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EFFECT OF EXHAUST GAS RECIRCULATION (EGR) ON PERFORMANCE, EMISSIONS AND COMBUSTION CHARACTERISTICS OF A LOW HEAT REJECTION (LHR) DIESEL ENGINE USING PONGAMIA BIODIESEL

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Keywords: Diesel engine, LHR diesel engine, Biodiesel (Pongamia), EGR, NO_x emission.
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ABSTRACT

The main objective of the present work is to study the performance, emission and combustion characterstics using single cylinder, four stroke, naturally aspirated, direct injection, water cooled diesel engine with exhaust gas recirculation (EGR) system on LHR engine with Pongamia biodiesel. The experiments are conducted varying the load at rated engine speed of 1500 rpm, and the percentage of EGR used being 5%, 10%, and 15%. It is observed that brake thermal efficiency increases for all fuels without EGR and with EGR up to 75% of load. At this load normal engine running on diesel exhibits 28.68%, followed by biodiesel without EGR, 5%, 10%, and 15% EGR with biodiesel on LHR engine are 27.42%, 24.4%, 27.05% and 27.1% respectively. At full load increasing the percentage of EGR there is an increase in smoke emission and the values being 99.22%, 99.9% and 99.9 for 5%, 10% and 15% EGR respectively. Carbon monoxide and HC emission for Pongamia biodiesel without EGR is lower than that of normal diesel engine for entire load operation. However increasing percentage of EGR there is increase in the CO emissions and the values being 0.925%, 1.32%, 2.53% for 5%, 10%, and 15% EGR respectively. Maximum peak pressure in the cylinder for biodiesel is 72.65 bars against 70.65 bars of that of diesel. A considerable reduction in NO formation is possible at 15% EGR with a little sacrifice in efficiency. Hence 15% EGR is optimum.

INTRODUCTION

In the present years fossil fuels are depleting day by day and their combustion products produces hazardous gases which not only affect the human beings but also the whole planet. To ease these problems today everyone is attracting towards alternative fuels. An important property of biodiesel is its oxygen content, which is usually not present in diesel fuel. Biodiesel fuels have been recently gaining importance due to some important advantages such as requiring little or no modification for use in existing diesel engines. Moreover, they are non-toxic, have higher biodegradability and contain almost no sulphur [1].

From various researches, it is observed that there are some difficulties associated with vegetable oils when used as fuel in diesel engines [2]. The difficulties associated with using raw vegetable oils in diesel engines are injector coking, severe engine deposits, filter gumming problems, piston ring sticking, and thickening of the lubricating oil [3]. In turn these problems lead to increased amount of smoke, hydrocarbon (HC) and carbon monoxide (CO) emissions, gum formation, and piston sticking in long-term use due to the presence of oxygen in their molecules and the reactivity of the unsaturated HC chains [4].

The diesel engine looses about 30% of the energy through coolant; about 30% of the energy is lost through friction and other losses [5]. To reduce these losses low heat rejection (LHR) engine is focused. Since LHR engine reduces the heat loss to surrounding and increases power output in turn brake thermal efficiency is increased [6].

The drawback of the LHR engine has to be considered seriously and effort has to be taken to reduce the increased heat loss with the exhaust and increased level of NO_x emission. The potential techniques available for the reduction of NO_x from diesel engines are exhaust gas recirculation (EGR), slower burn rate, reduced intake air temperature and particularly retarding the injection timing [7].

Paykani, et al [8] studied the effect of EGR on the performance and emissions characterstics of a diesel engine fueled with canola oil ethyl ester biodiesel. They found that CO, UHC emissions for biodiesel were higher than that of diesel fuel and also NO_x emissions increased directly with increasing biodiesel percentage.

Anandavelu et al. [9] studied performance and emissions with biodiesel on Kirloskar TV-I direct injection diesel engine with EGR. The main conclusions based on their experimental work carried on DI diesel engine without and with 15% EGR with diesel fuel and eucalyptus oil (EOF) blends are, the brake thermal efficiency was increased by about 3.8% for all EOF blends when compared with diesel operations without and with 15% EGR. They observed reduction in smoke with increased percentage of EOF in diesel. They found the maximum reduction in smoke emission for E40 blend in comparison to base diesel.

Harilal, et al. [10] conducted research work on effect of EGR on NO_x emission from C.I engine and they found that EGR displaces oxygen in the intake air and dilute the intake charge by recirculating exhaust gas to the combustion chamber. EGR lowers the oxygen concentration in combustion chamber and increase the specific heat of the intake air mixture, which results in lower flame temperatures. They concluded that 15% EGR rate reduces NO_x emission substantially without deteriorating engine performance in terms of thermal efficiency, bsfc and emissions.

Walke, et al**.** [11] studied the impact of exhaust gas recirculation on the performance of diesel engine. They found that BTE decreases with increasing EGR rates, and the concentration of smoke density increases, BSFC increases marginally with increasing EGR rates at high load. The EGR has definite impact on NO_x reduction.

