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EFFECT OF EXHAUST GAS RECIRCULATION ON PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINE FUELED WITH WASTE COOKING OIL METHYL ESTER

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ABSTRACT

In Compression Ignition engines, formation of NO_X is highly temperature dependent phenomenon and takes place when the temperature in the combustion chamber is very high (exceeds 2000 K). The problem of NO_X emission is also high when diesel engines are operated with biodiesel due to availability of more Oxygen. Therefore in order to reduce NO_X emission in the exhaust, it is necessary to keep peak combustion temperature under control. One simple way of reducing the NO_X emission of compression ignition 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. An experimental investigation was conducted to study the effect of Exhaust Gas Recirculation on diesel engine Performance and Emission characteristics fueled with Waste Cooking 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. Waste Cooking Oil Methyl Ester produced by Transesterificaton process was used to operate the engine. The different EGR rates ranging from 0% to 20% in steps of 5% for waste cooking oil methyl ester blends with diesel fuel were consider for the study of various Performance and Emission characteristics. 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.

Keywords: Exhaust Gas Recirculation (EGR), NO_X, Performance, Emission, WCOME.

1. INTRODUCTION

Stringent emission legislation has been made on NO_X emissions emitted from automotive diesel engines worldwide over past few years. Since fossil fuels are depleting day by day, there is a need to find out an alternative fuel to fulfil the energy demand of the world. Biodiesel is one of the best available substitute sources in place of diesel fuel. Diesel engines are typically characterized by low CO and HC emission when fueled with biodiesel, but the problem of NO_X emission is still remain high. 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.

1.1 Mechanism of NO_X formation

The major issue in understanding the mechanism of formation of NO_X and controlling is that combustion is highly heterogeneous in compression ignition engines. NO and NO_2 are lumped together as NO_X and there are some distinctive differences between these two pollutants. Both gases are considered toxic, but NO_2 has level of toxicity greater than that of NO.

NO is formed during the post flame combustion process in a high temperature region. The most widely accepted mechanism was suggested by Zeldovich[1]. The principle source of NO formation is the oxidation of nitrogen present in atmosphere air. The nitric oxide formation reactions are initiated by atomic oxygen, which forms from the dissociation of oxygen molecules at the high temperatures during the combustion process. The principle reactions governing in formation of NO are

$N_2 + O$ ------> $NO + N$,
$N + O_2$ ------> $NO + O$,
$N + OH$ ------> $NO + H$.
NO formed in the flame zone can be rapidly converted to NO_2 as
$NO + HO_2$ ------> $NO_2 + OH$
Subsequently, conversion of this NO_2 to NO occurs via
$NO_2 + O$ --------> $NO + O_2$

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.

1.2 EGR technique for NO_X reduction

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

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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

The popular explanations for the effect of EGR on NO_X reduction are increased heat capacity, dilution of the intake charge and ignition delay. The increased heat capacity has the effect of lowering the peak combustion temperature due to non-reacting matter present during combustion. According to dilution theory, the effect of EGR on NO_X is caused by increasing amount of inert gas in the mixture reduces the adiabatic flame temperature [14]. The ignition delay hypothesis asserts that became EGR causes an increase in ignition delay, it has same effect as retarding the injection timing.

1.3 Classification of EGR

EGR have been classified based on the temperature as

1.3.1 Hot EGR: Exhaust gas is circulated without being cooled, resulting in increased intake charge temperature.

1.3.2 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.

1.3.3 Partly cooled EGR: To avoid water condensation, the temperature of the exhaust gas is kept just above its dew point temperature.

2. LITERATURE

K Srinivasa Rao*et al*. [15, 16] studied diesel engine performance and emission characteristics using corn biodiesel and chicken fat biodiesel. They observed higher NO_X emissions with these biodiesels compared to petroleum diesel. Ghazikhani*et al*. [2] 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. Machocon*et al.* [3] studied effect of EGR with O_2 enrichment on the exhaust emission of diesel engine. They concluded that higher EGR with O_2 enrichment gives lower NO_X emissions and smoke. Avinashkumar*et al*. [4] studied the effect of EGR on exhaust gas temperature and exhaust opacity in CI engines. They found that the exhaust gas temperature reduce drastically by employing EGR. Thermal efficiency and brake specific fuel consumption are not affected significantly by EGR. Shahadat*et al*. [5] studied the combined effect of EGR and inlet air preheating on engine performance and emission in diesel engine. They found that at medium load conditions, NO_X, CO and bsfc decreased when inlet air preheating and EGR were applied together as compared to those during normal operation of the engine. Mahla*et al*. [6] studied the effect of EGR on performance and emission characteristics of natural gas fueled diesel engine. Their experimental result show that the application of EGR substantially NO_X, CO and smoke. Rajan and senthilkumar [7] studied the effect of EGR on performance and emission characteristics of diesel engine with sunflower oil methyl ester. They observed that B2O blend with 15% EGR rate possess 25% less NO_X emission compared to diesel fuel.

