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Effect of Exhaust Gas Recirculation (EGR) on the Performance and Emission Characteristics of Diesel Engine with Sunflower Oil Methyl Ester

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Abstract

Transesterified fuels (biodiesel) from vegetable oils are alternative fuels for diesel engines. They are renewable and offer potential reduction in CO and HC emissions due to higher O_2 contents in vegetable oil. Many research studies have reported that exhaust from biodiesel fuel has higher NOx emissions while HC and PM emissions are significantly lower than operated with diesel fuel. The aim of the present investigation is to reduce NOx emissions. Exhaust gas recirculation (EGR) is one of the most effective technique for reducing NOx emissions in compression ignition engines. A twin cylinder four stroke water cooled direct injection (DI) diesel engine was used for conducting test with (Sunflower methyl ester:SFME) biodiesel blends with diesel fuel combined with EGR technique. The results showed that for a 7.5kW power output, B20 SFME with 15% EGR rate produce 25% less NOx emissions compared to diesel fuel for the same level smoke emissions.

Keywords: Emission; Exhaustgas Recirculation; Sunflower Oil, Compression Ignition; Biodiesel.

1. Introduction

Compression ignition engine are preferred prime movers due to excellent drivability and higher thermal efficiency. Despite their advantages they produce higher levels of NOx and smoke emissions which will more harmful to human health. Hence stringent emission norms have been imposed. In order to meet the emission norms and also the fast depletion of petroleum oil reserves lead to the research for alternative fuels for diesel engines. Biodiesel from vegetable oils are alternative to diesel fuel for diesel engines. The use of biodiesel in diesel engines does not require any engine modification. Biodiesel gives considerably lower emissions of PM, carbon monoxide (CO) and hydrocarbon (HC) without any fuel consumption or engine performance penalties. Many researchers have found that with biodiesel fueled engine produces higher NOx emissions compared to diesel [9-13]. To achieve reductions in NOx emissions, exhaust gas

recirculation (EGR) can be used with biodiesel in the diesel engines. EGR is an effective technique of reducing NOx emissions from the diesel engine exhaust [1-4]. Controlling the NOx emissions primarily requires reduction of in-cylinder temperatures [2, 3]. However, the application of EGR results in higher fuel consumption and emission penalties, also EGR increases HC, CO, and PM emissions along with slightly higher specific fuel consumption [13]. EGR rates are sufficient for high load, also as the load increases, diesel engines tend to generate more smoke because of reduced oxygen. Therefore, EGR, although effective to reduce NOx, further increases the smoke and PM emissions [5]. Abd-Alla et al [1] performed experiments on a 9.0 kW rated power dual fuel (gaseous fuel- methane with diesel as pilot fuel) mode direct injection diesel engine to study the effect of inlet air temperature by the way of mixing of hot EGR and addition of diluents gas such as CO2 and N2 .They reported that the addition of CO2 gas in the intake charge resulted in moderate reduction of NOx emission but Unburnt hydrocarbon emission (UBHC) was increased. By increasing the intake charge temperature resulting in increase of NOx emission with decrease in UBHC, the brake thermal efficiency and power output increased due to reduced ignition delay. Also they suggested that the performance was improved at low load condition when the inake air temperature was increased. Deepak Agarwal et al [2] conducted a test on a single cylinder DI diesel engine and measured the performance and emission characteristics with rice bran methyl ester (RBME) and its blends as fuel with EGR system. They optimized and reported that 20% biodiesel blends with 15% EGR produce the less NOx, CO and HC emissions and also improved thermal efficiency and reduced BSFC.

Hountalaous et al [3] using 3D-multi dimensional model to examine the effect of EGR temperature on a turbocharged DI diesel engine with three different engine speeds, and they reported that high EGR temperature affects the engine brake thermal efficiency, peak combustion pressure, air fuel ratio and also soot emissions, and the combined effect of increased temperature and