Banapurmath, et al. [12] have conducted experiment on LHR engine operated on non-volatile vegetable oils with EGR. The percentage of EGR was varied from 5% to 20% in steps of 5%. The results showed that SFC and BTE were improved for both of the biodiesel fuels in the LHR engine. An EGR of 10% resulted in better performance with trade-off between NO_x and HC/CO emissions and hence 10% EGR is taken as the best of the range from 5 to 20%. Naga Kishore, et al. [13] investigated the result of hot EGR on the performance and emission characteristics of diesel engine with palm oil methyl ester. They conducted experiment on a single cylinder four stroke water cooled direct injection (DI) diesel engine with (Palm methyl ester: PME) biodiesel blends with diesel fuel combined with EGR technique. They found that for a 7.5kW power output, B10 and B20 PME with 8% EGR rate produce less NO_x emissions compared to diesel fuel for the same level smoke emissions and also they concluded that the total unburnt HC and CO emissions for B10 blend were decreased by 30% and 8% respectively compared to diesel fuel with EGR and smoke emissions were increased due to incomplete combustion.

Lokanatham, et al.[14] have investigated the performance, exhaust emissions and characteristics using diesel and biodiesel in conventional diesel engine and thermal barrier coated LHR engine and they found that the Jatropha oil methyl ester (JOME)biodiesel fueled LHR engine was quite identical to that of the conventional diesel engine. The BTE of LHR engine with biodiesel is decreased marginally than LHR engine operated with diesel. CO and HC emission levels are decreased but the NO_x emission level was increased due to the higher peak temperature. The maximum efficiency obtained in the case of LHR engine fuelled with biodiesel was lower than the LHR engine operated with diesel fuel. However the efficiency of the LHR engine with biodiesel fuel was well within the expected limits.

Avinashkumar Agrawal, et al.[15] studied the effect of EGR on the EGT and exhausts opacity in compression ignition engines and found that re-circulating part of the exhaust gas helps in reducing NO_x, but appreciable particulate emissions were observed at high loads, hence there was a trade-off between NO_x and smoke emission. They found that the exhaust gas temperatures reduce drastically by employing EGR. Donepudi Jagadish**,** et al**.** [16] Conducted tests on diesel engine operated on biodiesel with EGR. The results showed that EGR reduces the nitrous oxide emissions, as EGR rate increases the CO, UHC concentrations in the engine exhaust are increased. Better trade-off among HC, CO and NO_x has been found with EGR rate of 10 – 15 % with little loss in fuel economy. BSFC increases for pure biodiesel (palm stearin methyl ester), and decreased for B10, B20 in comparison to diesel.

Achuthanunni, et al. [17] conducted work on a diesel-biodiesel fuelled compression ignition engine with EGR. They conducted experiment on a single cylinder, four-stroke diesel engine with 10 % EGR and without EGR. The result showed that 40% NO_x emission was reduced by using EGR and the performance of biodiesel was found to be comparable with diesel at all loads. They concluded that NO_x emission was effectively controlled by 10% EGR. BTE of biodiesel is found to be comparable with diesel at all loads. They found that B20 has better performance compare to other biodiesel blends.

Anandkumar, et al. [18] studied the effect of EGR on the performance and emission characteristics of LHR diesel engine using electronic fuel injection (EFI) system fueled with biodiesel. They varied the EGR rates as 10%, 20% and 30%. The 20% EGR showed effective reduction in the NO_x emission; hence the 20% EGR is taken as optimum rate. Using B20 blends in LHR engine with EFI system the thermal efficiency of the engine is increased compared with LHR-B20. At 20% EGR BSFC is reduced. CO and HC emissions decreased by 17.3% in LHR engine operated with electronic fuel injection system compared with LHR-B10, due to better atomization of fuel and higher oxygen content in the fuel. The effects of EGR in CO and HC emissions increased with 20% EGR. NO_x emission is decreased due to dilution of the fresh charge entering in to combustion chamber. Smoke emission is reduced by 21% in LHR engine with electronic fuel injection fueled by B20 blends of biodiesel. Due to the high pressure, fuel injection system reduces the fuel droplet size which increases the entrainment of air results in low smoke emission.

Kanji, et al. [19] conducted experiment on EGR and catalytic converter by using blend of karanja biodiesel in diesel engine. In their work, before treatment as exhaust gas recirculation and after treatment system as catalytic converter used with karanja biodiesel in CI DI engine. This study investigate the suitable use of karanja biodiesel in conventional diesel engine and exhaust emissions like CO, HC, NO_x reduced simultaneously by the systems. They concluded that karanja biodiesel can successfully be used in diesel engine upto 30%. 15% EGR gives best performance without deteriorating engine performance. EGR is best method to reduce NO_x emission. Emissions like HC and CO can be reduced by catalytic converter.

Prathibha Bharathi, et al. [20] have studied the effect of EGR with karanja biodiesel and grooved piston with knurling in an internal combustion engine, in their work the performance of the engine is done with 20% of karanja biodiesel along with 10%, 15% and 20% EGR, with 9 grooved pistons with knurling configuration. They concluded that the BTE is increased by about 7.4%. The improvement in BSFC is about 2.9%. The EGT was lower and it was 3.8% less than normal engine. The reduction in the ignition delay was about 1.82%. The peak cylinder pressure was decreased by about 2.7%. The smoke emission in the engine was reduced by about 2.4%. The maximum reduction in NO_x emissions are about 13%. The maximum reduction in HC emissions are about 5.4%. The carbon monoxide emissions were found to be reduced by about 2.9%. Finally they concluded that that, the combination of karanja biodiesel with EGR20 and piston with nine grooves give better performance and reduced emissions.

