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Reduction of NOx Emissions with Low Viscous Biofuel Using Exhaust Gas Recirculation Technique

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Abstract: The demand of biodiesel as an alternate fuel is increasing due to fossil fuel depletion. The two most common types of biofuels are ethanol and biodiesel. In this study, plant species, Lemongrass (LG) (Cymbopogon flexuous) is discussed as a newer source of oil for biodiesel production. The chemical composition of LG was observed with Fourier Transform Infrared Spectroscopy (FT-IR). The properties of LG were found to be closer to that of neat diesel. In-order to enhance the properties of LG, a cetane enhancer namely Pyrogallol (PY), which acts as an anti-oxidant and Diethyl ether (DEE) which is highly volatile and has higher oxygen content was added. Blends LG+PY, LG+DEE and LG+PY+DEE are mixed with diesel and properties were determined. Test fuels are denoted as BE-1 (75% diesel 20% LG and 5% DEE), BE-2 (80% diesel 20% LG and 500ppm of pyrogallol) and BE-3 (75% diesel 20% LG, 5% DEE and 500ppm of pyrogallol) respectively. NOx formation is highly temperature dependant phenomenon and takes place when the temperature in the combustion chamber exceeds 2000k. Therefore, in order to reduce NOx emission in the exhaust, it is necessary to keep peak combustion temperature under control. Recirculating part of the exhaust gas helps in reducing NOx. So, the work was further extended with the application of Exhaust Gas Recirculation system (EGR) as a post treatment system for the reduction of NOx emission.

Keywords: Lemongrass oil, pyrogallol, diethyl ether, NOx, EGR, FTIR.

INTRODUCTION

Taking into consideration the facts such as depletion of fossil fuels and increasing environmental pollution causing global warming, we have made an experimental study about using a biofuel namely LG and thereby simultaneously reducing the NOx emission. Usage of biodiesel blends in a compression ignition engine gives lower carbon monoxide, hydrocarbon and smoke emission but the NOx emission is comparatively higher than normal diesel when using a biodiesel because of the presence of high oxygen content present in them, to overcome this factor EGR is been used. In this study B20 (20% lemon grass oil in a 100% fuel mixture) blend is been used which is considered to be the optimum blend because of its performance and emission characteristics were nearer to diesel fuel. Efficiency of B20 was closer to diesel than any other biodiesel blends of diesel and it meets all the requirements set in current fuel quality standards, according to the researchers [1,2] [9-11]. The properties of LG are closer to that of diesel, so LG is chosen above any other oils present, in this experimental study [2]. To enhance properties of the blend's additives are added to the biofuel. A cetane enhancer PY and a highly volatile material DEE was added to the blends and tested. The presence of high content of unsaturated fatty acids present in the biodiesel leads to a problem that biodiesel is prone to oxidation during storage period. This oxidation instability causes degradation of the fuel quality and will affect the engine performance [12,23]. PY helps in maintaining the kinematic viscosity for a long period of time compared with any other additives, it is also an organic compound which helps in homolysis during combustion of fuel [15,21,22]. According to the researchers PY was found to be the most effective antioxidant for oxidation and thermal stability, PY acts as an oxidation inhibitor [13,14]. The addition of higher oxygen content and highly volatile liquids such as DEE can be a promising technique increasing the efficiency of the biodiesel blends in diesel engine without any engine modifications in the engine [16,18,20].It has a very high cetane number, higher oxygen content, low auto ignition temperature, higher miscibility in diesel fuel, low viscosity, higher heat of vaporization, significant energy density and extensive flammability limits [17]. DEE is mainly used to improve fuel properties and

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combustion characteristics in diesel engine [19]. To reduce the NOx emission produced by the usage of biodiesel a unique technique is followed which is recirculating a portion the exhaust gas back into the cylinder [7]. EGR can reduce the NOx emission in a compression ignition engine fuelled with biodiesel blends. In this experimental study hot EGR is been used, which would increase the intake charge temperature, thereby affecting combustion and exhaust emissions [3,5]. The minimum NO was obtained at the highest level of EGR [8]. In hot EGR exhaust gas is recirculated without being cooled, resulting in increased intake charge temperature, 25 percentage of EGR shows decrease in NOx levels and optimum results were obtained with 25 percentage EGR anyhow there is a trade off with smoke and hydro carbon emission [4,6].

