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# Emission Characteristics of a CI engine with the addition of different additives

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**Abstract:** In Indian cities, automobile pollution has become a great menace. The vehicular population is continuously increasing, which causes rapid increase in pollution too. The temperature keeps rising due to the pollution. The presence of carbon dioxide in the atmosphere increases the temperature. The objective of the present study is to investigate the effects and emission characteristics of petro diesel and biodiesel blends on a four stroke single cylinder diesel engine when additives are added. Biodiesel fuel used in this study was prepared from fats in goat and sheep. Biodiesel is produced by the transesterification process and subsequently the additives methyl oleate and pyrogallol are blended with the petro diesel - biodiesel blends and petro diesel. The additives are used as an alternative to solve some technical problems generated by the use of petro diesel – biodiesel blends added in varying proportions. The results showed a reduction of 53% NOx, 25% HC, 77% smoke and there was no significant reduction in CO when methyl oleate was added to Petro diesel – biodiesel blend, and there was also reduction of 56 % NOx, 33% HC, 88% smoke and an increase of 17% CO when pyrogallal was added to Petro diesel – biodiesel blend.
**Keywords**: Fats, Biodiesel, Pyrogallal, MethylOleate, Emission.

## Introduction

Emissions from automobiles pollute the urban air to a great extent. Photochemical reactions between unburned hydrocarbons and nitrogen oxides happened mostly by vehicles which were responsible for production of a number of secondary pollutants in the atmosphere. The unseasonal mist appearing in many cities especially in the morning is the result of photochemical reactions between the vehicular air pollution and secondary pollutants present in the air. Environmental advantages are more in biodiesel comparing with petro diesel. Several researchers have observed an increase in NOx emissions from biodiesel when compared with petro diesel[1–] . The only disadvantage in using biodiesel is, it increases the rate of NOx emissions in the atmosphere. It is imperative that the NOx emissions from biodiesel have to be reduced to petro diesel combustion levels for universal acceptance of biodiesel. During petro /bio diesel fuel combustion, NOx is produced .NOx can be produced by two major ways during petro diesel fuel combustion: Zeldovich (thermal) mechanism and the Fennimore (prompt) mechanism. The rate of the Zeldovich reactions is flame temperature dependent, where as the Fennimore pathway is more complex. Free radicals formed from the fuel react with Nitrogen to finally form NOx in the Fennimore mechanism. These reactions take place early in the combustion process depending partly upon the fuel radical concentration and it's process of production[4].

Data available indicates that the chemical makeup of biodiesel influences the amount of NOx formed during its combustion[5]. There was a strong positive correlation between the iodine value of the fuel and NOx .The NOx emissions increased as the iodine value increased .These papers reflect the role of double bonds in elevating NOx output .It is understandable that the increase in free radical generation is the cause for increase in NOx output by some biodiesels. The cleaning up of free radicals during combustion may reduce or eliminate the increase in NOx. Antioxidants are known to be free radical cleaning agents.

Special attention is focused on the stability of biodiesel during its storage and use. Esters of unsaturated fatty acids are unstable to the action of light .When the biodiesel is exposed to air, auto oxidation of biodiesel causes degradation in the fuel quality by affecting properties such as kinematic viscosity, acid value and peroxide value. A method for increasing the resistance of fatty derivatives against auto oxidation is to treat them with antioxidants [6].

The influence of different synthetic and natural anti oxidants on the oxidation stability of biodiesel from rapeseed oil , sunflower oil , used frying oil and beef tallow have been investigated[7]. It is observed that the synthetic antioxidant pyrogallol enhanced the induction periods of methyl esters from rape seed oil, used frying oil and tallow. A good correlation was found between the improvement of oxidation stability and fatty acid composition .The potential of different synthetic phenolic antioxidants to improve the oxidation stability of biodiesel prepared from different feedstocks was investigated[8]. At antioxidant concentrations of 1000mg/kg an improvement in oxidation stability could be achieved with all antioxidants tested[9].