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. Kasaka*et al*. [9] found that at low loads EGR combined with intake heating can favourably reduce HC emission with improvement in thermal efficiency. Salim [10] operated the diesel engine in dual fuel mode with natural gas and found inferior performance and emissions at low loads. EGR was found to be a method of improving engine performance and emission of such engine, however application of EGR leads to penalties. In case of diesel engine these penalties include higher specific fuel consumption and particulate matter emissions. Effectively a trade-off between NO_X and particulate matter is observed with the use of EGR [11-13].

3. 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 Waste Cooking Oil Methyl Ester (WCOME) blends with diesel by volume 0%(B0), 10%(B10), 20%(B20) and 30%(B30). 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.

4. EXPERIMENTAL SETUP

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

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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 Figures 1 and 2. The technical specifications of the engine are given in Table-1.

Figure-1. Engine.

Figure-2. EGR set up.

Table-1. 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

Digital control panel was used to collect the required engine data. INDUS make model 205 exhaust gas analyzer is used to investigate emission characteristics. Carbon mono oxide (CO), Hydro carbon (HC), oxides of nitrogen (NO_X), Carbon dioxide (CO_2) and oxygen (O_2) emissions can be measured using exhaust gas analyzer. The analyzer uses the principle of Non-Dispersive Infra-Red (NDIR) for measurements. Figure-3 shows the exhaust gas analyzer used for this investigation. The technical specifications of exhaust gas analyzer are given in Table-2. Waste cooking oil methyl ester (WCOME) produced by Transesterification process was used to run the engine for this study. The properties of WCOME, diesel fuel and ASTM standards are given in Table-3.

Table-2. 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

Figure-3. Exhaust gas analyzer.

Table-3. Properties of fuels.

Property	**Unit**	**PD**	**WCOME**	**ASTM Standards**
Density	g/cc	0.831	0.88	0.87-0.89
Kinematic Viscosity at 40ºC	cSt	2.58	5.75	1.9-6.0
Flash Point	ºC	50	162	130 minimum
Calorific value	kJ/kg	4250 0	39620	37500

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5. RESULTS AND DISCUSSIONS

B0 [diesel fuel], B10 [10% WCOME + 90% diesel by volume], B20 [20% WCOME + 80% diesel by volume] and B30 [30% WCOME + 70% diesel 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 fueled with waste cooking oil methyl ester blends with diesel. The variation of performance characteristics BSFC, BTE, EGT and emission characteristics NO_X, HC, CO with EGR are discussed as follows.

5.1 Brake Thermal Efficiency (BTE)

The trends of BTE for B0, B10, B20 and B30 fuels with EGR are shown in Figure-4. At full load and lower EGR rates, it is clear that the BTE remains unaffected by EGR. 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 by exhaust gas.

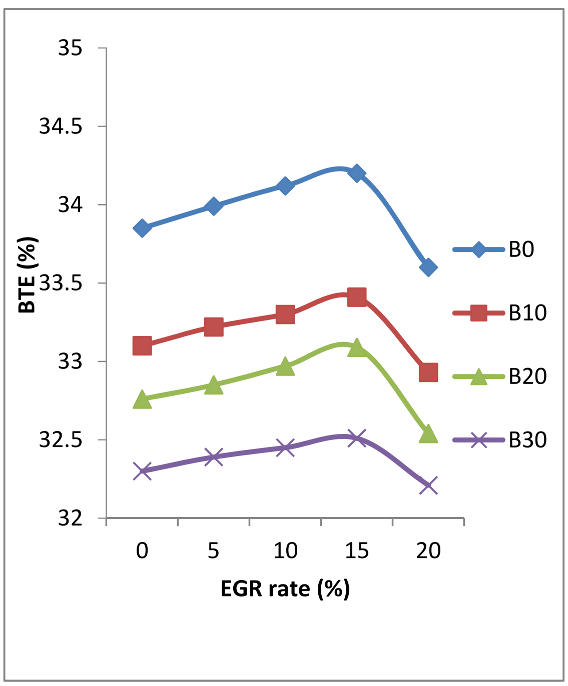

Figure-4. Variation of BTE with EGR.

5.2 Brake Specific Fuel Consumption (BSFC)

The variation of BSFC for all fuels with EGR is shown in Figure-5. It is observed from this graph that the BSFC is fairly independent of EGR at lower rates. 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.

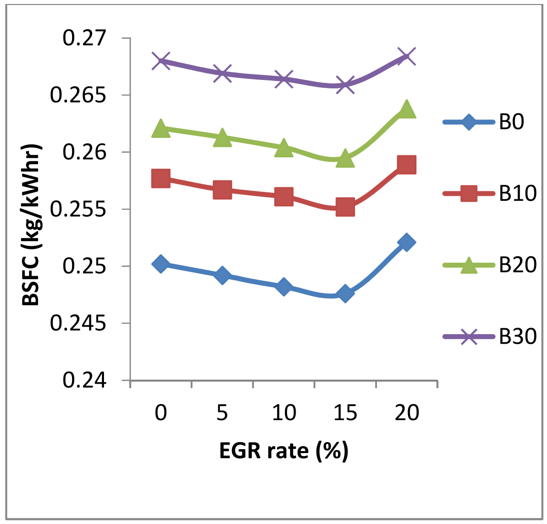

Figure-5. Variation of BSFC with EGR.

