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Case Study of Exhaust Gas Recirculation on Engine Performance

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Abstract: *Exhaust gas recirculation (EGR) is a designed widely used system to reduce the exhaust emissions, particularly nitrogen oxides (NOx). The EGR system recirculates a fraction of exhaust gases into the intake manifold where it mixes with the fresh incoming charge. In Compression Ignition engines, formation of NO_X is highly temperature dependent phenomenon and takes placewhen the temperature in the combustion chamber is very high (exceeds 2000 k). An experimental investigation was conducted to study the effect of Exhaust Gas Recirculation on diesel engine Performance.*
Keywords: *Petrol and Diesel engine, EGR, NOx emissions, engine performance, and emission analysis.*

I. Introduction

The emission problem is one of the most interesting challenges in automotive technology and it is reached at alarming level. Stringent emission legislation has been made on NO_X emissions emitted from automotive diesel engines worldwide over past few years. Because exhaust pollutants emitted to atmosphere by automobiles are the serious hygienic and environmental risk and the main source of air pollution.In internal combustion engines, NOx formation is temperature dependent phenomenon and takes place when the temperature of the charge in the engine combustion chamber exceeds 2000 K[1]. Over past few years, stringent emission regulations have been imposed on NOx, smoke and particulate emissions emitted from automotive diesel engines worldwide. Diesel engines are typically characterized by low fuel consumption and very low CO emissions. However, the NOx emissions from diesel engines still remain high. Hence, in order to meet the environmental regulations, it is highly desirable to reduce the amount of NOx in the exhaust gas.To reduce NOx emission in the exhaust, it isnecessary to keep combustion temperature under control. Exhaust gas recirculation is the effective technique for nitrogen oxides reduction.The literature surveyshows many studies of the various effects of EGR on NOx emissions on internal combustion engines.

II. Definition of exhaust Gas Re-Circulation

In exhaust gas recirculation process, a fraction of the engine out exhaust gas is re-circulated to the engine. Oxides of nitrogen are formed when the temperature inside the combustion chamber exceeds the critical temperature so that the molecules of nitrogen and oxygen combine. Inter-mixing the incoming air with re-circulated exhaust gas basically cuts off some percentage of the oxygen going into the combustion chamber and lowers the adiabatic flame temperature. The exhaust gas increases the specific heat of the mixture and lowers the peak combustion temperature. NOx formation progresses faster at higher temperatures. EGR serves to limit the formation of NOx [2]. There is no doubt that EGR is very effective in reducing oxides of nitrogen, but it also has adverse effects on the engine efficiency. As it contains a lot of particulate matter, it may also contaminate the lubricating oil and can also foul the intake manifold. Intermixing the incoming air with re-circulated exhaust gas, lowers the adiabatic flame temperature and reduces the excess oxygen. The exhaust gas increases the specific heat of the mixture and lowers the peak combustion temperature. NOx formation progresses faster at higher temperatures. EGR serves to limit the formation of NOx.

2.1 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 somedistinctive 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 [3]. 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.

$O + N_2 = NO + N$
$N + O_2 = NO + O$
$N + OH = NO + H$

2.2 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 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 ofEGR on NO_X is caused by increasing amount of inert gas in the mixture reduces the adiabatic flame temperature. The ignition delay hypothesis asserts that became EGR causes an increase in ignition delay, it has same effect as retarding the injection timing.

2.3 Experimental Setup-

An experimental investigation was carried out to investigate the influence of exhaust gas recirculation on the performance and exhaust emission of a diesel engine. The engine used for the investigation was computerized single-cylinder, four-stroke, and water cooled diesel engine with eddy current dynamometer. The technical specifications of the engine are given in Table I, and the schematic of the experimental setup is shown in Figure 1. The power output of the engine was measured by an electrical dynamometer. AVL gas analyzer was used for the measurement of amounts of exhaust emissions. For smoke opacity measurement AVL smoke meter was used. Rota meters were used to measure the volume flow rates of inlet charge as well as exhaust gas to be re-circulated. Digital control panel was used to collect data such as torque, water flow of engine etc. A known quantity of exhaust gas with air was re-circulated into the combustion chamber and was performed with manually controlled EGR valve. The exhaust gas that came out from the engine was at very high pressure and temperature [4]. The measurements were taken after steady state of the engine for each set of readings.