Fuel lubricity can be enhanced by the addition of lubricity additives like methyl oleate .They comprise a range of surface active chemicals. They have an affinity for metal surfaces, and they form boundary films that prevent metal to metal contact that leads to wear under light to moderate loads. Recently, fatty acid methyl esters (biodiesel) have successfully been used as diesel fuel lubricity improver[10]. The hydroxyl group is significant because it facilitates plasticization and adhesion of oil esters[11]. When the unsaturation of the biodiesel increased, lubricity enhancement is also increased. In the C18 series methyl oleate demonstrates the best performance as a lubricity enhancing additive[11]. The increase of unsaturation reduces the cetane number, and the increase in chain length increases the cetane number.

## Experimental Details

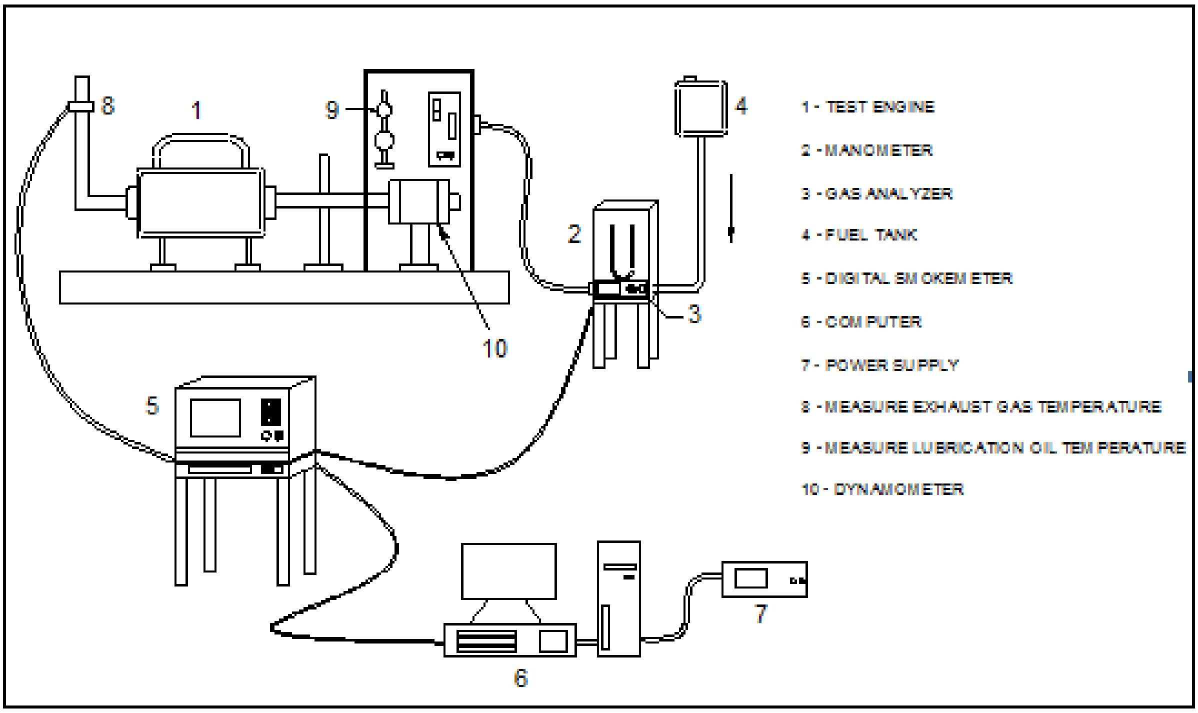


**Fig1. Schematic of the Experimental Setup**

## Material and Methods:

Waste animal (goat & sheep) fat was obtained from meat shops in and around Hosur Taluk, Krishnagiri District, Tamilnadu, South India. It was cooked in a vessel to remove the moisture. The temperature was gradually increased to 80˚C to extract the oil from the fat. The hot oil was strained in a white cloth to remove the residue.

