Comparative Study On The Performance, Combustion And Emission Of A DI-Diesel Engine Tested With Methyl Esters Of Jatropha And Palm Kernel Oils With Cold EGR Technique Implementation.

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Abstract

Tail pipe emission control has become one of the most interesting challenges in automotive technology.Researchers across the globe are concentrating on to reduce the emissions with high environmental impact either by adapting to new technologies or alternate fuels or both.In this paper, cold EGR technique by replacing a part of incoming air is used with the implementation of biodiesels suchas JatrophaMethyl Ester and Palm Kernel Methyl Ester are testedin a direct injection, single cylinder diesel engine and compared in the areas of combustion, engine performance and exhaust emission. Biodiesels are known to reduce the exhaust emissions, except for the oxides of Nitrogen. An attempt is made to assess the NO reduction aspect with EGR.

Keywords: JME, PKME, EGR, NHRR, CHRR, NO, HC, CO

1.0 Introduction

Partial recirculation of exhaust gas has recently become essential, in combination with other techniques, for attaining lower emission levels **[1]**. Reasons for this trend are firstly, the proposal of the future European directive establishes separate, and even more stringent, limits for NO_X emissions. Secondly, further reductions in NO_X emissions have probably become the most difficult target to attain, owing to the associated reverse effect of other recently used techniques, such as high supercharging, an improved mixing process by more efficient injection systems etc. Thirdly, the advent of a new age exhaust gas recirculation (EGR) valves and new developments in electronic controls allow a better EGR accuracy and shorter response time in transient conditions.Fourthly, the most common operating conditions, mainly in passenger cars, have moved to lower engine loads, owing to the increase in urban traffic density, and it must be considered that it is mainly at partial loads where EGR is indicated because of its higher oxygen content. Finally, the inclusion in the early1990s of particulate emission regulations, which are more stringent than those of smoke opacity, has redirected efforts to reduce emissions in terms of mass rather than in terms of concentration, which can be favored by reducing the total exhaust mass flow rate.

EGR is one of the most effective techniques used for NO_Xreduction in internal combustion engines. However, the implementation of EGR incurs penalties in other areas. In the case of Diesel engines, EGR worsens specific fuel consumption and particulate emissions **[2, 3]**. In particular, EGR aggravates the trade-off between NO_X and particulate emissions, especially at high loads. The application of EGR can also affect adversely the lubricating oil quality and engine durability. Also, EGR has not been applied practically to heavy duty Diesel engines because wear of piston rings and cylinder liner is increased by EGR. It is widely considered that sulfur oxide in the exhaust gas strongly relates to the wear. The results showed that the sulfur oxide concentration in the oil layer is related strongly to the EGR rate, inversely with engine speed and decreases under light load conditions. It was also found that as the carbon dioxide levels are increased due to EGR, the combustion noise levels also increase, but the effect is more noticeable at certain frequencies. Furthermore, whatever the carbon dioxide content of the intake mixture, it has been observed that as the engine load is increased, the noise levels decrease **[4]**. By increasing the EGR ratios, the heat release rates during premixed combustion, which is characterized by rapid burning and which significantly governs NO_X formation, can be suppressed more efficiently. Furthermore, the combined effects of EGR and supercharging achieved a considerable improvement in combustion along with a reduction in NO_X. The results show that NO_X can be reduced almost in proportion to the EGR ratio and that an approximately50% NO_X reduction at a 20% EGR ratio can be achieved without deteriorating smoke and unburned HC emissions **[5].**

Implementation of EGR resulted in a trade-off between reduction in NOx and increase in soot, CO and unburnt hydrocarbons. A large number of studies have been conducted to investigate this. It is indicated that for more than 50% EGR, particulate emissions increase significantly, and therefore use of a particulate trap is recommended. The change in oxygen concentration causes change in the structure of the flame and hence changes the duration of combustion. It is suggested that flame temperature reduction is the most important factor influencing NO formation **[6, 7]**.

Literature**[8-10]** cites three mechanisms through which EGR affects combustion, and reduces NOx formation.