5.3 Exhaust Gas Temperature (EGT)

The variation of Exhaust Gas Temperature with EGR is shown in Figure-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. The reasons for exhaust gas temperature reduction are relatively lower availability of oxygen for combustion and higher specific heat of intake air mixture.

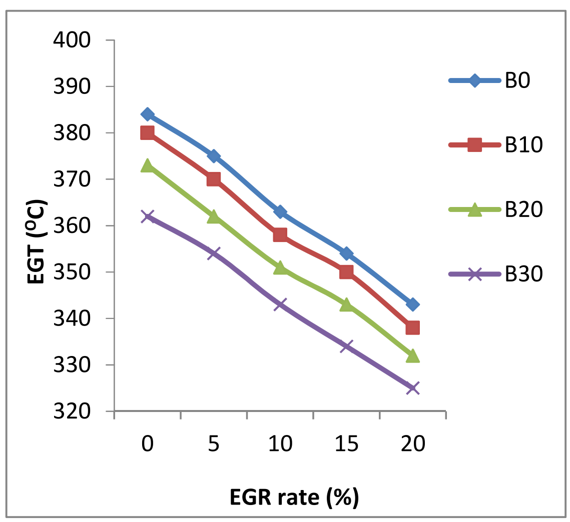

Figure-6. Variation of EGT with EGR.

5.4 NO_X emission

Figure-7 shows the main benefit of EGR in reducing NO_X emission from CI engine. NO_X emission decreases significantly with EGR rates for all fuels. The reasons for the reduction in NO_X emission using EGR in CI engines are reduced oxygen concentration and

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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.

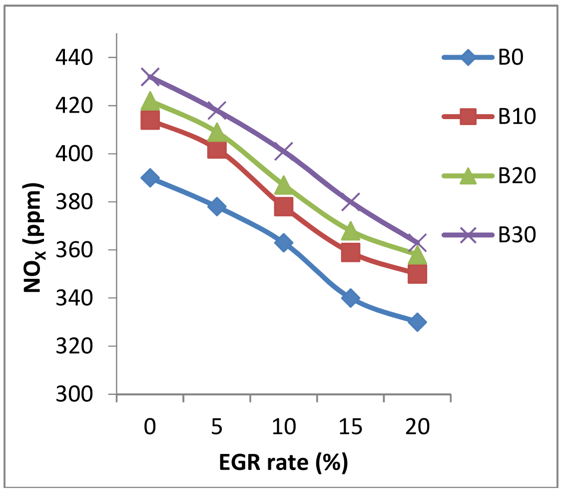

Figure-7. Variation of NO_X emission with EGR.

5.5 HC emission

Figure-8 shows the variation of unburnt HC emission of diesel and WCOME blends with EGR. The HC emission increases with EGR rates. 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.

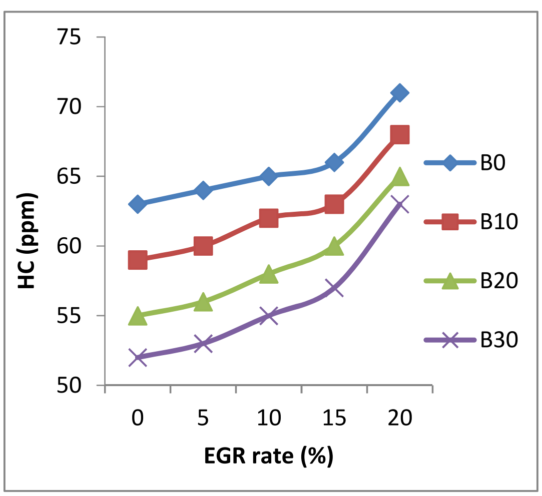

Figure-8. Variation of HC emission with EGR.

5.6 CO emission

Figure-9shows the variation of CO emission of B0, B10, B20 and B30 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.

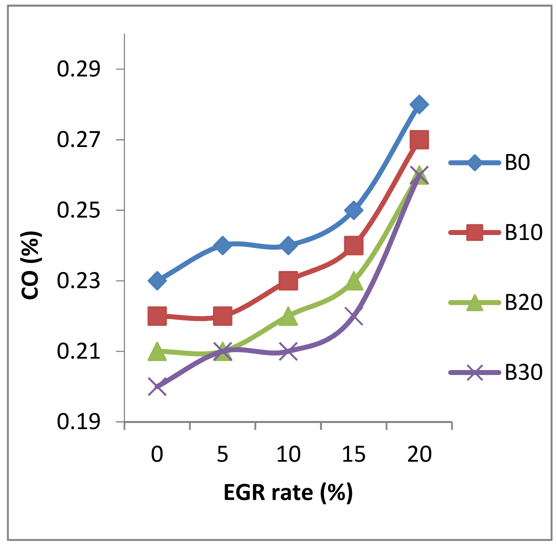

Figure-9. Variation of CO emission with EGR.

6. CONCLUSIONS

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 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.

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 above 15% EGR rate.

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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