend as additive. Performance and emission characteristics of diesel engine were studied for 10%, 20% and 30% (by weight) polanga oil with neat diesel. Iron oxide nanoparticles were added in three difference concentrations viz., 100, 200 and 300 ppm levels in all the three polanga oil – diesel fuel blends to study their effects on engine performance. The engine was loaded at five different brake powers for each polanga oil – diesel – iron oxide nanoparticle fuel blends. It was observed that the presence of iron oxide nanoparticle reduces the ill effects of polanga oil in diesel. At 25% polanga oil blend with diesel and iron oxide nanoparticles concentration of 150 ppm, the engine performance was observed to be similar to that of running on neat diesel. Hence doping of iron oxide nanoparticle with Polanga oil – Diesel fuel could be one of the potential substitutes for diesel in running CI engines.
Keywords: Polanga oil, iron oxide, nanoparticles, IC engine.

1. Introduction

International Energy Agency (IEA) projected that the global oil reserves are sufficient enough to meet out the demand up to the year 2030 [1]. Burning of fossil fuels also causes severe environmental deterioration due to built up of green house gases. The wide-spread pollution caused by these fuels and fast depletion of oil resources led to develop better and cleaner strategies towards continuous energy supply. To sustain the oil supply, it is necessary to find out the suitable alternatives/substitutes. Engines running on diesel fuel are the main energy source for heavy duty vehicles, agricultural pumps for irrigation, power generators etc. Thus, finding out suitable, efficient and sustainable substitutes to diesel fuel is essential to meet the increasing energy demand. Non edible Vegetable oils (NVOs) are very good substitute for diesel fuel in internal combustion engines because of their abundant availability, renewable in nature and lower emissions. Agarwal et al. [2] classified the problems associated with using NVOs as fuel in diesel engines into two groups namely operational and stability. High viscosity, presence of poly unsaturated fatty acids and extremely low volatility of NVOs are responsible for these operational and stability problems. To overcome these challenges, transesterfication of NVOs and direct blending of NVOs with diesel were identified as the suitable techniques. Even though transesterification of NVOs gave good results in engine performance and emissions but the increased production costs associated with it restricts the widespread usage of biodiesel. Hence, direct blending of NVOs with diesel becomes very attractive in terms of production and cost. Many researchers [3,4,5,6] studied the performance of diesel engines using various NVOs (rape seed oil, karanja oil, jatropha oil etc) blended with diesel fuel. It was observed that there was improvement in emissions levels but the engine performance was severely affected by these NVOs – diesel blended fuel due to poor fuel atomization and inefficient mixing with air [7,8,9]. Newer technologies have to be developed to increase the performance of engines using these blended fuels.

Polanga seed oil (PSO) was chosen for blending with diesel fuel owing to its comparable calorific value with diesel and also its high percentage of saturated fatty acids (24.96%) when compared to other NVOs which increase the cloud point, cetane number and stability. Transesterfication of PSO is difficult and cumbersome process due to its high saturated fatty acids content. Even though PSO is available in large quantities in tropical countries like India, Malaysia, Indonesia and Phillipines, utilization of PSO as fuel was restricted due to high viscosity and acid value [10]. Hence, the main objective of this research work was to experimentally evaluate the possibilities of using PSO directly blended with diesel. To overcome challenges associated with POD blends and to enhance the engine performance, iron oxide nanoparticles were used as additive. Recent studies on tribological behavior of nanoparticles added to lubricating oils concluded that the addition of nanoparticles reduces the friction between the moving surfaces due to deposition of nanoparticles in the scars and grooves on the surfaces [11]. It was also reported that iron oxide nanoparticles form condensation sites in combustion zone and burn more carbon which reduces soot formation [12]. Based on these scientific investigations, the performance of CI engines was studied using POD with iron oxide nanoparticles additive. To study the effect of iron oxide nanoparticles concentration in the engine performance, the amount of nanoparticles in the blend was changed from 100, 200 and 300 ppm in POD blend.

2. Materials and Methods

2.1 Materials

Polanga oil and diesel were purchased from local suppliers. Polanga oil was produced from the seeds of tree called punna belongs to the family *Clusiaceae* and its botanical name is *Calophyllum inophyllum* L. It is a medium to large size tree with shining leaves and golden seeds grow in sandy land near coastal belt [10]. The properties of polanga oil and diesel were analyzed as per ASTM standards and given in (Table 1). Iron (II III) Oxide nanoparticles of size < 50 nm (TEM) were purchased from Sigma Aldrich. The specifications of compression ignition diesel engine used in the experimental study were listed in (Table 2).

