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Effect of Exhaust Gas Recirculation on Performance and Emission Characteristics of a Diesel Engine Running with Corn Oil Biodiesel

Mohd Riyazuddin[1], Srinivas Valmiki[2]
1(PG Scholar, Department of Thermal power of Engineering, PDA College of Engineering, KALABURAGI)
2 (Associate professor,Department of Mechanical Engineering, PDA College of Engineering, KALABURAGI)

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. An experimental investigation was conducted to study the effect of Exhaust Gas Recirculation on diesel engine Performance and Emission characteristics fueled with Corn Oil Methyl Ester and its blends with diesel. The EGR setup required for this work was developed on a single cylinder, direct injection, water cooled compression ignition engine. Corn Oil Methyl Ester produced by Transesterification process was used to operate the engine. The different EGR rates ranging from 0% to 10% in steps of 5% for Corn oil methyl ester blends with diesel fuel were consider for the study of various Performance and Emission characteristics. For all blends reduced NOx emission was observed with EGR. The better engine characteristics were obtained with EGR rate of 10% for all fuel blends.

Keywords — **Biodiesel, corn oil methyl ester, performance, emission, combustion.**

I. Introduction.

Economic growth of a country is very much dependent on the long term availability of energy. The sources of energy should be safe and environment friendly. Diesel engine is preferred prime movers for power generation due to its excellent drivability and higher thermal efficiency. Despite their advantages they produce higher levels of emissions which have significant effect on human health. Since fossil fuels are depleting day by day, there is a need to find out an alternative fuel to fulfill the energy demand of the world. Biodiesel is one of the best available substitute sources in place of diesel fuel. Diesel engines emit comparatively lower HC and CO emissions when operated with biodiesel, but problem of NOx emission is more. Hence in order to meet Environmental legislation and reduce emissions, it is highly desirable to reduce the amount of NOX in the exhaust gas when biodiesels are used in diesel engines. Formation of NOX is very less at the temperature below 2000K. Hence any technique that can keep the instantaneous local temperature in the combustion chamber below 2000K will be able to reduce NOX formation. The lower combustion temperature can be maintained by exhaust gas recirculation (EGR) technique.

A. EGR technique for NOx reduction.

Exhaust consists of CO2, N2 and water vapour mainly. When a part of this exhaust gas is re-circulated to the engine cylinder, it acts as diluents to the combustion mixture. This also reduces the O2 concentration in the combustion chamber. The specific heat of EGR is much higher than fresh air; hence EGR increases the heat capacity (specific heat) of the intake charge, thus decreasing the temperature rise for the same heat release in the combustion chamber.
EGR percentage is defined as
% EGR = Volume of EGR * 100 / Total intake charge into the cylinder.

II. Literature

Yokomura et al. [1] have suggested that exhaust gas recirculation is one of the most effective ways for nitrogen oxides (NOx) reduction process. A.K. Agrawal et al. [2] reported that in diesel engines NOx formation is very much dependent upon temperature. To reduce NOx emission in the exhaust of a diesel engine, it is necessary to keep combustion temperature under control.Y. Yoshimoto [3] reported that 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. Mahla et al. [4] studied the effect of EGR on performance and emission characteristics of natural gas fueleddiesel engine. Their experimental results show that the application of EGR substantially decreases NOX. Nurun Nabi et al [5] 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 [6] 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 [7] 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.

Ghazikhani et al. [8] studied the effect of EGR and engine speed on CO and HC emissions of dual fuel HCCI engine. They observed that increasing engine speed at constant EGR rate leads to increase in CO and UHC emissions due to incomplete combustion caused by shorter combustion duration and less homogeneous mixture. Results also show that increasing EGR reduces the amount of oxygen leads to incomplete combustion and therefore increases HC & CO emission, decreases NOX emission due to lower combustion temperature. R.M.Wagner et al. [9] tried to achieve lower emission of NOX using highly diluted intake mixture. At very high EGR rate (around 44%) NOX emission decreased sharply but these high EGR rates significantly affect the fuel economy. Rajan and senthilkumar [10] studied the effect of EGR on performance and emission characteristics of diesel engine with sunflower oil methyl ester. They observed that B20 blend with 15% EGR rate possess 25% less NOX emission compared to diesel fuel.

