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Experimental Evaluation of Jatropha Oil Methyl Ester (JOME) and Fish Oil Methyl Ester (FOME) in a Compression Ignition Engine with Exhaust Gas Recirculation

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ABSTRACT

Simultaneous reduction of soot and oxides of nitrogen (NO_x) is a prime requirement for modern day diesel engine to meet the increasingly stringent emission standards. Exhaust gas recirculation (EGR) is one of the most effective techniques for reducing oxides of nitrogen emissions in diesel engine. This study is an attempt to analyse experimentally the performance and emission characteristics of methyl esters of jatropha oil methyl ester (JOME) and fish oil methyl ester (FOME) blends with diesel with and without exhaust gas recirculation on a stationary single cylinder diesel engine. Compared with the diesel fuel, the performance of 20% methyl ester blends and 20% EGR shows a considerable reduction of oxides of nitrogen 6.1 g/kWh for JOME blends and 6.3 g/kWh for FOME blends compared with 7.3 g/kWh for Diesel. Adverse effects are a reduction of brake thermal efficiency 25.6% for FOME blends and 26% for JOME blends compared with 28.4% for diesel, an increase of unburnt hydrocarbons 0.8 g/kWh for JOME and 0.9 g/kWh for FOME compared to 0.7 g/kWh for diesel and carbon monoxide 23.0 g/kWh for JOME and 25.5 g/kWh for FOME compared to 16.8 g/kWh for diesel. Considering both NO_x and soot emissions, 20% EGR is observed to be optimum for both 20% JOME and 20% FOME.

Keywords: Combustion analysis, Emission control, Exhaust gas recirculation, FOME, JOME

INTRODUCTION

Reducing air pollutants and increasing fuel efficiency of Internal Combustion engines are a primary concern for all developing nations. Fast depleting fossil fuel and its impact on the environmental add to the concern. Bio-diesel taken from edible, non-edible oils and animal fats can be used as a fuel in a compression ignition engine with little or no modifications

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(El-Kasaby & Nemit-Allah, 2013; Raj et al., 2010). Hydrocarbons are present in the exhaust gas runs with alternate biofuel blends with diesel (Payri et al., 2009). Researchers conclude oxygenated fuels reduce emissions. Studies also report that nearly 20% of the blends show favourable performance and combustion characteristics when using diesel engine. Higher fatty acid content helps to reduce hydrocarbon emissions. Demirbas analysed the sources of biodiesel and their global projections (Demirbas, 2008).

Bio-fuels are easily available and benefit the environment, economy and consumers. Even though biodiesel offers a reduction in smoke, unburnt hydrocarbon (UBHC) and carbon monoxide (CO) emissions, it produces more nitrogen oxides (NO_x) than the diesel fuel, but it can be reduced by using recirculated exhaust gas (Agarwal et al., 2006). The factors that help in reducing the NO_x emissions are engines which recirculate exhaust gas along with the incoming fuel vapour which decreases oxygen available during combustion which slows down the reaction of the combustion product, so that temperature of the product decreases, which in turn reduces the NO_x (Abd-Alla, 2002) and also the peak combustion temperature is reduced as the heat capacity of vapour and carbon dioxide is higher (Pradhan el al., 2014).

The premixed combustion in an optical diesel engine helps to reduce emissions and improves engine performance (Fang et al., 2009). The results show heat release rate is dominated by this combustion pattern and the injection timing is retarded. There is a delay in the peak heat with increased biodiesel percentage. The fuel particles stick on the engine cylinder walls which is found during the all the test conditions. Recirculated exhaust gas reduces the NO_x emission considerably with biodiesel blends with diesel in a direct injection diesel engine (Ruijun et al., 2009). The percentage increase in recirculated exhaust gas results in longer ignition delay and the combustion is delayed e while the duration of the combustion is reduced. The NO_x emissions are reduced with recirculated exhaust gas but increases with other omissions. The soot emissions increase sharply while using recirculated exhaust gas but NO_x emission decreases considerably (Bhaskar et al., 2013) .

The air-fuel ratio affects exhaust emission due to oxygen availability which affects the exhaust emissions (Murali Manohar et al., 2012; Heffel, 2003). The recirculated exhaust gases increase specific heat and decrease the flame temperature thus, reducing rate of NO_x formation (Abd-Alla, 2002). The recirculated exhaust engines emit a lower quantity of exhaust gases compared with non-EGR engines (Hountalas et al., 2008). At low loads, EGR reduces hydrocarbon emission and at the same time improves brake thermal efficiency (Talibi et al., 2017). The EGR is also used to increase fuel efficiency (Bai et al., 2010; Galloni et al., 2014). However, the use of EGR leads to an increase in soot emissions and emits unburned hydrocarbons (20-30%) compared with conventional engines (Ladommatos, et al., 2000). Therefore, in this work 20% EGR is used to study the performance with jatropha oil methyl ester (JOME) blend with diesel.