Table 1. Properties of Polanga seed oil and neat diesel

Properties	PSO	Diesel
Specific gravity @ 15˚C	0.9374	0.84
Kinematic viscosity @ 40˚C in cSt	57.8	3
Flash point (˚C)	227	68
Fire point (˚C)	238	106
Cloud point (˚C)	+14	224
Pour point (˚C)	7	6
Gross calorific value kcal/kg	9945	10580
Cetane no	48.1	54

Table 2. Engine specifications

Make	Kirloskar TV-1
Type	Vertical cylinder Direct Ignition diesel engine
No. of cylinder	1
Bore × stroke	87.5 mm × 110 mm
Compression	17.5:1
Cycle	Diesel
Speed	1500 rpm
Rated brake power	5.4 kW
Fuel injection pump	MICO in line with mechanical governor and flange mounted
Injection pressure	220 kg_f/cm^2
Ignition time	23˚ before TDC (rated)
Ignition system	Compression ignition
Dynamometer	Eddy current

2.2 POD – iron oxide nanoparticles blend preparation

The weighed quantities of iron oxide nanoparticles were dispersed in certain quantity of neat diesel using ultrasonic stirrer to have homogeneous mixture. It was observed that the iron oxide nanoparticles completely dispersed in diesel. This nanoparticles diesel mixture is used to make up the required quantity of diesel and blended with polanga seed oil is different proportions as given in (Table 3). This mixture of diesel, polanga seed oil and nanoparticles was used as fuel for the engine performance test.

Table 3. Composition of POD – iron oxide nanoparticles fuel blends

Trial No.	Neat Diesel (g)	Polanga Oil (g)	Iron oxide nanoparticles (ppm)	Specific gravity	Kinematic viscosity (cSt)	Calorific value (kJ/kg)
1	960	109	100	0.8353	3.49	44084
2	960	108	200	0.8373	3.62	44028
3	960	107	300	0.8375	3.39	44003
4	862	217	100	0.8475	4.38	43647
5	862	216	200	0.8483	4.45	43609
6	862	215	300	0.8489	4.51	43584
7	760	329	100	0.8545	5.92	43310
8	760	328	200	0.8554	6.01	43275
9	760	327	300	0.8556	6.02	43266
10	1000	0	0	0.834	2.8	45240

2.3 Experimental set up

A vertical, water cooled, single cylinder, four stroke direct injection KIRLOSKAR TV – 1 engine was used for this research work. The engine was coupled with an eddy current dynamometer for applying different load conditions as in (Figure 1). The specification of the test engine was given in (Table 2). The fuel injection system consisted of three-hole type injector with a MICO plunger pump of 8 mm diameter operated by the camshaft. The injection timing recommended by the manufacturer was 23˚C before TDC (static) was followed. The operating pressure of the nozzle was set at the rated value of 220 kg_f/cm^2. Cooling of the engine was accomplished by supplying water through the jackets on the engine block and cylinder head.