III. Present work

In the current study an experimental investigation was carried out to study the effect of exhaust gas re-circulation on diesel engine performance and emission characteristics fueled with Corn Oil Methyl Esters(COME) blends with diesel by volume 0%(B0), 20%(B20), 40%(B40), 60%(B60) and 100%(B100). The experimental EGR setup for this works was developed on a single cylinder, direct injection, water cooled compression ignition engine. The partly cooled EGR was used for this study. The different EGR rates employed are 0%, 5% and 10% for the study of various performance and emission characteristics of the engine. The charge temperature can be controlled by regulating EGR quantity. The EGR rates can be adjusted by operating the suitable values in the exhaust flow lines. The required percentage of EGR in admitted air can be maintained by measuring air and EGR flow rates using orifice and U-tube manometer arrangement

IV. Experimentation.

The engine used for the investigation was computerized single cylinder, four stroke, water cooled and direct injection compression ignition engine with eddy current dynamometer. The necessary modifications were carried out to develop EGR setup in the engine. Air box with diaphragm is installed in the EGR route to minimize the pressure pulses of exhaust gas coming out of the engine during exhaust stroke at high pressure. A "U" tube manometer was used to measure the EGR rates. The quantity of EGR was controlled with manually operated valve. A typical schematic of experimental set up and EGR set up is shown in fig. 1 & 2. The technical specifications of the engine are given in table I.

Fig -1: Experimental set up

Fig -2: EGR set up

Table -1: Engine Specifications

Sl No	Parameters	Specification
01	Manufacturer	Kirloskar oil engines Ltd. India
02	Model	TV-SR, naturally aspirated
03	Engine	Single cylinder, DI
04	Bore/stroke	87.5mm/110mm
05	C.R.	16.5:1
06	Speed	1500 RPM, constant
07	Rated power	5.2KW
08	Working cycle	Four stroke
09	Response time	4 micro seconds
10	Type of sensor	Piezo electric
11	Crank angle sensor	1-degree crank angle
12	Dynamometer	Eddy current dynamometer

Digital control panel was used to collect the required engine data. Carbon mono oxide (CO), Hydro carbon (HC) and oxides of nitrogen (NOx) emissions are measured using exhaust gas analyzer. Corn Oil Methyl Ester (COME) produced by Transesterification process was used to run the engine for this study. The properties of COME, diesel fuel and the instrument used in determining the property are given in table 2.

Table -2: Fuel properties

Fuel Properties	Diesel	Corn Oil Methyl Ester	Apparatus used
Fuel density in kg/m^3	830	849.3	Hydrometer
Calorific value (kJ/kg)	42500	37942.18	Bomb calorimeter
Flash point in ^oC	56	173	Pensky-martein's Apparatus
Fire point in ^oC	65	179	Pensky-martien's apparatus
Kinematic viscosity at 40^oC in m^2/s	$3.9x10^{-6}$	$9.65x10^{-6}$	Redwood viscometer

IV. Results and discussions

B0 [Diesel fuel], B20 [20% COME + 80% Diesel by volume], B40 [40% COME + 60% Diesel by volume], B60 [60% COME + 40% Diesel by volume] and B100 [COME biodiesel] fuels were used to run the engine in this work. The different EGR rates considered for current study are 0%, 5% and 10%. All the tests were conducted at full load and rated speed of 1500 rpm to study the effect of EGR on engine performance and emission characteristics. The variation of performance characteristics BTE, BSFC, EGT and emission characteristics NOx, HC, CO with EGR are discussed as follows.

B. Performance characteristics.

1. Brake Thermal Efficiency:

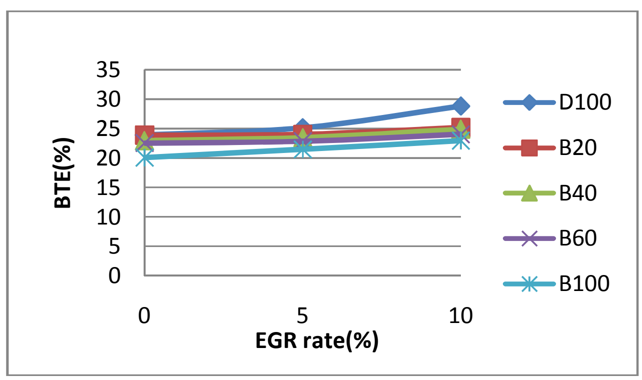

Fig -3: Variation of brake thermal efficiency with EGR

The variation of BTE of all the fuels at full load with EGR is shown in fig-3.It is observe that brake thermal efficiency of all the blends are lower than that of diesel when operated without EGR, this is attributed to more amount of fuel consumption for blends as compare to diesel. BTE tends to increase with increase in the EGR rate upto 10%. This increase in BTE is due to re-burning of hydrocarbons that enter in to the combustion chamber with the recirculated exhaust gases.