MATERIALS AND METHODOLOGY

Under this section the materials used such as lemongrass oil, pyrogallol, diethyl ether and EGR are discussed and the methods such as blending the fuel, experimental setup and engine testing are explained briefly.

Lemongrass Oil

Lemongrass (Cymbopogon flexuous), is a tropical perennial plant which yields aromatic oil. The name lemongrass is derived from the typical lemon-like odour of the essential oil present in the shoot. Lemongrass oil was extracted by steam distillation method, steam generated from external boiler was introduced into the chamber in which lemongrass gets heated and due to high temperature, lemongrass oil was extracted from lemongrass. The properties of lemongrass obtained are closer to diesel. The viscosity seems to be little higher than diesel. Neat lemongrass oil could be used as a new alternate fuel in compression ignition engines without any engine modification. LG has a comparable calorific value (83%) with neat diesel. Higher proportions of LG with diesel fuel exhibited higher NOx emissions and the more engine vibrations. In this experimental study LG is mixed with diesel in 20% to the total volume, B20 respectively with the addition of additives. The properties of LG such as density, calorific value, flash point, fire point, viscosity and cetane index determined and shown in table. 1, lemongrass is shown in fig.1. further to identify the characteristic functional group present in LG FT-IR (Fourier transform infrared spectroscopy) was carried out.

TABLE 1. Properties of Lemongrass oil

PROPERTIES	LEMONGRASS OIL
Gross calorific value MJ/kg)	36.27
Kinematic viscosity at 40°C	4.18
Density	0.820 g/cc
Flash point °C	50
Fire point	63ºC
Cetane index	38

(a)

(b)

FIGURE 1. Lemongrass and Lemongrass Oil

FTIR OF LEMONGRASS

FT-IR is used to identify the characteristic functional groups present in the oil. The machine used is ALPHA-ATR which has a wavelength of 4000-400 cm-1. The chemical bond present in the oil will stretch, contract and absorb the infrared radiation in a wavelength which affects the bond the most when the infrared light is passed through the oil sample. The highest peak absorbed was at 2923cm-1 and 2855cm-1, the peak absorptions show the presence of OH group which shows the presence of aldehydes (1740cm-1), alkyl, aryl halides (1171.49 and 717.94 cm-1) and nitro compounds (1446.88cm-1).