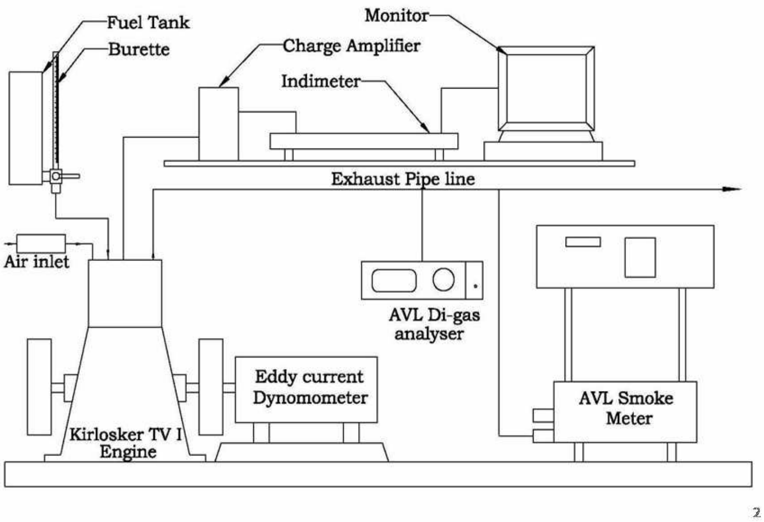

Figure 1: Schematic representation of engine set up

2.4 Experimental procedure

Performance and emission tests experiments were conducted using the different proportions of iron oxide nano particle and PDO blends. Important operating parameters such as engine shaft speed, generator output, fuel consumption rate, airflow rate, exhaust gas temperature and engine cooling water temperature were measured and performance characteristics such as brake thermal efficiency, specific fuel consumption etc were determined using fundamental relations. The test engine was coupled with an eddy current dynamometer as a loading device. A Photo sensor with a digital rpm indicator was used to measure the engine speed. The load of the engine was obtained from dial gauge reading with five discrete load conditions, varied from 0% to 100% in steps of 20%.

During each run, the engine was allowed to run with neat diesel and blends at a constant speed of 1500 rpm for nearly 30 min, to attain the steady state conditions at the lowest possible load. The temperature of the lubricating oil and temperature of the engine cooling water were maintained constant at 65˚C and 70˚C respectively to eliminate their influence on the results. The flow rate of cooling water was maintained at 7 l/min. Temperature of the exhaust gas was measured using Chromel-Alumel (k-Type) thermocouples. A digital indicator with automatic room temperature compensation facility was used. Carbon mono oxide (CO), hydrocarbon (HC), Carbon-di oxide (CO_2), Oxygen (O_2) and NO_x were measured using exhaust gas analyzer. AVL smoke meter was used to measure the smoke density of exhaust gas. The exhaust gas sample was allowed to pass through the cold trap (moisture separator) and filter element to prevent water vapour and periodically calibrated with standard gas as per the instruction provided by the manufacturer. Smoke density was measured in terms of Hartridge Smoke Unit (HSU) and Oxides of nitrogen was measured in terms of ppm.

All the measurements were recorded by a data acquisition system. Each experiment was conducted thrice and average values were taken for further calculations. The possibilities of errors that could arise during the experiments were measured to prove the accuracy of the measurements. Hence the error analysis was carried out based on the accuracy and percentage uncertainties of the instruments used in these experiments [8]. The total percentage of uncertainties of these experiments were calculated to be ± 3%.

3. Results and Discussion

3.1 Properties of POD – iron oxide blended fuel

The specific gravity, viscosity and gross calorific value of POD (10%, 20% & 30% by weight) – Iron oxide nanoparticles (100, 200 & 300 ppm) blended POD fuel were tested and listed in (Table 3). The specific gravity of the blends was observed to be 2.5% lesser than the neat diesel specific gravity. It was observed that the viscosity of the blends increased with the increase in the concentration of PSO. Increase in viscosity resulted in poor atomization of fuel in the cylinder. Hence the blending of PSO with neat diesel was restricted with the maximum 30% of PSO by weight. The calorific values of POD blends were only below 5% lesser than the calorific value of neat diesel.

3.2 Performance studies

Engine performance was studied for each fuel blends given in Table 3. Brake thermal efficiency (BTE) and Brake specific energy consumption (BSEC) were calculated based on the experimental investigations at five different load conditions. All the experiments were performed at constant engine speed of 1500 rpm. Following equations were used for calculating the BTE and BSEC.

$$BP = \frac{2.\pi.R.N.T}{60 \times 1000} \qquad (1)$$

$$BSEC = \frac{FC \times CV}{BP} \qquad (2)$$

$$HI = \frac{FC \times CV}{3600} \qquad (3)$$

$$BTE = \frac{BP}{HI} \times 100 \qquad (4)$$

Where, R – dynamometer arm length = 0.195 m; N – speed in rpm; T – torque in N.m; BP – brake power in kW; FC – fuel consumption in kg/hr; BSEC – brake specific energy consumption in kJ/kW.hr; CV – Calorific value of the fuel blend; HI – heat input in kW; BTE – Brake thermal efficiency.

