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Performance, Emission and Combustion Characteristics of A Diesel Engine Using Grape Seed Oil Methyl Ester-Based Fuels

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Abstract

In this present work, grape seed oil methyl ester (GOME) was tested as diesel fuels in neat and blended forms. The blends were prepared as 25% ,50%,75% and 100% grape seed oil methyl ester separately with standard diesel on a volume basis used as intake charge with 30% Exhaust Gas Recirculation (EGR) and without EGR.. In this investigation carried out single cylinder water cooled diesel engine. The performance, emission and combustion characteristic were determined with and without EGR for all the blends. The reduction in NO_X, HC emissions were observed from GOME and its diesel blend along with the increased CO, smoke density compared to those of standard diesel without and with EGR investigation.

Keywords: Grape seed oil Methyl ester: EGR, Diesel engine performance: Exhaust emissions: Combustion characteristic

Introduction

In the earth, there are several forms of energy sources such as solar power, nuclear power wave energy which results from moon gravitational pull and earth geothermal energy which originates in the world. Current world energy situation is heavily dependent on fossils fuels and coal which a non renewable energy source. These energy sources may deplete in time if proper energy management actions are not taken soon which questions the energy security of the future. The best option to handle this problem is to introduce of renewable energy sources and its increased role in addressing the world energy need [1].

Studies on internal combustion engines have been recently concentrated on alternative fuels. The increases in alternative fuel investigation are caused by two main factors, a rapid decrease in world petroleum reserves and important environmental concerns originating from exhaust emission. Besides these, some other aspects such as demand from local sources, lessening the import of crude oil and creating new employments have been promoted these investigations [2]. Emission from automobiles are currently a dominant source of air pollution representing CO,NO_X, HC,CO_2 emissions are globally added to the green house effect which results in global warming [3]. Several alternative fuels have been tried in order to reduce these emissions.

The above concerns have led to development, by research of a range of alternatives to IC engines. Alternative fuels that can be used with current IC engines. There are various alternative fuels that can be used with little or no modification in present day internal combustion engines. Various fuels have been considered as substitutes for the hydrocarbon based fuel. The alternative fuels that replace the petroleum based fuels are Liquefied Petroleum Gas (LPG); Compress Natural Gas (CNG), hydrogen (H_2); Biogas producer gas and Liquefied Natural Gas (LNG) [4, 5].

The substitution of diesel fuel with produced agricultural sources has important advantages likely the improvement of the CO_2 balance preserving crude oil reserves, opening new markets and capability of biological decomposition [6]. Although vegetable oils have some similar physical fuel properties with diesel fuel in terms of energy density, cetane number, heat of vaporization and stoichiometric air /fuel ratio, the use of neat vegetable oils or its blends as fuel in diesel engine leads to some problems such as poor fuel atomization and low volatility mainly originated from their high viscosity, high molecular weight and density. It is reported that these problems may cause important engine failures such as piston ring sticking injector coking, formation of carbon deposits and rapid deterioration of lubricating oil after the use of vegetable oils for a long period of time [7].

There are different methods used for improving fuel properties and decreasing viscosity and density of oils such as dilution of vegetable oils with solvents, pyrolysis, micro emulsification with alcohols and Transesterification [8-10]. Although most of these methods do not eliminate the problems completely, dilution of oils with solvents and micro emulsions of vegetable oils decreases the viscosity [11, 12]. Furthermore, a study on the animal fat emulsions with ethanol and water as a diesel engine fuel reports that emulsification causes drastic reduction in smoke, NO_X, HC and CO emissions as compared to neat fat and neat diesel fuel [13]. Similarly, it is revealed that emulsification of vegetable oils yield to reduce levels of soot and NO_X emissions [14]. On the other hand, transesterification is a widely applied, convenient and most promising method for reduction of viscosity and density of vegetable oils [15-17]. This method is applied for producing esters by means of a reaction occurred to employ the enhanced reaction rate. At the end of the reaction glycerol, an important by product of transesterification process is formed. A detailed description of the transesterification process can be found in the literature [15, 18]. This exhaust of diesel engines fuelled with neat biodiesel or its blends with diesel fuel have been studied by many investigators. It has been usually reported that there are reduction in carbon monoxide, hydrocarbon and smoke emission while NO_X emissions are increasing exhaust gas recirculation has been examined to reduce NOx emission with biodiesel [19-27]. It has been shown that the oxygen content in biodiesel is the main factor for reducing pollutant emissions and increasing nitrogen oxides as a result of better combustion [28]. On the other hand, It has a slight increase in the fuel consumption compared to diesel fuel [29-32].These changes can be attributed to the lower heating value of biodiesel.

The main objective of this experimental study is to determine the performance and exhaust emissions of a diesel engine. Using grape seed oil methyl ester and its properties were determined. Then this biodiesel was blended with diesel and tested in the diesel engine with and without EGR method. Finally the results for GOME blend were compared with those for diesel fuel.