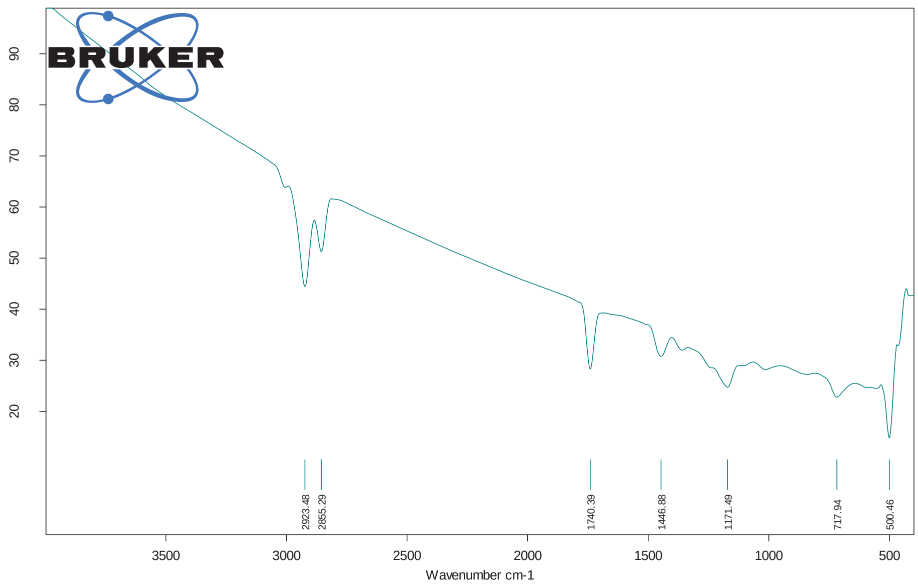


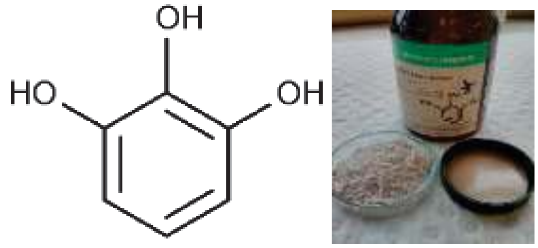
FIGURE 2. FTIR of Lemongrass

Pyrogallol

The introduction of pyrogallol a cetane enhancer into lemongrass oil could possibly lead to a change in the mechanism of oxidation process. Pyrogallol displays excellent antioxidant efficiency over the temperature range. High content of unsaturated fatty acid leads to a problem that biodiesel is prone to oxidation during storage period. This oxidation instability causes degradation of fuel quality and will affect engine performance. Pyrogallol a phenolic compound has been used as an antioxidant additive to prevent biodiesel oxidation. As reported in many researches pyrogallol is one of the best phenolic antioxidants. It helps to improve the fuel properties, pour point, cetane number and maintaining the kinematic viscosity of the fuel for a long storage period. Addition of pyrogallol enhanced the fuel properties such as performance and emission parameters. Pyrogallol is refined into extremely fine powder by the process of ball milling by using zirconia ceramic balls. The grinding is done at a speed of 250 rpm for about 2 hours. Properties of PY are shown in table 2.

TABLE 2. Properties of PY

Properties	PY
Molecular formula	$C_6H_6O_3$
Chemical name	Benzene-1,2,3- triol
Molecular weight (g/mol)	126.11
Density (g/cm3	1.45
Flash point (°C)	230



(a) (b)

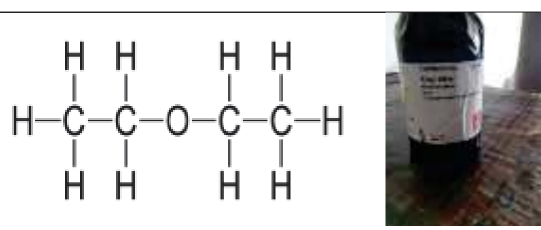
FIGURE 3. Pyrogallol

Diethyl Ether

The addition of higher oxygen content and high volatility fuels, such as diethyl ether and ethanol can be a promising technique for using biodiesel blend efficiently in diesel engines without any modifications in engine. It can increase the oxygen contents, which may further improve the particulate emissions. The use of additive enhanced the performance of engine and reduced BSFC. Emissions such as NOx, CO, particulate matter etc will be reduced when fuelled with biodiesel. DEE has some favourable features for blending with diesel fuels, including a very high cetane number, low viscosity, higher heat of vaporization, significant energy density, higher oxygen content, low autoignition temperature, extensive flammability limits and high miscibility in the diesel fuel. It improves the fuel properties and combustion characteristics in diesel engine. The properties of DEE are shown in table 3.

TABLE 3. Properties of DEE

PROPERTIES	DIETHYL ETHER
Grosscalorific value MJ/kg)	34.05
Kinematic viscosity at 40°C	0.23
Density	720
Flash point °C	-40
Cetane index	>125



(a) (b)

FIGURE 4. DEE

EGR

NO and NO_2 are together termed as NOx but both are different pollutants, NO is colourless and odourless gas where as NO_2 is a reddish-brown gas with pungent smell. NO_2 is five times more toxic than NO. NOx formation is highly temperature dependent phenomenon and takes place when the temperature inside the combustion chamber exceeds 2000K. In order to reduce NOx EGR technique is used.