Manieniyan, et al. [21] studied engine operation on DI diesel engine operating with biodiesel with EGR. In their work Madhua oil was used to prepare the biodiesel. In their work EGR percentage is varied as 5%, 10%, 15% and 20%. The result shows that NO_x emissions were reduced using EGR for diesel and bio diesel. SFC was lower in 20% EGR with diesel and 10% EGR with biodiesel compare without EGR. BTE of biodiesel was found to be comparable with diesel, at all loads with and without EGR. In all load 20% EGR level NO_x was reduced in both diesel and biodiesel. With increases in EGR level, the NO_x value gets reduced. With EGR CO emission increases due to oxygen deficient operation but still at low level compared to diesel operation without EGR.

Pratik, et al**.** [22] conducted experiment on a single cylinder four strokes DI diesel engine operating with varying cooled EGR system. The test was conducted on different load and constant speed. Engine operating with cooled EGR was able to reduce NO_x up to 65% and reduction in BTE and increases in smoke, CO and UBHC were observed compared to diesel.

Selvan**,** et al. [23] studied the performance and emission analysis of a single cylinder diesel engine using jatropha oil with EGR. They used B10, B20, B30, blend of jatropha methyl ester and cooled EGR in order to reduce pollutant from diesel engine emission of NO_x, CO, HC, were recorded and compared with petro diesel. Various performance parameters were evaluated such as BTE, BSFC, SEC, TFC were calculated. Result showed that the reduction of NO_x and BTE decreased with the application of EGR and jatropha blends bio-diesel. They concluded that with the effect of EGR, BTE decreases with B10, B20 and B30 when compared to naturally aspirated diesel engine. With EGR B10, B20 and B30 blends, BSFC values were increased compared to EGR incorporated engine. NO_x emission decreased with EGR, CO emissions increased and HC emissions decreased in all blends of jatropha oil. B20 is the best blend with diesel showed better results with BTE, BSFC, total fuel consumption and reduced NO_x emission with 10 % of EGR.

In this present work, piston is coated with metal matrix composite material (MMC). It is also observed in literature review that a very few work has been done on use of Pongamia biodiesel on a single cylinder LHR diesel engine with EGR system and MMC coated piston. An attempt is made in this work to evaluate performance, emission and combustion characterstics of a single cylinder LHR diesel engine using Pongamia biodiesel with EGR system.

Fuel Properties

Table 1 shows the different fuel properties of interest such as density, kinematic viscosity, flash point, fire point and calorific value of diesel and Pongamia biodiesel.

Table 1 Properties of Diesel and Pongamia biodiesel

Fuel samples properties	Diesel	Pongamia Biodiesel
Fuel density in $\frac{kg}{m^3}$	830	885
Kinematic viscosity at 40^{o}C in cst	4.6	5.60
Flash point in ^{o}C	51	56
Fire point in ^{o}C	57	63
Calorific value in $\frac{kJ}{kg}$	43000	37,500

EXPERIMENTAL SET UP AND METHODOLOGY

Figure 1 shows the schematic diagram of the complete experimental engine test rig with EGR arrangement. The engine tests were conducted on a single cylinder four-stroke, naturally aspirated, direct injection and water cooled diesel engine. The engine specifications are shown in Table 2. The experiments are conducted varying the load at rated engine speed of 1500 rpm, and the percentage of EGR used being 5%, 10%, and 15%. Basically the air flow is recorded from the U-tube manometer. Then by controlling exhaust gate valve, the exhaust gas is recirculated into the engine cylinder. The EGR percentage is calculated by using the following formula,

$$\% \text{ EGR} = \frac{\text{Mass of air admitted without EGR} - \text{Mass of air admitted with EGR}}{\text{Mass of air admitted without EGR}}$$

The constant speed, variable load test are conducted to evaluate the performance, emission and combustion characteristics of engine with EGR.. The different loads being 0%, 10%, 25%, 50%, 75%, and100% of rated power and three load tests are conducted by keeping the percentage EGR as5%, 10%, and 15%. The performance parameters such as BTE, BSFC, EGT and the emissions measured are CO, HC, NO_X and smoke. And also combustion characteristics like cylinder pressure, cumulative heat release rate, and net heat release rates are recorded. AVL Dismoke 480smoke meter is used for smoke measurement and AVL Ditest gas 1000five gas analyzer is used for emission measurement.

Figure 1. Overall view of the experimental setup with EGR arrangement

Metal matrix thermal barrier coating composition and thickness of layers are shown in Table 3. The surface to be coated is initially prepared by cleaning process. This is done usually to get rid of foreign materials bound to the substrate. First the substrate surface is mechanically cleaned by conventional dry cleaning process using compressed air. Then it is grit blasted to get rough surface for effective bonding with the bond coat. This is followed by ultrasonic cleaning.

The prepared surface is then coated with zirconium oxide of 0.1 mm thickness, over a 0.1 mm thickness 50% zirconium oxide and 50% alumina oxide and then which is coated over 0.1mm thickness of 25% zirconium oxide and 75% alumina oxide and finally this coated over a 0.15mm thickness of nickel chromium(Ni-Cr) bond coat.