Production of Grape Seed Oil Methyl Ester

Transesterification is the process of using an alcohol (methanol) in the presence of a catalyst, such as potassium hydroxide to chemically break the molecule of the Grape seed oil in to methyl esters of the grape seed oil with glycerol as by product.

First, the grape seed oil was heated to about 70°C in a reactor. Then , the catalyst was mixed with methyl alcohol to dissolve and added to the heated grape seed oil to the reactor, after the mixture was stirred for 1 hr at a fixed temperature of about 70°C, it was transferred to another container and the separation of the glycerol layer was allowed . Once the glycerol layer was formed in bottom of the vessel, the methyl ester layer formed at the upper part of the container was transferred to another vessel. After that, a washing process was carried out to remove unreached reminder of methanol and catalyst using distilled water and blown air. Then, a distillation process at about 110°C was applied for removing water contained in the esterified grape seed oil. Finally, the produced grape seed oil methyl ester [GOME] was left to cool down. The production process of GOME is presented schematically in Fig .1

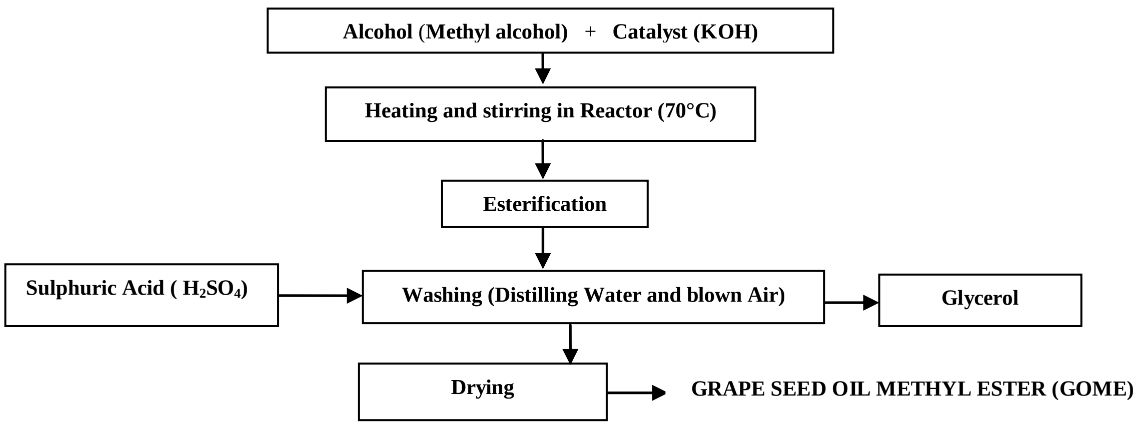

Figure 1: The flow chart of the grape seed oil methyl ester (GOME) production process

Experimental Setup and Test Procedure

The experimental set up consists of one cylinder, four stroke, and DI diesel engine. The schematic outline of the experimental set up is shown in Fig. 2. The specifications of the test engine given in Table 1. The test bed contains instruments for measuring various parameters such as fuel consumption, exhaust emission, combustion characteristic. Experiments were performed with diesel fuel and biodiesel blended up to four different ratios, namely GOME25, GOME50, GOME75, and GOME100.

An eddy current dynamometer was employed for measuring the engine torque. The fuel consumption measurement was performed by a glass burette having a volume of 10 ml and a stopwatch. An U tube manometer with an orifice plate was used for measuring the air flow rate. The exhaust gas temperature was measured by K type thermocouple submerged into the exhaust pipe. The exhaust emissions of carbon monoxide (CO) and Nitrogen oxides [NO_X] were measured by AVL gas analyzer. The test of diesel fuel and blended GOME were performed at various load at constant speed condition. The engine was tested with and without Exhaust Gas Recirculation (EGR).