- Dilution Mechanism: The potentially increased mixing time and longer burn duration caused by EGR’ s dilution effect result in lowered flame temperatures.
- Thermal Mechanism: The increased heat capacity of an EGR-laced mixture results in lowered flame temperatures.
- Chemical mechanism: Increased dissociation from the more complex EGR molecules (such as CO_2 and H_2O) result in lowered flame temperatures. In this study, combination of classical measurements, such as pressure-based diagnostics, and advanced in cylinder visualization techniques, such as the video scope and two-color pyrometry, has been used to assess the relative importance of those flame temperature reducing mechanisms, and also to guide future modeling efforts. In turn, the mechanisms associated with NOx formation and destruction strongly depend on flame temperature **[11]**. In addition, for NOx formation to occur, high concentrations of nitrogen and oxygen must also be present. The combustion inside a diesel engine provides both these essential conditions. Based on the rate of heat release analysis corresponding mass fraction burned was roughly 65 %. It should be noted that the effect of EGR on flame temperatures should not be confused with bulk gas temperature trends.. Clearly, the thermal EGR mechanism plays a dominant role in the observed reduction in flame temperatures, and hence NOx emissions, with increasing EGR rate.

In this work, cold EGR technique in which a part of the incoming air replaced by cooledexhaust gas is used with the implementation of neat biodieselsi.e.Jatropha Methyl Ester (JME) and Palm Kernel Methyl Ester (PKME).The reason for selecting the biodiesels as alternate fuel is because of their better lubricating property which decreases the possible wear and tear of the cylinder when compared to diesel. This attempt makes use of an alternate fuel with the combination of a technique (EGR) known to reduce the emissions. Biodiesels are known to reduce the exhaust emissions, except NO_x. An attempt is made to assess the NO reduction aspect and any change in the performance of the engine with EGR. In addition to the conventional performance strategy, engine combustion analysis is also performed to gain more insight in to the combustion phenomenon which implicitly changes with the EGR rate and the type of fuel used.

2.0Experimental set up and Experimentation

The experimental setup (Fig.1) consisting of a Direct Injection diesel engine and an Exhaust gas recirculation system(EGR) which is used to circulate and measure defined percentages of cooled exhaust gas replacing a part of the incoming air. Experimentation is carried out at various engine loads (Engine Loading device is eddy current dynamometer) to record the cylinder pressure (measured by means of a Piezo Electric transducer)and finally to compute heat release rates with respect to the crank-angle (measured via crank angle encoder). Engine performance data is acquired to study the performance along with the engine pollution parameters. The smoke values in HSU, the exhaust gas temperatures and exhaust gas analysis of different components of exhaustare measured and compared. Exhaust gas recirculation (EGR) of 4%, 7%, 12%, and 14% are implemented andengine performance is analyzed for the parameters mentioned above.

Fig.1: Shows the experimental set up consisting of DI Diesel Engine with EGR system

2.1 Direct injection Diesel Engine

A single cylinder, four stroke, Direct Injection (DI) diesel engine (make Kirloskar company, Pune) is used for conducting the experimentation .The details of the engine are given below.

Table 1: Specifications of the single cylinder DI Diesel Engine

Rated Horse power	5 hp	Injection pressure	200 kg/cm^2	Bore	80 mm
Rated Speed	1500rpm	No of Cylinders	1	Compression ratio	16.5
No of Strokes	4	Stroke	110 mm		

2.2 Exhaust gas recirculation system

The exhaust gas from the engine is collected into a cylinder which is water cooled and the cold gas is sent into another cylinder in parallel which is connected to the engine inlet. A separate piping with a control valve from an air tank is connected to the pipe from the second cylinder of the EGR system which leads to the engine inlet. The filtered exhaust gas is also controlled by a valve as shown in Fig. 1.

There are two flow measuring devices with the hotwire anemometer arrangement as shown in Fig.1. One device is for measuring the neat air coming in from the accumulator and other device is meant to measure the filtered gas from the exhaust cylinder. Based on these two measurements and making use of the definition for the percentage of exhaust gas recirculation, convenient software is designed to instantly calculate the percentage mass wise. By controlling the fresh air valve and the exhaust valve, the percentage of EGR can be adjusted to the desired value.

3.0 Results Discussion

The experimentation is conducted on the engine operated at normal room temperatures of 30^0C to 34^0C with Jatropha Methyl Ester (JME) and Palm Kernel Methyl Ester (PKME) at five discrete part load conditions. The data collection is done independently for the above said oils. The engine is initially made to run at 1500rpm continuously for one hour in order to achieve the thermal equilibrium under operating conditions. After this period, combustion pressure is monitored for every load on the engine. Fuel consumption is measured at each load. From the P-θ signatures obtained, the net heat release rates (NHRR) and cumulative heat release rates (CHRR) have been derived with the computer program designed based on the Gatowski heat release rate model. Exhaust gas parameters including temperatures and smoke intensity measurements are also made at different loads. The same procedure is repeated for different EGR percentages using Palm Kernel Methyl Ester (PKME).