Table 2 Engine specifications

Manufacturer	Kirloskar oil engines Ltd, India
Model	TV-SR, naturally aspirated
Engine	Single cylinder, DI
Bore/stroke	87.5mm/110mm
C.R.	17.5:1
Speed	1500r/min, constant
Rated power	5.2kw
Working cycle	Four stroke
Injection pressure	200bar/23 deg before TDC
Type of sensor	Piezo electric
Response time	4 micro seconds
Crank angle sensor	1-degree crank angle
Resolution of 1 deg	360 deg with a resolution of 1deg

Table 3 Composition of thermal barrier coating (LHR) with dimensions

100% ZrO_2	0.1mm
50%ZrO_2 + 50%Al_2O_3	0.1mm
25% ZrO_2 + 75%Al_2O_3	0.1mm
Bond coat (Ni-Cr)	0.15mm

RESULT AND DISCUSSIONS

Performance Characteristics

In this section performance parameters, i.e, BTE, SFC, and EGT are compared and discussed for different percentage of EGR conditions.

Brake Thermal Efficiency

The variation of brake thermal efficiency with brake power for diesel on normal engine, pure biodiesel on LHR engine without EGR, 5%, 10%, 15% EGR with pure biodiesel on LHR engine is as shown in figure 2. It is observed that brake thermal efficiency increases for all fuels without EGR and with EGR up to 75% of load. At this load normal engine running on diesel exhibits 28.68%, followed by biodiesel without EGR, 5%, 10%, and 15% EGR with biodiesel on LHR engine are 27.42%, 24.4%, 27.05% and 27.1% respectively. The same trend is observed at full load. However thermal efficiency decreases at full load for all fuels and combinations due to admission of more fuel (rich fuel) at full load.

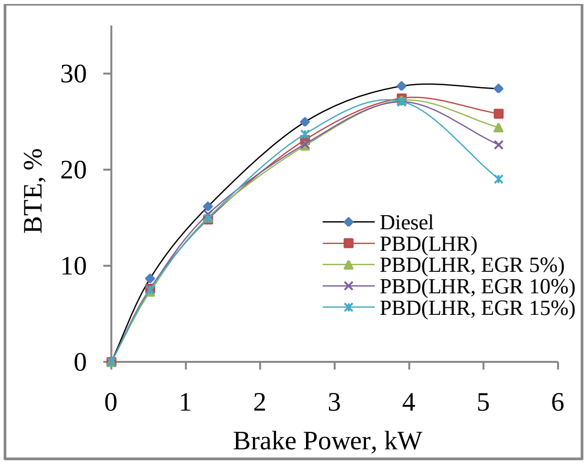

Figure 2. Variation of BTE with brake power

Specific Fuel Consumption

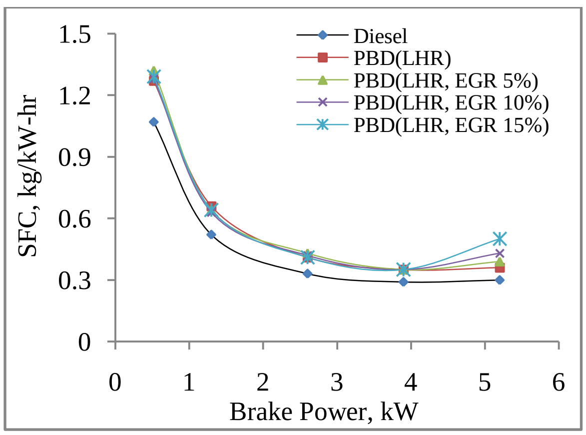

Figure 3. Variation of SFC with brake power

Figure 3 shows the variation of specific fuel consumption with brake power for diesel on normal engine, pure biodiesel on LHR engine without EGR, 5%, 10%, and 15% EGR with pure biodiesel on LHR engine. It is observed that specific fuel consumption in diesel on normal engine and LHR engine with biodiesel, 5%, 10% and 15% EGR decreases up to 75% of load. Minimum specific fuel consumption appears for diesel i.e.0.29 kg/kW-hr. Minimum specific fuel consumption for biodiesel without EGR, 5%, 10% and 15% EGR appears same i.e.0.35 kg/kW-h. However at full load SFC increases with increase in percentage of EGR.

Exhaust Gas Temperature

Figure 4 shows variation of exhaust gas temperature with brake power. It is found that EGT increases with increase in load for normal engine with diesel, LHR engine with biodiesel, 5%, 10% and 15% EGR. EGT of biodiesel is lower than that of diesel for entire range of load. At maximum efficiency point EGT of biodiesel is 418.1°C against 469.6°C of that of diesel. EGT with 5%, 10% and 15% EGR are close with that of biodiesel without EGR.

