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Exhaust Gas Recirculation as a NOx Reduction Technique for Modified POME Fuelled Diesel Engine

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ABSTRACT:

The exhaust gas recirculation (EGR) consists of reverting a certain portion of the exhaust gases into the engine cylinder. EGR dilutes the air-fuel mixture in the cylinder reducing the combustion chamber temperature and NOx with a penalty in the value of brake thermal efficiency. EGR as a NO_x reduction technique for modified POME fuelled diesel engines has been investigated in the present work. The EGR rate is varied from 0% to 20% for the present study. An EGR rate of 10% has been optimized which results in the decrease in brake thermal efficiency by 3.4%, peak pressure (PP) by 5.6%, heat release rate (HRR) by 10.8% and oxides of nitrogen (NO_X) by 1.2% as compared to that without EGR. An increase in emissions such as carbon monoxide by 5%, unburnt hydrocarbons by 10.5% and smoke by 12.8% are observed.

KEYWORDS:

Palm oil methyl ester; Exhaust gas recirculation; Nozzle injector geometry; Injection opening pressure

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1. Introduction

High levels of NO_x emitted from diesel engines damages the human respiratory tract and can cause chronic lung disease. The reaction of NO_x and smoke results in the formation of smog. NO_x also causes acid rain which damages vegetables, buildings, and water bodies. NO_x emission leads to secondary emission, which contributes to global warming. Oxide of nitrogen is formed at very high temperatures and depends on the level of oxygen content in the burnt mixture. Hebbar [1] presented the Zeldovich mechanism of NO_x formation and stated that NOx is formed at or above the temperature of 1800 K. Retarding the IT, EGR and combination of exhaust gas recirculation with other techniques are the effective methods to control the NO_x shown by Prabhu et al [2], the exhaust gas recirculation consists of recirculating a certain percentage of the exhaust gases back to the test rig cylinder thereby increasing the heat capacity of the cylinder AF combination. This will result in the reduction of the temperature of the combustion chamber & hence the NO_x emission. But the CO_2 present in the exhaust gases will reduce the oxygen needed for the combustion of the AF combination and therefore decreases useful work output and the unburnt fuel amount increases [3].

Finer fuel atomization enhanced AF amalgamation and homogenization of the air-fuel mixture can be achieved by the modification of the piston and nozzle injection geometry. Jaichandar et al [4] tested and found that TRCC shape performed better with reduced emissions except for NO_x in a Pongamia Oil Methyl Ester fuelled engine as compared to the shallow depth Re-entrant combustion chamber. Shivashimpi et al [5], found that Palm Oil Methyl Ester fuelled engine fitted with TRCC shaped combustion chamber and operated with optimized injection parameters like IT of 27º BTDC, 240 bar IOP, and 5-hole nozzle geometry gives enhanced performance and poorer emissions properties apart from NO_x as in comparison with other piston shapes. Thus, it is evident that the efforts to improve the combustion process in a bio-fuelled CI test rig by the alteration of the piston shape and the injection-related parameters will result in higher NO_x emissions. EGR is found to be a very effective technique to reduce nitrogen oxide emissions. In this technique, a certain percentage of exhaust gases are sent back into the engine cylinder. Dhanraj et al [6] optimized the EGR rate to 20% for the CI test rig powered by TSME 20 for better performance and a decrease in NO_x. Shrivastava et al [7] optimized the EGR rate as 10% for the biodiesel blends (B50 and B100) made of KOME-diesel for the reduction in emissions. Saravanan et al [8] used the optimum combination of injection parameters such as 2.5◦ CA and 240 bar with 15% EGR is an approach to modify the combustion process to control both NO_x and smoke density from CRBOME fuelled diesel test rig.

Naik et al [9] obtained the improved performance and reductions in emission properties of a test rig powered by Balanites Aegyptiaca blends (B10 & B20) when used along with a 10% EGR rate over D100. An exhaustive literature survey conducted shows that exhaust gas recirculation will decrease the NO_x emissions but with a penalty in the value of BTE and an increase in other emissions. A 10% to 20% EGR rate has been optimized in most of the cases as a trade-off between oxides of nitrogen, smoke opacity along BTE. This research is undertaken to study the combined impact of the piston shape, nozzle geometry, injection-related parameters along with EGR on the performance, emission and combustion properties of POME fuelled of the test rig.