EGR can reduce NO emissions in a CI engine fuelled with diesel and biodiesel blends. With EGR fuel consumption and air fuel equivalence ratio can be decreased. The specific heat of the EGR is much higher than fresh air, hence EGR increases the heat capacity of the intake charge, thus reducing the temperature increase for the same heat release in the combustion chamber. Compared with conventional diesel fuel, the exhaust NO was reduced significantly with biodiesel blends and 25% EGR due to less oxygen available in the recirculated exhaust gases which lowers the flame temperature in the combustion. NOx level is reduced highly with 25% EGR. CO and O2 emission were optimum with 25% EGR. In this study hot EGR is used.

HOT EGR: Exhaust gas is recirculated without being cooled, resulting in increased intake charge temperature.

EGR rate is calculated by the formula:

$$\%EGR = \frac{volume\ of EGR}{Total\ intake\ charge\ into\ the\ cylinder} * 100$$

An EGR control valve is provided in the intake manifold to regulate the exhaust gas entering the cylinder. An orifice meter is installed in the route of EGR into the cylinder to measure the volumetric air flow rate of the EGR. Simultaneously the flow of intake air into the cylinder i.e. exhaust gas + atmospheric air is also measured using another orifice meter, to get the total intake charge into the cylinder.

Engine Setup

The engine in which the experiment is carried out is shown in fig.5 and the engine details are mentioned below.Engine Details: IC Engine set up under test is Kirloskar TV1 having power 5.20 kW @ 1500 rpm which is 1 Cylinder, four stroke, Constant Speed, Water Cooled, Diesel Engine, with Cylinder Bore 87.50(mm), Stroke Length 110.00(mm), Connecting Rod length 234.00(mm), Compression Ratio 17.50, Swept volume 661.45 (cc)Performance Parameters of the engine: Orifice Diameter (mm): 20.00, Orifice Coefficient Of Discharge: 0.60, Dynamometer Arm Length (mm): 185, Fuel Pipe diameter (mm): 12.40, Ambient Temp. (Deg C) : 27, Pulses Per revolution : 360, Fuel Type : Diesel, Fuel Density (Kg/m^3) : 860, Calorific Value Of Fuel (KJ/kg) : 41014

FIGURE 5. Kirloskar Tv1 Engine With Line Diagram

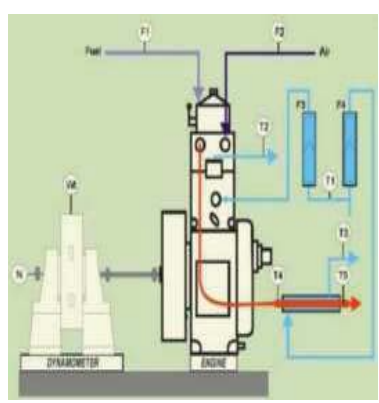


FIGURE 6. Kirloskar Tv1 Engine Line Diagram

TABLE 4. Engine Specifications

Points	Nomenclature
T1	Inlet temperature of water jacket in calorimeter and engine jacket
T2	Outlet temperature of water from engine jacket
T3	Outlet temperature of water from calorimeter
T4	Inlet temperature of exhaust gases into calorimeter
T5	Outlet temperature of exhaust gases from calorimeter
F1	Fuel supply to engine cylinder
F2	Air flow to engine cylinder
F3	Water flow to the engine jacket
F4	Water flow to calorimeter
N	Non-contact type speed sensor (Engine shaft speed)
W	Load sensor (Eddy current dynamometer

METHODOLOGY

In this experimental study, three biodiesel blends with different additives are tested with 25% EGR in a single cylinder, four stroke, water cooled diesel engine. The test blends and their compositions are listed below,

Blend 1: BE-1 (75% diesel+ 20% LG and 5% DEE) with 25% EGR.

Blend 2: BE-2 (80% diesel 20% LG and 500ppm of PY) with 25% EGR.

Blend 3: BE-3 (75% diesel 20% LG, 5% DEE and 500ppm of PY) with 25% EGR.

These three blends are been tested, their test results are analysed and discussed below.

RESULT AND DISCUSSION

This experimental study concerns mainly about the reduction of NOx emission in diesel engines. The engine parameters for performance characteristics such as brake thermal efficiency, specific fuel consumption and emission characteristics such as NOx emission, Carbon monoxide emission, hydrocarbon emission, and smoke emission are discussed from the results obtained from engine testing.