MATERIALS AND METHODS

Jatropha Oil Methyl Ester (JOME)

Jatropha oil methyl esters are well-proven alternatives to petroleum diesel. The main reasons for choosing jatropha oil in this work are its environmental friendly nature, cost-effective, the plants are easy to cultivate and need very little water, grow in all climatic conditions and soils, has high yields, and they have 50-year lifespan (Axelsson et al., 2012). Additionally, Jatropha oil can be used as a substitute for petroleum diesel to reduce the cost of importing petroleum products. The jatropha oil is extracted and refined through transesterification process.

The transesterification process is based on the chemical reaction of a triglyceride with alcohol in the presence of a catalyst potassium hydroxide, producing biodiesel and glycerine. Castor, palm, sunflower, pea nut and soybean oils can be used as biodiesel sources, but all these are used for cooking purposes. Hence, instead of using edible oils to produce biodiesel, non-edible oils can be used for the same. Low cost renewable raw material is a very important requirement for economical production of biodiesel.

Among the vegetable oils, jatropha oil has very good properties. It is non-edible oil and has comparatively higher calorific value and cetane rate. Based on literature review, it is the best substitute for fossil fuel.

Fish Oil Methyl Ester (FOME)

Biodiesel produced from fish oil is very effective and a cheaper alternative to diesel. Fish oil is produced from large quantities of tissue waste, such as the viscera, fins, eyes, and tails. These discarded tissue wastes, and by-products can be converted to bio-diesel at a low cost. India has a long coastline with excellent potential for marine fishing. Biodiesel-based fish oil is easy to produce and provides cleaner-burning fuel. Biodiesel and blended diesel, (Petroleum-based diesel mixed with biodiesel), could potentially replace or reduce petroleum-based diesel fuel requirement of the country. Even though biodiesel produces less smoke, UBHC and CO emission and NO_x emissions are higher which can be reduced by using exhaust gas recirculation (EGR).

Fish oil methyl ester has long carbon chain fatty acids to optimise the combustion process and reduces emissions efficiently. The by-product obtained from this transesterification process is glycerine which is used for pharmaceutical and cosmetic purposes. Biodiesel obtained from the trans-esterification of fats and oils is a possible fuel for diesel engines. Transesterification is a chemical process of transforming large triglyceride molecules into smaller, straight chain molecules which are similar to the molecules present in diesel fuel (Leung et al., 2010). The process takes place by reacting to the vegetable oil with an alcohol in the presence of a catalyst. Most modern diesel engines have direct injection fuel systems which are more sensitive to fuel spray quality than indirect injection engines and they require a fuel with properties that are closer to diesel fuel. The fuel properties of biodiesel from FOME, JOME and Diesel fuel are shown in Table 1. The composition of fatty acids in JOME and FOME is given in Table 2.

Table 1
Fuel properties of biodiesel from FOME, JOME and diesel fuel

Fuel Property	Unit	Source	Diesel	Limits as per IS 15607-2005 ASTM D6751	JOME	FOME
Density at 15°C	kg/m^3	Measured	830	860-900	882	890
Kinematic Viscosity at 40°C	cSt	Measured	3.52	1.9-6.0	4.5	5.2
Flash Point	°C	Measured	54	120 min	160	157
Calculated Cetane Index	-	Measured	50	-	54	52.5
Calorific Value	MJ/kg	Measured	43.5	-	39.64	38.65
Element O	wt. %	Given by Supplier	-	-	10.8	8.1

Table 2
Comparison of fatty acid composition (wt %) of fish oil methyl esters and jatropha oil methyl esters

Types of Fatty Acids	Chemical Structure	Type	JOME*	FOME*
Myristic Acid	C14:0	S	0.70	4.98
Palmitic Acid	C16:0	S	15.30	19.42
Palmitoleic Acid	C16:1	US	-	6.43
Heptadecanoic Acid	C17:0	S	-	1.74
Stearic Acid	C18:0	S	9.60	3.80
Oleic Acid	C18:1	US	40.60	20.22
Linoleic Acid	C18:2	US	33.40	3.20
Linolenic Acid	C18:3	US	0.30	1.20
Arachidic Acid	C20:0	S	-	3.56
Eicosadienoic Acid	C20:2	US	-	0.45
Eicosatetraenoic Acid	C20:4	US	-	2.20
Eicosapentaenoic Acid	C20:5	US	-	7.80
Behenic Acid	C22:0	S	-	1.25
Docosapentaenoic Acid	C22:5	US	-	3.25
Docosahexa-Enoic Acid	C22:6	US	-	18.25
Saturated Fatty Acids (S)	C14-C18		25.60	33.37
Unsaturated Fatty Acids (US)	C18:1,2,3		74.30	24.62
Long Carbon-chain Fatty Acid	C20-C22		-	36.76

* provided by the supplier

Fatty acid composition of FOME used in the present work is comparable with that of FOME used by other researchers Wisniewski et al., 2010; (Lin and Li, 2009; Preto et al., 2008). Table 2 shows that fatty acids in FOME are composed of long-chain hydrocarbons ranging from C:20 to C:22. Such long-chain hydrocarbons are generally not found (or found only in traces) in biodiesel derived from edible and non-edible oils. There are no long-chain hydrocarbons ranging from C:20 to C:22 in JOME.

