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Original Research Paper

Experimental Analysis on the Running of CI Engine with Pongamia Oil-Diesel as Fuel for Exhaust Gas Recirculation (EGR) Technique

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Abstract: Present days, I.C engines are the fundamental parts of shipping and automatic farming system, etc. Hence there is an exponentially up-surge in utilization of Diesel and gasoline products. At the same time Diesel is an exhaustive source of energy and recent pitch in Diesel prices have focused interest in bio-fuels and also it has resulted that biodiesel-oiled engines produce comparatively fewer CO, unburned HC and smoke emissions, but higher emissions of NOx. Exhaust Gas Recirculation is observed as best technique to reduce NOx emission in recent days as the flame-temperature inside the cylinder decreases. A one-cylinder, H_2O cooled with constant speed DICI engine was used for the research. In exhaust gas quantity of CO, HC, NOx and smoke opacity was determined to estimate the emissions and to assess performance of test-rig BTE, BSFC, Air/Fuel ratio, ME, VE and EGT parameters were considered. Both for base and combination of PME performance and emission parameters were evaluated at 20% EGR, CR 17.5 and FIP 200 bar. Collaboration of EGR with combination of PME increased concentration resulted in slightly reduced BTE, increased BSFC, decreased Air/Fuel ratio, decreased VE, increased EGT, minute decrement in ME and absolute lower NOx emissions, little increase in HC and small increment in smoke opacity. Overall, it is practical that at full load PME60 has similar or significant impact on performance and emission variables compared with baseline.

Keywords: PME, EGR, Engine Emissions, Performance Characteristics

Introduction

From the previous findings it is clear that to reduce NOx creation inside the burning chamber EGR is best technique. Exhaust comprises of major percentage of CO_2, N_2 and H_2O vapors contents. Portion of burnt gas is dispersed through the engine burning chamber; it reacts as dilutant to the combination present in combustion chamber. On the other side it also reduces the amount of O_2 percentage inside the cylinder. Heat capability of the intake-charge raises causes high specific heat of EGR, thus inside the combustion chamber results in decreasing temperature rise for the equivalent amount heat release. The EGR system shown in Fig. 1:

$$\%EGR = \{(Volume\ of\ EGR*100)/(Total\ intake\ charge\ into\ cylinder)\}$$

Quantity of exhaust gas that is to be dispersed should be thoroughly monitored; otherwise it would result in lowering the engine efficiency.

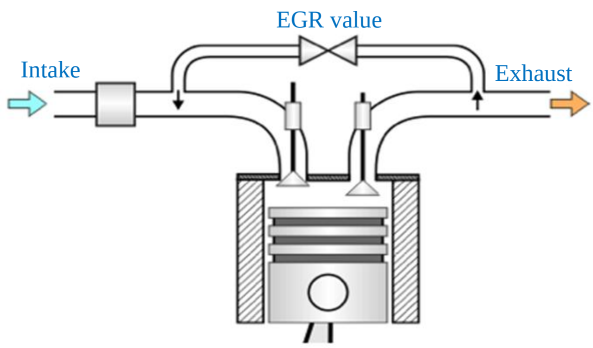

Fig. 1: EGR System (Copyright of Yanmar Co. Ltd.,)

Pongamia oil has been derived from the seeds of the Millettiapinnate tree, which is inhabitant to tropical and moderate Asia. This oil has very close or similar properties to that of diesel fuel, because of which it has been selected for investigation.

The basic properties of pongamia oil are almost alike to diesel fuel, then, pongamia oil and diesel were run in the CI engine as test fuels and its emission and performance variables of the engine were evaluated. The trial results disclose that biodiesel showed the improved emission parameters to that of diesel. The output power of pongamia biodiesel was comparable with diesel oil (Arul Nicholas *et al*., 2019).

The evaluation of CI engine by EGR with mixed fuels has carried-out. The effect on BP, BSFC, BTE has reported. Additionally, features of response surface methodology on minimization of NOx, smoke and BSFC has been carried out using mixed oil, EGR %, injection timing, etc., (Dubey *et al*., 2019).

CI setup operated in laboratory under peak load (85% of full load), unchanging speed (2000 rpm) and a variety of EGR rates 5-40% (with 5% rise). Various evaluations like oil run, EGT, emission and exhaust smoke test was done. The consequences show superior fuel cutback and decreased pollution intensity for the low heat rejection unit. The outcome revealed that, at 5%-EGR with TB-10, both NOx and smoke were decreased by 26 and 15%, correspondingly. In addition, TB-20 along with 10%-EGR was also able to decrease both NOx and smoke emission by 34 and 30%, correspondingly contrast to baseline with no EGR (Modi *et al*., 2018).