3.1 Engine Combustion Analysis

The pressure traces have been recorded at all loads and at all percentages of EGR for both the biodiesels. From the pressure curves,it can be understood that the delay period is increasing with the increase of EGR rate for both the cases of JME and PKME. This can be assessed from the start of combustion (which can be observed by sudden rise in the pressure) in P-θ(Pressure-Crank Angle) plots in figures 3&4. For both the cases of JME and PKME, the peak pressures are falling with the increase in EGR percentage. The increased ignition delay with the increase in EGR may be held responsible for the reduction of peak pressures**.** This fall in peak pressures with the increase in EGR percentage may also be attributed to the levels of dilution imparted by the increase in re-circulated exhaust gas.

Figures 5&6depict the net heat release rate plots at full load derived from the pressure- crank angle signatures using Gatowski theory. Maximum net heat release rate(NHRR) is more in the PKME combustion with EGR when compared to the case of JME with EGR. Combustion lag was identified for PKME with EGR implementation relative to neat applications under similar conditions. NHRR curves for JME and PKME(Fig.5& Fig.6) depict significant decrease in the net heat release with the introduction of the exhaust gas in most of the cases which may be due to the dilution. This clearly highlights the possibility of low temperature combustion in both the cases.However, the frequency of the diffused combustion in the case JME with EGR is higher with lower amplitudes when compared to the PKME combustion with EGR

With the increase of EGR, pronounced diffused combustion is observed in both the cases of JME and PKME which is quite clearly evident from the Cumulative Heat Release Rate (CHRR) curves (Fig.7 & Fig. 8). In absolute terms JME has better diffused combustion than the PKME operation with and without EGR. This can be assessed from the absolute values of CHRR in the range of 400^0 to 500^0 of crank rotation. At 498^0 the absolute CHRR values for 0% EGR (no EGR) for JME and PKME are 191J/deg and 287J/deg respectively. These values are increasing with EGR percentage.Combustion in later stages is more erratic in both the cases of JMEwith EGR as well as PKME with EGR which may have led to '*After combustion*'. PKME has higher CHRR values than JME for a given percentage of EGR.

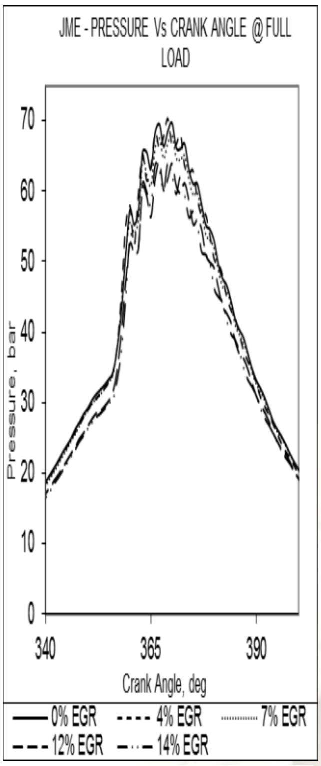

Fig.3shows the pressure traces for all EGR percentages at full load

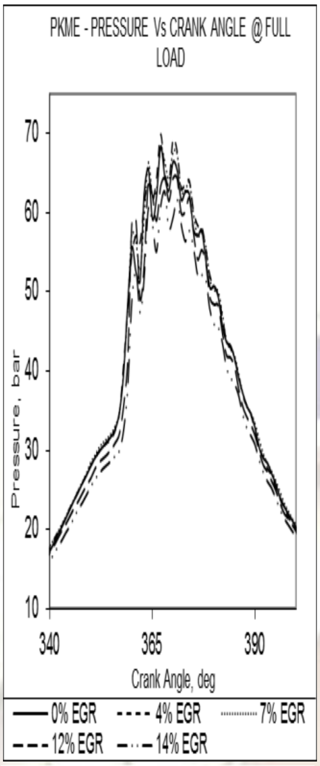

Fig.4Shows the pressure traces for all EGR percentages at full load

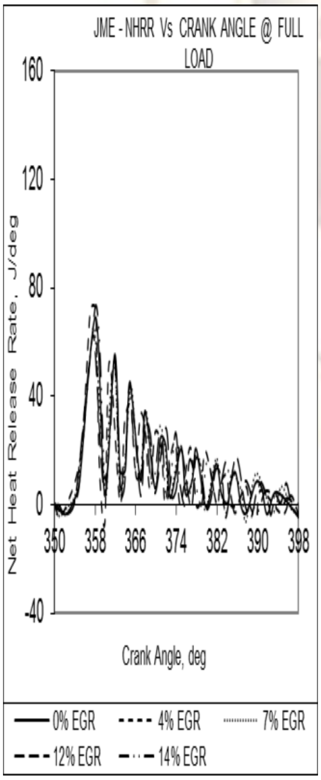

Fig.5 Shows NHRR vs Crank Angle curves for all EGR percentages at full load with JME