It is also observed that 25.6% of JOME and 33.37% of FOME comprises saturated fatty acid methyl esters. Another key point is the presence of high content of poly-unsaturated fatty acid in FOME with more than three double bonds which are not present in JOME. The presence of high amount of unsaturated fatty acid in FOME leads to low oxidation stability. Therefore, after preparation, FOME must be utilised as quickly as possible to avoid precipitation in fuel injector and fuel injection pump. Present experimental work is confined to analysing performance, emission, and combustion characteristics with Jatropha Oil Methyl Esters blend with diesel in a compression ignition direct injection (CIDI) engine. The effects on performance, emission and combustion are analysed in depth. The tests are conducted on a single cylinder diesel engine coupled with an electrical dynamometer. Standard smoke meter and the gas analyser is used to measure HC, CO, and NO_x values.

RESULTS AND DISCUSSION

An optimum percentage of methyl esters in the blend is necessary as simultaneous reduction of soot and NO_x is desirable. The variation of soot and NO_x values normalised with respect to baseline diesel operation at rated power output for various percentages of JOME and FOME in the blends shows that 20% blends are observed to be optimum considering both NO_x and soot emissions (Reitz et al., 2015; Bhaskar et al., 2017). The brake thermal efficiency of 20% JOME and 20% FOME is marginally lower than that of diesel (Elsanusi et al., 2017). It can be observed that CO, HC and soot emissions are lower while NO_x emissions are higher for 20% methyl ester blends compared with diesel (Sassykova et al., 2017). From the previous experimental results and from literature survey, it is concluded that 20% JOME and 20% FOME can be successfully used in existing diesel engines without any modifications (Dias et al., 2013). 20% JOME and 20% FOME are observed to be optimum for CI engines from the results of investigations carried out but they exhibit higher NO_x emissions compared with diesel fuel. Simultaneous reduction of soot and NO_x is a prime requirement for modern day diesel engines to meet the increasingly stringent emission standards. Three important factors which lead to the formation of NO_x in diesel engines are high temperature, availability of oxygen and residence time for the reaction to complete. As observed from the literature, recirculated exhaust gas is the most effective method to reduce the NO_x emissions (Labecki & Ganippa, 2012), as it reduces the in-cylinder temperatures and availability of oxygen. The recirculated exhaust gas reduces the oxygen concentration of the intake mixture (Verhelst et al., 2009). It also lowers the peak combustion temperature and reduces the NO_x emission. In the present work, part of the exhaust gases from the engine exhaust is cooled down to 30°C and admitted along with the intake air in the manifold. Cooled EGR was used throughout the experimental investigation. At high percentages of EGR, high levels of UBHC, CO and soot emissions are observed in the exhaust. The EGR rate is calculated based on carbon dioxide (CO_2) in the intake charge and exhaust gas and the ratio is limited to 0.3. The results are compared with those of diesel without EGR.

Experiments are conducted with 10%, 20% and 30% EGR for 20% blends of JOME and FOME. The optimum EGR rate is decided considering the variation of NO_x and soot emissions at various EGR rates for both the methyl ester blends. Figure 1 and 2 show the trade-off between NO_x and soot emissions with various percentages of EGR for 20% JOME and 20% FOME at rated power output. Since the units of NO_x and soot density are different, normalised values of NO_x and smoke are indicated. It can be observed that approximately 20% EGR gives the optimum NO_x and soot emission for both 20% JOME and 20% FOME. Hence, further results are presented only for 20% EGR for both the blends of JOME and FOME.

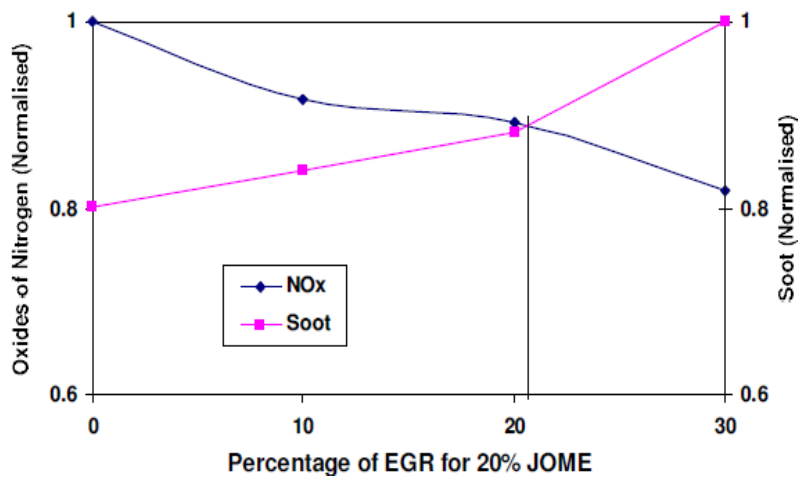

Figure 1. Trade-off between oxides of nitrogen and soot emissions for 20% JOME for various EGR percentages