## General Procedure:

Two methods to obtain biodiesel were: Acid-transesterification with $H_2SO_4$ as catalyst and pre-esterification with acid as catalyst followed by basic-transesterification with KOH as catalyst. Acid-transesterification was carried out in a 1 L glass reactor, immersed in a temperature controlling bath, equipped with a thermostat, mechanical stirring, sampling outlet, and condensation system. Pre-esterification and basic-transesterification reactions were carried out in a 500 mL spherical glass reactor, provided with a thermostat, magnetic stirring, sampling outlet and condensation system. All the materials were completely dried. In acid-transesterification reaction, 500 g of animal fats were heated in the reactor, when fats reached 60 ºC, methanol and catalyst ($H_2SO_4$) were added, in established amounts for each experiment, and the stirring system was connected, taking this moment as zero time. The mixture was stirred vigorously at reflux of methanol for 48 h; samples of 20 $cm^3$ were taken out at 10 h spaced intervals. Samples and reaction final mixture were placed in decantation funnels and were allowed to stand overnight to ensure the complete phase separation (methyl esters and glycerol). The glycerol phase (bottom phase) was removed and the biodiesel phase (upper phase) was heated at 85 ºC to remove methanol. The biodiesel was neutralized with KOH (20% needed KOH to neutralize the added $H_2SO_4$ as catalyst) and it was washed with deionized water to reach neutral pH.

In pre-esterification, 250 g of animal fats were heated in the reactor at the reaction temperature; in this moment methanol and acid catalyst were added and stirring of the mixture started (zero time). At evenly spaced intervals, samples of 1 $cm^3$ were taken out from the reaction mixture and its acid value was measured . After the established reaction time under vigorous stirring, the mixture was placed in a decantation funnel and allowed to stand overnight. Two phases could be identified, the upper phase consisted of methanol, catalyst, $H_2O$ and impurities and the bottom phase mainly consisted of fats and the esterified fatty acids. The phases were separated and the esterified product was then transesterified by basic catalysis, using same system as pre-esterification and similar procedure. The esterified product was weighed and the suitable amount of methanol and catalyst (KOH) were added. After reaction time, the mixture was placed in a decantation funnel; glycerol phase was separated, methanol was eliminated and biodiesel phase was washed with deionized water to remove catalyst.It was identified that viscosity and density of the biodiesel meets specifications required by ASTM D6751 and EN14214.

**Table 1: Specifications of Engine**

| | |
|---|---|
| Make | Kirloskar |
| No of cylinders | Single |
| Cooling | Water |
| Fuel | Diesel |
| Speed | 1450-1550rpm |
| HP | 5HP |
| Starting | Crank |
| Lubrication | Forced |
| Bore(mm) | 80 |
| Stroke(mm) | 110 |
| Compression ratio | 16.7 :1 |
| **Dynamometer** | |
| Type | Powermag |
| Cooling | Air |
| Load measurement method | Strain gauge |
| Max speed | 3000rpm |
| HP | 5HP |
| Coupling Type | Direct |
| Loading | Auto loading system, done through the computer |

An experimental study was conducted on a single cylinder, four stroke diesel engine. The general specifications of the test engine are shown in the table 1. A kirloskar type standard engine test bed which consists of an electrical dynamometer. The electrical dynamometer is a swinging field direct current (DC apparatus rated for 3.75kW.The engine speed was measured with a magnetic pickup sensor. The schematic view of the test equipments is shown in figure 1. Diesel fuel flow was measured with a high precision electronic balance. Exhaust gas temperature and lubricating oil temperatures were measured with a multipoint electronic temperature indicator. The thermocouples used were NiCr-Ni type which can measure upto 1200˚C.

An AVL DI GAS 444 Gas Analyzer was used to determine the percentage of carbon monoxide, hydrocarbon, carbon dioxide, oxygen and nitrogen oxides. The engine was allowed to run for several minutes to attain the steady state conditions. After attaining steady state conditions , the probe is inserted into the exhaust pipe of the engine. The exhaust gas flows over the reactor in the gas analyzer. After the analyzer attained the steady state condition , the different values of five gases are displayed. An AVL437 smoke meter was employed to determine the smoke intensity. The readings are displayed on the monitor of the smoke meter.