The pongamia is mixed with diesel in the different proportions like B0, B20, B40 and B100 with the variation in injection pressures like 180 and 200 bar and %EGR at 5 and 10%. Resulted that pongamia biodiesel blend (B40) indicated slight raise in BTE with the decline of exhaust gas temperature and also less fuel consumption. Additionally, established that there exists minor fall in emissions. Concluded that pongamia biodiesel (B40) utilized as, replacement fuel for DICI engine without major alterations (Banashankari Nimbaland and Navindgi, 2018).

The analysis of key scientific features measured throughout modeling of piston ring–liner lubrication and friction losses examinations. Survey emphasizes outcomes of piston-ring dynamics, lubricant rheology, parts geometry, surface topography and assumed methods, over frictional losses involved by the piston ring-pack (Delprete and Razavykia, 2017). Therefore, analysis is dedicated to illustrate the synthesis of major technical features, study hard work, summary and obstacles that should be emphasized concerning piston skirt/liner lubrication and piston movements and strike (Delprete and Razavykia, 2018). Piston secondary movement is estimated by lubrication theory and equilibrium of forces and moments, to study the effect of wrist pin position, piston skirt/liner clearance and oil rheology. Numerical technique and finite dissimilarity scheme utilized to describe piston peculiarity and hydrodynamic pressure over the skirt (Delprete *et al*., 2019).

Ignition delay, increased heat capacity and mixing of inducted charge with noble gases are the three different famous explanations which are quite influential with EGR in case of NOx reduction. EGR causes an increase in ignition delay which leads to the retarding in the timing of injection. The heat capacity premise determines that dispersion of engine exhaust gases through the intake fresh charge uplifts the heat capacity which ultimately lowers high combustion temperature. According to dilution hypothesis, increasing the amount of noble gases in the combination decreases adiabatic flame temperature thus resulting in reduced NOx formation in the engine cylinder (Holman, 2002).

Experimental explorations reveal that BTE is little raised and BSFC is reduced at low loads with EGR contrast to without EGR. But at superior loads, BTE and BSFC are roughly alike with EGR than with no EGR. EGT is reduced with EGR, but NOx reduces considerably. Practically found that 15%-EGR rate effective to reduce NOx substantially with no worsening unit performance (Hussain *et al*., 2012).

Diverse approaches are utilized to reduce the NOx emission. In this study EGR technique is utilized the CI engine with B20 biodiesel as fuel. Madhua oil is employed to prepare the bio-diesel. Tests executed on one-cylinder, 4-stroke, H_2O-cooled, DI CI engine with EGR and without EGR at various level (5, 10, 15 and 20%). The outcome reveals that NOx emission is reduced using EGR for diesel and bio-diesel (Manieniyan and Sivaprakasam, 2013).

The systems that are affected by the application of EGR are: BSFC, lubricating system, diesel engine combustion characteristics, the BTE, the combustion parameters of DI CI engines, speed, CO_2 and HC emissions, the performance characteristics of turbocharged CI engine, fuels, temperature, on EGR rates, the durability of engine components and cooled EGR and the challenges of cooled EGR (Semakula and Inambao, 2017).

The trial setup is run by corn seed oil bio-diesel mixture. Specific features are explored at diverse EGR ratios (5, 10 and 15%) and consequences are contrasted with baseline. From the synthesis of the trial outcomes, it is summarized that the NOx are reduced by raise in EGR-ratio (Ramakrishna *et al*., 2020).

The %EGR flow rate of mass ranged 0 to 20% graduated in intervals of 5%. During this experiment all the tests were conducted at constant 1500 rpm, to examine outcomes of EGR on emission and performance when useless-cooking oil is applied together through diesel blends (Rao *et al*., 2015).

The test-rig of the ethanol-fueled diesel engine (EFDE) by EGR is formed. Utilizing above unit, the specific variables of EFDE in dissimilar situations of EGR (ethanol + coating, ethanol + coating + 10%EGR, ethanol + coating + 20%EGR) are done. Wholly, it is proved that deviation in the %EGR rates has a major influence on all above characteristics of EFDE (Saravanan *et al*. 2020).

