Performance and Emission Analysis of Eucalyptus Oil-artocarpus Heterophyllus Methyl Ester Supported by EGR System on LHR Engine

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Abstract
The present experiment deals with the study of effects of using Exhaust Gas Recirculation (EGR) system on the performance and emission characteristics of LHR engine using Artocarpus heterophyllus methyl ester-eucalyptus oil blends. The test blends are AHME50Eu50 (Artocarpus heterophyllus methyl ester 50% and Eucalyptus oil 50%), AHME50Eu50+15%EGR and diesel. The optimum results we get with presence of EGR system in AHME50Eu50 in LHR engine. The presence of EGR system creates a low oxygen content for combustion and reduces the NOx emission. The graph depicts that addition of 15% EGR gives the best performance in BSEC, BSFC, BTE and emission wise when coupled with LHR engines. Most notably NOx emission rate is decreased by the presence of the EGR and BSFC is brought under acceptable limit. It also said to improve the cold flow properties of the AHME-eucalyptus oil blend.

Keywords
Artocarpus Heterophyllus Methyl Ester; Low Heat Rejection Engine; Conventional Engine; Exhaust Gas Recirculation System

I. Introduction
After the emergence of industrial revolution, the demand for energy has become an inevitable part in serving the man kind in the late 19th century. Fossil fuel serves as a basic resource for energy and plays a vital role in any country. The fact that the fossil fuels are non-renewable and can become extinct one day has diverted all our minds for the search of alternates that could aid the scenario from getting worse. It is also equally important to maintain a balance in the ecosystem by equal dependence on all the resources available on the earth rather entirely consuming a single type of fuel. Another major factor that knocks our mind is that the fossil fuels are the backup for pollution especially air pollution. Union of concerned scientists has stated that "passenger vehicles and heavy duty trucks are the main sources of pollution which includes ozone layer depletion, particulate matter and other smog forming emissions".

It has also reported that the transportation contributed more than half of carbon monoxide and NOX and almost quarter of hydrocarbons emitted into our air in the year 2013. The price of the alternate fuel also draws the focus which determines its use. While considering factors like replenish- ability, price and lower emissions the biodiesel projects itself as an ideal alternate fuel for petrol or diesel. Biodiesel is defined as "the mono alkyl esters of long chain fatty oils or animal fats, for use in compression ignition engines [3]. Due to the abundance of petroleum diesel fuel which was lower in cost comparatively, vegetable oils gained less attention except in times of hike in oil prices and oil shortages. Tireless work by researchers such as Martin Mittlebach furthered development of biodiesel fuel industry in early 1990's. It is ecofriendly and non-biodegradable. As it is obtained from vegetable oils, it is renewable and can reduce the emissions of greenhouse gasses.

There are several ways to produce biodiesel from vegetable oil. One efficient and most commonly used method for extracting biodiesel from vegetable oil is transesterification process. Transesterification of vegetable oil was conducted in 1853 by scientists E.Duffy and J.Patrick even before the diesel engine became functional [1]. This process yields three smaller molecules which are lower in viscosity and remain easy to burn in a diesel engine. In this method the oil reacts with alcohol in the presence of a catalyst which is acidic or basic in nature. Potassium hydroxide is the effective catalyst used which is alkaline in nature. Transesterification process constitutes as a base for the production of modern biodiesel, whose trade name is fatty acid methyl ester.

The efficiency of the diesel engine can be improved by coating the combustion chamber with suitable insulation of ceramic materials and this type of engine is called low heat rejection engine. Since two third of the heat energy is lost to the exhaust and coolant and only one third is utilized to obtain useful work, the use of LHR engine increases the thermal efficiency of the engine. Utilization of biodiesel in low heat rejection engine has further reduced the emissions and has increased the combustion chamber temperature, fuel economy, multifuel capability and has reduced engine noise.

The LHR engine is insulated with a thin layer of thermal barrier coating which doesn't allow the heat of the combustion chamber to escape out of the cylinder there by increasing the fuel economy and It was also found that NOx emission increased with the use of LHR engine coated with PSZ.