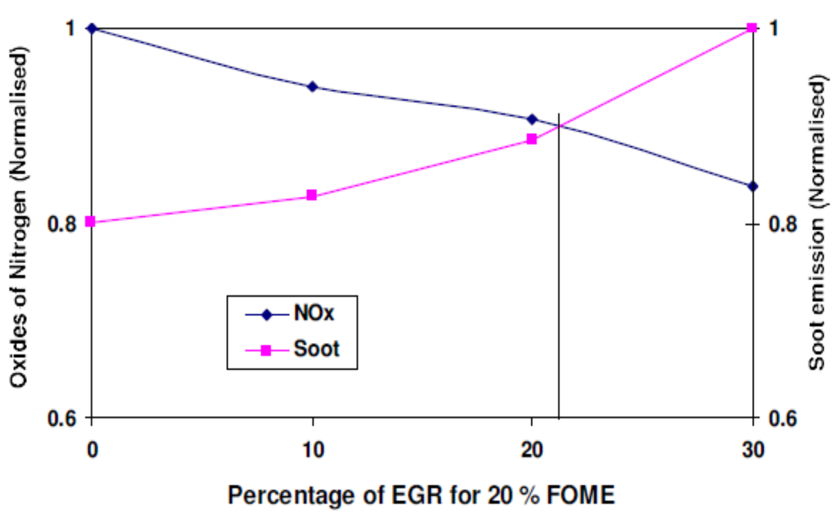

Figure 2. Trade-off between oxides of nitrogen and soot emissions for 20% FOME for various EGR percentages

Heat Release Rate

Figure 3 and Figure 4 show the variation of heat release rate with crank angle at rated power for 20% methyl esters with and without EGR. With EGR, the oxygen available for combustion is reduced which retards the start of combustion and decreases the peak heat release rate. This may lower the peak combustion temperature and decrease NO_x emission with EGR. The figure shows that at rated power output, the peak heat release rate decreases from 66.5 J/°CA for 20% JOME without EGR to 58.7 J/°CA with 20% EGR while it is 77.5 J/°CA in diesel. It is observed that the heat release rate after TDC is higher when the exhaust gas is re-circulated. In the case of 20% FOME, the peak heat release decreases from 70.5 J/°CA for 20% FOME without EGR to 65.8 J/°CA with 20% EGR at rated power output.

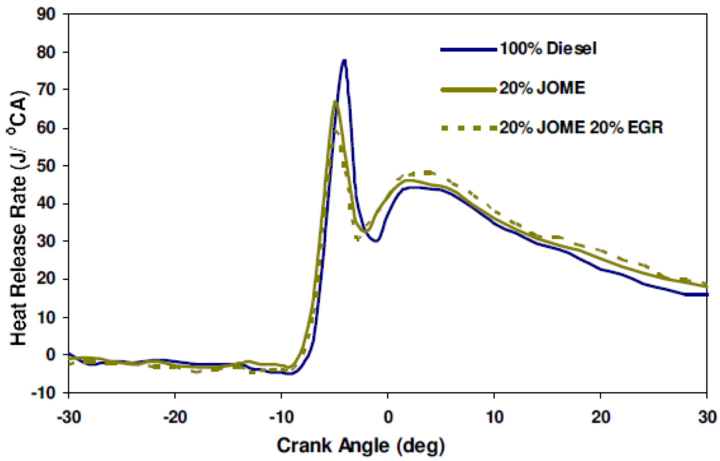

Figure 3. Variation of heat release rate with crank angle at rated power output for JOME with and without 20% EGR

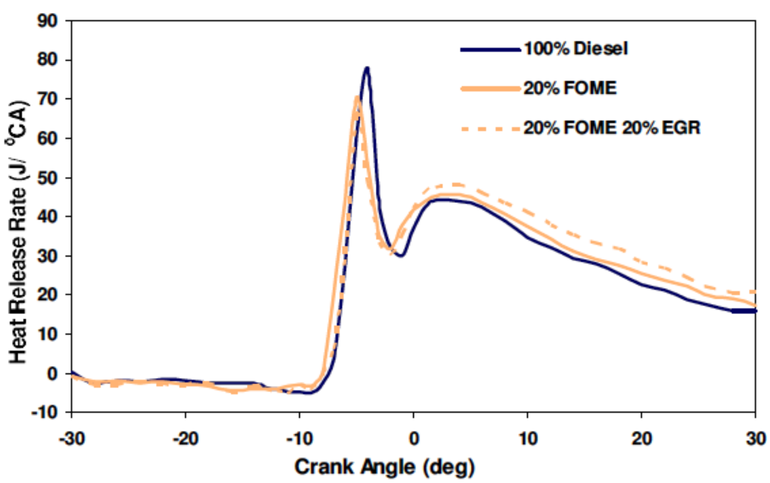

Figure 4. Variation of heat release rate with crank angle at rated power output for FOME with and without 20% EGR

Pressure-Crank Angle Diagram

Figure 5 and Figure 6 show the variation of in-cylinder pressure with crank angle at rated power output for 20% methyl esters respectively with 20% EGR and without EGR. With EGR, the oxygen availability is reduced, and the start of combustion is delayed. It is observed that with EGR, the in-cylinder pressure is marginally low before the occurrence of peak pressure compared to that without EGR for both the methyl esters. The exhaust gas reused increases the heat capacity of the charge in the cylinder and reduces pressure and temperature. It is also observed that in-cylinder pressure with EGR is higher over the entire range of operation.