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decreased O2 concentration resulted low NOx emissions. Also they suggested that EGR cooling is necessary to retain the low NOx emissions and prevent rising of soot emissions without affecting the engine efficiency at high EGR rates. Ken Satoh et al [4] investigated on a naturally aspirated single cylinder DI diesel engine with various combinations of EGR, fuel injection pressures, injection timing and intake gas temperatures affect exhaust emissions and they found that NOx reduction ratio has a strong correlation with oxygen concentration regardless of injection pressure or timing. NOx reduction ratio is in direct proportion to intake gas temperatures. EGR may adversely affect the smoke emission because it lowers the average combustion temperatures and reduces the oxygen intake gases, which in turn keeps soot from oxidizing. Also they suggested that for a given level of oxygen concentration the cooled EGR reduces more NOx with less EGR rates than does at hot EGR.Nurun Nabi et al [6] reported that NOx emission was slightly lower and CO emission almost identical or slightly lower for 15% NOME blends than that of neat diesel for every EGR rate. Pradeep and Sharma et al [7] have studied performance of a single cylinder DI diesel engine with Jatropha oil methyl ester biodiesel (JBD) with hot EGR .They optimized 15 %EGR gave the adequate reduction of NOx emission with minimum possible smoke,CO,UBHC emissions. And further increased EGR rates produced more NOx emissions.Saravanan et al [8] performed a series of test on a single cylinder water cooled DI diesel engine with hydrogen was used as dual fuel mode with EGR technique and their results showed increase in brake thermal efficiency and lowered smoke level, particulate and NOx emissions due to absence of carbon in hydrogen fuel.

The main objective of the present research is to investigate the effect of exhaust gas recirculation with sunflower methyl ester (SFME) blends and diesel fuel and also is to investigate the emissions and performance of a diesel engine with biodiesel as fuel. In this experimental study, 15 % EGR has been taken as optimum quantity for analysis.

2. Materials and Methods

2.1. Transesterification

Sunflower oil is considered as feedstock for the biodiesel production. The method of biodiesel production is known as transesterification.Thetransesterification reaction is given below.

$$
\begin{array}{lcccc}
CH_2\text{—}OOC\text{—}R_1 & & & R_1COOR' & CH_2\text{—}OH \\
| & & & & | \\
CH\text{—}OOC\text{—}R2 & + & 3R'OH \xrightarrow{\text{Catalyst}} & R_2COOR' \quad + & CH\text{—}OH \\
| & & & & | \\
CH_2\text{—}OOC\text{—}R_3 & & & R_3COOR' & CH_2\text{—}OH \\
\text{Vegetable oil} & & \text{Methyl alcohol} & \text{Fatty Acid Esters (Bio-Diesel)} & \text{Glycerol}
\end{array}
$$

Transesterification is a chemical process of transforming large, branched, triglyceride molecules of vegetable oils and fats into smaller, straight chain molecules, almost similar in size to the molecules of the species present in diesel fuel. The process takes place by reacting the vegetable oil with an alcohol in the presence of catalyst. Methyl esters are preferred as methanol is non hygroscopic and is less expensive than other alcohols. The optimum proportions are for one litre of sunflower oil, the requirement of methanol and NaOH are 200 ml and 8.0 grams respectively. The properties of diesel, sunflower oil, sunflower methyl ester are listed in table.1

Table1. Properties of diesel and Sun flower methyl ester.

Property	Diesel	Sunflower oil	SFME
Kinematic viscosity at 38° C (mm^2/s)	2.7	34.0	37.1
Density (kg/m^3)	840.0	960.0	878.0
Calorific value (MJ/kg)	42.5	36.5	38.5
Flash point (° C)	52.0	276.0	224.0
Cetane Number	47.0	37.0	58.0

2.2. Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) is used for controlling the NOx emissions.EGR is an effective technique of reducing NOx emissions from the diesel engine exhaust. EGR involves replacement of oxygen and nitrogen of fresh air entering in the combustion chamber with the carbon dioxide and water vapor from the engine exhaust. The recirculation of part of exhaust gases into the engine intake air increases the specific heat capacity of the mixture and reduces the oxygen concentration of the intake mixture. These two factors combined lead to significant reduction in NOx emissions. EGR (%) is defined as the mass percentage of the recirculated exhaust (MEGR) in total intake mixture (Mi).

$$\%\,EGR = \frac{\text{Mass of air admitted without EGR} - \text{Mass of air admitted with EGR}}{\text{Mass of air admitted without EGR}}$$

2.3. Experimental Setup

The engine used in this experiment was a twin cylinder four stroke water cooled, NA, DI diesel engine coupled with mechanical loading. A digital AVL-444 five gas analyzer is set up to find the emission characteristics of the engine. Instrumentation is provided for the measurement of fuel consumption and load on brake drum. The arrangement of experimental set up is shown in figure 1The specifications of the test engine is given in Table 2.The experiment was conducted with conventional diesel fuel, and blends of sunflower methyl ester (SFME).