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To improve the BTE and simultaneous reduce emissions, testing was done with constant rate of EGR 10% attached to low heat rejection CI unit improved via 8 YSZ (8% mol. yttria-stabilized zirconia) ceramic material layered cylinder head and liner fuelled by minimal blend B85A15 by vol. (Karanja based bio-diesel 85% + additive diethyl ether 15%). The outcomes reveal that advancement of injection timing considerably enhanced all the explored variables except NOx for both the engines and in contrast to best outcomes are 6.5% improvement in BTE with the decrease of 4.5% brake specific energy consumption, 44% PM and 18.5% in NOx found for LHR unit fuelled by B85A15 at 330 BTDC with an 80% load contrast to RE with baseline. The best arrangement of RE found to be baseline at injection timing 310 BTDC through 80% load (Vamsi Krishna *et al*., 2018).

Engine alteration by decreasing Nozzle Hole Diameter (NHD) (i.e., from the normal value of 0.28 to the adapted value of 0.20 mm) revealed as an effectual approach in developing engine parameters. But, it also leads to considerable rise in NOx as a key challenge. Study was intended at beating challenge by applying of a partly-cooled EGR setup. Further particularly, Mahua oil bio-oil mixture (B20) and pure diesel tested on a changed CI engine over 5 different engines loads and in the existence of unstable EGR rates. Wholly findings of examination, the designed engine alteration in the existence of partly-cooled 10%EGR rate could be suggested as favorable combustion conditions for 20% mix of Mahua oil and diesel (Kumar *et al*., 2018).

A review of the literature indicates various ways to improve performance and emissions reduction. The few gaps/objectives that can be drafted from the above reviews are as follows:

- The investigation is carried out under fixed operating conditions like injection pressure 200bar, CR17.5 and 20%EGR
- The pongamia is mixed with diesel in the different proportion like B60
- Very less research on the combination of EGR system with pongamia-biodiesel
- Temperature reduction for exhaust gases recirculated in EGR system was neglected

Experimental Setup

A one cylinder, H_2O cooled, four stroke, constant speed, DICI engine is utilized for the experimentation conducted depicted in Fig. 2. The features of experimented test rig were represented in Table 1.

Fig. 2: Single cylinder Kirloskar diesel engine

Table 1: Technical description

Engine testing (Product code)	One-cylinder, 4-stroke and Diesel Fuel (224)
Engine Make	Kirloskar made (Model TV1-Type)
Power	Produces 5.2 kW, 1500 rpm, stroke length of 110mm, cylinder dia. of 87.5 mm, connecting rod length 234 mm, crank radius 55 mm, 661 cc, CR17.5
Dynamometer	Eddy current
Air box	Mild Steel
Fuel tank	Glass column for fuel metering with capacity of 15 litters
Calorimeter	Pipe-in-pipe
Piezo sensor	Capacity of 5000PSI
Data acquisition device	NI USB-6210, 16-bit, 250kS/s
Piezo powering unit	Model AX-409
Temperature sensor	K- Type.
Temperature transmitter	Two wires, RTD, Range 0-100°C
Load indicator	Range 0-50 Kg, Supply 230VAC
Load sensor	Strain gauge, ranges from 0-50 Kg
Fuel flow transmitter	Type-DP, Ranges from 0-500 mmWC
Air flow transmitter	Pressure transmitter, Range (-) 250 mmWC
Software	“Engine soft” Engine performance analysis software
Rotameter	40-400 LPH
Optional	Computerized Diesel injection pressure measurement

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Experimental Methodology

After all precautions, the test-rig is started and achieved idling state at speed 1500 rpm.

Simultaneously, all analyzers and meters for measurements are turned-on and the proper arrangements and settings for measurements are performed with suggested ways as per manufacturer's direction manual.

Once steady condition achieved, preparations and settings for the parameters are recorded through computer for following trials.

Trials are conducted at 20%EGR with different load conditions like 0, 25, 50, 75 and 100% load. The speed at all loads is adjusted to stable value (i.e., 1500 mm).

The above conditions, methods of procedures are repeated for the experiments with diesel and diesel blended fuels.

After the experimentation with proposed blends of fuels, the data calculations and analysis were carried out.

Results and Discussion

The presentation of the test-rig determined in terms of Brake Specific Fuel Consumption (BSFC), Brake thermal efficiency (BTE), Air/fuel ratio, Volumetric Efficiency (VE) and Exhaust Gas Temperature (EGT) and Mechanical Efficiency (ME).

