Effect of EGR on Diesel Engine Performance and Exhaust Emission Running with Cotton Seed Biodiesel

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***Abstract*--** **Biodiesels produced from vegetable oils are an attractive alternative fuel which are renewable and offer significant reduction of carbon monoxide and hydrocarbon emission due to higher oxygen content. Biodiesels can be easily mixed with petroleum diesel to form blends, and is free of sulphur. Emission control has become one of the most important challenges in diesel engine. The main drawback of use of biodiesels in diesel engines is its higher NO_X emissions. The aim of the present work is to reduce NOx emissions of a diesel engine fueled with cotton seed biodiesel. One simple way of reducing the NO_X emission of diesel engine is by injection delay of fuel in to combustion chamber. This method is effective but increases the fuel consumption, which necessitates the use of more effective NO_X reduction technique like exhaust gas recirculation (EGR). Recirculating part of the exhaust gas along with fresh air admission helps in reducing NO_X.**

A single cylinder four stroke direct injection water cooled diesel engine operated with cotton seed biodiesel (CSBD) and petroleum diesel (PD) blends such as 0% (PD), 10% (CSBD10), 20% (CSBD20) and 30% (CSBD30) are used for the present emission and performance study. Different EGR rates such as 0%, 5%, 10%, 15% and 20% are considered for this study. The speed of the engine is kept as constant at 1500 rpm. The performance of the engine in terms of brake specific fuel consumption& brake thermal efficiency and emission characteristics such as oxides of nitrogen, hydrocarbon & carbon monoxide are studied. For all blends reduced NO_X emission was observed with EGR. The better engine characteristics were obtained with EGR rate of 15% for all fuel blends. The observations reveal that cotton seed biodiesel with EGR can be used to reduce NOx.

***Index Term*--EGR, cotton seed biodiesel, exhaust emission and performance**

1.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 NO_X in the exhaust gas when biodiesels are used in diesel engines.

Formation of NO_X 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 NO_X formation. The lower combustion temperature can be maintained by exhaust gas recirculation (EGR) technique.

Exhaust consists of CO_2, N_2 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 O_2 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

EGR have been classified based on the temperature as **1) Hot EGR:** Exhaust gas is circulated without being cooled, resulting in increased intake charge temperature. **2) Fully cooled EGR:** Exhaust gas is fully cooled before mixing with fresh intake air using water cooled heat exchanger. In this case, the moisture present in the exhaust gas may condense and the resulting water droplets may cause undesirable effects inside the engine cylinder. **3) Partly cooled EGR:** To avoid water condensation, the temperature of the exhaust gas is kept just above its dew point temperature.

A.K. Agrawal et al. [1] 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. Yokomura et al. [2] have suggested that exhaust gas recirculation is one of the most effective ways for nitrogen oxides (NOx) reduction process. 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 fueled diesel engine. Their experimental results show that the application of EGR substantially decreases NO_X. Ladommatos et al. [5] tested the effect of exhaust gas recirculation on diesel engine emissions. They noticed a large reduction in NOx emissions at the expense of higher particulate and unburnt hydrocarbon emissions. D.Agarwal [6] suggested that controlling the NOx emissions primarily requires reduction of incylinder temperatures.

Ghazikhani et al. [7] 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 NO_X emission due to lower combustion temperature. R.M.Wagner et al. [8] tried to achieve lower emission of NO_X using highly diluted intake mixture. At very high EGR rate (around 44%) NO_X emission decreased sharply but these high EGR rates significantly affect the fuel economy. Rajan and senthilkumar [9] 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 NO_X emission compared to diesel fuel.