3. Results and Discussion

Engine tests were carried out using diesel at 1500 rpm and different EGR rates in order to study the effect of EGR on the smoke density and NOx concentration in the exhaust emissions. Higher amount of smoke in the exhaust is observed when the engine is operated with EGR compared to without EGR. Smoke emissions increases with increasing engine load and EGR rates.EGR reduces availability of oxygen for combustion of fuel, which results in relatively incomplete combustion and increased formation of PM and reducing NOx emissions from diesel engine. Using biodiesel in diesel engine, smoke is decreased with increase in NOx. Thus, biodiesel with EGR

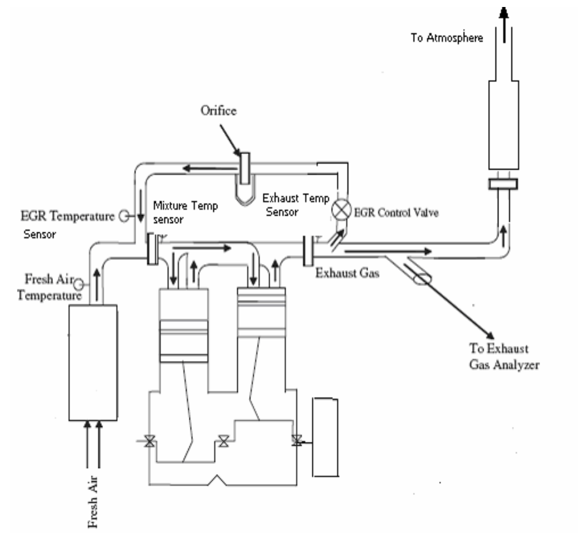

Figure 1.Experimental setup using EGR

Table 2. Engine specifications.

Make	Kirloskar
Engine type	Twin cylinder, Vertical direct Injection, Water cooled.
Bore/stroke	80/110mm
Rated power	7.4 kW
Compression ratio	16.5:1
Rated speed	1500 rpm

can be used to reduce NOx and smoke intensity simultaneously. A series of exhaustive engine test were carried out which levels, an optimum of 15% EGR can be used with B20 and B40 SFME of biodiesel. The performance and emission data were analyzed for thermal efficiency, BSFC, exhaust gas temperature, HC, CO, NOx and smoke emissions.

3.1. Performance Analysis

Engine tests were carried out using diesel at 1500 rpm and different EGR rates in order to study the effect of EGR on the smoke density and NOx concentration in the exhaust emissions. Higher amount of smoke in the exhaust is observed when the engine is operated with EGR compared to without EGR. Smoke emissions increases with increasing engine load and EGR rates.EGR reduces availability of oxygen for combustion of fuel, which results in relatively incomplete combustion and increased formation of PM and reducing NOx emissions from diesel engine. Using biodiesel in diesel engine, smoke is decreased with increase in NOx. Thus, biodiesel with EGR can be used to reduce NOx and smoke intensity simultaneously. A series of exhaustive engine test were carried out which levels, an optimum of 15% EGR can be used with B20 and B40 SFME of biodiesel. The performance and emission data were analyzed for thermal efficiency, BSFC, exhaust gas temperature, HC, CO, NOx and smoke emissions.

3.1.1. Brake Thermal Efficiency

Figure 2 shows the variations of brake thermal efficiency of diesel and sunflower methyl ester blends (SFME) with and without EGR. It is observed that from the figure the brake thermal efficiencies are increased with increase in load with EGR at lower load due to re-burning of hydrocarbons that enter in to the combustion chamber with the recirculated exhaust gases and at full load operation the brake thermal efficiency not affected by exhaust gases. The brake thermal efficiencies are improved with increasing concentration of bio diesel and its diesel blends due to the higher oxygen present in the bio diesel.B20 SFME with 15 % EGR shows 4 % increase in brake thermal efficiency at lower load (0-75%) compared to diesel without EGR.