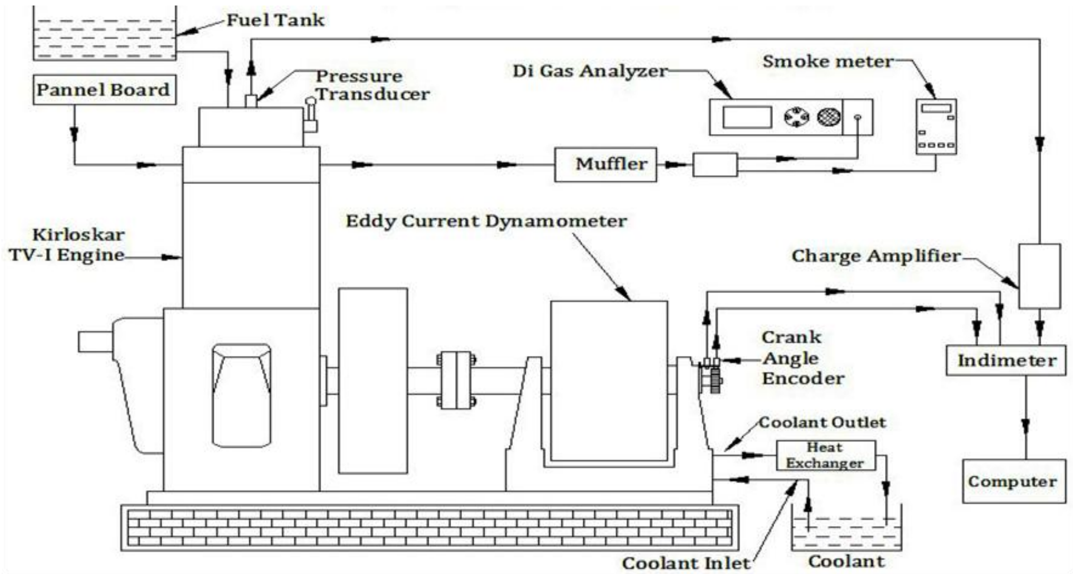

Figure 2: Schematic diagram of the experimental setup

Table 1: Test engine specifications

Type	Four stroke, kirloskar make, compression ignition, direct injection, constant speed, vertical, water cooled
No of cylinders	One
Bore	87.5mm
Stroke	110mm
Compression ratio	17.5:1
Rated power	5.2 kW
Rated speed	1500 rpm
Dynamometer	Eddy current
Start of injection	23°BTDC
Injection pressure	220 bar
Type of injection	Mechanical pump-nozzle injection
No of nozzle holes	3
Lubricating oil	SAE40

Result and Discussion

The fuel properties, Performance, emission and combustion analysis of the GOME based fuels are compared to diesel fuel.

Fuel properties

The properties of GOME blends are comparable to diesel fuel. Although its heating value is lower, density and kinematic viscosity of GOME are higher than those of the diesel fuel. The higher flash point of GOME makes it safe for transportation and storage. The specific gravity and kinematic viscosity of the GOME were determined at 100% GOME and 50% GOME respectively, shown in table 2. As expectedly, the specific gravity and kinematic viscosity of the GOME gradually decrease with adding diesel fuel. It is seen that kinematic viscosity is 4.90 cSt at 100% GOME and decreases gradually to 3.76 cSt at 50% GOME. Additionally, the specific gravity decreases from 0.8816 at 100% GOME to 0.8515 at 50% GOME.

Table 2: The properties of diesel fuel and GOME

Fuel	Diesel Fuel	GOME 100%	GOME 50%
Specific gravity at 15°C	0.84	0.8816	0.8515
Kinematic viscosity at 40°C (cSt)	3.24	4.90	3.76
Lower heating value (kJ/kg)	44,645	42,389	43,599
Flash point (°C)	55	161	87
Fire point (°C)	58	173	92
Density@15C in gm/cc	0.835	0.8808	0.8507
Calculated cetane index	50	55	52
Pour point (°C)	-23	-6	-9

Performance and emission analysis

The variations in the performance of the engine with and without EGR fuelled with GOME blended with diesel 25% 50% 75% and 100% which are indicated by GOME 25% [25% GOME + 75 % Diesel], GOME 50% [50% GOME + 50 % Diesel], GOME 75% [75% GOME + 25 % Diesel], GOME 100% [100% GOME + 0 % Diesel] , respectively.

Brake thermal efficiency

The brake thermal efficiency (BTE) of blended GOME fuels at various loads is without EGR shown in Fig. 4. It is observed from the figure that the BTE of diesel fuel is slightly higher than that of GOME and other GOME blends. The BTE for full load of standard diesel, GOME 25, GOME 50, GOME 75 and GOME 100 are 26.89, 26.59, 26.15, 25.82, and 25.26, respectively. The higher BTE observed in the case of the diesel fuel. The slightly decrease in the BTE for blended fuel may be due to combined effect of its lower heating value and higher viscosity. The BTE of blended GOME fuels at various load with EGR shown in fig. 5. It is observed from the figure use of 30% EGR had a positive effect on engine efficiency at full load compared to without EGR. The BTE was standard Diesel fuel, GOME 25, GOME 50, GOME 75 and GOME 100 compared to without EGR increases 0.23%, 0.39%, 0.57%, 0.76% and 0.63, respectively. Due to presence of EGR, temperature of the intake air was increased which significantly. Encourage the combustion process in positive direction. This explains the increases of BTE in case of EGR.