M. Pourfallah et. al[10] Studied the Effect of Reformer Gas and Exhaust Gas Recirculation on Homogeneous Charge Compression Ignition Engine Operation. In their study they concentrated mainly on combustion characteristics of HCCI engine with EGR. They observed very poor thermal efficiency at higher EGR rates. S. Jafarmadar, J. Pashae[11] conducted Experimental Study of the Effect of Castor Oil Biodiesel Fuel on Performance and Emissions of Turbocharged DI Diesel. The results show that maximum decrease in PM emission compared to that of pure diesel fuel is 73.2% and observed in B15 at 50% load. Also, the maximum increase in BSFC and No when compared to those of pure diesel fuel are 10.7 and 15.6% and observed in B30 at 50% load and B20 at 50% load, respectively. The results show that in B15 and at 25% load, NO and PM emissions decreases 6 and 64% respectively and BSFC increases 1.5%. Parviz Soltani Nazarloo et. al[12] Investigated the effect of EGR rates on performance and emissions of a DI diesel engine fuelled with biodiesel blends. Reductions in NO and exhaust gas temperature were observed but emissions of HC and CO were found to have increased with usage of EGR. The engine performance and efficiency obtained in biodiesel case were less, which could be attributed to lower calorific value of biodiesel. The increased of BSFC obtained with biodiesel are lower than that of diesel fuel when applying same EGR rate.

2. 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 cotton seed biodiesel (CSBD) blends with diesel by volume 0%(PD), 10%(CSBD10), 20%(CSBD20) and 30%(CSBD30). 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 ranging from 0% to 20% in steps of 5% were consider 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

3. 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 minimise 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 is shown in fig. 1 & 2. The technical specifications of the engine are given in table I.

Fig. 1. Engine

Fig. 2. EGR set up

Digital control panel was used to collect the required engine data. INDUS make exhaust gas analyzer is used to investigate emission characteristics. Carbon mono oxide (CO), Hydro carbon (HC) and oxides of nitrogen (NO_X) emissions are measured using exhaust gas analyzer. Fig.3. shows the exhaust gas analyzer used for this investigation. The technical specifications of exhaust gas analyzer are given in Table II. Cotton seed biodiesel(CSBD) produced by Transesterification process was used to run the engine for this study. The properties of CSBD, diesel fuel and ASTM standards are given in table III. The viscosity of CSBD is 4.7 cSt which is in the range of 1.9 to 6.0 prescribed by the ASTM standards. And also the problem of high viscosity of CSBD to be usable in diesel engine, only maximum of 30% blends (CSBD) was considered for the tests. CSBD 30 has viscosity less than 4.7 cSt. Hence CSBD UP TP 30% blend may not have the effect on fuel injection durability.

Table I
Engine specification

Manufacture and type	Kirloskar Oil Engine and AV1
Engine	Single Cylinder Direct Injection Compression Ignition
Admission of air	Naturally aspirated
Bore / Stroke	80 mm / 110 mm
Compression ratio	16.5:1
Max power	3.72 kW
Rated speed	1500 rpm
Dynamometer	Eddy Current Dynamometer

Fig. 3. Exhaust Gas Analyzer

Table II
Exhaust gas analyzer specifications

Exhaust Gas Analyzer make and model: INDUS make and PEA 205		
Type of Emission	Range	Resolution
NO_X (ppm)	0-5000	1
HC (ppm)	0-15000	1
CO (%)	0-15.0	0.01

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Table III
Properties of fuels

Property	**Unit**	**PD**	**CSBD**	**ASTM Standards**
Density	g/cc	0.831	0.879	0.87-0.89
Kinematic Viscosity at 40^oC	cSt	2.58	4.7	1.9-6.0
Flash Point	^oC	50	165	130 minimum
Calorific value	kJ/kg	42500	38175	37500

4. RESULTS AND DISCUSSIONS

PD [diesel fuel], CSBD10 [10% CSBD + 90% PD by volume], CSBD20 [20% CSBD + 80% PD by volume] and CSBD30 [30% CSBD + 70% PD by volume] fuels were used to run the engine in this work. The different EGR rates ranging from 0% to 20% in steps of 5% were consider for current study. 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 NO_X, HC, CO with EGR are discussed as follows.

4.1 Brake Specific Fuel Consumption (BSFC)

Fig. 4 indicates the variation of BSFC for all fuels with EGR. From the figure it is observed that at lower EGR rates the BSFC is fairly independent. BSFC slightly increases with EGR rates above 15%. This may be due to the fact that the formation of rich mixture because of less oxygen availability.