Figure 2 shows the changes in the brake thermal efficiency of different blends at five different engine load conditions (brake power). The BTE of the engine reached maximum of 27% at 4.2 kW brake power i.e., 80% load, for all the POD blends and neat diesel. This shows that the performance of the engine fuelled by POD – iron oxide nanoparticle blends was on par with that of neat diesel. It was observed that the increase in the polanga oil content in the blend decreases the efficiency marginally by 5%. This was due to the increase in the viscosity of the POD blend which influenced the combustion process negatively. It was known from the reported research works, presence of iron oxide nanoparticles in POD blends [13,14] affected the BTE in the following ways., (a) Enhancement of thermal properties such as thermal conductivity, thermal diffusivity and convective heat transfer co efficient, (b) The droplets of the fuel blend is ignited at lower temperature than pure diesel, (c) Increase in vapour pressure of the blend indicating increased evaporation, (d) Helped to form micro emulsion and improve spray characteristics by explosive vapourization, (e) Improved lubricity of the blends by reducing friction between moving parts, (f) Reduced ignition delay of the blend by donating oxygen. From the (Figure 3), it was observed that the brake specific energy consumption was same for both neat diesel and blended POD fuel. At minimum load condition, the BSEC reached the maximum of 26 MJ/kW.hr. From the 60% load condition, the BSEC was constant at 13.5 MJ/kW.hr. (Figure 4) shows the changes in the exhaust gas temperature for different load condition. It was learnt that the exhaust gas temperature for the blended POD was slightly higher than the neat diesel above 80% load conditions. This might be due to the enhanced heat transfer properties by the addition of iron oxide nanoparticles.