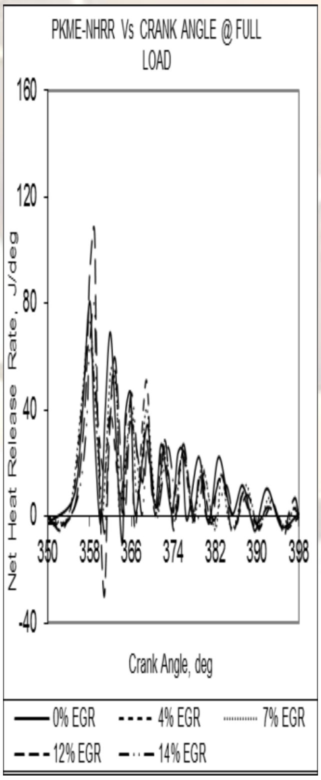

Fig.6 Shows NHRR vs Crank Angle curves for all EGR percentages at full load with Diesel

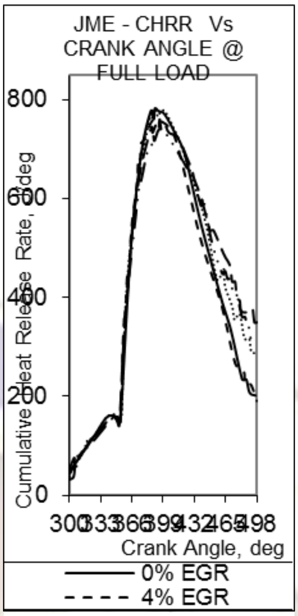

Fig.7 Shows CHRR vs Crank Angle curves for all EGR percentages at

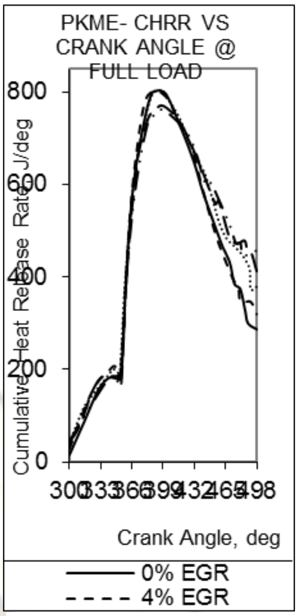

Fig.8 Shows CHRR vs Crank Angle curves for all EGR percentages at

3.2 Engine performance Analysis

The specific fuel consumption (SFC) and thermal efficiency curves for both the biodiesels used are shown in Figures from 9 to 12.At full load, minimum SFC of 0.31 kg/kW-hr is observed for JME with 7% EGR and this value is also minimum when compared to all other EGR percentages with JME implementation.There is about 11%decrease in SFC in the case of JME with 7% EGR when compared to neat JME application at the same load.Specific fuel consumption and Brake Thermal Efficiency for PKME over the range of EGR application are observed to have narrowed down to insignificant levels. Though marginal, 7% EGR is the most effective case even with PKME.

The effectiveness of 7% EGR can also be gauged in the case of brake thermal efficiency versus Brake Power curves. The brake thermal efficiency is 30.2% for JME with 7% EGR and at full load(Fig. 11). This efficiency is the maximum one when compared to the ones with the other EGR percentages. There is a steep hike of about 11% of brake thermal efficiency when compared to the neat JME operation (i.e. with no EGR). Excess Oxygen in the recirculated gas is responsible for sufficient combustion to reduce the specific fuel consumption in the case of JME at higher loads. This can be acclaimed to increase in thermal efficiency at higher loads and higher EGR rates as observed above.

In the case of PKME at 7% EGR which, coincidentally happened to be the case in which the brake thermal efficiency reached its maximum value at full load, the brake thermal efficiency recorded is

26%. This value is lesser than the peak value at full load operation with JME and 7% EGR operation. Obviously there is about16% increase in thermal efficiency when JME is used.