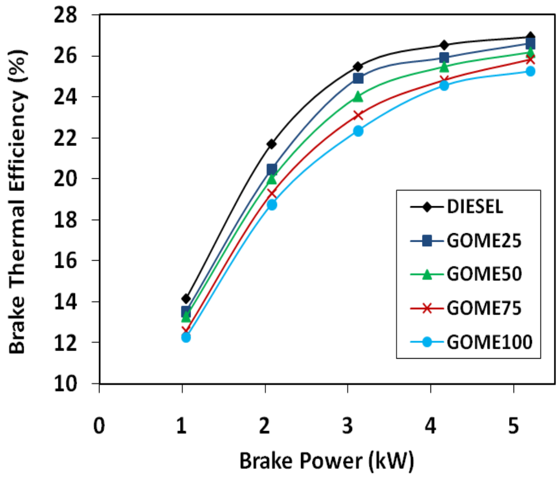

Figure 4: BP v/s BTE without EGR

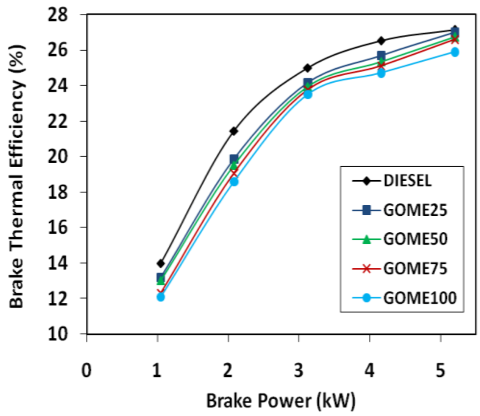

Figure 5: BP v/s BTE with 30% EGR

Brake specific fuel consumption

Fig. 6 shows the variation of brake specific fuel consumption with load for neat diesel and blended GOME. It was observed that BSFC [kg/kWh] without EGR was standard diesel fuel, GOME 50 and GOME 100 are 0.27, 0.29 and 0.33, respectively. Fig. 7 shows the variation of BSFC with load for neat diesel and blended GOME fuel with EGR. It was observed that BSFC [kg/kWh] decreases with the increase in brake power. This trend was maintained in all cases where as the BSFC of neat diesel, GOME 50 and GOME 100 are 0.26, 0.28 and 0.29 with 30% EGR, respectively at full load. But BSFC in case of with EGR was less compared to that of without EGR. This was due to better mixing of GOME with air resulting in complete combustion of fuel. When EGR was applied BSFC decreased and increased with GOME.

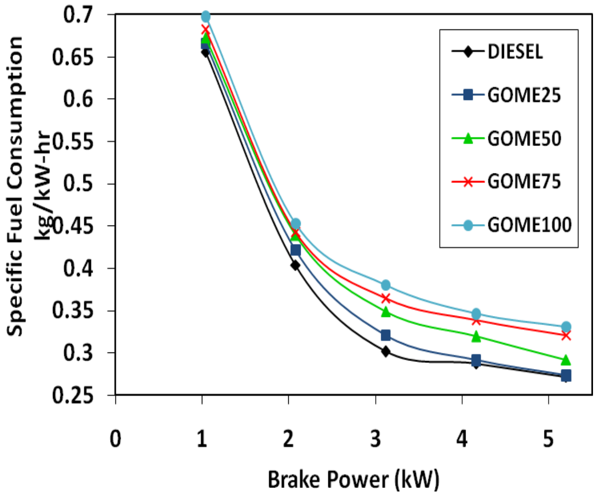

Figure 6: BP v/s SFC without EGR

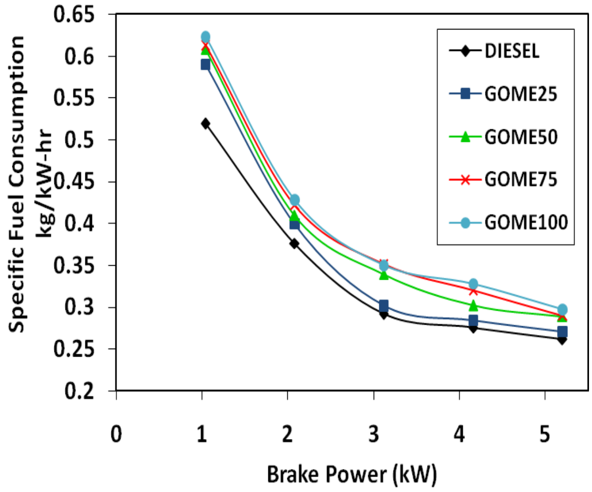

Figure 7: BP v/s SFC with 30% EGR

Hydrocarbon

Fig. 8 shows the variation of hydrocarbon (HC) with load for neat diesel and blended GOME without EGR. It could be observed that HC emission for GOME 100 was 90.3 ppm whereas that for GOME 50 was 94.6 ppm and neat diesel fuels it was 100.5 ppm. The reduction of HC emission in case of increasing the GOME without EGR was due to the absence of carbon in hydrogen. In the case of EGR Fig. 9 shows there was lower excess oxygen available for combustion. The lower excess oxygen concentration results in rich air fuel mixtures at different locations inside the combustion chamber. This heterogeneous mixture does not combust properly and results in higher HC emission formed.