2. Fuel properties, instrumentation, and experimental methodology

The characterisation of the fuel property has been carried out in our laboratory and is enumerated as in Table1. The required arrangement made for the experimentation is as shown in Fig. 1. Diesel fuel-powered test rig is run at the manufacturer has set conditions such as IOP of 205 bar and 23ºBTDC IT. The experiments are conducted at 1500 rpm. The test rig parameters selected for the biofuel operation are IT-27 º BTDC, IOP-240 bar, nozzle geometry -5 holes, 80 % of engine load and TRCC piston shape, which have been optimized in our earlier research. An Exhaust gas recirculation setup has been built up in the laboratory. Torque measured device as Eddy-current-dynamometer is used in our experiment work and the U tube manometer (MX201, 0 to 100 mm) is used for the measurement of air quantity. A Hartridge smoke meter is used for the measurement of smoke. A DELTA 1600S-non-dispersive infrared gas-analyzer is used for other emissions such as HC, oxide of nitrogen, etc. The specification for the experimental rig has been shown in Table 2. A piezoelectric transducer is used to measure the inline-cylinder gas pressure. The combustion chamber used and the 5-hole nozzle geometry is as shown in Fig. 2. The engine is run at different loads using AG-10 eddy current dynamometer after ensuring a supply of a sufficient quantity of water through the engine. EGR is varied from 0% to 20% for each load of the engine and readings are taken. The EngineSoft software is used for obtaining the digital readings.

Fig. 1: Experimental setup with EGR arrangement

Table 1: The details of POME fuel properties

Property	Diesel	POME
Density (kg/m^3)	840	879
Energy density (kJ/kg)	43,000	38,395
Viscosity at 40 ºC (cSt)	2.44	3.94
Flash point (ºC)	75	159
Cetane number	45-55	58
Carbon residue (%)	0.1	---
Pour point (ºC)	-5	6.7
Sulphur (%)	0.005	0.05
Moisture (vol. %)	0.02	0.05
Acid value (mg KOH/g)	0.35	0.800
Distillate (ºC) range	160 with 90%	360 with 97%

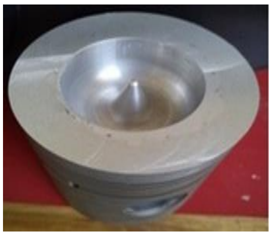

Fig. 2: TRCC piston shape

Table 2: Specifications of TV 1 (Kirloskar) CI engine

Parameter	Specification
Nozzle injection pressure	200-240 bar
No. of cylinders	1
No. of strokes	4
Rated-power	5.2 kW (7 HP @ 1500 rpm)
Bore	87.5 mm
Stroke-length	110 mm
Compression ratio	17.5:1
Max. power	7.5 kW (@ 1500 -3000 rpm)
Dyno. arm-length	180 mm
Fuel measurement range	0-50 ml

3. Results and discussion

EGR is the most effective method to reduce NO_x and PM. The fuel Injection parameters such as IT 27ºBTDC, 240 bar injection pressure, 5 holes nozzle geometry have been optimized for better performance and emissions from the experiments conducted previously by us on the POME biodiesel fuelled engine fitted with TRCC shape. The engine is modified with the said engine parameters and operated at different loads. The engine was first run without EGR and then with varied EGR rates. EGR rate is restricted to a maximum value of 20% as a further increase in EGR rate causes drastic deterioration of the combustion process. EGR rate is varied by using a valve provided in the EGR loop. The emissions along with the exhaust gas temperature and the fuel consumption were recorded. The performance, combustion, and emission characteristics of POME fuelled diesel engines at different EGR rates have been compared with those of pure diesel without EGR at 80% load for the analysis and selection of a nominal EGR rate as a trade-off between NO_x, smoke opacity and performance.

The effect of EGR on the brake thermal efficiency (BTE) is evident in Fig. 3 at all the loads. A higher value of BTE is obtained for the diesel-fuelled engine as compared to the bio-fuelled engine. Recirculation of CO_2 in the exhaust gases reduces the O_2 concentration in the combustion mixture. As a result of this useful work output decreases and unburnt fuel amount increases [3]. Hence the BTE of the engine is found to decrease with the EGR rate. The BTE observed for diesel fuel is 31.25% in an engine under baseline engine conditions (3 holes nozzle geometry, 23 ºBTDC, 205 bar IOP, CR 17.5 and HCC shape) at 80% load. Similarly, the BTE observed for POME fuel with varied EGR rate in engine are 29.3%, 28.8%, 28.3%, 27.8%, 27.3% for 0%, 5%, 10%, 15%, 20% EGR respectively under the modified engine conditions (5 holes nozzle geometry, 27 ºBTDC, 240 bar IOP, CR 17.5 and TRCC shape) at 80% load. BTE is found to increase up to 80% of load and thereafter it decreases.