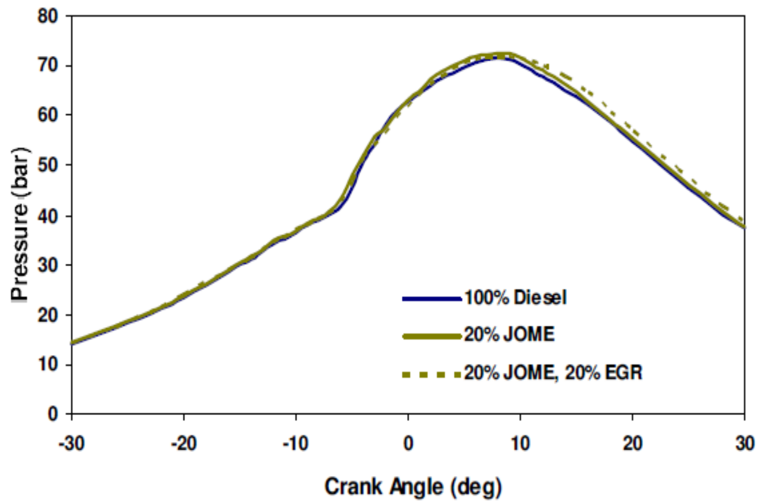

Figure 5. Variation of In-cylinder pressure with crank angle at rated power output for JOME and diesel blend with and without 20% EGR

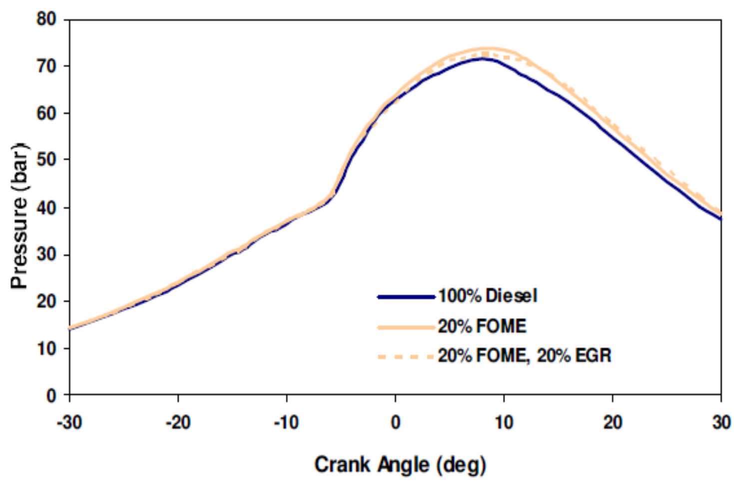

Figure 6. Variation of In-cylinder pressure with crank angle at rated power output for FOME and diesel blend with and without 20% EGR

The variation of performance and combustion characteristics of 20% methyl esters compared with diesel without EGR and with 10, 20 and 30% EGR at rated power output is shown in Figures 7 and Figure 8. As EGR increases, the brake thermal efficiency and exhaust gas temperature decrease. The effect is more pronounced at higher EGR rates. It is observed that ignition delay increases, and peak pressure decrease with increase in EGR for 20% methyl esters. The figure shows the variation of emission of 20% methyl esters with and without EGR compared with diesel at rated power output. NO_x emissions are higher for 20% JOME and 20% FOME blend without EGR. As methyl esters are oxygenated fuels, they have higher combustion temperature and NO_x emission. Experiments were conducted with 10, 20 and 30% EGR and the investigations show that with EGR, NO_x emission is reduced but UBHC, CO and soot emissions increase. For both the methyl esters up to 20% EGR, UBHC and CO emissions are lower compared with diesel. Further increase in EGR increases the UBHC and CO emissions