Exhaust gas recirculation is a method employed to reduce NOX emission from diesel engines. A part of exhaust gas is recirculated to the intake manifold along with the fresh air. This reduces the NOx emission by lowering the flame temperature.

In this study, an experiment has been conducted to study the performance and emission characteristics of EGR system supported LHR engine fuelled with AHME-eucalyptus oil blend.

II. Biodiesel Preparation

A. Base Oil
The biodiesel used in this process was extracted from Artocarpus heterophyllus. Artocarpus heterophyllus is known as Jackfruit. It is widely grown in countries like India, Thailand, Cambodia, Indonesia, Bangladesh and Mexico. It is an ornamental evergreen tree which can grow upto a height of 15 to 45 meters. The plant is

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propagated through grafting technique. It is cultivated in India for its fruit value whereas in Southeast Mexico and in other countries it is commercially grown for its latex which is used to prepare chewing gum. It is seasonal and occurs twice in a year from Jan-Feb and then from May-July. Its fruit is a large berry, 20-40 cm in diameter. The fruit contains more seeds. The seeds appear to be hard and lustrous. The fruit is sweet and malty in taste. They have an oil content of 23-30% and can be used to produce biodiesel. Jackfruit seed oil is obtained by expeller pressing. It is converted into biodiesel through transesterification process

Fig. 1: Photographic View of Artocarpus Heterophyllus Seed and Fruit

B. Eucalyptus Oil

Eucalyptus tree is predominantly seen in India. The eucalyptus oil is extracted from its leaves through steam distillation process. The most popular one is the cineole based oil. Research depicts that cineole based eucalyptus oil prevents the separation problem with ethanol and petroleum fuels. Eucalyptus oil has a low centane number. This reduces its cold flow properties.

C. Transesterification Process

This process involves the utilization of sodium hydroxide (1% w/w of oil) as a catalyst. Methanol (5:1 molar ratio to Jackfruit oil) was mixed with sodium hydroxide in a narrow neck flask. The mixture was shaken well enough to dissolve sodium hydroxide in methanol. About 1 liter of Jackfruit seed oil was added to the mixture. The flask was heated to a temperature around 65ºC on a hot plate provided with a magnetic stirrer arrangement. After 120 minutes the reaction was stopped and the content was allowed to settle down. This resulted in the formation of two layers. The upper layer was methyl ester and the bottom one was glycerol which is heavy in nature. The glycerol was removed from the flask thorugh a drainage valve. The rest of the mixture was heated to a temperature of 100ºC to remove water and excess alcohol. The resultant was Jackfruit methyl ester, the one we need as biodiesel. In this experimental study the compatibility of Artocarpus heterophyllus seed oil as biodiesel has been experimentally investigated using an LHR engine.