Blends of animal fat (goat & sheep) based biodiesel fuel B20 – (blended in volume at the ratio of 20% with diesel fuel) and petro diesel fuelwere used in this experiments. Five fuel samples were prepared for pyrogallal and methyl oleate. They are 1000mL of petro diesel,1000mL of B20,1000mL of B20 + 10g of additive, 1000mL of B20 + 20g of additive , 1000mL of B30 + 30g of additive Experiments were conducted at different load conditions at constant speed (1500 rpm).Before each test ,the engine was warmed up with diesel fuel. Engine oil temperatures were kept stable around 80˚C. The parameters like exhaust gas temperature, CO, $CO_2$, $NO_x$, HC and smoke intensity were noted at different load conditions(20%,40%,60%,80% & 100%) for each sample .

## Results and Discussion

The evaluation of exhaust emissions on the single cylinder diesel engine was done.

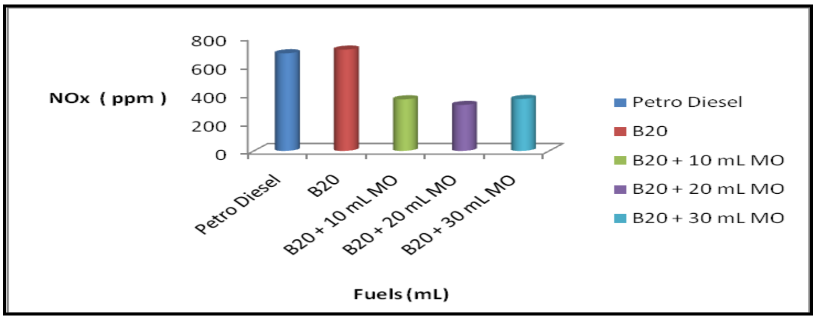


**Fig 2.Comparison of NOx emissions among Petrodiesel and the biofuel blends**

The variation of NOx emissions is shown in Fig. 2. It is observed that the use of B20 fuel increased NOx emissions. The use of biodiesel generally results in higher NOx emissions, due to its high cetane number [12, 13]. As biodiesel contains more oxygen, it improves fuel oxidation during combustion which results in higher local temperatures [12, 13, 14]. Thus, NOx emissions are increased by a thermal formation mechanism. Added to this, the different physical properties of biodiesel such as density, viscosity, bulk modulus and speed of sound, caused advancing the injection timing in the pump and nozzle fuel systems [14,15,16,17]. Biodiesel produced from animal fats has a higher concentration of saturated fatty acids and thus, it has a lower iodine number and higher cetane number than other biodiesels [18,19]. Therefore, density, viscosity and speed of sound were increased with the decreasing of compressibility and with the saturation ratio of the biodiesel. Ultimately, advancing injection timing and higher cetane number extend the combustion duration. These are the major reasons of NOx formation. The cleaning up of free radicals during combustion either reduces or eliminates NOx. Antioxidants are known as free radical cleaning agents. The fig. 2 shows that NOx has been reduced to an extent of 55% by B20 + 20 mL of MO. The reason for reduction of the NOx emissions is due to the increase of the cetane number of the fuel. The effect of antioxidant addition on NOx emissions from an 80% petrodiesel and 20% biodiesel blend resulted in the increase of the cetane number of the fuel. This leads to the reduction of NOx emissions [20].