Performance Analysis

Under this topic the engine performance characteristics such as brake thermal efficiency and specific fuel consumption for the three blends BE-1, BE-2 and BE-3 are tested with 25% of EGR in a single cylinder, four stroke, constant Speed, water Cooled, diesel Engine and their results are discussed below.

Brake Thermal Efficiency

Brake thermal efficiency is a brake power from the heat engine which indicates the thermal input from the fuel injected into the engine cylinder. It is used to evaluate how well the engine converts heat from the fuel into mechanical energy. The brake thermal efficiency from testing all the three biodiesel blends under 25% EGR conditions were obtained and tabulated. As, different additives are used in all the three blends there are variations in the brake thermal efficiency under varying brake mean effective pressure. From the results obtained graph was drawn and compared between the various blends of biodiesel and with that of normal diesel in Fig 7. Fig 7 represents that the average brake thermal efficiency of the blended samples is 5.89% higher than that of diesel. BE-1, BE-2 and BE-3 are higher than that of diesel by 5.80%, 5.67% and 6.20% respectively. At BMEP 6.25 the value of diesel increases when comparing with all three blends, the difference between diesel and the blends BE-1, BE-2 and BE-3 with 25% EGR are 0.95, 1.11 and 0.15. BE-3 shows better percentage increase and considered to be the optimum one. The reduced break thermal efficiency at BMEP 6.25 is due to the usage of 25% of EGR at higher loads. This is due to the deficiency of oxygen concentration in the intake charge during higher load conditions. Due to the use of EGR there is an increase in CO_2 and H_2O concentration in the intake which directly decreases the peak combustion temperature of the engine because of their higher specific heat capacity.

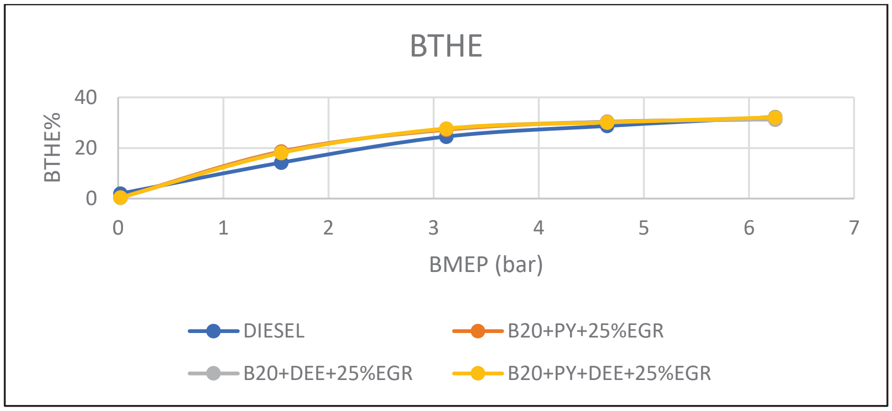


FIGURE 7. Brake Thermal Efficiency

Specific Fuel Consumption

Specific fuel consumption is to determine the amount of fuel burned by the engine for each unit of power output, which in turn determines effectiveness of the engine. The Specific fuel consumption values obtained from the engine test is tabulated and the graph is drawn with varying brake mean effective pressure and compared with the values of diesel under normal conditions. Fig. 8 represents the Specific fuel consumption graph. From the graph, the average values of all the three blends when compared to diesel is about 23.51% higher. Each blend shows more SFC than diesel at various BMEP. The lowest among the blends is BE-3 with 25% EGR which is 21.34% more than that of diesel, but all the three blends with 25% EGR shows lower SFC than diesel at BMEP's 1.55 and 3.12 but further increases after that. The increased SFC is due to the lack of O_2 followed by higher level of atmospheric air being displaced by exhaust gases. The flow of exhaust gas into the cylinder lowers the combustion temperature which results in the consumption of more fuel in maintaining the engine speed at a given load. This also reduces the exhaust gas temperature.