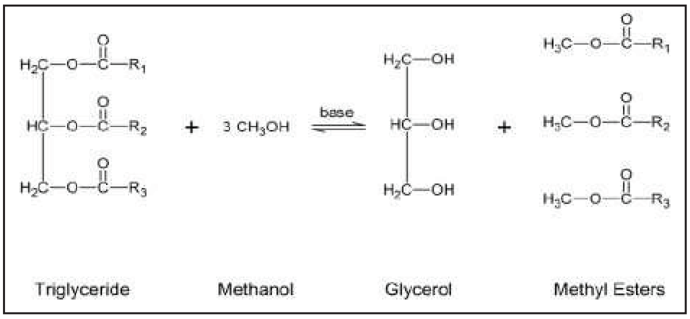

Fig. 2: Tans-esterification Reaction

III. Low Heat Rejection Engine

As stated before low heat rejection engine is the one in which cylinder head, piston, cylinder wall and valves are coated by an insulation called thermal barrier coating. This is done in order to minimize the heat loss to the engine coolant and exhaust. LHR ensures high thermal efficiency, lower emissions, lower fuel consumption and avoidance of cooling system from the engine. Ceramic coatings like TiO_2, Al_2O_3, mullite, CaO/MgOZrO, YSZ are employed in engines as TBC. PSZ and YSZ are the most popular TBC material which has good advantage in performance. The barrier coatings form two layers. One is called bond coat and the other is the top coat. The bond coat serves for the purpose of reducing the thermal stresses created between the top coat and the substrate due to difference in coefficient of thermal expansion. The bond coat also protects the substrate from oxidation and corrosion. Generally metallic alloys are employed as TBC. Many research works and studies have been done on LHR engine since 1970. Some researchers found an improvement in the thermal efficiency, NOX emission reduction, increase in exhaust energy availability, reduction in heat loss on the other hand some researchers contradict the fact that there was no improvement in thermal efficiency. Plasma spray method is the widely used thermal spraying method to coat TBC in the engine. It is highly potential in melting the substrate. In this study the diesel engine was converted into LHR engine by coating it with PSZ and the engine's combustion, performance and emission characteristics were studied.

Due to increase in combustion chamber temperature the ignition delay is reduced which in turn has normal combustion. Thus the oxygen content and temperature inside the chamber is high enough for NOx formation. Here comes EGR system which reduces NOx due to decreased level of oxygen in the combustion chamber.

IV. Exhaust Gas Recirculation System

Exhaust gas recirculation is a method employed to reduce NOX emission from diesel engines. This system involves the recirculation of a part of the exhaust gas in the intake manifold along with the fresh air. This reduces the oxygen level of the air entering the combustion chamber. The heat absorbing capacity of the air along with exhaust gas increases due to the fact that the specific heat of exhaust gas is higher when compared to air. Due to the fall in oxygen level in the combustion zone the flame temperature reduces. Thus the NOX level decreases. The application of 10-20 % of EGR helps majorly in reducing the NOx and smoke formation, along with small increase in particulate matters without affecting the engine's performance. Application of 10% of EGR to the engine system, provides only small amount of reduction in the general NOx and smoke formation. With the application of 15% of EGR to the engine system, large amount of reduction in NOx and smoke emission is recorded with small traces of reduction in particular matters.

But on the same hand, when a 20% of this EGR method is subjected along with the engine system, it causes formation of those particulate matters to be more than expected. It was also reported that increasing the quantity of EGR by more than 20% will result in increase in smoke emission and fuel consumption. Hence, to have an optimum reduction in both NOx and smoke formation without any change in the performance of the engine, it was required for us to apply 15 % of the EGR to our test engine.

V. Experimental setup

The experiment was conducted on a Kirloskar tv1 model single cylinder four stroke water cooled diesel engine. This engine developed 5.2 Kw at a speed of 1500 rpm. Engine specifications are shown in the Table 1. The engine was connected AG10 model eddy current dynamometer having its own control system. A constant air flow through orifice meter was maintained with the help of a surge tank fixed at the inlet side of the engine. The exhaust temperature was measured with the help of a K type thermocouple in conjunction with a digital temperature indicator. The fuel flow rate was calculated with a burette and a stopwatch. The engine performance was evaluated using Lab view based engine performance analysis software package "EnginesoftLV". The entire experimental setup is shown in fig. 3. The engine exhaust emission involving HC, CO, CO_2, NOx are measured by NDIR (non dispersive infrared) principle through selective absorption with the help of AVL444DI gas analyzer. The exhaust smoke level was measured by light extinction principle with the help of AVL444DI gas analyzer.

Table 1: Specification of the engine

Details	Specification
Type	Four stroke, kirloskar make, Compression ignition, Direct injection And water cooled
Rated power & speed	5.2kW & 1500 rpm
Number of cylinder	Single cylinder
Compression ratio	17.5: 1
Bore & stroke	87.5 mm & 110 mm
Method of loading	Eddy current dynamometer
Dynamometer arm length	0.185 m
Type of injection	Mechanical pump-nozzle injection
Inlet valve opening	4.5° before TDC
Inlet valve closing	35.55° after TDC
Exhaust valve opening	35.55° before BDC
Exhaust valve closing	4.5° after TDC
Injection timing	23° before TDC
Injection pressure	220 bar
Lubrication oil	SAE 40

VI. Experimenting Fuels

The test fuels used in this experiment are of different types. The eucalyptus oil it blended with AHME in the ratio of Eu30% and AHME 70%. Diesel is used as one of the test fuels. The fuels are tested in conventional engine, LHR engine and LHR engine with EGR system.