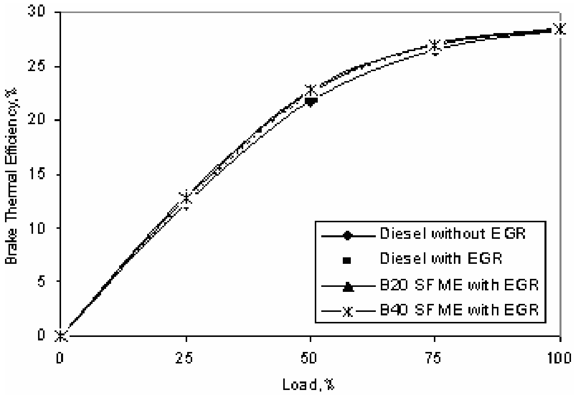

Figure 2. Variation of Brake thermal efficiency with Load.

3.1.2. Brake Specific Fuel Consumption (BSFC)

Figure 3 shows the variations of BSFC for diesel and biodiesel blends and with and without EGR. The brake specific fuel consumptions are lower for diesel at lower loads operated with EGR when compared to without EGR. However, at higher engine loads, BSFC with EGR is almost similar to that of without EGR for diesel fuel. The brake specific fuel consumptions are increased with increasing concentration of biodiesel blends when the engine is operated on biodiesel blends with EGR due to lower calorific value and high viscosity of the sunflower methyl ester when compared to diesel with and without EGR. The brake specific fuel consumptions are increased about 10 % for B20 and 15 % for B40 sunflower methyl ester blends at full load operation with EGR.

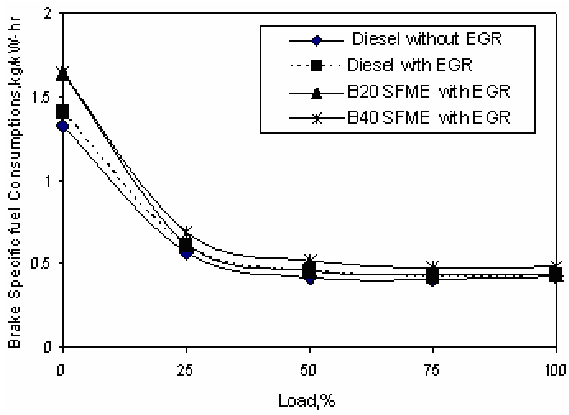

Figure 3. Variations of Brake Specific fuel Consumptions with Load.

3.1.3. Exhaust Gas Temperature

Figure 4 shows the variations of exhaust gas temperature with diesel and blends of biodiesel with EGR.It can be observed that with increase in load, exhaust gas temperature also increases. The exhaust gas temperature was found to be lower for EGR-operated engine with diesel due to lower availability of oxygen for combustion and higher specific heat of intake exhaust gas air mixture. The temperature of the exhaust gases for B20 and B40 sunflower methyl ester were observed lower than the diesel without EGR.

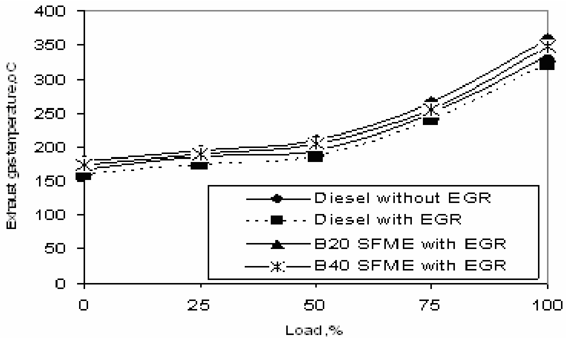

Figure 4. Variation of Exhaust gas Temperature with Load.

3.2. Emission Characteristics

3.2.1. Unburnt Hydro Carbon Emissions (UBHC)

Figure 5 shows the variations of UBHC emissions of diesel and sunflower methyl ester blends with and without EGR. The UBHC increases with increase in load and EGR rate. because of lower oxygen content available for combustion, that is lower excess oxygen concentration results rich mixture which results incomplete combustion and results higher hydro carbon emission. It is also observed from the graph the 20% and 40%biodiesel blend with 15% EGR gives 5 % and 15 % lower UBHC emissions with full load compared to diesel with EGR.