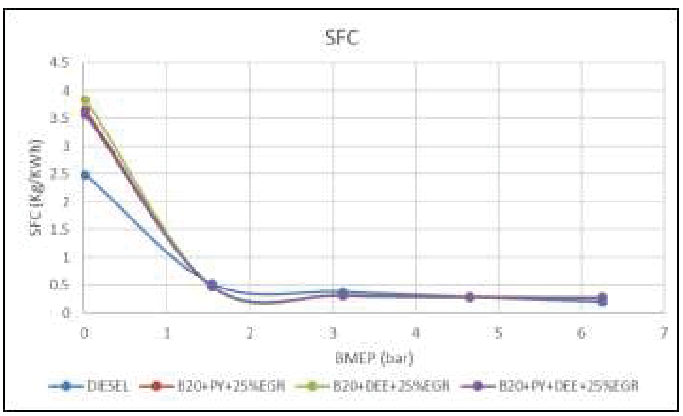


FIGURE 8. Specific Fuel Consumption

Emission Analysis

Various emission characteristics such as CO, HC, NO_x, and Smoke for the three blends BE-1, BE-2 and BE-3 are tested with 25% of EGR in a single cylinder, four strokes, water Cooled diesel Engine and their results are compared with that of diesel fuel under normal conditions and are discussed below.

CO Emission

Carbon monoxide is considered to be an intermediate product during the combustion of hydrocarbon fuel. CO emission is due to the lower flame temperature, low or high equivalence ratios, physical and chemical properties of the fuel and insufficient residence time. With EGR conditions there is a drop in CO emission due to the replacement of fresh O_2 in the intake charge by the exhaust gas being recirculated. The additive PY lowers the ignition delay period, improves the air fuel mixing and the higher activation energy leads to complete combustion of fuels. The CO emission for the blends from the engine testing are tabulated and graph is draw for the following, fig 8represents the emission of CO for the blends BE-1, BE-2, BE-3 under 25% EGR conditions for all the three blends and diesel with varying BMEP and the results are discussed. From fig 8, the average of CO in all the three blends under varying BMEP is comparatively lower than diesel by 0.047%, BE-1 is 0.045% lower than diesel, BE-2 is 0.042% lower than diesel and BE-3 is 0.061% lower than that of diesel and considered to be the optimum one. This is due to the presence of PY and DEE both present in the blend BE-3. There is a sudden rise in the values at BMEP 1.55 and 4.65 for all the blends but it decreases with increase in BMEP.

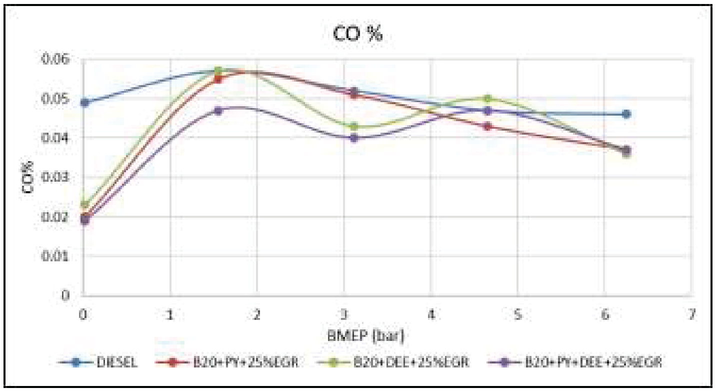


FIGURE 9. CO Emission

HC Emission

Hydro carbon emission is due to the improper combustion of the fuels. HC is the incompletely burnt fuel particles coming out through the exhaust. This may be either in gaseous state or in solid state. The cause for the formation of hydrocarbons are rich or over lean mixture, incomplete evaporation of the fuel and insufficient oxygen content in the fuels. The HC emission for all the three blends BE-1, BE-2, BE-3 under 25% EGR conditions for all the three blends and diesel with varying BMEP is shown in fig 9. From fig 9, the average of HC emission for all the three blends when compared to diesel they are 24.24% lower than that of diesel whereas BE-1 is 22.22% lesser, BE-2 is 19.69% lesser and BE-3 is 30.80% lesser than that of diesel under 25% EGR and BE-3 with 25% EGR is considered to be the optimum one. The reduced HC is because of the higher oxygen content in the lemongrass oil and also in the additives PY and DEE used. Fig 10 shows that the HC emission increases with increase in BMEP, however the HC emissions are relatively lower than that of diesel, normally with the use of EGR, HC emission increases with increase in engine load conditions and EGR rate but in this experimental study with the use of PY and DEE in lemongrass oil mixed with diesel in B20 ratio, there is reduced HC level even with the use of EGR because of the presence of high oxygen values.