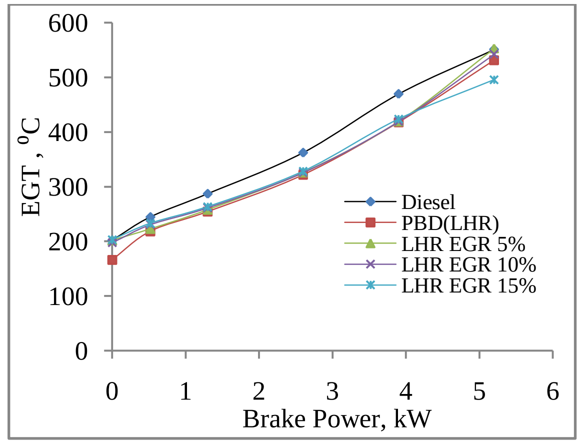

Figure 4. Variation of EGT with brake power

Emission Characteristics

In this section emission characterstics like CO, Smoke, HC, and NO_x are compared and discussed for different percentage of EGR conditions.

Carbon monoxide

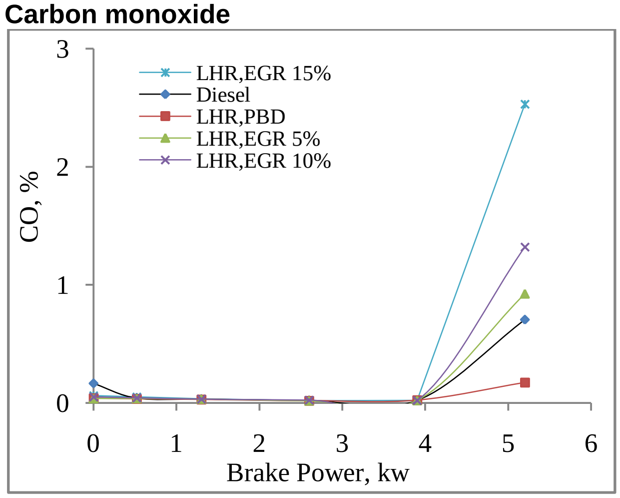

Figure 5. Variation of CO with brake power

Figure 5 shows variation of CO with brake power for normal engine with diesel, LHR engine with biodiesel without EGR, 5%, 10%, and 15% on LHR engine. For all combination of fuels up to 75% of the load CO emission is very low and constant. A typical value of CO emitted is 0.02% by volume. However from 75% to rated load CO emissions increases. At rated load CO emission for pure biodiesel on LHR engine without EGR is 0.174% against 0.705% against diesel. By increasing percentage of EGR increases CO emission with respect to biodiesel in LHR engine.

Smoke

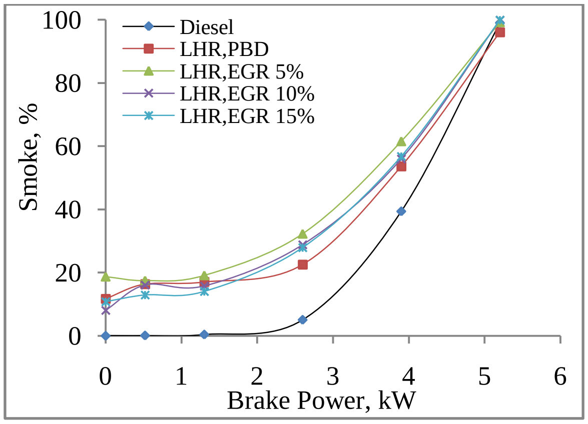

Figure 6. Variation of smoke with brake power

Figure 6 shows the variation of smoke with brake power for diesel on normal engine, pure biodiesel on LHR engine without EGR, 5%, 10% and 15% EGR with pure biodiesel on LHR engine. The smoke emission for biodiesel is higher than that of diesel at all loads. Further smoke emission increases with increase in percentage of EGR in biodiesel. The higher amount of smoke with the biodiesel may be due to dilution of charge the free carbon particles present in the mixture unable to find the oxygen for complete combustion. At rated load smoke emission is 96% opacity against 98.99% opacity of that of diesel. However at lower loads deviation in smoke emission is higher for biodiesel than that of diesel.

Hydrocarbon (HC)

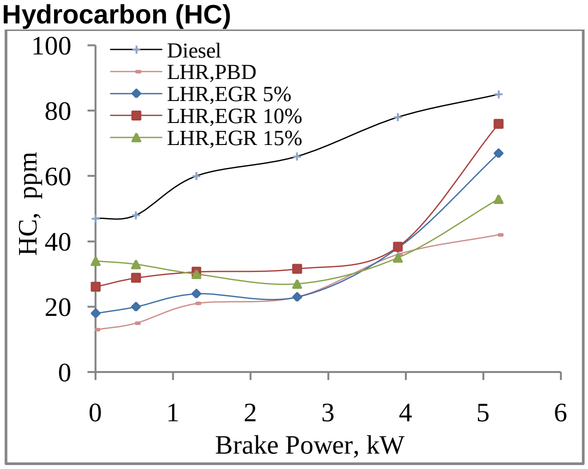

Figure 7 Variation HC with brake power

Figure 7 shows variation of HC with brake power for diesel on normal engine, pure biodiesel on LHR engine without EGR, 5%, 10%, and 15% EGR with pure biodiesel on LHR engine. Unburnt hydrocarbon gradually increases with increase in brake power for all combination of fuels in the engine. Unburnt hydrocarbon emission is lowest for biodiesel among all combination of the fuels. At rated load HC emission for biodiesel without EGR is 42 ppm against 85 ppm of that of diesel.