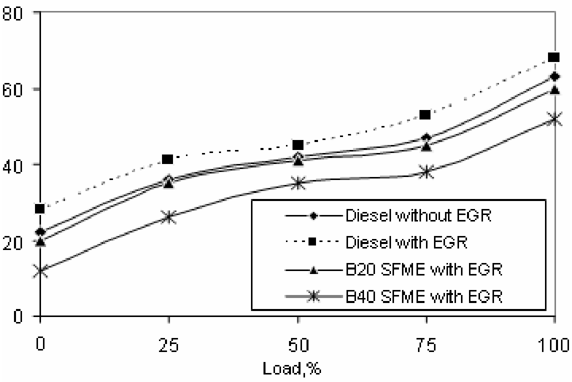

Figure 5. Variations of Hydrocarbon Emission with Load

3.2.2. Carbon Monoxide Emissions (CO)

Figure 6 shows the variations of CO emissions of diesel and sunflower methyl ester with EGR and without EGR. The CO increases with increase in load and EGR rate. However, CO emissions of SFME were comparatively lower. Higher values of CO were observed at full load for both diesel and biodiesel fuels with EGR. For biodiesel, the excess oxygen content is believed to have partially compensated for the oxygen deficient operation under EGR. Dissociation CO_2 to CO at peak loads where high combustion temperatures and comparatively fuel rich operation exists, can also contribute to higher CO emissions. It is observed that from the graph CO emissions are 10 % and 20 % lower for 20% and 40 % biodiesel blends respectively with full load compared with diesel when the engine is operated with EGR.

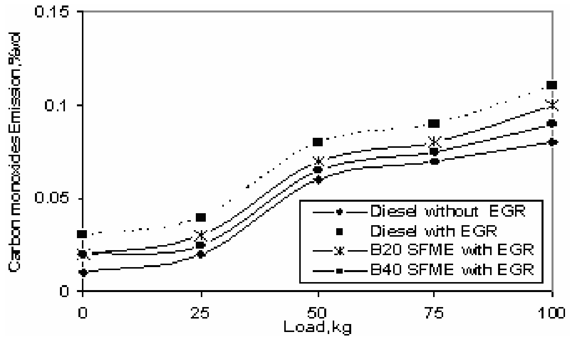

Figure 6. Variations of CO Emissions with Load.

3.2.3. Nitrogen Oxides Emission (NO_X)

Figure 7 shows the variations of NOx emissions of diesel and sunflower methyl ester with and without EGR. The degree of reduction in NOx at higher at higher loads. The reasons for reduction in NOx emissions using EGR in diesel engines are reduced oxygen concentration and decreased the flame temperatures in the combustion chamber. However, NOx emissions in case of biodiesel blends without EGR are higher than diesel due to higher temperatures prevalent in the combustion chamber. It is also observed from the graph the 20 % and 40 % biodiesel blends have 25 % and 14 % lower NOx emissions respectively with full load when compared to diesel fuel without EGR.

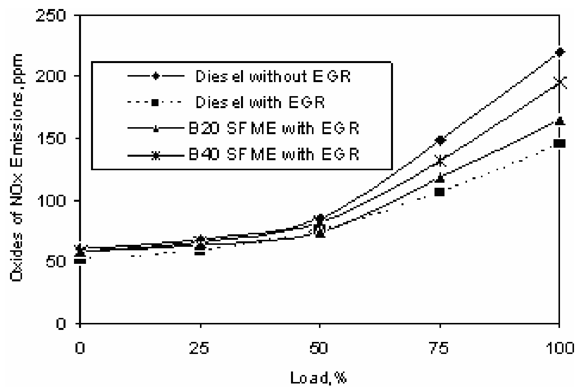

Figure 7. Variations of NOx Emissions with Load.

4. Conclusion

In this report the performance and emission characteristics of diesel fuel and diesel-SFME blends with exhaust gas recirculation were investigated. The results obtained of this study are summarized as follows.

1. Methyl ester of sunflower oil was prepared with lye catalyst NaOH and methanol.
2. Compared with conventional diesel fuel, the exhaust NOx was reduced about 25% at 20 % biodiesel blends with 15% EGR due to less oxygen available in the recirculated exhaust gases which lowers the flame temperature in the combustion chamber.
3. SFME blend with 15% EGR, which improves the 4% of brake thermal efficiency and 10 % increase in BSFC due to lower calorific value of the biodiesel.

4. The total unburnt HC and CO emissions were decreased by 5 % and 10 % for 20 % biodiesel blends respectively compared to diesel fuel with EGR and smoke emissions were observed as increases, due to incomplete combustion.
5. Engine operation with biodiesel while employing EGR were able to reduce 25 % NOx, and reduction in brake thermal efficiency and increase in smoke ,CO and UBHC were observed compared to diesel.

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