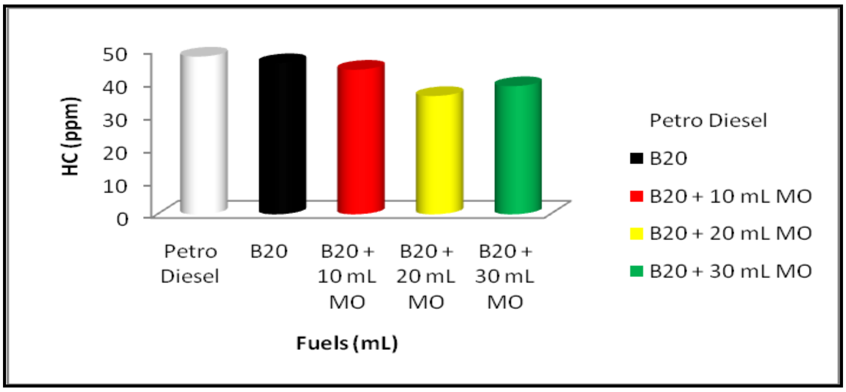


**Fig 3.Comparison of HC emissions among Petrodiesel and the biofuel blends.**

The above Fig. 3 shows the hydrocarbon emissions for different fuels. Since biodiesel is an oxygenated fuel , it improves the combustion efficiency and reduces the concentration of hydrocarbon (HC) emissions in the engine exhaust . Blending 20 mL of methyl oleate (MO) to B20 (blended with 20% by volume of biodiesel from goat and sheep fats and 80% by volume of petro diesel) greatly reduces HC emissions [21].

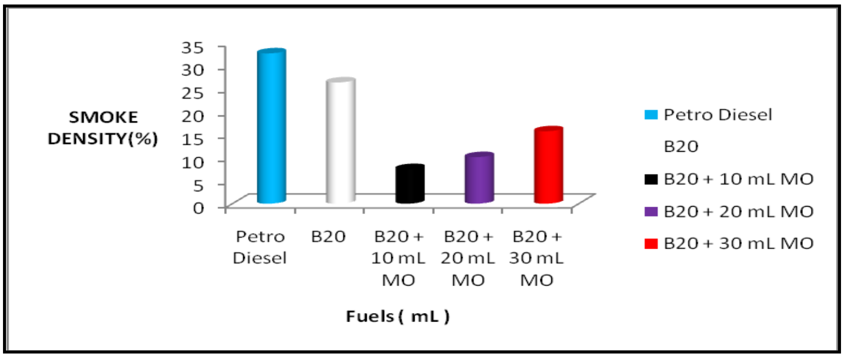


**Fig 4.Comparison of Smoke emissions among Petrodiesel and the biofuel blends.**

Fig . 4 depicts the variation of smoke emissions for different fuels. Since biodiesel is an oxygenated fuel, it produces less smoke than petrodiesel. The reason may be due to proper combustion of the fuel.

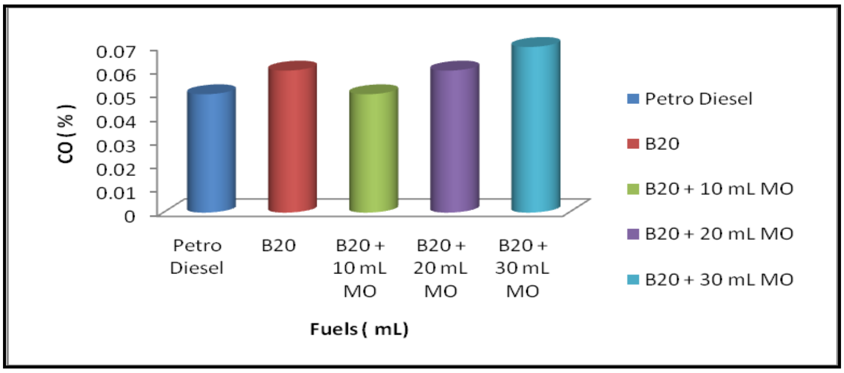


**Fig 5.Comparison of CO emissions among Petrodiesel and the biofuel blends**

The Fig. 5 depicts the variation of carbon monoxide emissions (CO) for different fuels. Factors causing combustion deterioration, due to high latent heats of evaporation, is responsible for the increased carbon monoxide (CO) emission. The delay in the ignition also produces high CO emissions [21]. This leads to a lower combustion temperature at lower loads. B20 + 10 mL of MO produces the same amount of CO as petro diesel. The other fuels produce more amount of CO than petro diesel.[22,23]