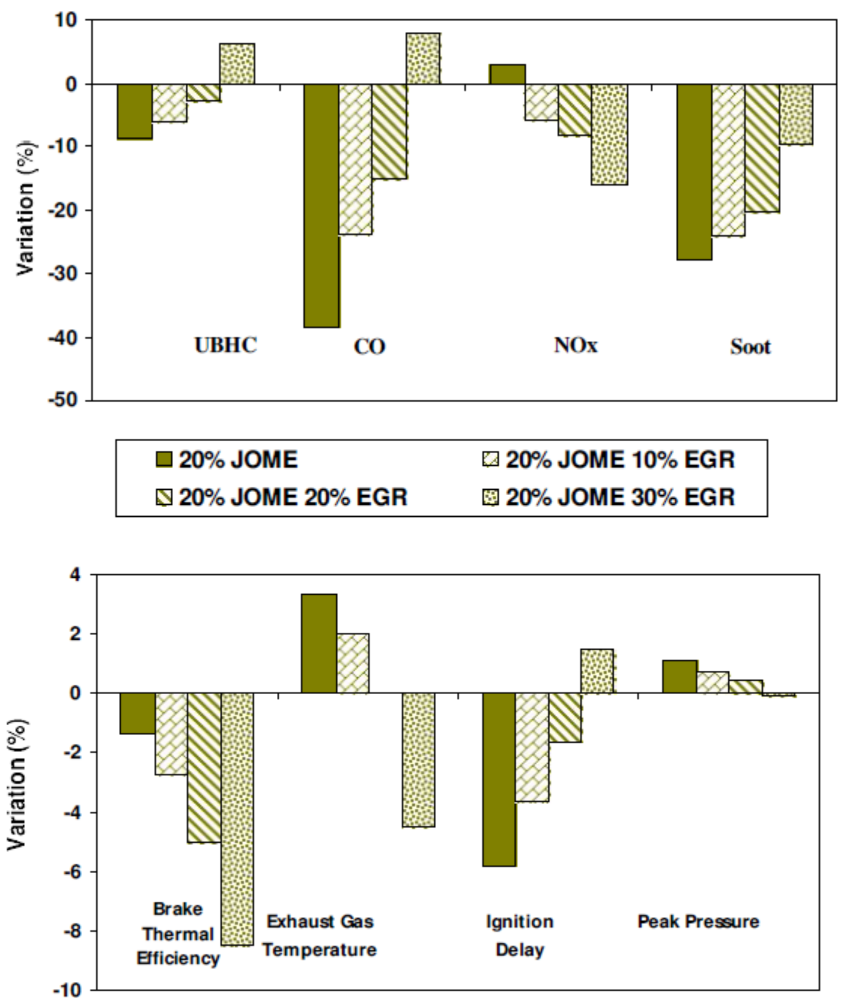

Figure 7. Variation of performance and combustion characteristics of 20% JOME compared to diesel without EGR and with 10,20 and 30% EGR at rated power output

significantly. Thus, it can be concluded that 20% EGR is optimum considering the emissions from both the methyl esters. The following are the summary of investigations carried out to study the effect of EGR with 20% JOME and 20% FOME blends in CIDI combustion mode:

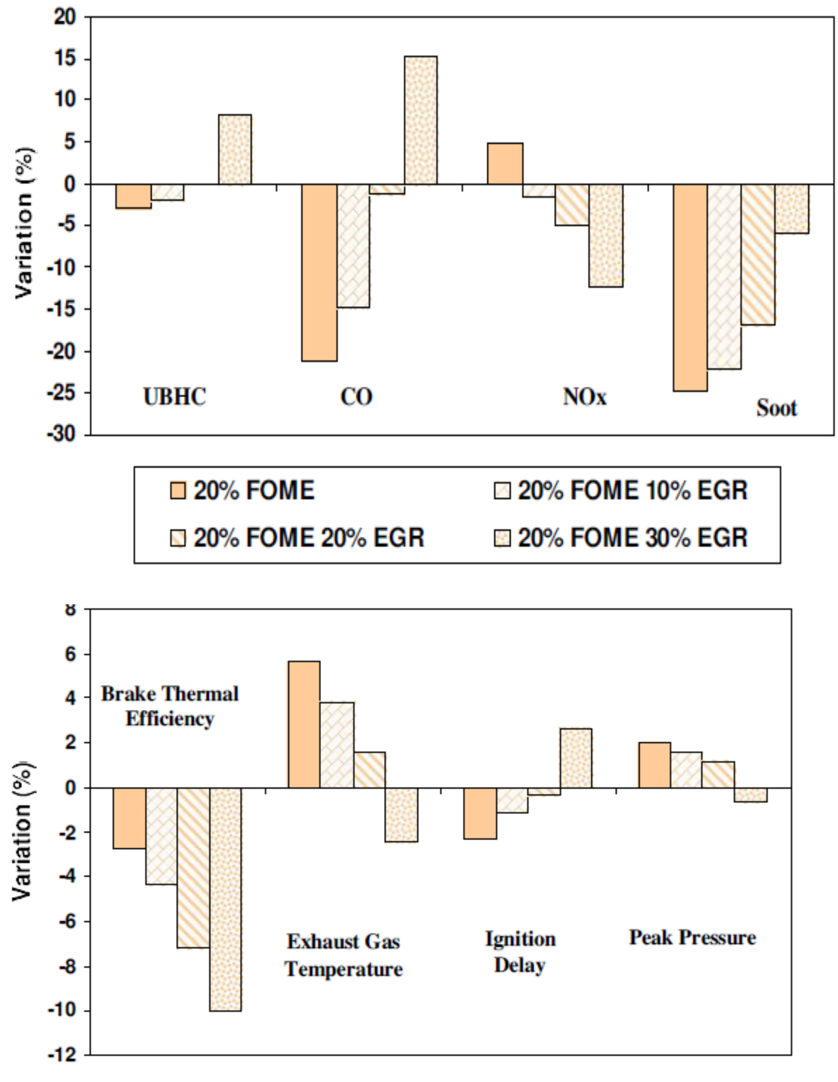

Figure 8. Variation of performance and combustion characteristics of 20% FOME compared to diesel without EGR and with 10,20 and 30% EGR at rated power output

Brake Thermal Efficiency

At rated power output, brake thermal efficiency decreased from 28.0% to 26.0% for 20% JOME when EGR flow rate varied between 0 and 30% while the variation was from 27.7% to 25.6% for 20% FOME compared with 28.4% for diesel.