The emission contents of the engine were calculated in terms of CO, HC, NOx and Smoke opacity.

Performance Parameters

Brake Thermal Efficiency

Figure 3 shows variation of BTE and %FLBP for PME blends compared with diesel. Results showed BTE for base is higher than any of the blends. The BTE is less for blend of PME because of less calorific value, higher viscosity and higher density. Higher viscosity results decreased fuel-breakup, vaporization and combustion hence decreased BTE for PME blend. BTE is low at low values of load and is increasing with rise of load for all blends of fuel causes to increase of brake power. For PME60 BTE is high at all loads values compared with all other blends and close to diesel. Hence for PME60 and PME20 the BTE is good.

Under 100% load operation, BTE for diesel is 32.25%. For PME blends, they were observed to be 31.64, 30.56 and 31.44% for PME20, PME40 and PME60 respectively.

Brake Specific Fuel Consumption

Figure 4 shows deviation of BSFC and %FLBP for PME combinations compared with diesel. BSFC is factor that indicates how resourcefully an engine is transforming fuel into work. The fuel consumption of an engine based mainly upon heating value of fuel, air/fuel ratio. The calorific value of diesel is more than calorific value of PME and its blend, higher the calorific value higher the heat released through burning and hence higher will be thermal efficiency. Lower calorific value of PME its blend leads to injection of superior quantity of fuel for same power output in contrast to diesel. It is clear from Fig. 4 that at all loads BSFC is more for blends of PME as compared to diesel. BSFC decreases with the increasing loads. This is due to more loads, cylinder wall hotness rose which reduce ignition delay and lead to improved combustion and reduced fuel consumption. It is observed that BSFC chased precisely overturn movement as that of BTE and decrease by the increase of engine load.