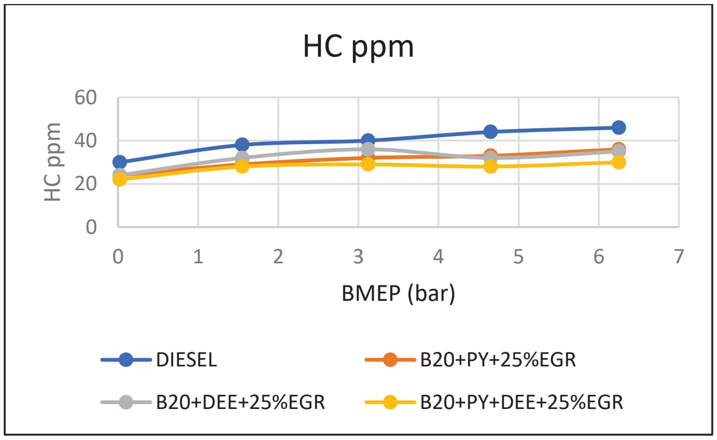


FIGURE 10. HC Emission

NOx Emission

NOx emission depends mainly upon the temperature in the engine chamber, NOx is formed when the engine temperature is above 2000K inside the engine only then nitrogen reacts with molecules of oxygen and forms nitrogen oxides, whereas NO_2 is a harmless gas but NO is five times more toxic than NO_2. This is due to the presence of high amount oxygen content in the fuels and in biodiesel NOx emission is high due to the high oxygenated fuels. In order to reduce the formation of NOx EGR is been used. NOx emission for all the three blends BE-1, BE-2, BE-3 under 25% EGR conditions for all the three blends and diesel with varying BMEP is shown in fig 11. From fig 10 the average NOx emission of all the three blends under varying BMEP with 25% EGR is found to be 40.03% lesser than that of diesel. BE-1 is 38.91% lesser, BE-2 is 39.72% lesser and BE-3 is 41.46% lesser than that of diesel under normal conditions. BE-3 with 25% EGR is considered to be the optimum fuel with reduced NOx percentage. The NOx of all the three blends increases with increase in BMEP. The reduced NOx is due to the use of EGR.

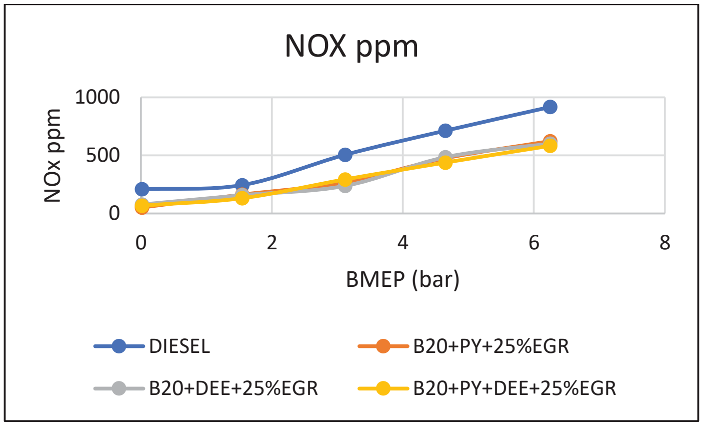


FIGURE 11. NOx Emission

Smoke Emission

Smoke emission in a diesel engine is due to the higher viscosity of the fuels, higher carbon and hydrogen ratios, deficiency of air during combustion, improper mixture of fuel, poor atomization and excessive fuel accumulation in the combustion chamber. Smoke emission for all the three blends BE-1, BE-2, BE-3 under 25% EGR conditions for all the three blends and diesel with varying BMEP is shown in fig 12.