Oxides of Nitrogen (NO_x)

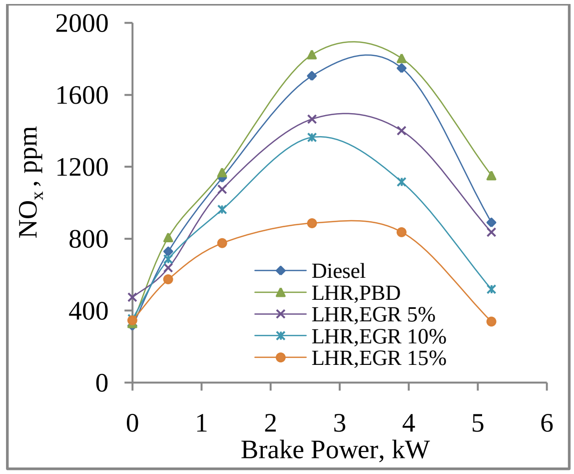

Figure 8. Variation of oxides of nitrogen with brake power

Figure 8 shows the variation of NO_x emissions with brake power for diesel, pure biodiesel on LHR without EGR, 5%, 10% and 15% EGR with biodiesel. NO_x emission first increases upto 60% of the load reaches maximum and then reduces for all combination of the fuels in diesel engine. NO_x emission in biodiesel for entire operation is higher than that of diesel. The maximum NO_x emission is 1824 ppm against 1705 ppm of that of diesel. The NO_x emission reduces with increasing percentage of EGR in biodiesel. The lowest NO_x emission is obtained for 15% of EGR. The maximum value corresponding to this case is 886 ppm against 1824 ppm of biodiesel.

Combustion Characteristics

This section deals with combustion characteristics like cylinder pressure, net heat release rate, and cumulative heat release rate against crank angle are compared and discussed for different percentage of EGR conditions.

Cylinder pressure

Figure 9 shows variation of cylinder pressure with respect to the crank angle. Burning of biodiesel with LHR engine begins at 9° BTDC and that of diesel is 5° BTDC. Apart from this the rate of burning of biodiesel is faster than that of diesel. Maximum peak pressure in the cylinder for biodiesel is 72.65 bars against 70.65 bars of that of diesel. With increase in percentage of EGR peak cylinder pressure slightly reduced.

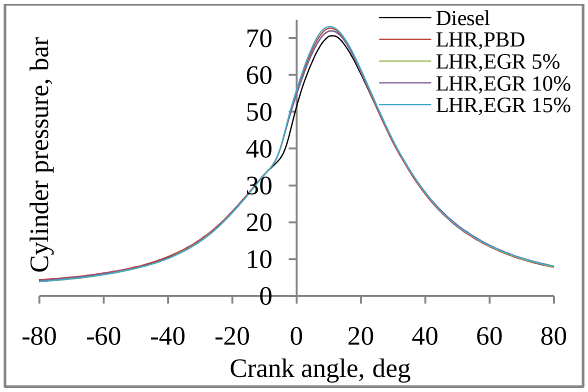

Figure 9. Variation of pressure with crank angle

Net heat release rate

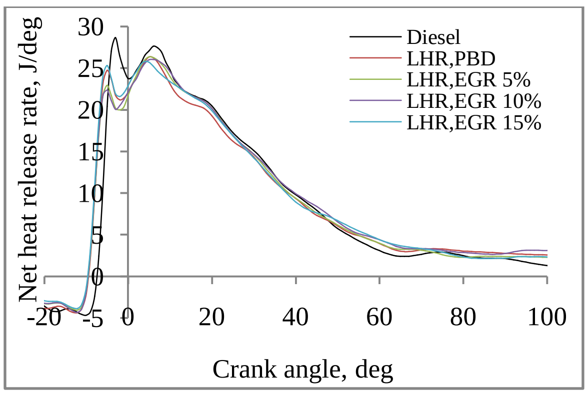

Figure 10. Variation of net heat release rate with crank angle

Figure10 shows the variation of net heat release rate with crank angle. Net heat release rate in the early stage of the combustion is lower for biodiesel in LHR engine than that of the diesel in normal engine. Heat release in the biodiesel is much earlier than that of the diesel. Rate of heat release is lower in premixed combustion phase in biodiesel with EGR and without EGR. However in the mixing controlled combustion phase heat release rate is higher for diesel and fairly constant for its combustion process.

Cumulative heat release

Figure 11 shows variation of cumulative heat release rate with crank angle. Cumulative heat release rate in premixed combustion phase is higher for diesel followed by biodiesel without and with EGR. In the controlled combustion phase cumulative heat release of biodiesel in LHR engine without and with EGR is higher than that of diesel.

It is observed that ignition delay is lower for biodiesel compared to that of diesel. This is because of readily available oxygen in the biodiesel even the same reason holds good for biodiesel with 5%, 10%, and 15% EGR on LHR engine. Because of lower ignition delay heat releases at the early stage of the combustion and it can be seen that the later combustion heat release rate is fairly constant and lower than that of diesel. In case of diesel burning starts 4^{o} later than that of biodiesel but there is steep increase in pressure with respect to crank angle. Because of this higher rate of pressure rise indicates that combustion of the diesel particles is faster in premixed phase combustion. Further burning of diesel takes places in controlled combustion phase. Due to complete combustion of diesel the exhaust temperature remains higher than that of biodiesel and smoke emissions are minimum for entire range of operations. Because of the lower smoke emission and complete combustion the efficiency of the diesel engine is higher for entire load of operation.