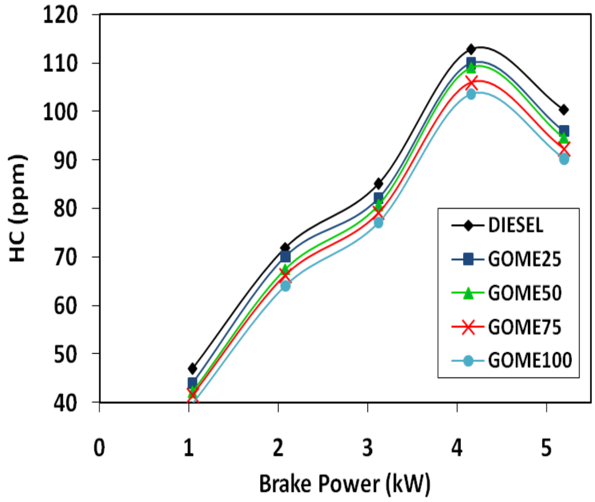

Figure 8: BP v/s Hydrocarbon without EGR

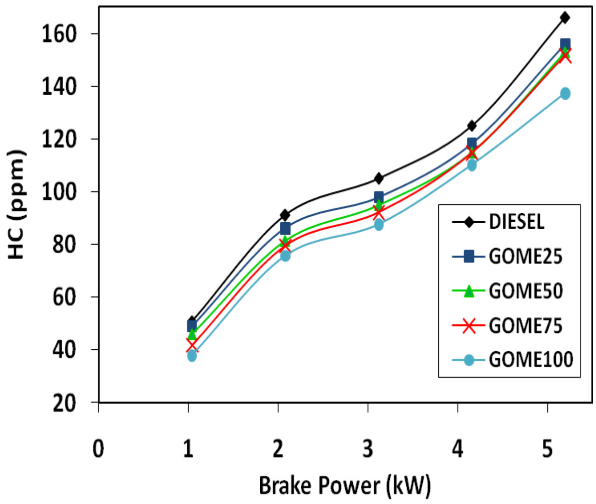

Figure 9: BP v/s Hydrocarbon with 30% EGR

Carbon monoxide

Fig. 10 depicts the variation of carbon monoxide (CO) with loads for neat diesel and blended GOME without EGR at full load CO emission for neat diesel operation was 0.39% by volume, while it was 0.74% by volume with GOME 50 and 1.03% by volume with GOME 100. In the case of with EGR Fig. 11 shows CO emission reduced when compared to without EGR for neat diesel operation, GOME 50 and GOME 100 was 0.19%, 0.31%, 0.69% by volume, respectively. Thus leading to lower CO emissions in comparisons to without EGR. Additionally, with EGR process decreases the viscosity of GOME and improves the oxidation of biodiesel in the cylinder. CO emission obtained GOME operations were lower than those without EGR operations.

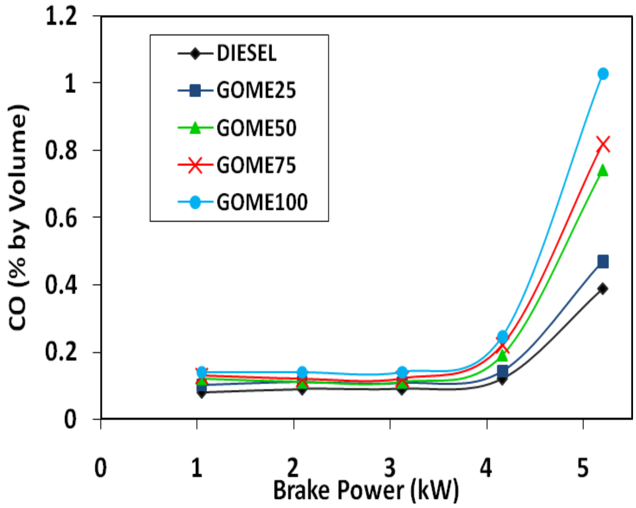

Figure 10: BP v/s CO without EGR

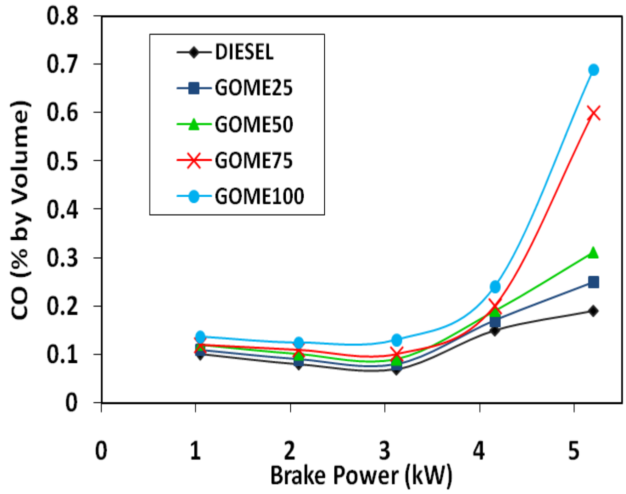

Figure 11: BP v/s CO with 30% EGR

Nitrogen of oxides (NOx)

Fig. 12 shows the percent variation of the NOx emission of the test engine for blended GOME with reference to diesel fuel without EGR. The NOx emission for the diesel fuel was 1118 ppm at full load. It was compared to GOME 50 and GOME 100 were 1015 ppm and 961 ppm, respectively. It seen that the GOME operations usually lower NOx emission at all proportion of GOME diesel blends compared to diesel fuel operations. Fig 13 shows that with EGR diesel fuel operation NOx formation was 573 ppm and that GOME 50 and GOME 100 was 534 ppm and 449 ppm , respectively at full load. So the NOx formation decreased with the use of EGR and increases the blended GOME.