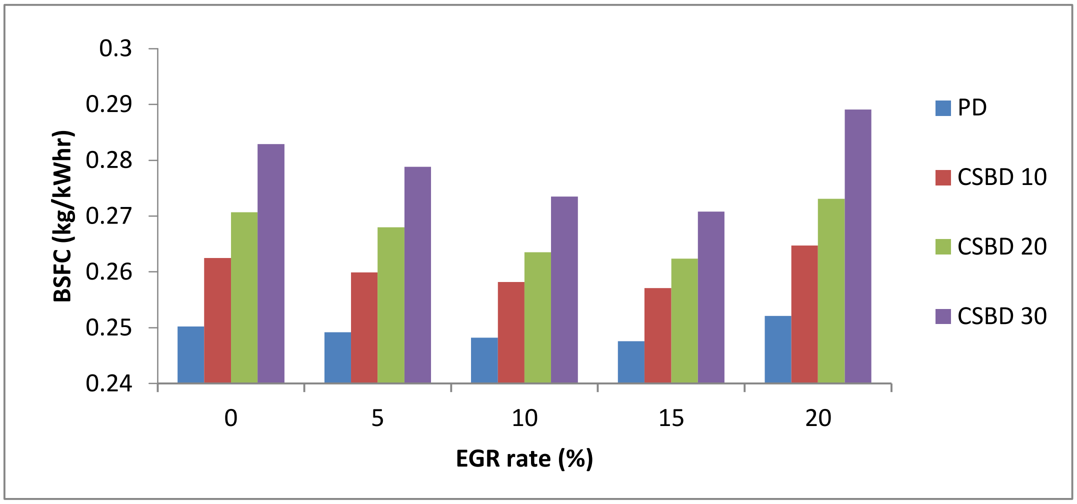

Fig. 4. Variation of BSFC emission with EGR

4.2 Brake Thermal Efficiency (BTE)

The variation of BTE with EGR for all fuels with EGR is shown in fig. 5. It is clear that the BTE remains unaffected by EGR at lower rates and full load. At EGR rates above 15%, the BTE tends to decrease slightly. This may be due to fact that the amount of fresh oxygen available for combustion gets decreased due to replacement of air by exhaust gas.

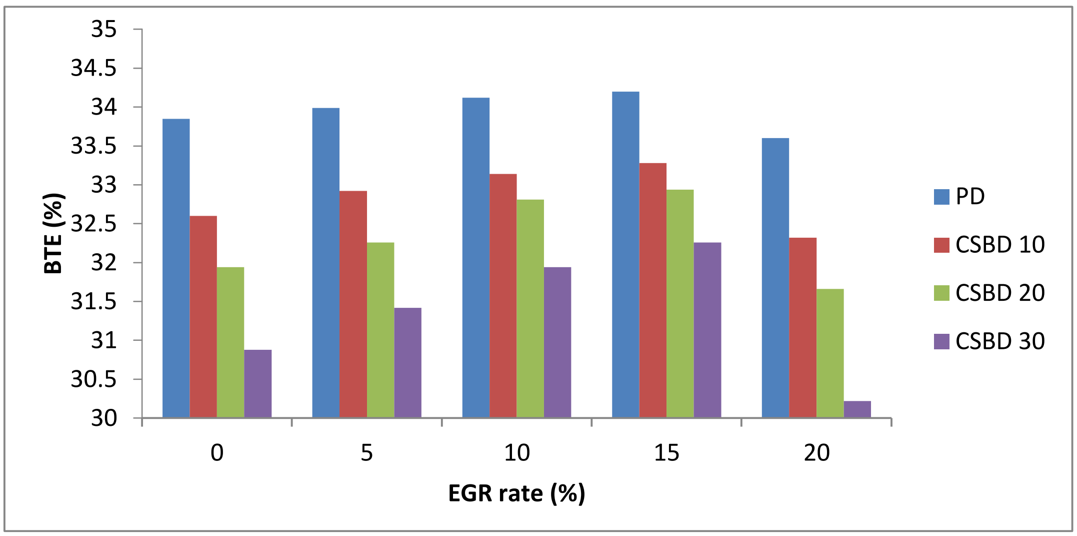

Fig. 5. Variation of BTE emission with EGR

4.3 Exhaust Gas Temperature (EGT)

The effect of EGR on Exhaust Gas Temperature for all fuels at full load is shown in fig.6. 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. The decrease in exhaust gas temperature is observed continuously with increase in EGR rates even above 15%.