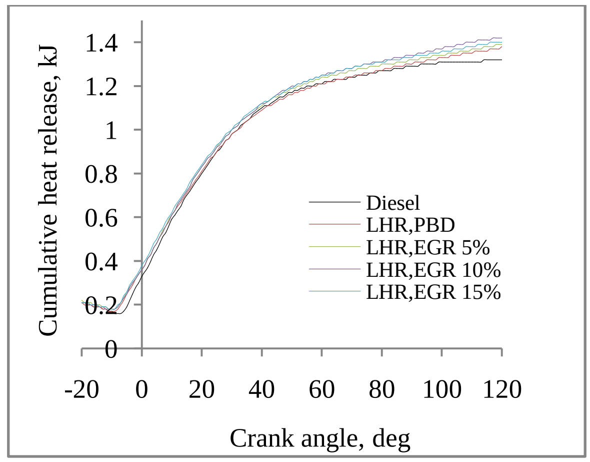

Figure 11. Variation of cumulative heat release rate with crank angle

In built oxygen availablity in the biodiesel not only reduces ignition lag but also reducess CO and HC compared to that of diesel. However due to availabity of oxygen in biodiesel readily reacts with nitrogen in air emits higher NO compared to that of diesel. By increasing the percentage of EGR decrease the NO_x formation. This attributes to reduction of temperature and availablity of oxygen in the fresh air inhailed. However increasing percentage of EGR increases emissions such as CO, HC, smoke in the engine. Eventually thermal efficiency decreases and SFC increases with increase percentage of EGR.

From this experiment it is clear that by increasing the percentage of EGR in fresh air inhailed reduces NO emission considerably. However this is achieved by sacrificing in performance.

Comparison of Results with the Literature for Validation

In order to validate the experimental findings of the present work, results are being compared with results availabe in the literature of N.R Banapurmath ,et al.[12]. The same being considerd as the specification and experimental set up of present work and work carried out by N.R Banapurmath, et al.[12] are similar.The results of 10% EGR running on PBD with LHR engine and the results of Banapurmath’s NOME(Neem oil methyl ester) and HOME(Honge oil) with 10% EGR on LHR engine are compared for validation.