2. Specfic fuel consumption:

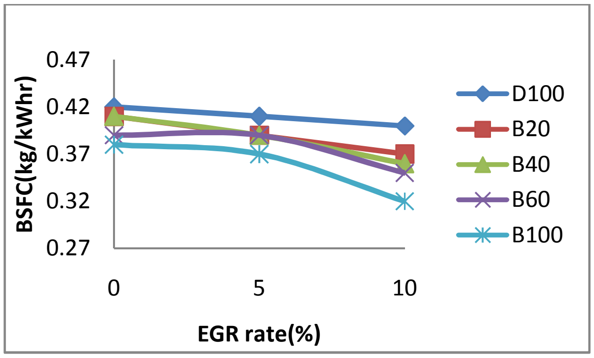

Fig -4: Variation of specific fuel consumption with EGR

The variation of BSFC for all the fuels with EGR at full load is shown in figure-4.It is observed that the BSFC for diesel is higher than the other fuels without EGR, as calorific value of diesel is higher than other fuels. BSFC tends to decrease as the EGR rate is increased upto 10% .This is due to utilisation of unburnt hydrocarbons when exhaust is recirculated in combustion chamber.

3. Exhaust Gas Temperature:

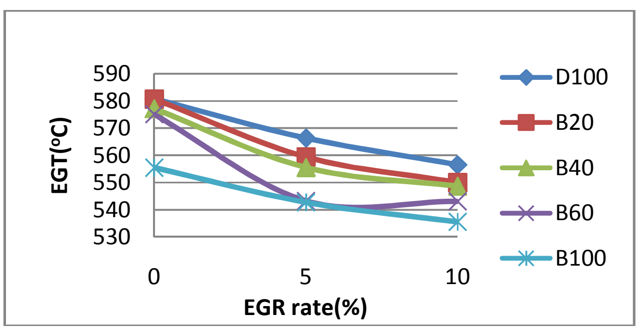

Fig -5: Variation of exhaust gas temperature with EGR.

The effect of EGR on Exhaust Gas Temperature for all fuels at full load is shown in fig-5. It has been observed that when the engine is operated with partly cooled EGR, the temperature of exhaust gas is generally lower than the temperature of exhaust gas at normal operating condition. EGT decreases with increase in EGR rate. Relatively lower availability of oxygen for combustion and higher specific heat of intake air mixture are the reasons for exhaust gas temperature reduction with EGR. EGT for diesel is higher than biodiesel blends and biodiesel at all the EGR rates. The decrease in exhaust gas temperature is observed continuously with increase in EGR rates upto 10% as shown in fig 5.

C. Emission characteristics

1. *Carbon monoxide*:

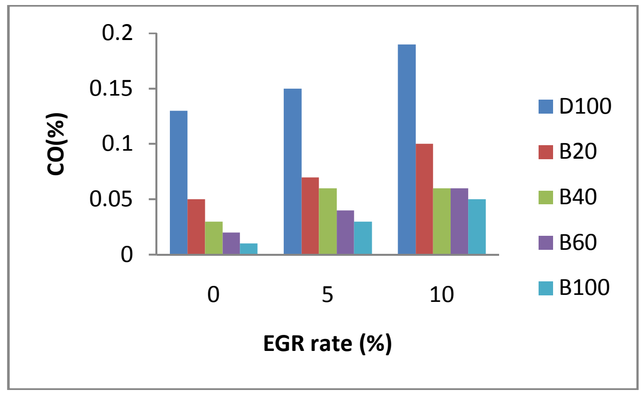

Fig -6: Variation of carbon monoxide with EGR.

Fig.6 shows the variation of carbon monoxide emission with EGR at full load for diesel and blends of corn oil biodiesel. The CO emission depends upon the strength of the mixture, availability of oxygen and viscosity of fuel. It is observed from the figure that the CO emission increases with increase in the EGR rate. This is due to lower availability of oxygen at higher EGR which leads to incomplete combustion resulting in the increase of CO emission.