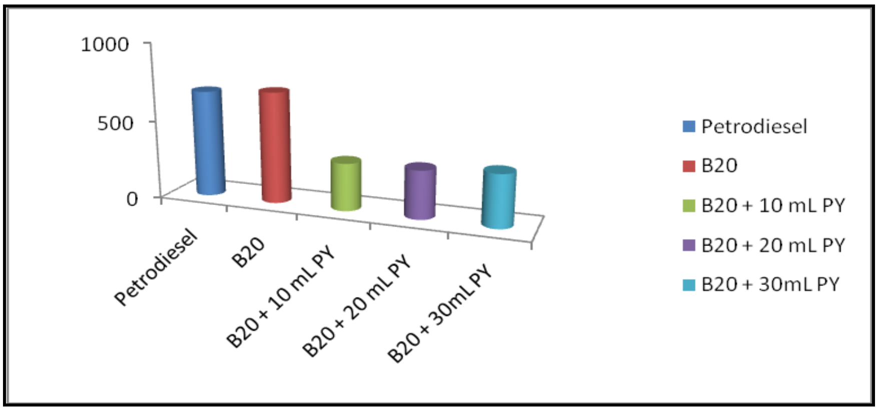


**Fig 6.Comparison of NOx emissions among Petrodiesel and the biofuel blends.**

Fig. 6 depicts the NOx emissions of the test engine running on Petro diesel B20, B20 + 10 mL PY, B20 + 20 mL PY and B20 + 30 mL PY . The corresponding engine emissions were observed to be 686ppm , 712 ppm , 304 ppm , 308 ppm and 335 ppm at a load of 50Nm over a constant engine speed of 1500rpm.It is apparent from the fig. 6 that the NOx emissions were more for biodiesel blended fuel.[14,15,16,17]

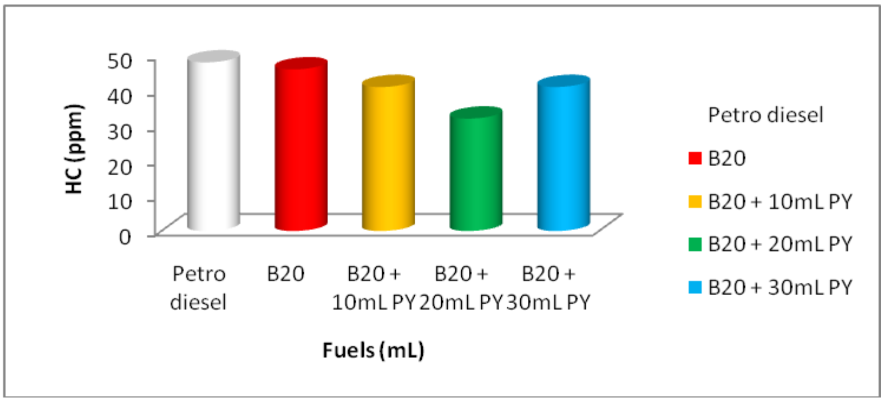


Fig. 7 shows the variation of hydro carbon emissions with respect to load for different fuels. The rate of HC emissions from biodiesel blended fuel are lower than that of petro diesel . It decreases with increase of biodiesel in the fuel . B20 + 20mL PY exhibits lower amount of hydro carbons release.[24]