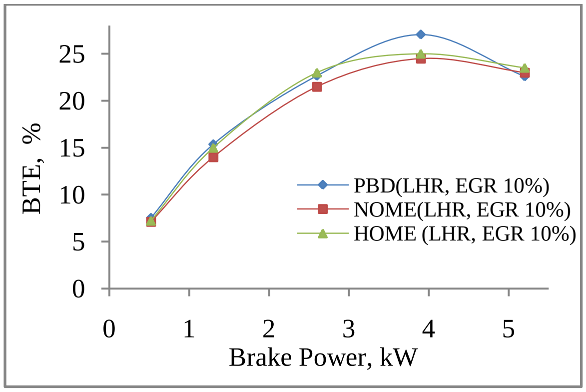

Figure 12. Variation of BTE with brake power

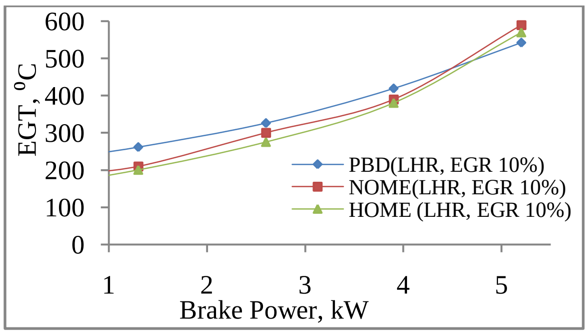

Figure 13. Variation of EGT with brake power

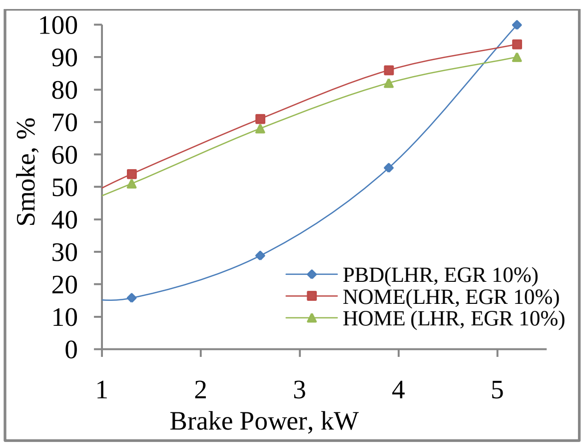

Figure 14. Variation of smoke with brake power

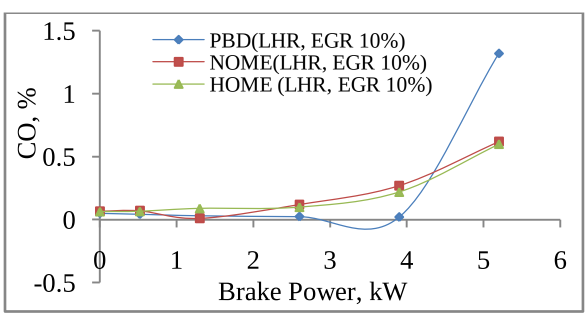

Figure 15. Variation of CO with brake power

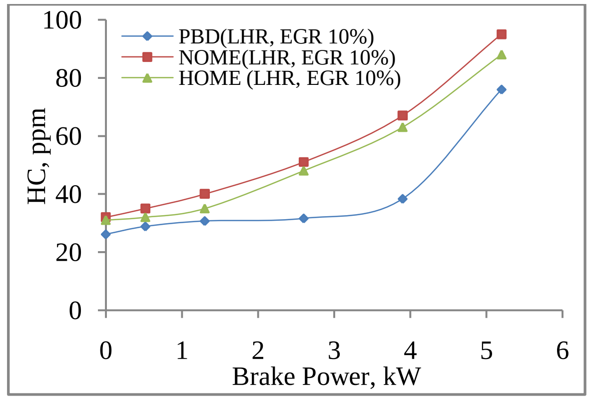

Figure 16. Variation of HC with brake power

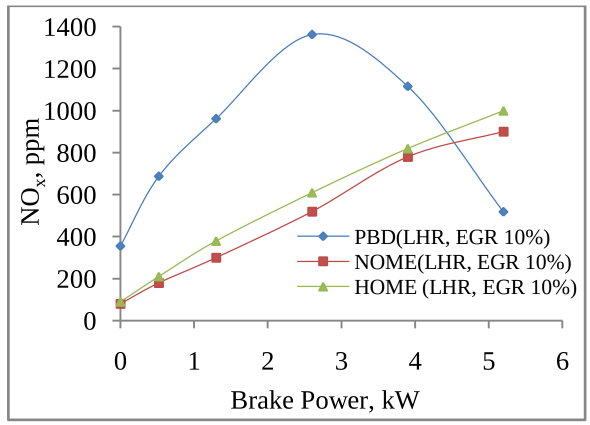

Figure 17. Variation of NO_x with brake power

Figure 12 shows variation of BTE with respect to the brake power for fuels and its combination taken for comparison. Brake thermal efficiency for Pongamia biodiesel of present work and honge biodiesel of Banapurmath at 10% EGR is almost same upto 60% of the load and there is an increase in thermal efficiency with Pongamia from 60% to 90% of load compared to honge biodiesel of Banapurmath, et al. However at maximum load brake thermal efficiency is lower than that of Banapurmath's honge biodiesel.

Figure 13 shows variation of EGT with respect to the brake power for fuels and its combination taken for comparison. Exhaust gas temperature using Pongamia biodiesel with 10% EGR in my work fairly higher than that of two oils used with Banapurmath with 10% EGR, which indicates that combustion is complete in the present engine than that of Banapurmath's engine.

Further this can be substrate by low smoke, low CO, low HC emission for entire load of operation in my engine than that of Banapurmath's fuel with 10% EGR.

However at maximum load smoke, CO emissions are higher and EGT is lower in the present work. i.e. why the efficiency of the pure biodiesel in present engine is lower than that of other engine. In the Banapurmath's engine the NO_x emission is continuously increasing and becomes maximum at rated load. However Pongamia tested in the present work the

NO_x emission increases and then reduces. NO_x emission for Banapurmath oil is higher at full load than that of my oil in the engine as seen from figures 14-17. Since EGT is higher for Banapurmath's oil, eventually higher NO_x emission. The results of that of Banapurmath's engine fairly matches with the results of that of the present work. Hence it validates results.

CONCLUSION

The conclusion from this experiment is as follows

- Brake thermal efficiency increases for all fuels without EGR and with EGR up to 75% of load. At this load normal engine running on diesel exhibits 28.68%, followed by biodiesel without EGR, 5%, 10%, and 15% EGR with biodiesel on LHR engine are 27.42%, 24.4%, 27.05% and 27.1% respectively.
- Neat biodiesel on LHR engine starts burning before that of diesel due to inbuilt oxygen content in Pongamia biodiesel. However rate of pressure increase for diesel is more than that of neat biodiesel on LHR engine.
- At full load the smoke emission for Pongamia biodiesel increases with increase in percentage of EGR, and the values being 99.22%, 99.9% and 99.9 for 5%, 10% and 15% EGR respectively. Smoke emission is more in 5%, 10% and 15% EGR than that of diesel in normal engine.
- Carbon monoxide and HC emission for Pongamia biodiesel without EGR is lower than that of normal diesel engine for entire load operation. However increasing percentage of EGR increases the CO emissions.
- NO increases with increase in load and reaches maximum at 65% -70% load decreases. By increasing the percentage of EGR there is a considerable reduction in the NO_x formation.
- NO_x emission with 5%, 10% and 15% is 52.23%, 70.36%, 80.6% lower than that of neat diesel in LHR engine.
- A considerable reduction in NO formation is possible at 15% EGR with a little sacrifice in efficiency. Hence 15% EGR is optimum.
- The results obtained were compared with the results of similar work in the literature review and the comparison validates experiment.

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