Exhaust Gas Temperature

At rated power output, the exhaust gas temperature without EGR is 460°C for 20% JOME and 470°C for 20% FOME. With 20% EGR, the exhaust gas temperature is 445°C for 20% JOME and 450°C for 20% FOME whereas in the case of diesel, exhaust gas temperature is 445°C. The exhaust gas temperature in the case of 20% JOME with 20% EGR is almost equal to that of diesel. The percentage variation in exhaust gas temperature is zero hence, it is not shown in the figure.

Unburnt Hydrocarbon Emissions

At rated power output, the UBHC emission varied between 0.7 and 0.8 g/kWh for 20% JOME when EGR is varied between 0 and 30% while the variation is from 0.7 to 0.9 g/kWh for 20% FOME compared with 0.7 g/kWh for diesel. 20% FOME with EGR shows higher UBHC emissions at all the power outputs compared with 20% JOME with EGR due to its lower percentage of oxygen and higher percentage of longer chain fatty acid components present in it.

Carbon Monoxide Emissions

CO emissions at rated power output for various EGR flow rates varied from 10.3 to 23.0 g/kWh for 20% JOME while they vary from 13.2 to 25.5 g/kWh for 20% FOME compared to 16.8 g/kWh for diesel. Higher CO in the case of FOME may be due to lower intrinsic oxygen available for combustion compared with JOME.

Oxides of Nitrogen Emissions

At rated power output, the NO_x emissions without EGR and with 10,20 and 30% EGR vary from 7.5 to 6.1 g/kWh for JOME while it varied between 7.6 and 6.4 g/kWh for 20 FOME compared with 7.3 g/kWh for diesel. Higher heat capacity of the mixture requires more energy, and lowers the flame temperature which reduces the NO_x emissions at rated power output.

Soot Emissions

At rated power output, the soot emissions with no EGR, 10, 20 and 30% EGR varied between 120 and 150 mg/m^3 for 20% JOME while the soot emissions varied between 125 and 156 mg/m^3 for 20% FOME compared with 166 mg/m^3 for diesel.

Ignition Delay and Peak Pressure

At rated power output, the ignition delay period increases as the percentage of EGR increases. Peak pressure is marginally lower with EGR for both the methyl esters at rated power output compared to without EGR.

The UBHC, CO and soot emissions increase as the percentage of EGR increases. With EGR, NO_x emissions are significantly lowered for both the methyl esters, Increasing the percentage of EGR decreases NO_x emissions significantly. Considering both NO_x and soot emissions, 20% EGR is observed to be optimum for both 20% JOME and 20% FOME.

CONCLUSION

Based on the results obtained from the above, the following conclusion may be drawn.

The brake thermal efficiency decreases marginally with 20% methyl esters with EGR. As the percentage of EGR increases, the brake thermal efficiency decreases further. The exhaust gas temperature decreases marginally with 20% methyl esters with EGR. The exhaust gas temperature with 20% JOME and 20% EGR equals to that of Diesel. The ignition delay increases as the percentage of EGR increases compared to that without EGR in diesel. Peak pressure is marginally lower with EGR for both the methyl esters at rated power output compared with without EGR. The UBHC, CO and Soot emissions increase as the percentage of EGR increases. With EGR, NO_x emissions are significantly lowered for both the methyl ester. Increasing the percentage of EGR decreases NO_x emissions significantly. Considering both NO_x and soot emissions, 20% EGR is observed to be optimum for both 20% JOME and 20% FOME.

RECOMMENDATIONS

The cost per hour of operation at rated power output for Diesel, 20% JOME with 20% EGR and 20% FOME with 20% EGR are US$1.30, US$1.60 and US$1.50 respectively. For 20% FOME, the cost is marginally lower than that of 20% JOME. Use of 20% FOME is recommended for use in coastal areas where it is easily available and 20% JOME is recommended for rural areas where it can be cultivated.

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REFERENCES

Abd-Alla, G. H. (2002). Using exhaust gas recirculation in internal combustion engines: A review. *Energy Conversion and Management, 43*(8), 1027–1042.

Agarwal, D., Sinha, S., & Agarwal, A. K. (2006). Experimental investigation of control of NO_x emissions in biodiesel-fueled compression ignition engine. *Renewable Energy, 31*(14), 2356–2369.

Axelsson, L., Franzén, M., Ostwald, M., Berndes, G., Lakshmi, G., & Ravindranath, N. H. (2012). Perspective: Jatropha cultivation in southern India: Assessing farmers' experiences. *Biofuels, Bioproducts and Biorefining, 6*(3), 246–256.

Bai, Y. L., Wang, Z., & Wang, J. X. (2010). Part-load characteristics of direct injection spark ignition engine using exhaust gas trap. *Applied Energy, 87*(8), 2640–2646.

Bhaskar, K., Sendilvelan, S., Nagarajan, G., & Sampath, S. (2017). Emission characteristics of biodiesel obtained from jatropha seeds and fish wastes in a diesel engine. *Sustainable Environment Research, 27*(6), 283-290.

Das, L. M., & Mathur, R. (1993). Exhaust gas recirculation for No_x control in a multicylinder hydrogen-supplemented S.I. engine. *International Journal of Hydrogen Energy, 18*(12), 1013–1018.

Demirbas, A. (2008). Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. *Energy Conversion and Management, 49*(8), 2106–2116.