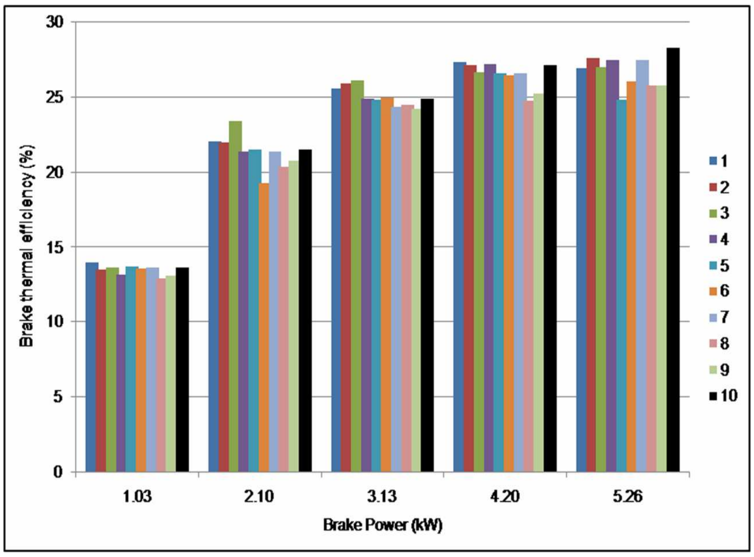

Figure 2: Brake thermal efficiency at different load conditions

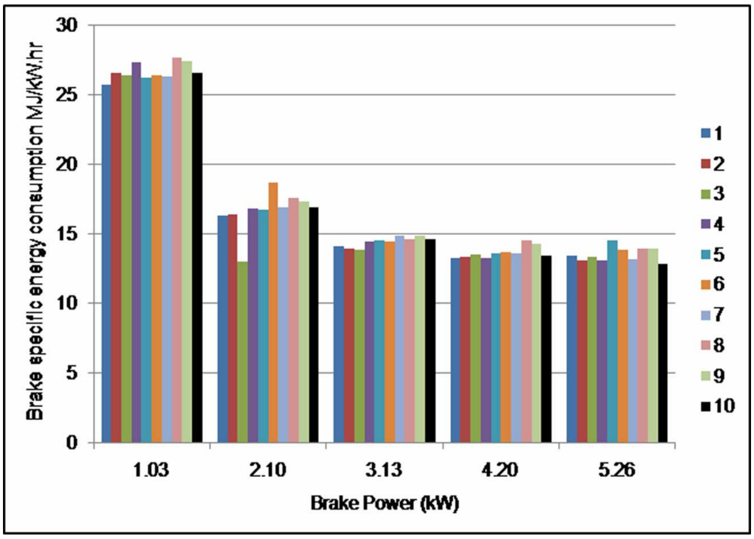

Figure 3: Brake specific energy consumption vs engine load

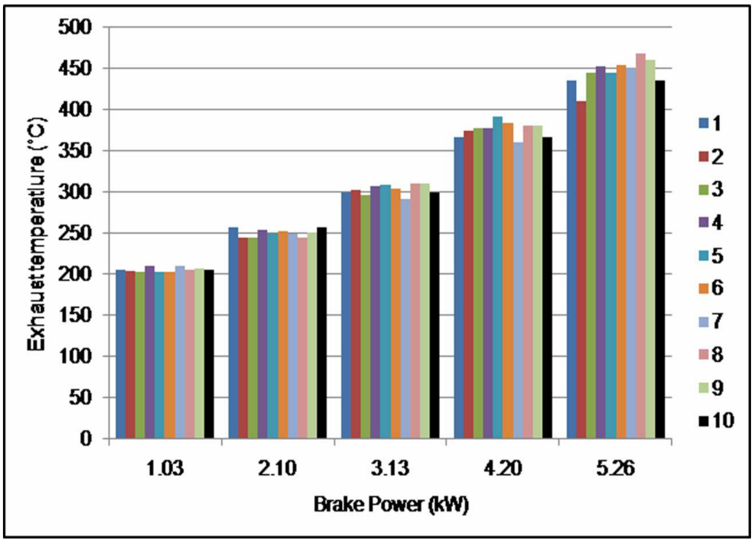

Figure 4: Variation in exhaust gas temperature

3.3 Emission studies

Emission parameters such as CO_2, CO, NO_x , HC and smoke density were measured and represented in the (Figures 5,6,7 and 8) respectively. It was noted that the trail runs 5,6,7,8 & 9 resulted in lower CO_2 emission when compared to neat diesel whereas in other trail runs, the CO_2 emission were found to be slightly higher than the neat diesel. Higher polanga oil content in the fuel blend led to lesser CO_2 emission due to the presence of oxygen content in the polanga oil and iron oxide nanoparticles act as catalyst for combustion of hydrocarbons [15]. Carbon monoxide emissions for the neat diesel and blended fuel were represented in the (Figure 6). It was observed that up to 65% load condition, the CO emission was within in the ± 5% range of diesel whereas from 80% load condition, it increased exponentially. This may be due to incomplete combustion at high load conditions. Hence it was suggested that the engine should not be loaded above 80% load to maintain the CO emissions. Bajpai et al. [3] reported that 20% blend of karanja oil with diesel was not recommended for diesel engines as far as CO emission was concerned. But from these experiments, it was observed that the CO emissions were within the limit of neat diesel at 65% load condition for 30% POD blend. It was reported that the iron oxide present in the fuel form condensation sites before the formation of carbon particles in the combustion zone and enhance the following combustion process [14]. The presence of iron oxide nanoparticles reduced the CO emission by catalyzing the combustion process which resulted in complete combustion at 70% load condition. In above 80% load conditions, the CO emission increases exponentially due to higher fuel content in the combustion chamber and poor atomization of fuel which leads to imcomplete combustion. It was known that the most important pollutants from the diesel engines are NO_x and smoke. The NO_x at different load conditions for all the blends and neat diesel was represented in (Figure 7). The NO_x emissions were significantly reduced for all the POD blend composition above 80% load. Formation of NO_x strongly depends on the temperature of combustion chamber. Increase in the combustion chamber temperature increased the NO_x emissions. Iron oxide acted as catalyst for the reaction between hydroxyl radicals present in the polanga oil and carbon atoms in the soot and lowered the oxidation temperature [13,15]. Hence the NO_x was reduced to 50% of that of neat diesel at higher polanga oil content in the blend due to presence of iron oxide nanoparticles. Presence of unburnt hydrocarbons in the engine exhaust gases were an important parameter to study the emission characteristics. The variation of unburnt hydrocarbons at different load condition was given in the (Figure 8). The unburnt hydrocarbons for the neat diesel fuel reached maximum 60 ppm at 100% load condition. The unburnt hydrocarbon content in the exhaust of 10% POD blend with 1% iron oxide nanoparticles fuel exactly matches with that of neat diesel but at higher POD blend (i.e., above 20%), the hydrocarbon emission is lesser than the neat diesel by 10-20%. This showed that the presence of iron oxide nanoparticles enhanced the combustion process by overcoming the adverse effect of high viscosity of blended fuel at higher concentration of polanga oil in the diesel.