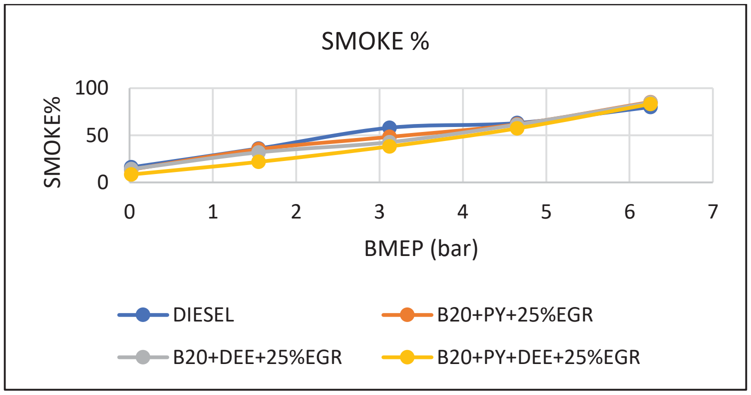


FIGURE 12. Smoke Emission

The emission of smoke for all the three blends on an average is 8.3% lower than that of diesel but with higher BMEP which is 6.25 (bar), the smoke emission difference of all the three blends with that of diesel exceeds diesel by 5.3%, 4.7% and 3.2% for BE-1, BE-2 and BE-3 respectively. But on an average the difference between diesel and the blends were BE-1 is 3.5%, BE-2 is 3.67% and BE-3 is 17.43% lower than diesel under normal operating conditions and BE-3 under 25% EGR is considered to be the optimum one.

CONCLUSION

In this experimental study, reduction of NOx emission while using a biofuel was mainly concentrated. In order to achieve the same lemongrass oil with additives diethyl ether and pyrogallol was used under 25% EGR condition. Lemongrass oil was blended with diesel in 20% ratio over 100% and the remaining was with diesel, diethyl ether and pyrogallol. The three blends were BE-1 (75% diesel 20% LG and 5% DEE), BE-2 (80% diesel 20% LG and 500ppm of pyrogallol) and BE-3 (75% diesel 20% LG, 5% DEE and 500ppm of pyrogallol) respectively. The blends were prepared and tested in CI engine with an EGR rate of 25% and the performance and emission characteristics were analysed.

- Property test and FT-IR test for lemongrass oil was carried out and found that the properties of lemongrass oil were nearly similar to that of diesel.
- The brake thermal efficiency on an average for the blends under 25% EGR is 5.89% higher than that of diesel, BE-1, BE-2 and BE-3 are higher than that of diesel by 5.80%, 5.67% and 6.20% respectively. BE-3 shows better percentage increase and considered to be the optimum one.
- The specific fuel consumption on an average for all the three blends with 25% EGR was higher than that of diesel by 23.5%.
- The HC emission was lower than that of diesel for all the three blends BE-1, BE-2 and BE-3 under 25% EGR conditions by 22.22%, 19.69% and 30.80% respectively and the blend BE-3 is considered to be the optimum one.
- The CO emission was lower than that of diesel for all the three blends BE-1, BE-2 and BE-3 under 25% EGR conditions by 17.92%, 16.73% and 24.30% respectively and the blend BE-3 is considered to be the optimum one.
- The NOx emission which was the most concentrated one in this study was lower than that of diesel for all the three blends BE-1, BE-2 and BE-3 under 25% EGR conditions by 38.91%, 39.72% and 41.46% respectively and the blend BE-3 is the one with much reduced NOx percentage.
- The smoke emission on an average was lower than that of diesel by 8.3% but is more than that of diesel at BMEP 6.25 bar and increases with increase in BMEP.

It was concluded that BE-3 with 75% diesel, 20% LG, 5% DEE and 500ppm of pyrogallol with 25% EGR was considered to have better performance and emission characteristics when compared with the other two blends.

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