Table 2: Properties of fuel.

Properties	Testing method	Diesel	AHME	Eucalyptus
Density@15ºC (kg/m^3)	ASTM 145	840	891	896
Kinematic viscosity @40ºC (cSt)	ASTM 121	2.9	5.7	2
Flash point (ºC)	ASTM 128	k54	178	58
Fire point (ºC)	ASTM 127	64	254	64
Gross heating value (kJ/kg)	ASTM 134	42,700	37,640	43,270
Cetane number	ASTM 345	49	45	18

VII. Testing Procedure

The experimental procedure was started using diesel as a fuel in the engine. After the duration of 30 minutes the engine was tested using various biofuels blends. The engine was allowed to run for about 10 min to 15 min for each fuel blend before the measurements were taken in order to achieve a stable condition. The engine was loaded by drawing electric current of full load condition in succeeding steps. This was done by controlling the current supplied to the eddy current dynamometer. The fuel supply is maintained to obtain a speed of 1500 rpm by adjusting the rack position of the fuel pump. All the test readings were taken at the ambient condition with the engine running at steady state condition. The experiment was conducted for three times and the average of three was taken for each test in order to get better accuracy in values. After the completion of tests, the fuel was switched back to standard diesel and was allowed to run for about 10 min to flush out the test fuels from thee fuel line and injection system. The exhaust gas sample was collected from exhaust pipe line and was passed through exhaust gas analyzer to calculate the amount of HC, CO, NOX. The smoke proportion was measured with the help of smoke meter.

VIII. Results and Discussion

A. Performance Characteristics

BSEC is the ratio between the energy obtained by burning the fuel for an hour and the actual power obtained at the wheels. The graph depicts the various results of BSEC with respect to change in corresponding brake powers for different test fuels in LHR engine supported by EGR system and conventional diesel engine. On analyzing the graph, we infer that at full load condition BSEC for LHR AHME50Eu50+15%EGR is lesser when compared to all other test fuels in diesel engine and LHR engine. It is clear that AHME50Eu50+15%EGR in LHR engine is 4%,9%,3% and 10% lesser than diesel, AHME50Eu50 employed in conventional engine and LHR engine respectively.

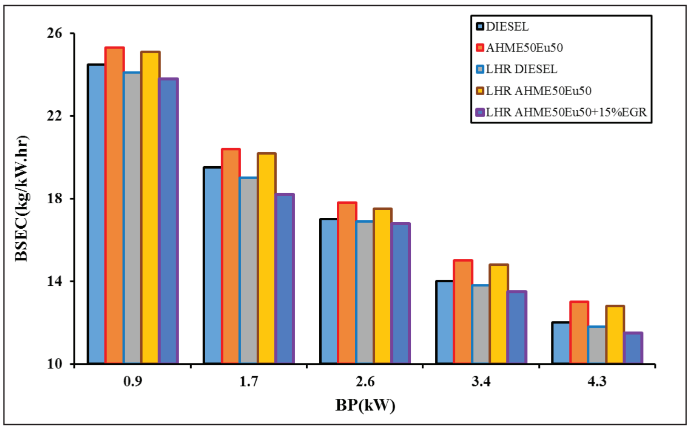

Fig. 3: Variation of Brake Specific Energy Consumption With Brake Power

It is found that for 15% EGR and AHME50Eu50 blend the BSFC decreases with the increasing load. This is the optimum composition of EGR or else when increased or decreased BSFC can vary according to the rates of EGR. One more reason for the increase in BSFC is due the LHR engine which is widely known for its heat insulating property that improves the calorific value of the fuel. This tends to shorten the ignition delay and the phase of combustion as well. Thus the fuel economy is enhanced. Out of all the five test fuels AHME50Eu50+15%EGR in LHR engine was found to be 11%,13%,6% and 13% lesser than diesel, AHME50Eu50 employed in conventional engine and LHR engine respectively.