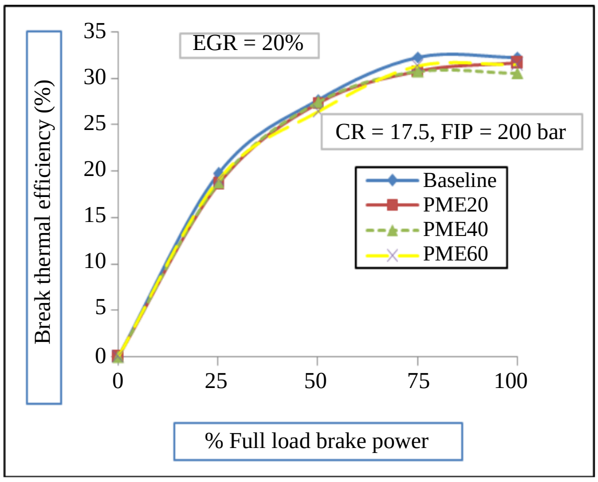

Fig. 3: BTE Vs %FLBP

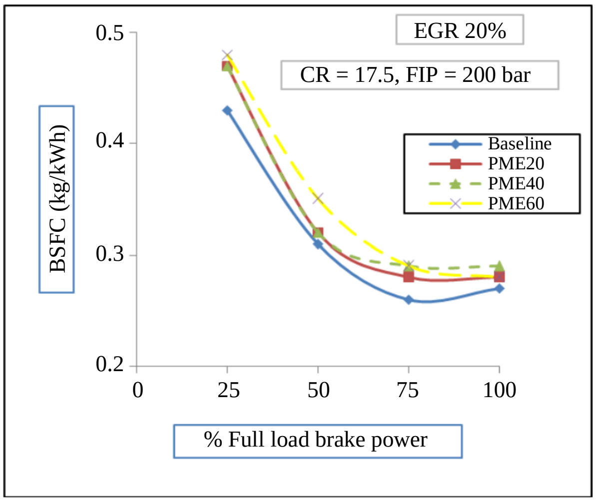

Fig. 4: BSFC Vs %FLBP

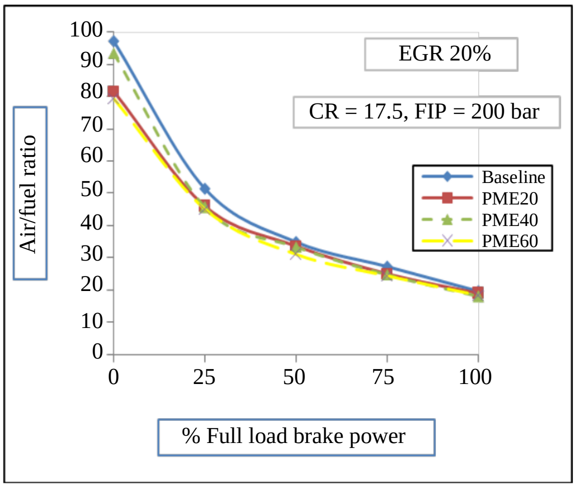

Fig. 5: Air/Fuel ratio Vs %FLBP of the engine

Under 100% load operation, BSFC of diesel 0.27 kg/kWh. For PME20, PME40 and PME60, they were observed to be 0.28, 0.29 and 0.28 kg/kWh respectively.

Air/Fuel Ratio

Figure 5 shows deviation of Air/Fuel ratio and %FLBP for PME blends in comparison with diesel. It is observed that, under 100% load operation, Air/Fuel ratio for diesel is 19.55%. For PME20, PME40 and PME60, they were observed to be 18.97, 17.99 and 18.39% respectively.

Volumetric Efficiency

Figure 6 shows variation of VE and %FLBP for neat PME in comparison with petro-diesel. The efficiency is high at low load and then start decreasing on increasing the load with all fuels. It is due to existence of O_2 in blend, assists in complete burning of oil even at peak loads thus liberates additional heat leads heating up of manifold and thus, decreases VE.

Volumetric efficiency for diesel is 78.29%. For PME20, PME40 and PME60, they were observed to be 78.03, 77.83 and 77.72% respectively.

Exhaust Gas Temperature

Figure 7 shows EGT variation and %FLBP for neat PME in comparison with diesel. It is due to higher fuel expenditure of blend.

Despite the fact that heating value of blend is poorer than diesel, more exhaust temperatures are credited to the existence of 11% O_2 in fuel which helps in entire burning. EGT for all the oils rises with raise in the load. Quantity of oil introduced raises with load to sustain output power and hence the heat release and EGT increase with rise in load. EGT is important feature for burning in chamber.