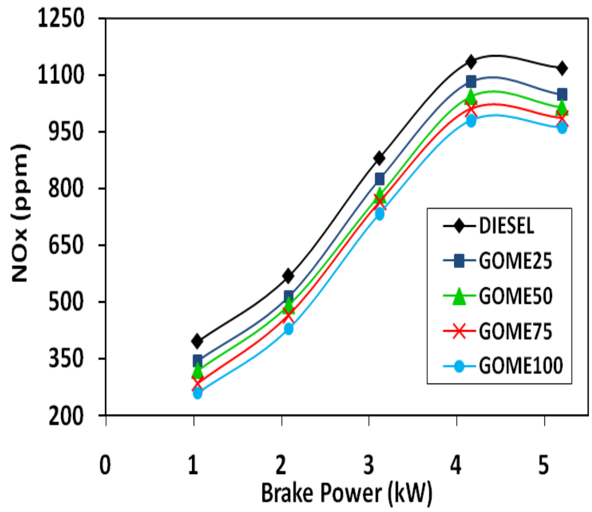

Figure 12: BP v/s NOx without EGR

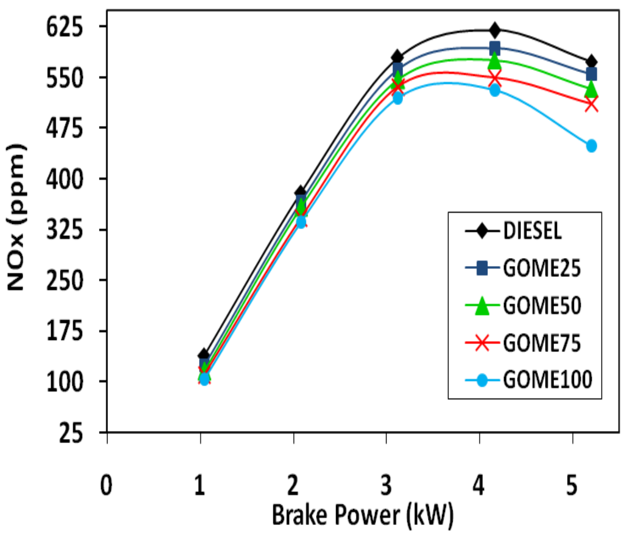

Figure 13: BP v/s NOx with 30% EGR

Smoke Density

Fig. 14 shows the percent variation of the smoke density emissions of the test engine for blended GOME without EGR at various loads to diesel fuel. It is seen that the blended GOME operations higher smoke density emissions at all proportion of GOME compared to diesel fuel operations. The smoke density with EGR Fig. 15 shows increases as compared to without EGR. The maximum increases in smoke density were obtained in the case of GOME 100.