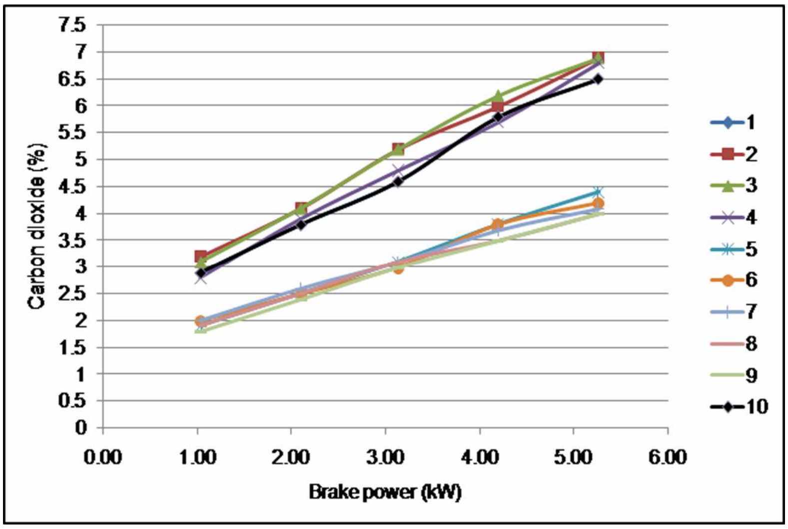

Figure 5: Carbon –dioxide concentration at different load condition

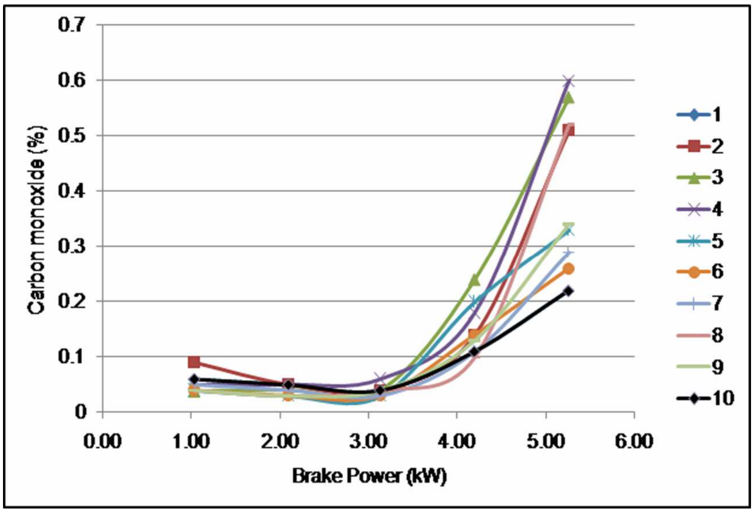

Figure 6: Carbon monoxide concentration at different load condition

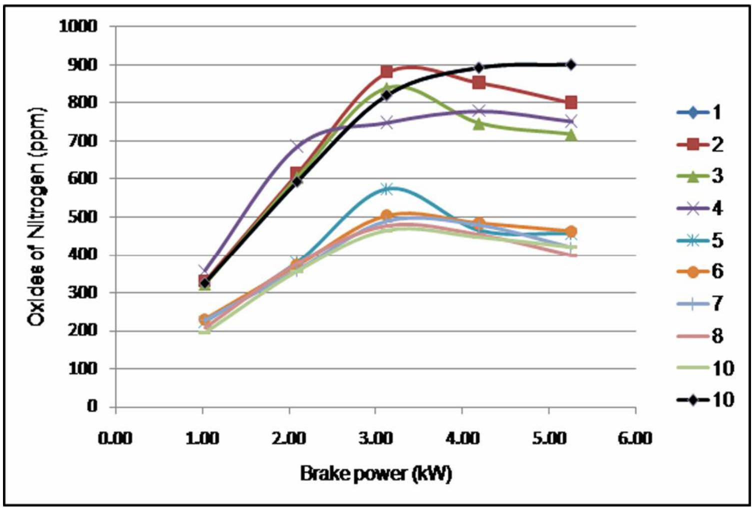

Figure 7: Oxides of nitrogen at different load conditions

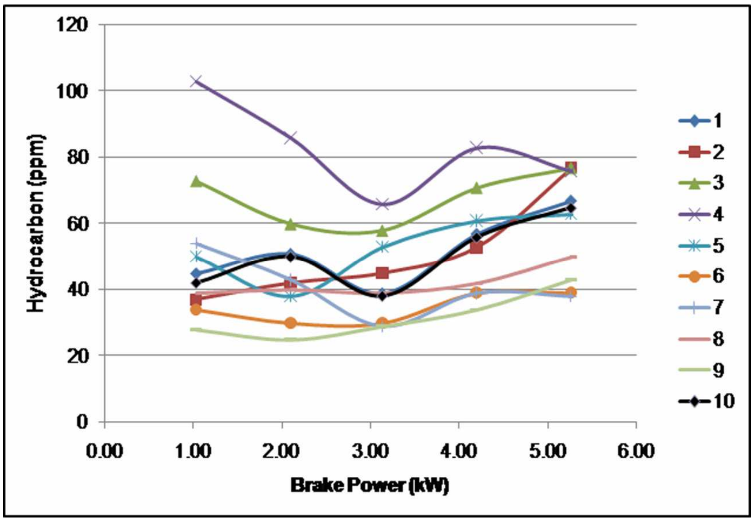

Figure 8: Concentration of hydrocarbons

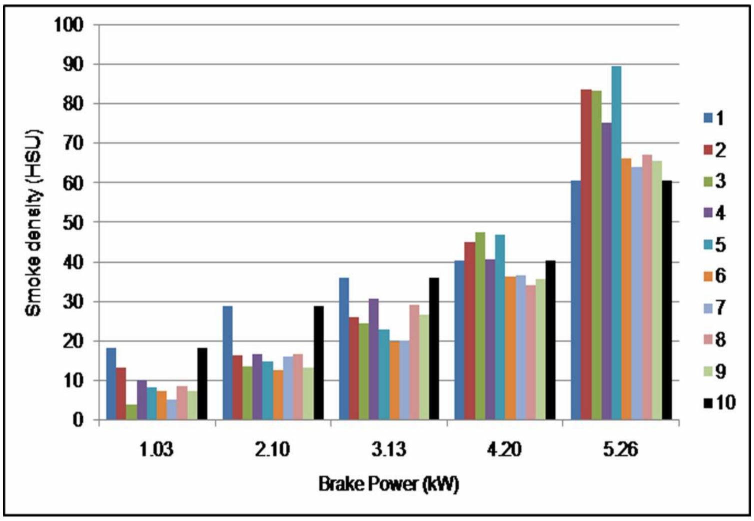

Figure 9: Smoke density

The variation of smoke density at different load condition was presented in the (Figure 9). The smoke density of 20% blend with 1% iron oxide nanoparticles was equal to neat diesel. At 10% polanga oil blend with 100 ppm iron oxide nanoparticles content, the smoke density was equal at all load conditions. Increase in the iron oxide nanoparticles content in the blend significantly reduced the smoke density by 10 – 15% with that of neat diesel up to 80% load condition. This was due to the presence of oxygen in polanga oil and iron oxide which helped complete combustion and reduced the elemental carbon in the exhaust. But the smoke density increases significantly at 100% load for all the blends.

4. Conclusion

Many researchers studied the performance of diesel engines using various NVOs – diesel blend but very few reported direct blending of polanga oil with diesel due to its high viscosity and acid value. In the present investigations, different POD blend compositions were prepared and tested with a single cylinder constant speed diesel engine. To enhance the performance of engine fuelled by POD blend, iron oxide nanoparticles were used as additive. From the exhaustive experimental studies, it could be concluded that