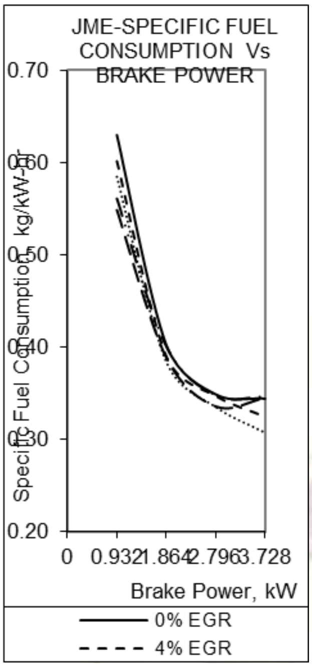

Fig.9 Shows SFC vs Brake Power curves for all EGR percentages with

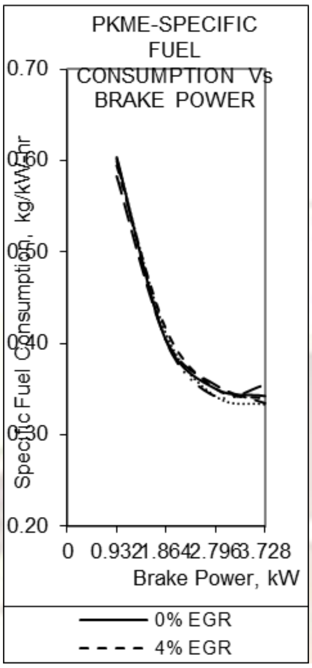

Fig.10 Shows SFC vs Brake Power curves for all EGR percentages with

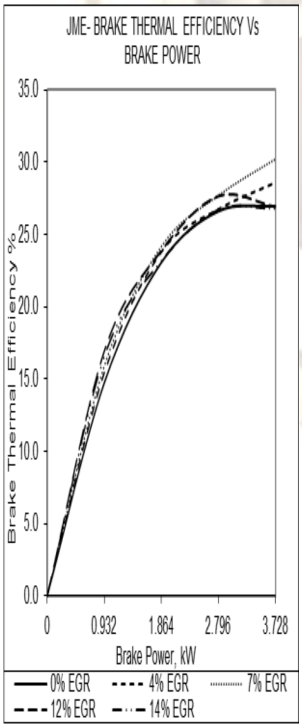

Fig.11 Shows Brake Thermal Efficiency vs Brake Power curves for all EGR percentages

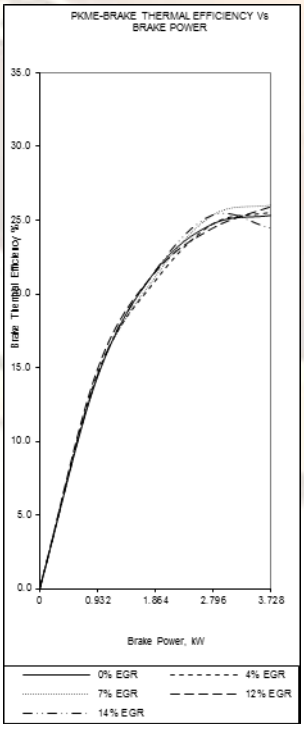

Fig.12 Shows Brake Thermal Efficiency vs Brake Power curves for all EGR percentages

3.3 Exhaust Emission Analysis

The engine was tested with four different percentages (4%, 7%, 12% & 14%) of exhaust gas recirculation for JME as well as PKME and the tail pipe emissions were investigated. The biodiesels were also run without EGR for comparison.

Referring to Fig.14, the NO emissions have progressively decreased with the increase of EGR. At full load with neat PKME operation, NO emission is 1483 ppm and with maximum EGR i.e. 14% the same emission has decreased to 1134 ppm. Reduction in emissions was observed at other loads also. Biodiesels are known to reduce exhaust emissions except for NO. With EGR, NO emissions reduced for both the biodiesels used.NO emission is slightly more at full load for the JME application(Fig.13) when compared to PKME application for all the EGR percentages. Moreover, in the case of JME, with EGR, the NO emission decreased and fallen by a maximum value of 240 ppm at full load.

HC release in the case of JMEoperation(Fig.15)hasdecreased up to 7% EGR and then increased for latter percentages. This trend is similar for all the loads. Same kind of trend is seen even with PKME operation (Fig.16)at full load. CO emission increased with increase in EGR at all the loads for both the biodiesels(Fig. 17& Fig. 18) used. JME produced lesser CO emission when compared to PKME at all loads and almost at all EGR percentages. CO emission found to be abnormally high at full load for PKME run. CO_2 is increased with the increase in EGR especially at higher EGR percentages for both the biodiesels(Fig. 19& Fig. 20) used.

Free air (λ) is decreasing with the increase of load and this is true with the JME as well as PKME operation (Fig.21& Fig.22). Air utilization will be more commensuration with the fuel consumption. Similar trend can be observed in the case of O_2 release in both the cases (Fig.23 & Fig. 24). Smoke levels also are increasing with the increase of EGR for both the biodiesels used. JME produced lesser smoke levels when compared to PKME and this is based on the heat release rate in the premixed and diffused combustion zones (Fig.25 & Fig. 26).