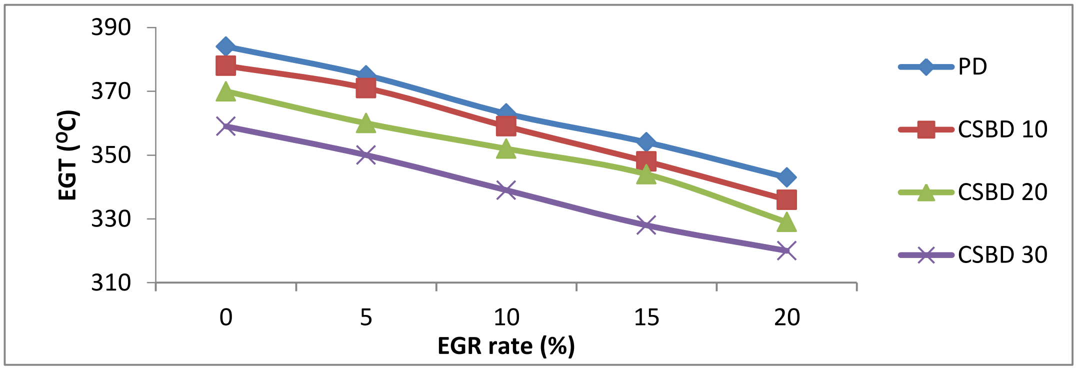

Fig. 6. Variation of EGT emission with EGR

4.4 NO_X Emission

The main benefit of EGR in reducing NO_X emission from CI engine is shown in Fig.7. Significant reduction of NO_X emission for all fuels is observed with EGR. The reasons for the reduction in NO_X 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 NO_X emission reduction may be more at higher loads compared to part loads. The reduction of NO_X emission is mainly due to decrease in incylinder temperature during combustion process because of less oxygen availability. At very high EGR rates NO_X 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 NO_X 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 NO_X reduction is required. Hence from the study 15% EGR rate is observed as limit for the tested engine.

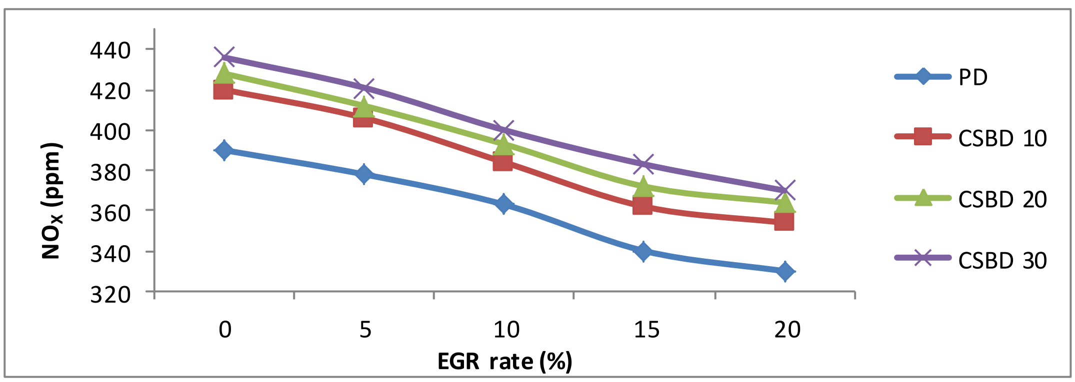

Fig. 7. Variation of NO_X emission with EGR

4.5 HC emission

The variation of unburnt HC emission of diesel and CSBD blends with EGR is shown in Fig.8. The HC emission increases with EGR rates for all fuels. Significant increase in HC emission is observed with EGR rates above 15%. Because of availability of lower oxygen for combustion results rich mixture which results incomplete combustion leads higher HC emission in exhaust.