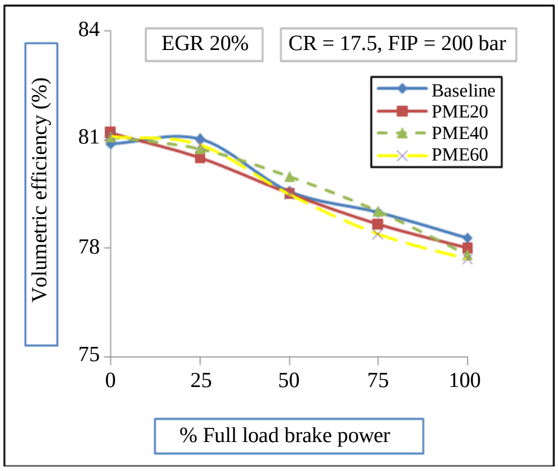

Fig. 6: Volumetric efficiency Vs %FLBP of the engine

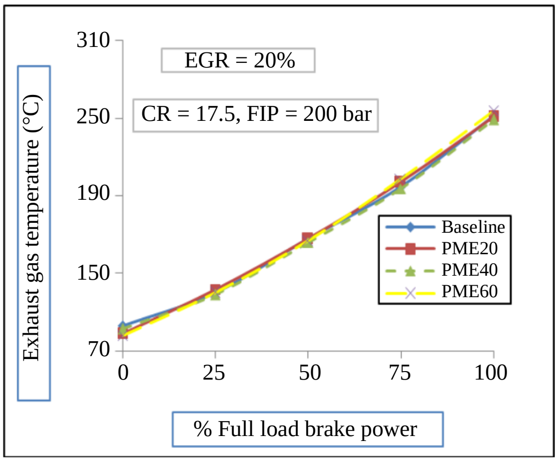

Fig. 7: EGT Vs %FLBP of the engine

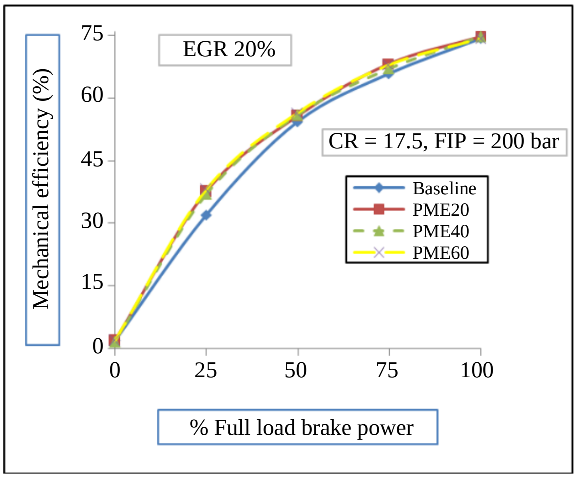

Fig. 8: Mechanical efficiency Vs %FLBP of the engine

It is observed that, under 100% load operation EGT for diesel is 251.74°C. For PME20, PME40 and PME60, they were observed to be 251.13°C, 248.83°C and 256.05°C respectively.

Mechanical Efficiency

Figure 8 depicts ME variation and %FLBP neat PME in comparison with petro-diesel. For all bio-diesel mixtures and diesel tested, mechanical efficiency always increases with rise in brake power, on the other hand Mechanical efficiency decreasing with increasing in the bio-diesel blend concentration.

Under 100% load operation, mechanical efficiency for diesel is 74.31%. For PME20, PME40 and PME60, they were observed to be 74.87, 74.73 and 74.31% respectively.

CO Emission

Figure 9 shows the CO Emission variation with percentage full load brake power (%FLBP) neat PME compared with neat diesel. Under 100% load operation, CO emission for diesel is 0.278% maximum. Whereas for PME blends, they were observed to be 0.251, 0.241 and 0.277% for PME20, PME40 and PME60 respectively.

HC Emission

Figure 10 shows the HC Emission variation with percentage full load brake power (%FLBP) for neat PME in comparison with diesel. Under 100% load operation, HC emission for diesel was 49 PPM. Whereas for PME blends, they were observed to be 59 PPM is maximum, 58 PPM and 58 PPM for PME20, PME40 and PME60 respectively.

NOx Emission

Figure 11 shows the NOx Emission variation with percentage full load brake power (%FLBP) neat PME in comparison with diesel. Under 100% load operation, NOx emission for diesel was1410 PPM maximum. Whereas for PME blends, they were observed to be 1338 PPM, 1391 PPM and 1375 PPM for PME20, PME40 and PME60 respectively.