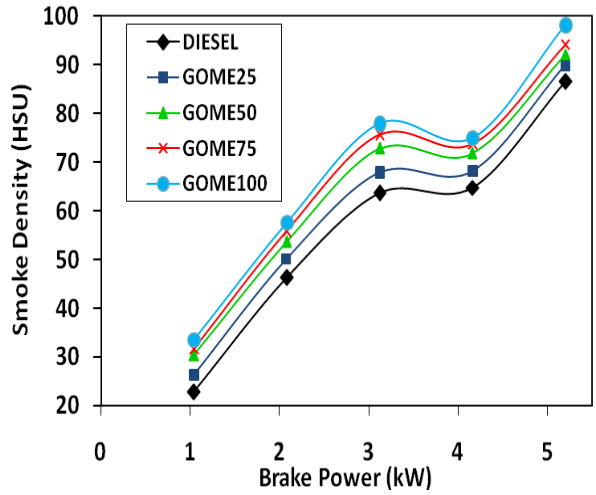

Figure 14: BP v/s Smoke density without EGR

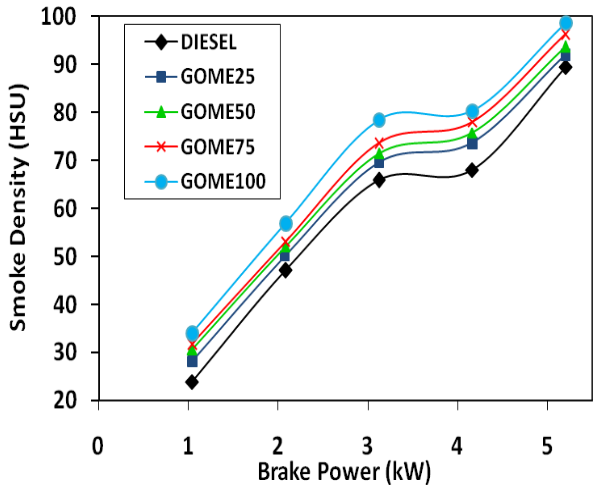

Figure 15: BP v/s Smoke density with 30% EGR

Combustion analysis

Figs. 16 and 17 show the comparisons of cylinder pressure of GOME 25, GOME 50, GOME 75 and GOME 100 with standard diesel at full load with and without EGR. It seen from the figure that the peak pressure with and without EGR for diesel was 60.69 bar and 60.36 bar, respectively. The cylinder peak pressure for with and without EGR GOME and its blend is lower that of diesel. At the time of ignition, less fuel/air mixture is prepared for combustion with vegetable oils; therefore more burning phase rather than in the premixed phase. The peak pressure mainly depends on premixed phase. Hence, lower pressure was observed for GOME and its diesel blend. Figs. 18 and 17 shows that GOME 100 does not display the pronounced first heat release peak. The quantity of diffusion burning indicated by the area under the second peak is highest for GOME 50 for the GOME 25, the first heat release peak was higher than that of GOME 100 due to reduced viscosity and better spray formation. The less Intense premixed combustion phase was due to the shorter ignition delay of GOME compared with that of standard diesel with and without EGR method.