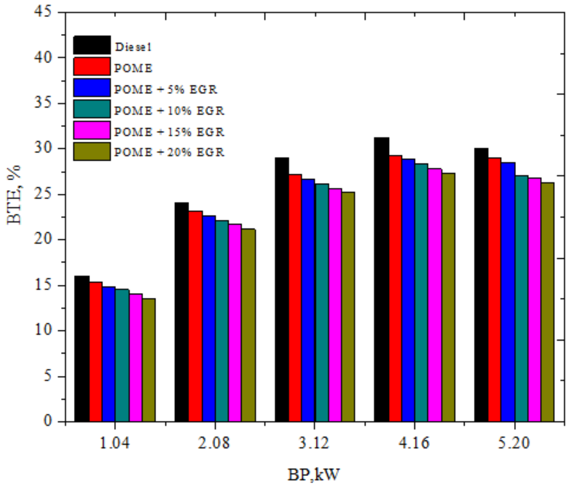

Fig. 3: Effect of EGR, nozzle geometry, IT and CC shape on BTE

The smoke opacity increases with EGR for both the Diesel and POME fuelled engines is shown in Fig. 4. The diesel fuel being less viscous with a lighter molecular structure gives improved combustion as compared to Biodiesel fuel and hence results in lower smoke levels. The smoke level increases with the EGR rate for POME fuelled engines due to reduced oxygen content and hence a poorer combustion process at higher EGR rates. Smoke level obtained for diesel fuel is46 HSU under baseline engine conditions at 80% load. Similarly, the smoke level observed for POME fuel with varied EGR rate in engine are 47 HSU, 50 HSU, 53 HSU, 55 HSU, 58 HSU for 0%, 5%, 10%, 15%, 20% EGR respectively under modified engine conditions at 80% load.

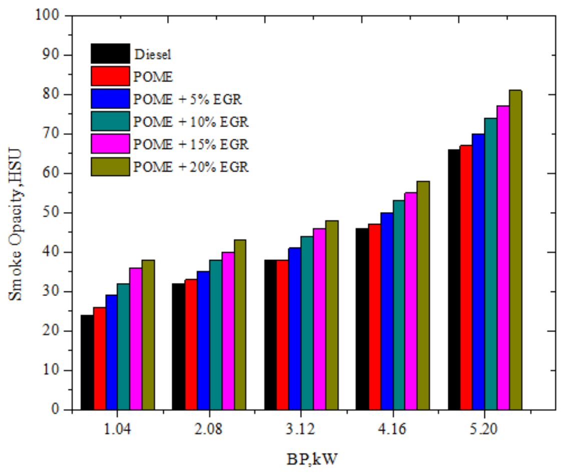

Fig. 4: Effect of EGR, nozzle geometry, IT and CC shape on smoke opacity

The variation of unburnt hydrocarbons (UBHC) and CO emissions with EGR is shown in Fig. 5 and Fig. 6 for both the fuels at all the loads. It is seen that both the said emissions will increase with load and with EGR rate. The decrease in oxygen concentration in the AF charge due to recirculated exhaust gases resulting in a poorer combustion process is the reason for the increase in the UBHC and CO Emissions with the EGR rate. Diesel fuelled engines in comparison to the bio fuelled engines result in lower emissions due to its better thermal efficiency. The experimental results show that Diesel fuel gives HC emissions as 36 ppm under baseline engine conditions at 80% load. The HC emissions operated with POME fuel with 0%, 5%, 10%, 15%, 20% EGR are 38, 40, 42, 44 and 48 ppm respectively under modified engine conditions at 80% load. The experimental results show that Diesel fuel gives 0.13% CO emissions under baseline engine conditions at 80% load. CO emissions operated with POME fuel with 0%, 5%, 10%, 15%, 20% EGR are 0.14, 0.143, 0.147,0.157 and 0.167% respectively under modified engine conditions at 80% load.