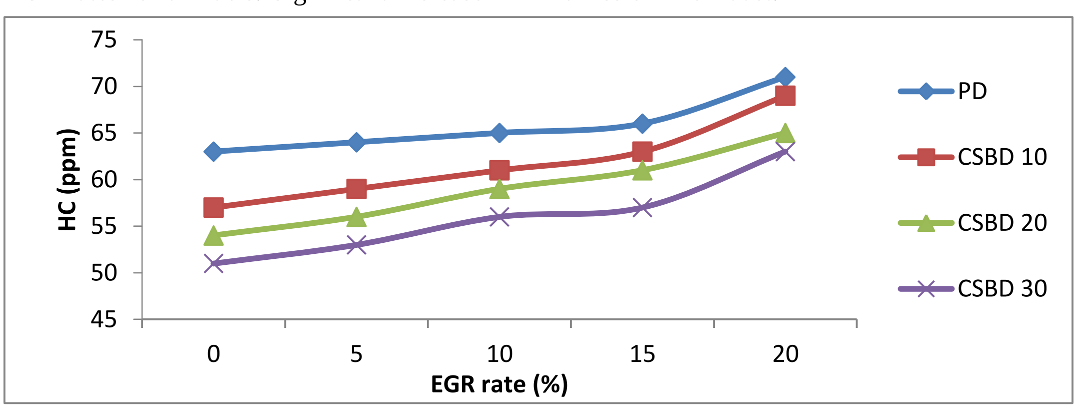

Fig. 8. Variation of HC emission with EGR

4.6 CO emission

Fig.9 shows the variation of CO emission of PD, CSBD10, CSBD20 and CSBD30 fuel with EGR rate at full load condition. The CO increases with increase in EGR rates. At higher EGR rates CO emissions are comparatively more because of lower availability of oxygen due to EGR leads to incomplete combustion results in increase of CO emission.

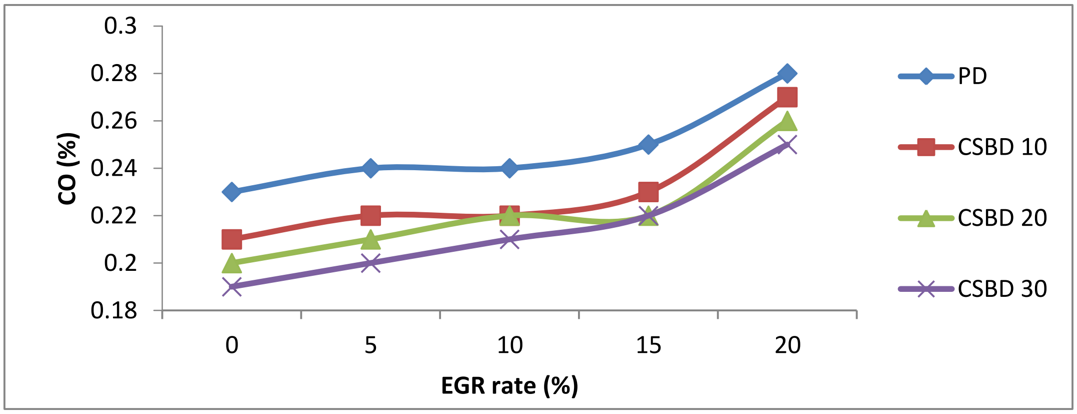

Fig. 9. Variation of CO emission with EGR

5. Conclusions

The lowest BSFC was obtained for all blends at 15% EGR. BSFC increases with increase of EGR rate above 15% because of formation of rich mixture due to insufficient oxygen supply. Increase of EGR rate up to 15% increases the BTE slightly. Further increase in EGR rate above 15% decreases BTE. At lower EGR rates the unburnt HC present in exhaust gets burned completely leads reduction in fuel consumption thereby increased BTE. EGR rates above15% cause less availability of fresh oxygen for combustion results in decrease of BTE. The highest BTE was obtained at 15% 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 NO_X emission with EGR. NO_X emission decreases with increase of EGR rate for all blends. HC and CO emission show same trend of increase with increase of EGR rate, however the rate of increase was observed more for EGR rates above 15%.

The EGR rate 15% shows better performance and lower NO_X emission. All blends at 15% EGR exhibited better characteristics compared to diesel at 0% EGR. Hence the problem of higher NO_X emission with biodiesel blends can be reduced with suitable EGR rates.

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