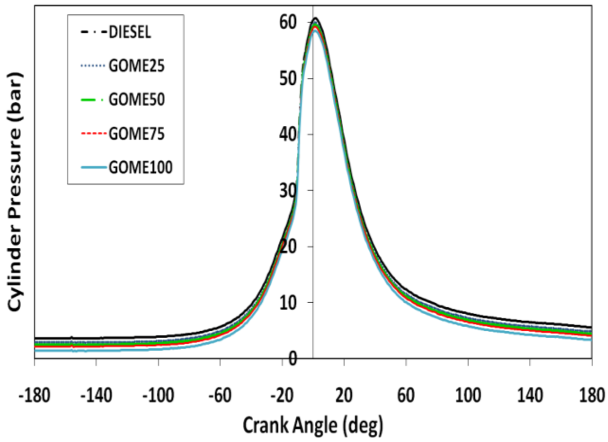

Figure 16: BP v/s Cylinder pressure without EGR

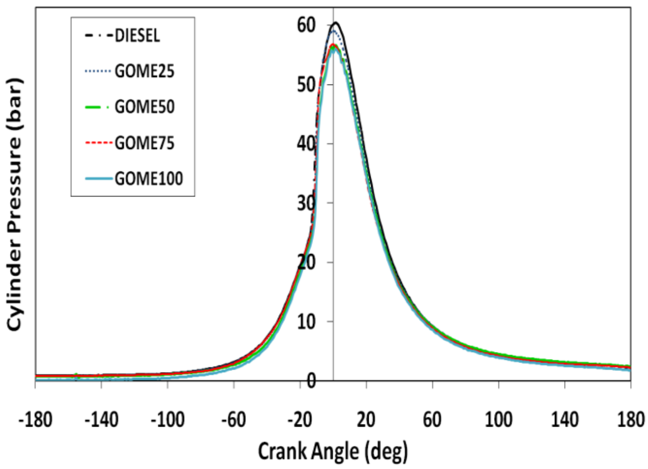

Figure 17: BP v/s Cylinder pressure with 30% EGR

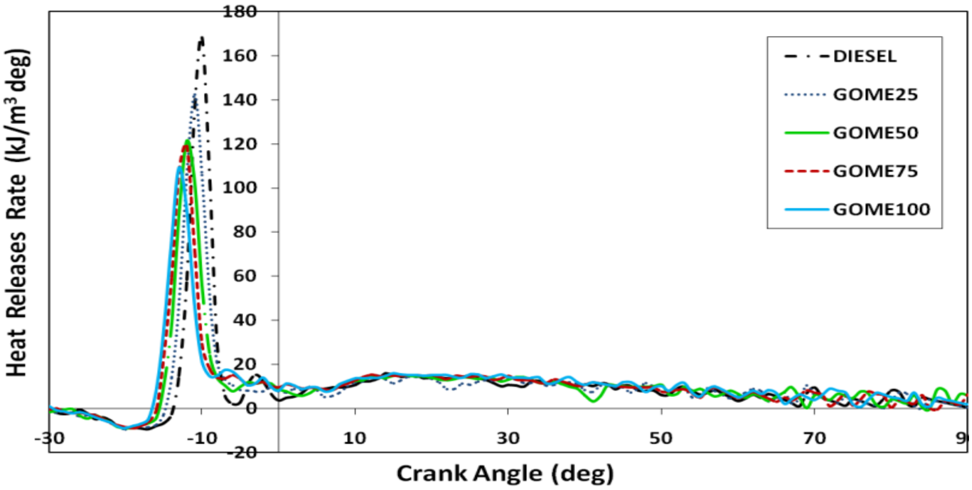

Figure 18: BP v/s Heat release rate without EGR

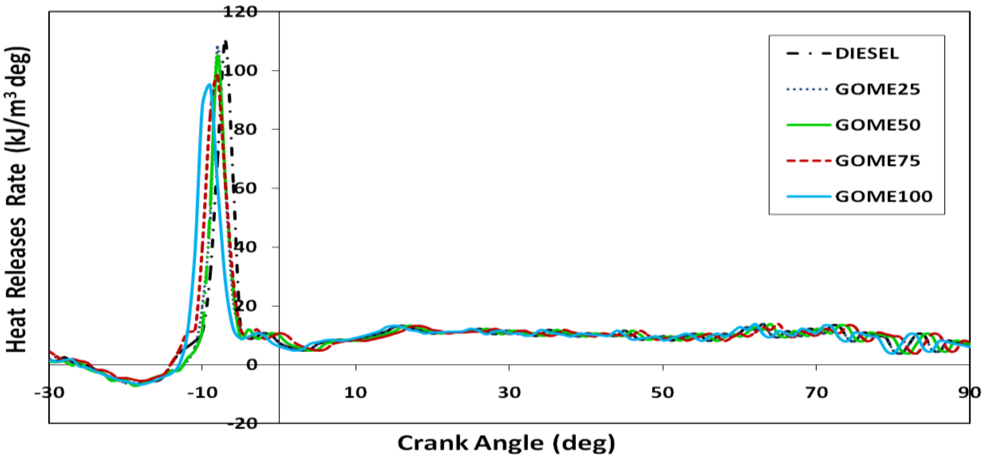

Figure 19: BP v/s Heat release rate with 30% EGR

Thermal cracking of the double bond carbon chains during the injection process resulted in the breakdown of the unsaturated fatty acids of higher molecular weight compounds. These volatile compounds probably contributed to the better ignition quality of the vegetable oil despite that fact that vegetable oils have much higher viscosities than standard diesel for with and without EGR method.

Table 3: Cylinder peak pressure, heat release rate and ignition delay of each fuel blend at full load

Fuel	Cylinder peak pressure ,bar	Max heat release, kJ/m^3 deg	Ignition delay degree crank angle	Cylinder peak pressure, bar	Max heat release, kJ/m^3 deg	Ignition delay degree crank angle
	with EGR			without EGR		
Std diesel	60.3	110	13	60.7	168.4	10
GOME 25	58.9	108	12	59.9	142.2	9
GOME 50	55.9	105	12	59.5	121.4	8
GOME 75	56.8	98	10	59.2	119.1	8
GOME 100	55.9	95	10	58.4	109.0	8

It is clear from Figs. 18 and 19 that premixed heat release of GOME 25 is higher than that of GOME 50 and GOME 100. GOME and its diesel blends without EGR higher heat release rate compared to that of GOME and its diesel blends with EGR.The quantified combustion parameters related to cylinder peak pressure, heat release rate and ignition delay are presented in Table 3.

Conclusion

The performance, emission and combustion characteristics of DI diesel engine fuelled with Grape seed oil methyl ester, GOME blends fuels with and without EGR have been analysed and compared with those of standard diesel. The conclusions are summarized as follows.

1. Compared to the diesel fuel, the brake thermal efficiency obtained with GOME 25, GOME 50, GOME 75, GOME 100 were moderately decreased. The BTE was standard diesel fuel and GOME diesel blends compared to without EGR increases in the case of with EGR.
2. There was an increase in BSFC for GOME and its diesel blends compared to that of standard diesel with and without EGR method. The BSFC was standard diesel fuel and GOME diesel blends compared to without EGR decreases with EGR method.
3. There was a decrease in HC and NO_x for GOME and its diesel blends compared to that of standard diesel with and without EGR method. The HC and NO_x was standard diesel fuel and GOME diesel blends compared with out EGR increases and decreases NO_x in the case of HC EGR method.

4. Compared to diesel fuel, CO obtained with GOME and its diesel blends were slightly increased. The CO was standard diesel fuel and GOME blends compared to without EGR moderately reduced in the case of with EGR method. There was an increases smoke density for GOME blends with and without EGR compared to std diesel. However, there was a reduction in smoke emissions without EGR operations for std diesel and GOME blends.

From the combustion analysis, a shorter ignition delay was observed for all the GOME blends. On the whole it is concluded that the Grape seed methyl ester oil and its diesel blends can be chosen as fuel in a diesel engine without any engine modification. The performance of the grape seed methyl ester and its diesel blends diesel engine was marginally better than that of conventional diesel engine in terms of exhaust emissions except smoke emission.

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