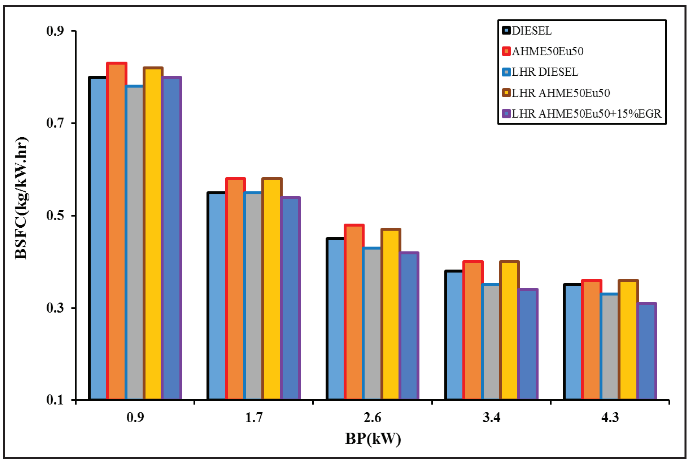

Fig. 4: Variation of Brake Specific Fuel Consumption With Brake Power

It is evident from the graph that BTE has increased in the case of AHME50Eu50+15% EGR in LHR engine when compared to all other test fuels. This may be due to the EGR which acts as a preheater for inlet fresh charge. Thus the unburned HC in the exhaust gas gets burned in the cylinder with the presence of abundant oxygen. This in turn hikes the calorific value of the fuel. Since the engine used is a LHR one, the heat escape to the surrounding is further reduced which is also a reason for higher BTE. The results for BTE in case of AHME50Eu50+15% EGR in LHR engine says that it is 7%,11%,3% and 10% higher than diesel, AHME50Eu50 employed in conventional engine and LHR engine respectively.

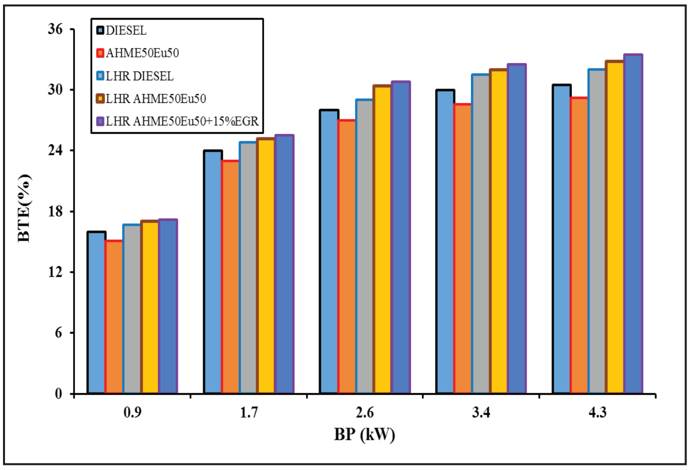

Fig. 5: Variation of Brake Thermal Efficiency With Brake Power

EGT results show that it is lesser in case of AHME50Eu50 with 15% EGR when compared to AHME50Eu50 without EGR in LHR engine. This is clear from the EGT graph. This may be due to reduction in oxygen level in the combustion chamber and higher specific heat of the air fuel mixture. Whereas in case of AHME50Eu50 without EGR tested in LHR engine, the EGT is observed to be too high when compared to all other test fuels. The main reason is because of low heat rejection by the engine which increases the calorific value of the fuel.