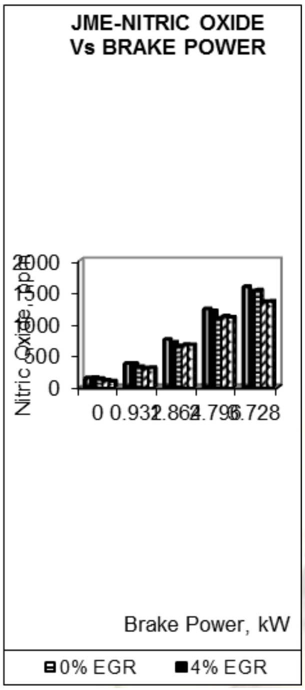

Fig.13 Shows NOvs Brake Power for all EGR percentages with JME

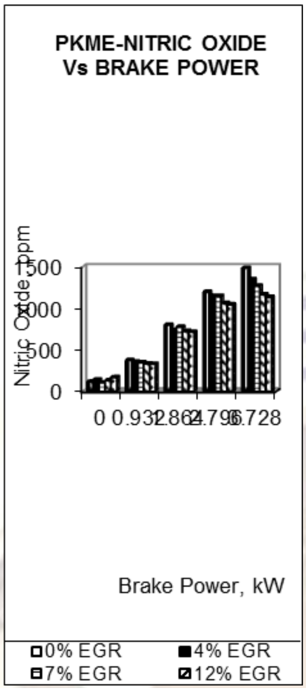

Fig.14 Shows NO vs Brake Power for all EGR percentages with PKME

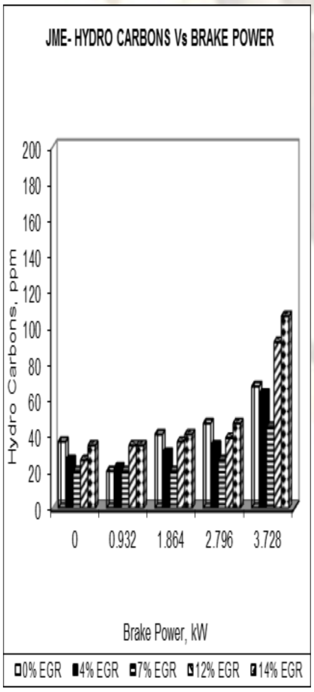

Fig.15 Shows HCvs Brake Power for all EGR percentages with JME

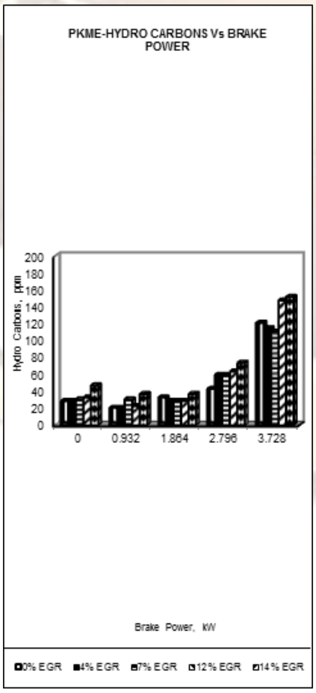

Fig.16 Shows HCvs Brake Power for all EGR percentages with PKME

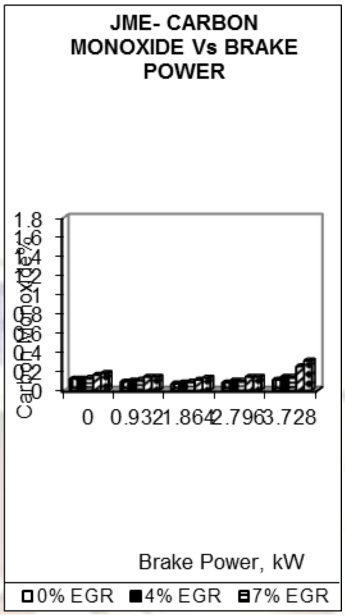

Fig.17 Shows CO vs Brake Power for all EGR percentages with JME

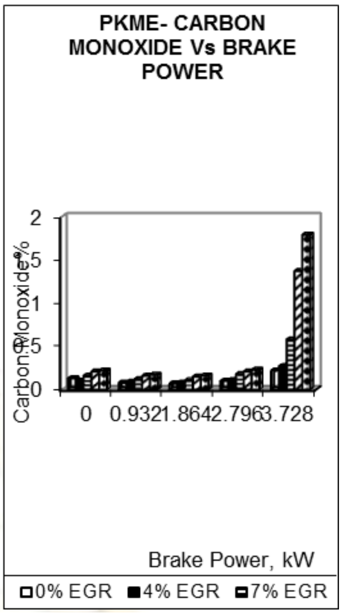

Fig.18 ShowsCOvs Brake Power for all EGR percentages with PKME

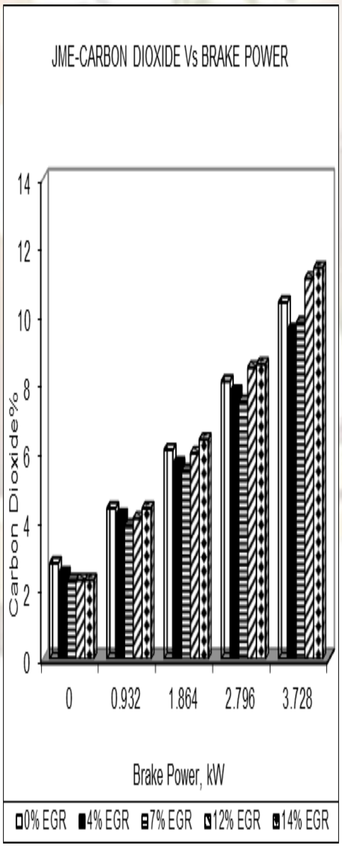

Fig.19 Shows CO_2vs Brake Power for all EGR percentages with JME Implementation

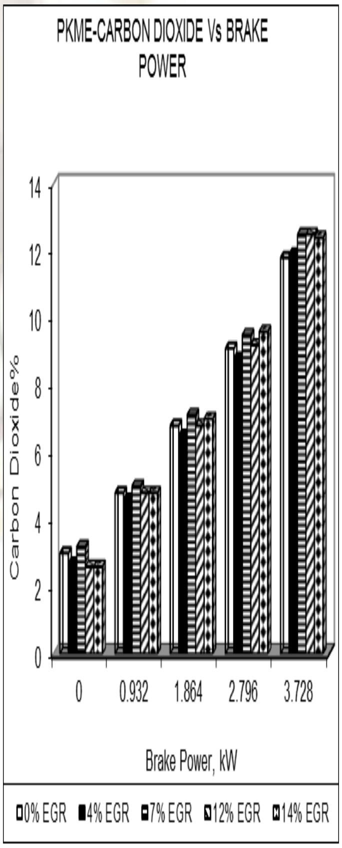

Fig.20 Shows CO_2vs Brake Power for all EGR percentages with PKME Implementation

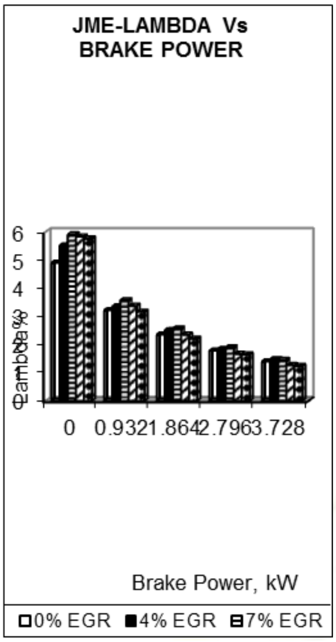

Fig.21 Shows Lambdavs Brake Power for all EGR percentages with JME

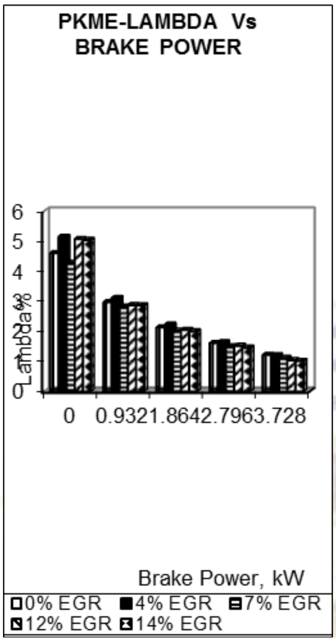

Fig.22 Shows Lambdavs Brake Power for all EGR percentages with PKME

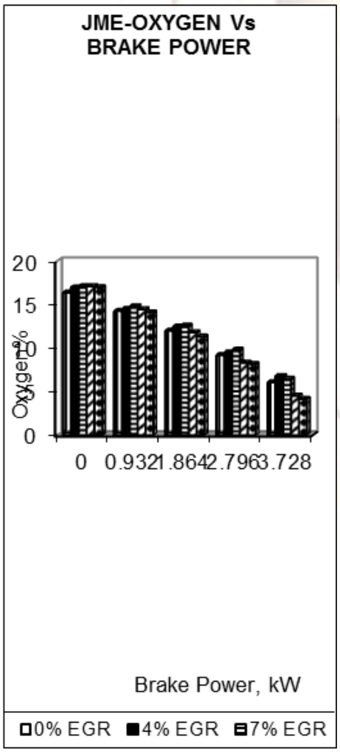

Fig.23 Shows O_2vs Brake Power for all EGR percentages with JME Implementation