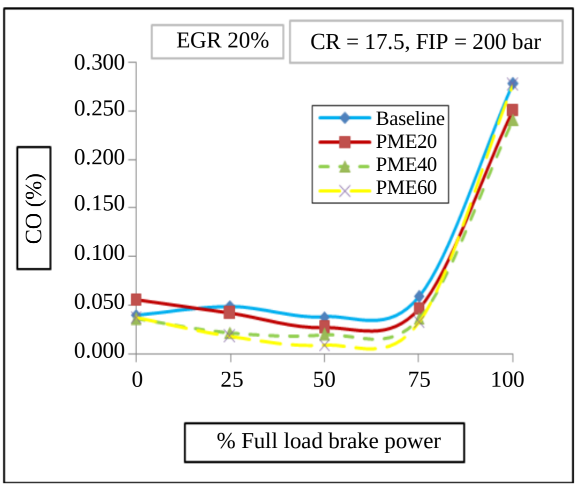

Fig. 9: CO Emission Vs %FLBP of the engine

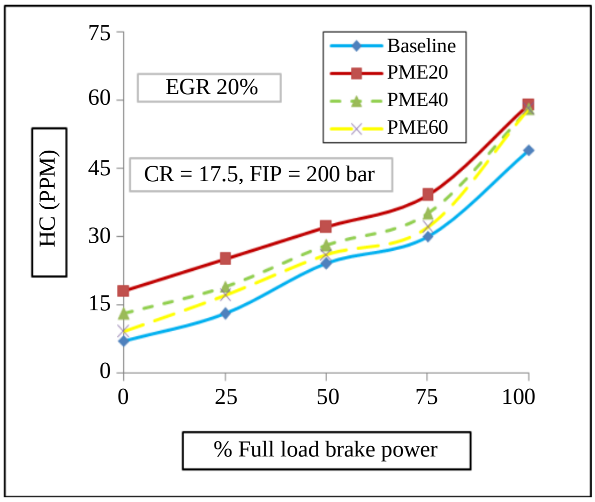

Fig. 10: HC Emission Vs %FLBP of the engine

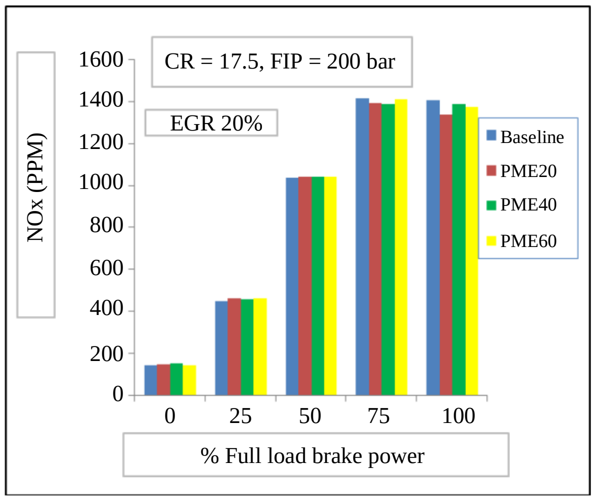

Fig. 11: NOx Emission Vs %FLBP of the engine

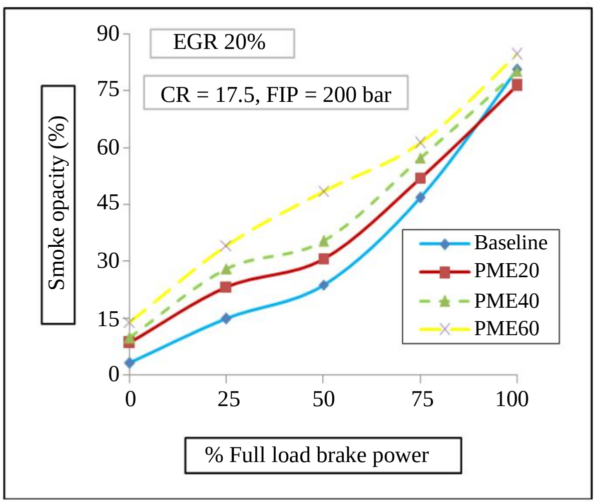

Fig. 12: Smoke Opacity Vs %FLBP of the engine

Smoke Opacity

Figure 12 depicts variation of Smoke-Opacity and %FLBP for PME in comparison with diesel. Under 100% load operation, Smoke Opacity for diesel is 80.6% maximum. For PME blends, observed to be 76.4, 80.3 and 84.6% for PME20, PME40 and PME60 respectively.

Conclusion

From the above investigation the utilization of diesel and pongamia blends as replacement fuel for CI engine, the subsequent specific outcomes are drawn.

At 100%-load condition Minute reduction in BTE of PME blends when compared to diesel. For PME20 PME40and PME60 BTE is very close to diesel throughout the engine operation.

All PME blends BSFC increases slightly contrast to diesel-oil throughout the test-rig operation.

Decrease in Air/Fuel ratio observed for all PME blends throughout the engine operation compared to base line.

The VE was comparatively low for all PME blends compared to base line at peak load. Whereas VE comparatively high for all PME blends compared to base line at low load.

The exhaust gas temperature remains almost same for all PME blends throughout the engine operation compared to base line. But slightly increased for PME60 blend under more load.

The ME increased for all PME mixtures throughout the engine operation compared to base line.

Percentage-CO was reduced for every PME combinations mixtures throughout the engine operation.

The quantity of HC was reduced with rise in concentration of PME. Compared to diesel little increase of HC for different PME mixtures throughout the engine operation.

Under all loads there exists absolute decrease in NOx emission for every PME combinations.

The %smoke-opacity was almost similar at peak load for PME60. But very little rise in %smoke-opacity throughout the engine operation for all PME blends.

From the above conclusions it is clear that PME60 has similar or significant impact on performance and emission parameters compared with baseline.

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Authors Contributions

Abdullah Al-Ghafis: Experimental data collection, plotting the graphs, collecting the literature reviews journal papers and final proof reading. Response to reviewers comments.

M Shameer Basha: Writing manuscript as per the format.

Ethics

This script is unique and includes private matter. Authors states that no ethical concerns may occur after publication of document.

References

Arul Nicholas, T., Venkatakrishna, A., Joy, N., & Mariadhas, A. (2019). Performance and emission analysis on diesel engine fuelled with neat pongamia biodiesel. International Journal of Ambient Energy, 1-7.

Banashankari Nimbaland & Navindgi, M. C. (2018). Experimental Investigation of Methods to Improve Performance of DI Engine using Pongamia Biodiesel by Varying Parameters. Int. Research J of Eng. and Tech., Volume: 05 Issue: 05.