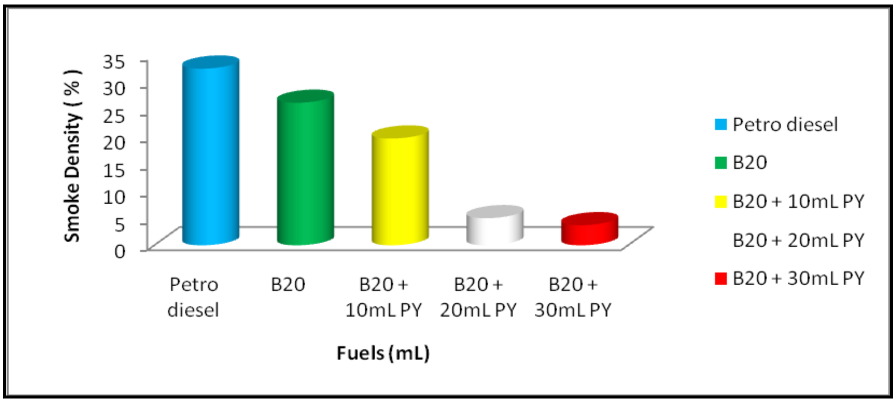


**Fig 8.Comparison of Smoke emissions among Petrodiesel and the biofuel blends.**

Fig.8 shows the variation of smoke emissions with respect to load for different fuels. This figure also shows that using biodiesel blended fuel is lower than that of petro diesel and decreased with increase of biodiesel in the fuel . But B20 + 30mL PY exhibits lower smoke density ( 3.7% ) . Lesser amount of unburnt hydrocarbons are present in the engine exhaust emissions. So, lower smoke density values are achieved with biodiesel blends , when compared to that of diesel.[25,26]

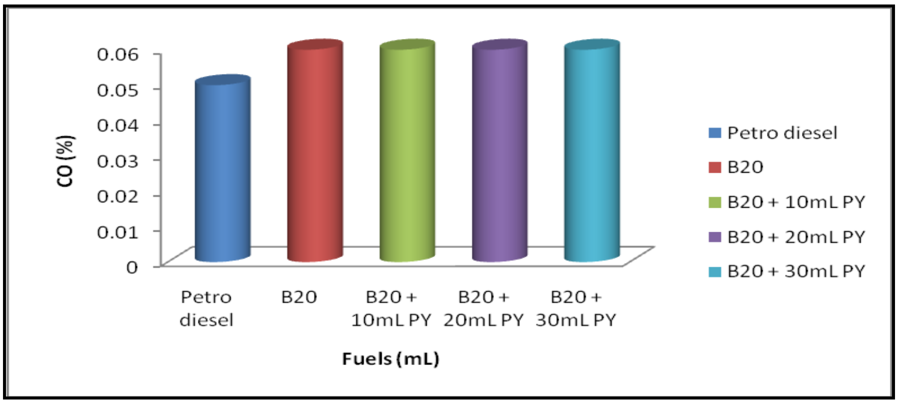


**Fig 9. Comparison of CO emissions among Petrodiesel and the biofuel blends.**

Fig. 9 shows the variation of Carbon monoxide (CO) with respect to load for different fuels. Factors causing combustion deterioration such as high latent heats of evaporation, could be responsible for the increased carbon monoxide (CO) emission. Another reason for the high CO emission is the increase in ignition delay. This leads to a lower combustion temperature at lower loads. The addition of the additive pyrogallal produces the same amount of CO as bio diesel. The other fuels produced slightly more amount of CO than petrodiesel. However, comparing B20, B20 + 10 mL PY, B20 + 20 mL PY, B20 + 30 mL PY with petrodiesel did not show any significant change in Carbon Monoxide (CO) emissions.[22,23] .

## Conclusions

The effect of petrodiesel biodiesel blend and the addition of additives to the biodiesel blend on the CI engine's emission (Smoke density, HC, NOx, and CO) characteristics were studied in detail for the steady state operation conditions. The following conclusions are drawn for the different fuel concentrations:

1. NOx emissions reduced by 53 % when B20 + 20mL MO was used as the fuel compared to petro diesel.
2. HC is reduced by 25 % when B20 + 20mL MO was used as the fuel compared to petro diesel.
3. Smoke emissions is reduced by 77 % when B20 + 10 mL MO was used as the fuel compared to petro diesel.
4. CO emissions were similar for petro diesel and B20 + 10 mL MO.
5. A NOx emission is reduced by 56 % when B20 + 10 mL PY was used as the fuel compared to petro diesel.
6. HC reduced by 33 % when B20 + 20 mL PY was used as the fuel compared to petro diesel.
7. Smoke emissions is reduced by 89 % when B20 + 30 mL PY was used as the fuel compared to petro diesel.
8. CO emissions increased by 17 % when B20, B20 + 10 mL PY, B20 + 20 mL PY and B20 + 30 mL PY were used as the fuel compared to petro diesel.

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