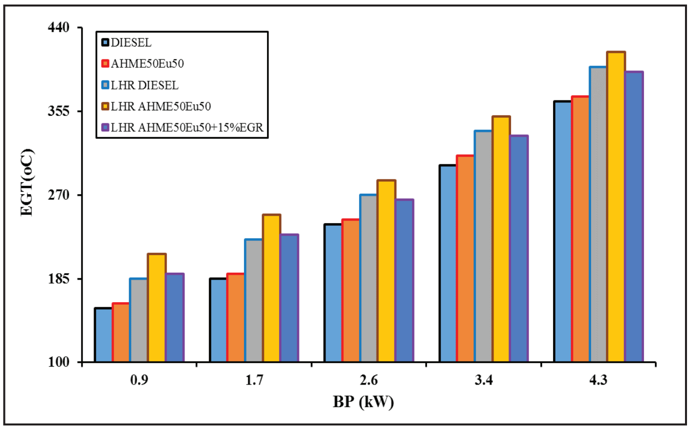

Fig. 6: Variation of Exhaust Gas Temperature With Brake Power

B. Emission Characteristics

It is inferred from the graph that CO is emitted in higher concentration in the case of AHME50Eu50 with 15% EGR when compared to AHME50Eu50 without EGR in LHR engine. This increase in CO is found to be 11% at full load condition. And the obvious reason for this hike is the EGR system. The fact that the oxygen concentration inside the combustion chamber is lower for EGR system which leads to non-uniform combustion. Thus the incomplete combustion produces more of CO in the atmosphere. Among the tested fuels, after diesel in conventional engine, the higher CO emission is seen in the case of AHME50Eu50+15%EGR.

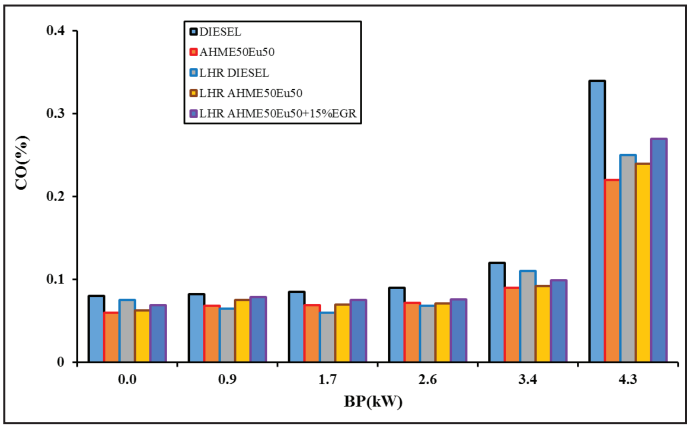

Fig. 7: Variation of Carbon Monoxide With Brake Power

At higher loads the oxygen content reduces drastically inside the combustion chamber due to EGR. Thus the available oxygen content in the cylinder is not sufficient for the complete combustion of the fuel. In addition to this the HC concentration keeps increasing in the combustion chamber due to UHC from the EGR into the cylinder. Thus the experiment on LHR engine with EGR system fuelled with AHME50Eu50 has shown higher HC emission next to diesel in conventional engine. AHME50Eu50+15%EGR in LHR engine at full load gives out 18%, 9% and 19% higher HC when compared to diesel in LHR engine and AHME50Eu50 employed in conventional engine and LHR engine respectively.

The positive impact of using EGR system is reflected mainly on NOx emission. At lower loads the NOx emission can be moderate but at higher loads it produces noticeable decrement when AHME50Eu50+15%EGR in LHR engine are employed. This is because at higher loads the oxygen level reduces drastically.

As we know oxygen is one of the main reasons for NOx emission and reduction in its amount can reduce oxides of nitrogen. Another reason is due to lower flame temperature. From the test results, the NOx emission has reduced by 16% at full load condition for AHME50Eu50+15%EGR when compared to AHME50Eu50 without EGR.