Dias, J. M., Araújo, J. M., Costa, J. F., Alvim-Ferraz, M. C. M., & Almeida, M. F. (2013). Biodiesel production from raw castor oil. *Energy, 53*, 58-66.

El-Kasaby, M., & Nemit-Allah, M. A. (2013). Experimental investigations of ignition delay period and performance of a diesel engine operated with Jatropha oil biodiesel. *Alexandria Engineering Journal, 52*(2), 141–149.

Elsanusi, O. A., Mohon R. M., & Sidhu, M. S. (2017). Experimental investigation on a diesel engine fueled by diesel-biodiesel blends and their emulsions at various engine operating conditions. *Applied Energy, 203*, 582-593.

Fang, T., Lin, Y. C., Foong, T. M., & Lee, C. Fon. (2009). Biodiesel combustion in an optical HSDI diesel engine under low load premixed combustion conditions. *Fuel, 88*(11), 2154–2162.

Galloni, E., Fontana, G., & Staccone, S. (2014). Numerical and experimental characterization of knock occurrence in a turbo-charged spark-ignition engine. *Energy Conversion and Management, 85*, 417–424.

Heffel, J. W. (2003). NO_x emission reduction in a hydrogen fueled internal combustion engine at 3000 rpm using exhaust gas recirculation. *International Journal of Hydrogen Energy, 28*(11), 1285–1292.

Hountalas, D. T., Mavropoulos, G. C., & Binder, K. B. (2008). Effect of exhaust gas recirculation (EGR) temperature for various EGR rates on heavy duty DI diesel engine performance and emissions. *Energy, 33*(2), 272–283.

Labecki, L., & Ganippa, L. C. (2012). Effects of injection parameters and EGR on combustion and emission characteristics of rapeseed oil and its blends in diesel engines. *Fuel, 98*, 15–28.

Ladommatos, N., Abdelbalim, S., & Zhao, H. (2000). The effects of exhaust gas recirculation on diesel combustion and emissions. *International Journal of Engine Research, 1*(1), 107-126.

Leung, D. Y. C., Wu, X., & Leung, M. K. H. (2010). A review on biodiesel production using catalyzed transesterification. *Applied Energy, 87*(4), 1083-1095.

Lin, C. Y., & Li, R. J. (2009). Engine performance and emission characteristics of marine fish-oil biodiesel produced from the discarded parts of marine fish. *Fuel Processing Technology, 90*(7–8), 883–888.

Murali Manohar, R., Prabhahar, M., & Sendilvelan, S. (2012). Experimental investigation of combustion and emission characteristics of engine is fueled with diesel and UVOME blends of B20K and B80K. *European Journal of Scientific Research, 76*(3), 327-334.

Payri, F., Bermdez, V. R., Tormos, B., & Linares, W. G. (2009). Hydrocarbon emissions speciation in diesel and biodiesel exhausts. *Atmospheric Environment, 43*(6), 1273–1279.

Pradhan, P., Raheman, H., & Padhee, D. (2014). Combustion and performance of a diesel engine with preheated *Jatropha curcas* oil using waste heat from exhaust gas. *Fuel, 115*, 527–533.

Preto, F., Zhang, F., & Wang, J. (2008). A study on using fish oil as an alternative fuel for conventional combustors. *Fuel, 87*(10–11), 2258–2268.

Raj, C. S., Arul, S., Sendilvelan, S., & Saravanan, C. G. (2010). A comparative assessment on performance and emissions characteristics of a diesel engine fumigating with methanol, methyl ethyl ketone, and liquefied petroleum gas. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 32*(17), 1603-1613.

Reitz, R. D., & Duraisamy, G. (2015). Review of high efficiency and clean reactivity controlled compression ignition (RCCI) combustion in internal combustion engines. *Progress in Energy and Combustion Science, 46*, 12-71.

Ruijun, Z., Xibin, W., Haiyan, M., Zuohua, H., Jing, G., & Deming, J. (2009). Performance and emission characteristics of diesel engines fueled with diesel-dimethoxymethane (DMM) blends. *Energy and Fuels, 23*(1), 286–293.

Sassykova, L., Gil'mundinov, Sh., Nalibayeva, A., & Bogdanova, I. (2017). Catalytic systems on metal block carriers for neutralization of exhaust gases of motor transport. *Revue Roumaine de Chimie, 62*(2), 107-114.

Talibi, M., Hellier, P., & Ladommatos, N. (2017). The effect of varying EGR and intake air boost on hydrogen-diesel co-combustion in CI engines. *International Journal of Hydrogen Energy, 42*(9), 6369-6383.

Verhelst, S., Maesschalck, P., Rombaut, N., & Sierens, R. (2009). Increasing the power output of hydrogen internal combustion engines by means of supercharging and exhaust gas recirculation. *International Journal of Hydrogen Energy, 34*(10), 4406-4412.

Wisniewski, A., Wiggers, V. R., Simionatto, E. L., Meier, H. F., Barros, A. A. C., & Madureira, L. A. S. (2010). Biofuels from waste fish oil pyrolysis: Chemical Composition. *Fuel, 89*(3), 563–568.