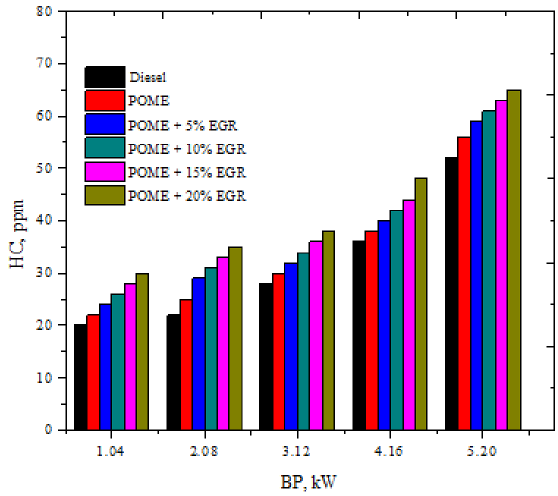

Fig. 5: Effect of EGR, nozzle geometry, IT and CC shape on Unburned Hydrocarbon Emissions

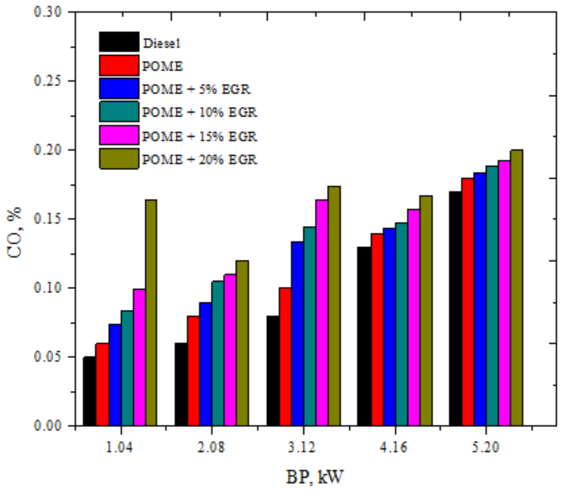

Fig. 6: Effect of EGR, nozzle geometry, IT and CC shape on Carbon monoxide emissions

The variations of NO_x emissions with EGR at all the loads for the Diesel and POME fuelled engines can be seen in Fig. 7. The diesel engine results in more NO_x emissions in comparison to the bio-fuelled engine at all the loads because of its higher CV and better combustion process [10-12]. It is also seen that NO_x emissions decrease with the increased amount of recirculated exhaust gases. The exhaust gas recirculation increases the heat capacity of the fuel mixture in the cylinder. The replacement of the oxygen content of the AF charge by CO2 of the exhaust gases results in a poorer combustion process. These will reduce the temperature of the combustion chamber and hence the NO_x emissions decrease with the increase in EGR rate. Experimental results show that NO_x emission for diesel fuel is 1090 ppm under baseline engine conditions at 80% load. NO_x emission for POME fuel at 0%, 5%, 10%, 15%, 20% EGR rate are 1085, 1080, 1072, 1064 and 1058 ppm respectively under modified engine conditions at 80% load. The peak pressures obtained at different EGR rates at 80% load are shown in Fig. 8. The diesel fuel because of its higher C.V and lower viscosity will give a higher value of peak pressure as compared to that obtained by using the POME fuel. Peak pressures obtained for the POME fuelled engine go on decreasing with the increasing EGR rates. This is because of the increased deterioration of the A/F ratio and lesser O_2 availability at higher EGR rates. Peak pressure obtained for diesel fuel is 74 bar under baseline engine conditions at 80% load. The values of peak pressure obtained for POME fuelled engine at 0%, 5%, 10%, 15%, 20% EGR rate are 72, 70, 68, 66 and 65 bars respectively under modified engine conditions at 80% load.