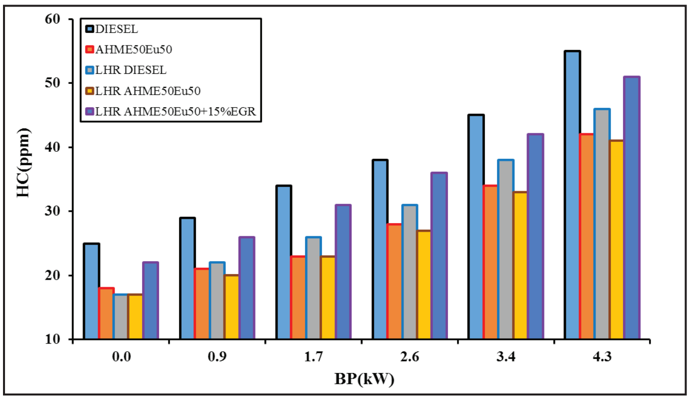

Fig. 8: Variation of Hydrocarbon With Brake Power

For the same condition, the NOx emission has reduced by 5% for AHME50Eu50+15%EGR when compared to AHME50Eu50 in conventional engine.

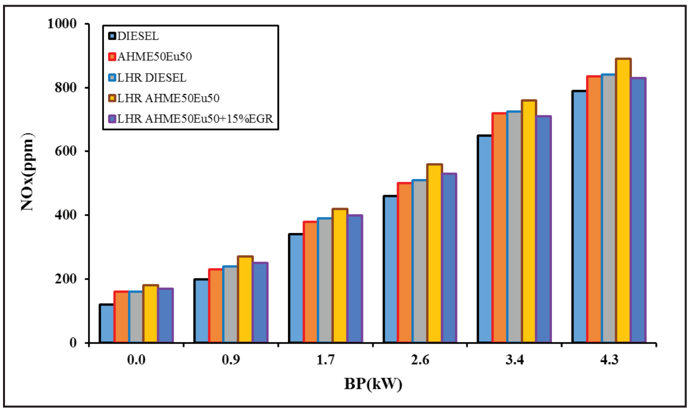

Fig. 9: Variation of NOx with brake power

Smoke emission signifies the presence of particulate matter. Smoke emission is found to be higher for AHME50Eu50+15%EGR than AHME50Eu50 without EGR at maximum load. EGR increases the soot formation as the presence of oxygen at higher load decreases. This results in incomplete combustion and deposition of carbon particles. At maximum load condition for AHME50Eu50+15%EGR in LHR engine gives 49 HSU only whereas AHME50Eu50 in conventional engine gives 51 HSC.

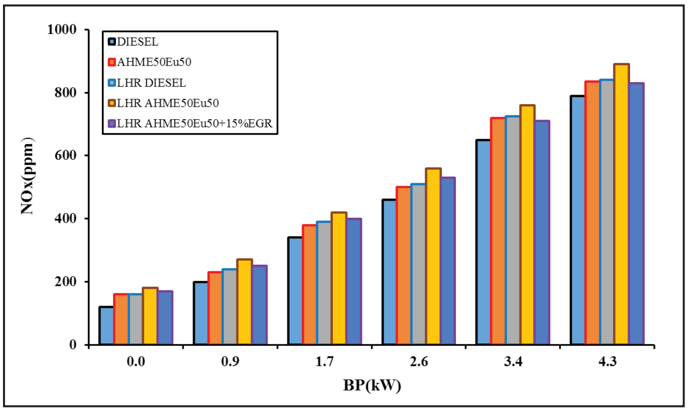

Fig. 10: Variation of smoke with brake power

IX. Conclusion

EGR system is an efficient way to reduce NOX emissions. In this experimental study, efforts were taken to know the effect of EGR when combined with LHR engine fuelled with AHME and eucalyptus oil in the composition of AHME50Eu50+15%EGR. Its results were compared to other fuels and a conclusion was made. It was observed that EGR system reduced NOX emission significantly in the case of AHME50Eu50+15%EGR in LHR engine. For the same fuel blend in LHR engine BSEC, BSFC, EGT were found to decrease for higher loads and BTE was found to increase due to EGR. 15% EGR rate has showed reduction in NOx emission. HC, CO and smoke emissions were increased for AHME50Eu50 with 15% EGR in LHR engine. Further, increase in CO, HC and smoke can be reduced by after treatment techniques of the exhaust gas.

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