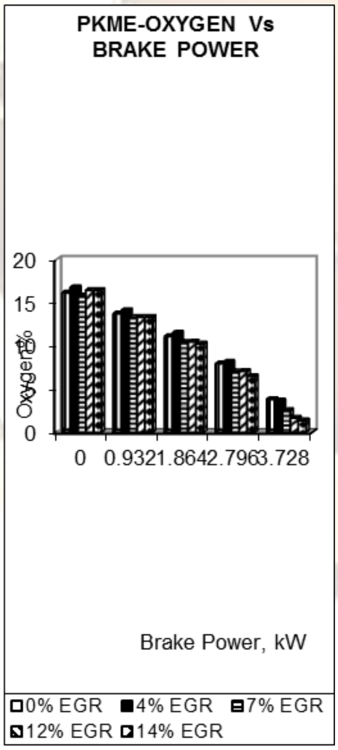

Fig.24 Shows O_2vs Brake Power for all EGR percentages with PKME Implementation

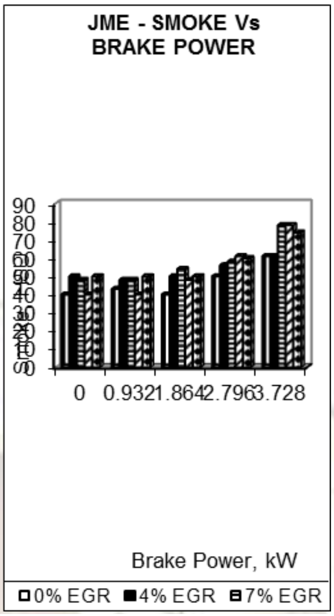

Fig.25 Shows Smokevs Brake Power for all EGR percentages with JME

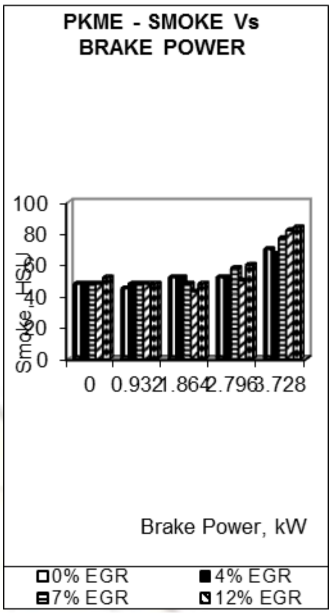

Fig.26 Shows Smokevs Brake Power for all EGR percentages with PKME

4.0 Conclusions

1. JME and PKME operation with exhaust gas recirculation has resulted in reduced peak combustion pressures at all loads. Further, peak pressures reduced with the increase of EGR rate resulting in significant drop in NO emission levels.
2. NHRR curves for JME and depict significant decrease in the net heat release with the introduction of the exhaust gas in most of the cases which may be due to the dilution. This clearly highlights the possibility of low temperature combustion in both the cases.
3. JME has better diffused combustion than that ofPKME operation. This can be assessed from the absolute values of CHRR in the range of 400^0 to 500^0 of crank rotation. 7% EGR is the ideal EGR for both biodieselswith moderate absolute CHRR values as can be assessed from CHRR curves.
4. 7% EGR produced better performance measured via specific fuel consumption and brake thermal efficiency for JME operation. At this percentage the performance is better even when compared to neat JME operation (i.e. 0% EGR). In the case of PKME marginal improvement is seen at 7% EGR when compared to other EGR percentages including PKME with no EGR.
5. Greater amount of '*after combustion*' for PKME operation has been observed, which further increased with the EGR percentage. This phenomenon can be ascertained from CHRR curves in diffused combustion stage

leading to higher emissions except NO at higher EGR rates. Same is true even with JME but to a lesser extent when compared to PKME.

6. There is conspicuous increase in the exhaust temperatures with the increase of load for both the bio-diesels. Exhaust gas temperatures for PKME are found to be relatively high compared to JME implementation. This is because of incidence of increased *after combustion* with respect to increase in EGR.
7. NO emissions have progressively decreased with the increase of EGR for PKMEas well as JME application. This decrement is more in PKME when compared to JME. From the point of view of exhaust emission levels and the performance of the engine 7% EGR application is observed to be ideal.

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