Delprete, C., & Razavykia, A., (2017). Piston ring–liner lubrication and tribological performance evaluation: A review. J Eng. Tribology.

Delprete, C., & Razavykia, A., (2018). Piston dynamics, lubrication and tribological performance evaluation: A review. Int. J of Engine Research.

Delprete, C., Razavykia, A., & Baldissera, P. (2019). Detailed analysis of piston secondary motion and tribological performance. International Journal of Engine Research, 1468087419833883.

Dubey, A., Ansari, N. A., Kumar, G., Arora, A., & Sharma, A. (2019, November). A Review on Performance and Emission of CI Engine using Exhaust gas recirculation (EGR). In IOP Conference Series: Materials Science and Engineering (Vol. 691, No. 1, p. 012028). IOP Publishing.

Holman, J., (2002). Heat Transfer, 9th edition, McGrawHill, New York.

Hussain, J., Palaniradja, K., Alagumurthi, N., & Manimaran, R. (2012). Retracted: effect of exhaust gas recirculation (EGR) on performance and emission characteristics of a three cylinder direct injection compression ignition engine.

Kumar, M. V., Babu, A. V., Kumar, P. R., & Reddy, S. S. (2018). Experimental investigation of the combustion characteristics of Mahua oil biodiesel-diesel blend using a DI diesel engine modified with EGR and nozzle hole orifice diameter. Biofuel Res. J, 5(3), 863-871.

Manieniyan, V., & Sivaprakasam, S. (2013). Experimental analysis of exhaust gas recirculation on DI diesel engine operating with biodiesel. International Journal of Engineering and Technology, 3(2), 129-135.

Modi, A. J., Gosai, D. C., & Solanki, C. M. (2018). Experimental Study of Effect of EGR Rates on NO x and Smoke Emission of LHR Diesel Engine Fueled with Blends of Diesel and Neem Biodiesel. Journal of The Institution of Engineers (India): Series C, 99(2), 181-195.

Ramakrishna, R. E., Keerthana, B. V. S., Dhana Raju, V., & Sai Mahith, A., (2020). Mitigation of NO_X emissions with application of exhaust gas recirculation on diesel engine fuelled with diesel-corn seed oil biodiesel blend. Int. J. of Ambient Energy.

Rao, K. S., Mutyalu, K. B., & Ramakrishna, A. (2015). Effect of exhaust gas recirculation on performance and emission characteristics of diesel engine fueled with waste cooking oil methyl ester. ARPN Journal of Engineering and Applied Sciences, 10(11), 4799-4804.

Saravanan, P., Kumar, N. M., Ettappan, M., Dhanagopal, R., & Vishnupriyan, J. (2020). Effect of exhaust gas re-circulation on performance, emission and combustion characteristics of ethanol-fueled diesel engine. Case Studies in Thermal Engineering, 100643.

Semakula, M., & Inambao, F. (2017). The Effects of Exhaust Gas Recirculation on the Performance and Emission Characteristics of a Diesel Engine–A Critical Review. International Journal of Applied Engineering Research, 12(23), 13677-13689.

Vamsi Krishna, K., Sastry, G. R. K., Krishna, M. V. S., & Jibitesh Kumar, P. (2018). Performance and Emission analysis of optimal DEE blended Pongamia pinnata L. biodiesel fuelled to EGR coupled Low Heat Rejection (LHR) Diesel Engine. MSandE, 377(1), 012164.

Nomenclature

Notation	*Description*
B0	Baseline/Neat diesel
PME20/B20	20% blend of biodiesel
PME40/B40	40% blend of biodiesel
PME60/B60	60% blend of biodiesel
B100	100% Pongamia methyl ester
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
CI	Compression Ignition
CO	Carbon monoxide
CO_2	Carbon dioxide
CR	Compression ratio
DICI	Direct injection compression ignition
EGR	Exhaust gas recirculation
EGT	Exhaust gas temperature
FIP	Fuel injection pressure
FLBP	Full load brake power
HC	Hydrocarbons
H_20	Water
IC	Internal Combustion
LPH	Liter Per Hour
ME	Mechanical efficiency
NOx	Oxides of nitrogen
PM	Particulate matter
PME	Pongamia Methyl Ester
PPM	parts per million
PSI	Pound/Square Inch
VE	Volumetric efficiency
%EGR	Percentage of Exhaust gas recirculation