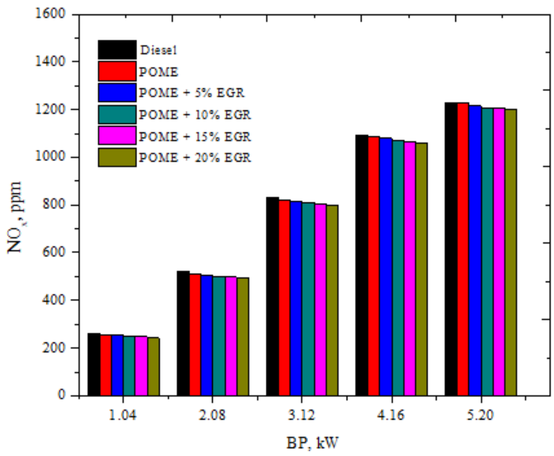

Fig.7: Effect of EGR, nozzle geometry, IT and CC shape on NOx emissions

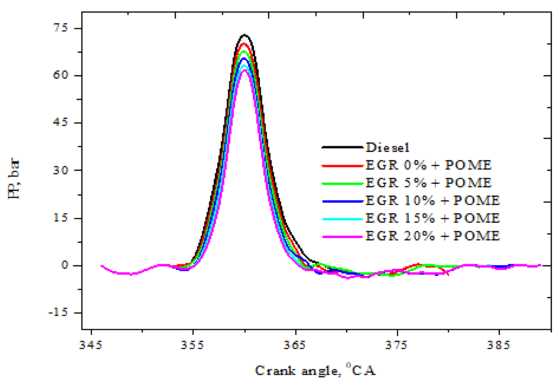

Fig. 8: Effect of EGR, nozzle geometry, IT and CC shape on peak pressure

The Heat Release Rates (HRR) of both the diesel and bio fuelled engines are shown at different EGR rates at 80% load is shown in Fig. 9. The diesel fuel will result in a higher value of HRR as compared to the POME fuel [13]. HRR obtained decreases with an increase in the percentage of exhaust gas recirculated for the POME fuelled engine. This is because of the decrease in the combustion rate due to reduced oxygen content with an increased amount of recirculated gases. The value of MHRR (Maximum heat release rate) obtained for diesel fuel is 70J/°CA under baseline engine conditions at 80% load. MHRR obtained for POME fuelled engine at 0%, 5%, 10%, 15%, 20% EGR rate are 65, 60, 58, 56 and 54J/°CA respectively under modified engine conditions 80% load.

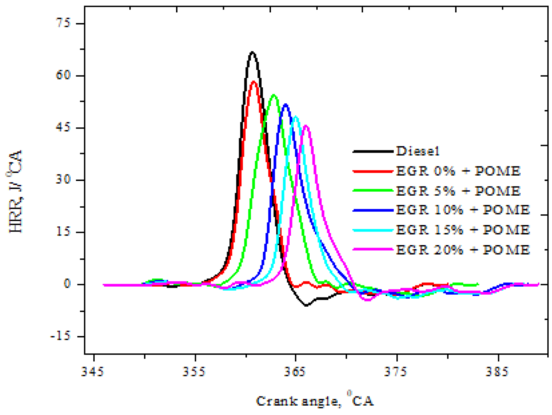

Fig. 9: Effect of EGR, nozzle geometry, IT and CC shape on the heat release rate

4. Conclusion

It is found that by recirculating a certain portion of the exhaust gases back to the biodiesel-fuelled engine, NO_x emissions can be reduced. But the recirculation of the exhaust gases will replace the O_2 in the air-fuel mixture with CO_2. This will lead to incomplete combustion, which is evident from the decrease in peak pressure, HRR and BTE. The increase in the amount of recirculated gas also results in the emissions such as CO, UBHC and smoke increasing drastically. An increase in EGR rate from 0 to 10% is optimized from the viewpoint of NO_x reduction and penalty in power output which results in the decrease in brake thermal efficiency by 3.4%, peak pressure (PP) by 5.6%, HRR by 10.8% and oxides of nitrogen (NO_x) by 1.2%. A drastic increase in emissions such as carbon monoxide (CO) by 5%, unburnt hydrocarbon (UBHC) by 10.5% and smoke by 12.8% are observed. Overall, the following conclusions can be drawn as follows. A reduction of 1.2% in NO_x is achieved with a penalty of 3.4% in the value of BTE for an EGR rate of 10% as compared to without the EGR rate. POME fuelled diesel engine with 10% EGR gives a reduction of PP and HRR by 5.6% and 10.8% respectively as compared to without EGR. POME fuelled diesel engine with 10% EGR gives an increase in CO, UBHC and smoke emissions. CO, UBHC and smoke emissions increase by 5%, 10.5%, and 12.8% respectively as compared to without EGR. A nominal EGR rate of 10% is chosen such that the trade-off is done concerning smoke and NO_x emissions with acceptable engine performance an improvement in the value of BTE can be obtained by improved fuel atomization, which can be achieved by advanced fuel injection strategies such as multiple injection strategies (MIS) and CRDI fuel injection systems.

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