the POD blend with iron oxide nanoparticles additive could be adopted as an alternative fuel for existing conventional diesel engines without any major modifications in the engine. Addition of iron oxide nanoparticles considerably influenced the engine performance and emission at high POD blend ratio. Many of the performance and emission parameters were equal to that of neat diesel above 20% polanga oil content in diesel with iron oxide nanoparticles at different load conditions. Performance of blend of 900 ml diesel, 300 ml polanga oil and 100 ppm nano particles was observed to be closer to neat diesel performance at 80% load conditions. But it was also observed that the change in the iron oxide nanoparticles concentration in POD blend fuel did not have major impact either in performance or emission of engine. Hence, it was concluded that the iron oxide nanoparticles in the fuel blend can be maintained at its lowest concentration. Further to these experimental studies, investigations on the escape of iron oxide nanoparticles through the exhaust gas and engine corrosion studies were to be carried out before using nanoparticles as additive in large scale. Theoretically, all the iron oxide nanoparticles present in the fuel blend took part in the combustion process by supplying oxygen and agglomeration of iron nanoparticles would take place due to high temperature in the combustion chamber. Experiments were in progress to characterize the exhaust gases and corrosion aspects of engine fuelled with POD blend with iron oxide nanoparticles. High costs of iron oxide nanoparticle do have major impact on the economy of diesel engines.

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