2. Hydrocarbon:

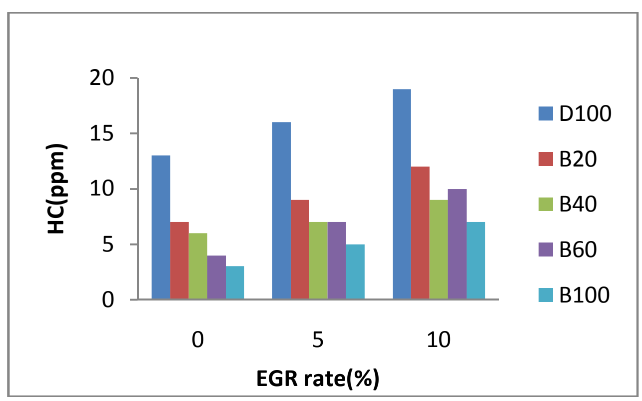

Fig -7: Variation of hydrocarbon with EGR.

Fig-7 shows the variation in the quantity of unburnt hydrocarbons with change in EGR rate at full load. It is observed that HC emission increases with increase in EGR rates. At higher EGR rates, less amount of oxygen is available for combustion resulting in rich mixture which results in incomplete combustion, leads to higher HC emission.

4. *No_x*:

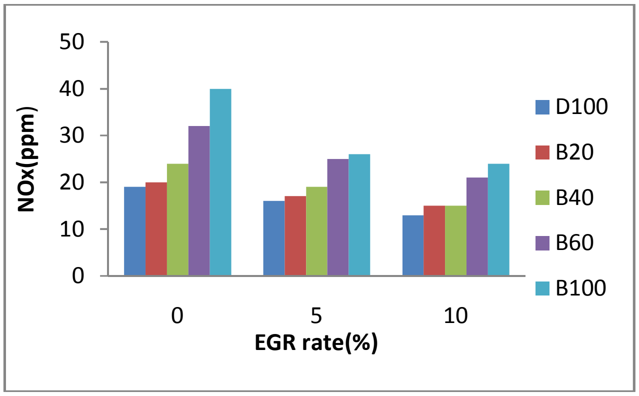

Fig -8: Variation of NOx with EGR.

The main benefit of EGR in reducing NOx emission from CI engine is shown in Fig-8. Significant reduction of NOx emission for all fuels is observed with EGR. The reasons for the reduction in NOx emission using EGR in CI engines are reduced oxygen concentration and decreased flame temperature in the combustion chamber. At lower loads oxygen is available in sufficient quantity but at higher loads oxygen reduces drastically, therefore NOx emission reduction may be more at higher loads compared to part loads. The reduction of NOx emission is mainly due to decrease in in cylinder temperature during combustion process because of less oxygen availability. At very high EGR rates NOx emission decreased drastically, but it leads the increased BSFC and decreased BTE. Engine performance (BTE and BSFC) need to be compromised to get very low NOx emission in the exhaust. Higher EGR amounts are not advisable in engine performance point of view, because efficiency (BTE) of the engine decreases with higher EGR rates. But NOx emission from the engine decreases with increases of EGR rates. Hence a trade-off between engine efficiency and NOx reduction is required.

V. Conclusions.

Increase of EGR rate up to 10% increases the BTE slightly. At lower EGR rates the unburnt HC present in exhaust gets burned completely leads to the reduction in fuel consumption thereby increased BTE.

The lowest BSFC was obtained for all blends at 10% EGR. The highest BTE was obtained at 10% EGR for all blends of fuel.

The temperature of exhaust gas continuously decreases with increase of EGR rate. The higher specific heat of intake air and exhaust gas mixture and lower oxygen availability are main reasons for lower EGT with EGR.

Decrease of combustion temperature due to lower oxygen availability results lower NOx emission with EGR. NOx emission decreases with increase of EGR rate for all blends.

HC and CO emission show same trend of increase with increase of EGR rate.

The EGR rate 10% shows better performance and lower NOx emission. All blends at 10% EGR exhibited better characteristics compared to diesel at 0% EGR. Hence the problem of higher NOx emission with biodiesel blends can be reduced with suitable EGR rates.

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