III. Indentations And Equations

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Where –

$C_{p/a}$: the specific heat of air at constant pressure

$C_{p/EGR}$: the specific heat of recycled exhaust gases at constant pressure

$C_{p/m}$: the specific heat of the mixture of air and recycled exhaust gases at constant pressure t_a: the temperature of fresh air

t_m: the temperature of mixture

t_{EGR}: the temperature of recycled exhaust gases

The values of specific heats were calculated and then the percentage of recycled exhaust gases was determined.

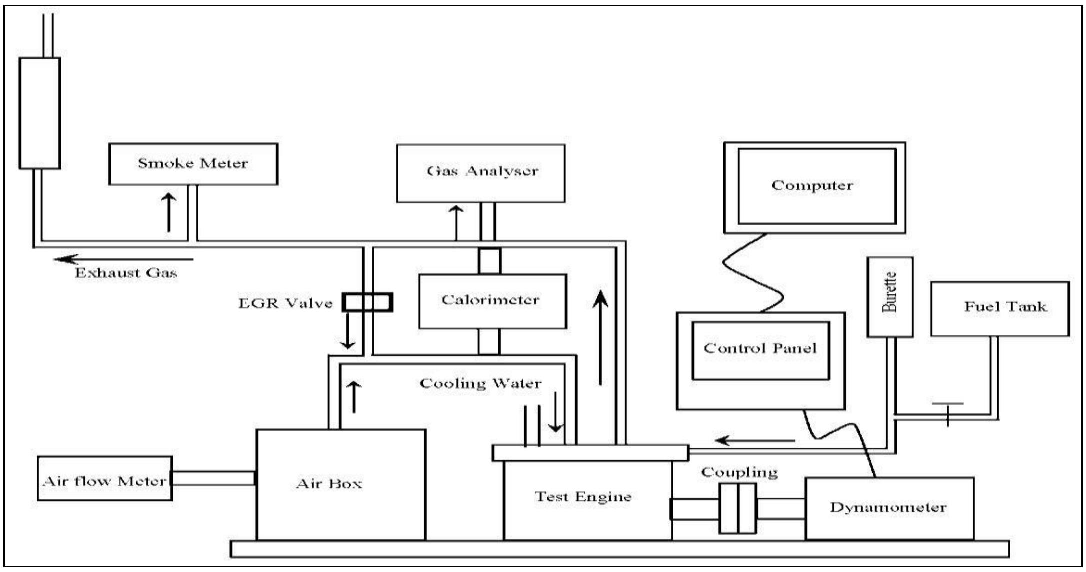


Fig.1: Schematic of Experimental Setup

Table1. Engine specifications

Type of engine	Water cooled Four stroke
Number of cylinder	one
Bore	87.4mm
Stroke	110mm
Compression ratio	17.5:1
Rated speed	1500 rpm
Maximum Power	5.2kW(7hp)
Maximum torque	30N-m

Table-2: Properties of Test fuels

Properties	Diesel
Fuel Density (kg/m3)	835.8
Low heating value (kJ/kg)	42500
Cetane number	48

IV. Result and Discussion

The experiment was carried out in a four stroke single cylinder, water cooled diesel engine at 1500 rpm and different EGR rates to study the effect of EGR on the performance of the engine like brake thermal efficiency and specific fuel consumption and emission characteristics also for NOx concentration Higher amount of smoke emission is observed in the exhaust 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 [6]. Also, biodiesel with EGR can be used to reduce NOx and smoke intensity simultaneously.

V. Brake Thermal Efficiency

The bellow graph shows the variations of brake thermal efficiency with brake power of diesel engine. It is observed from the figures that the brake thermal efficiencies are increased with increase in load with or without EGR at lower load. This is due to re-burning of hydrocarbons that enter in to the combustion chamber during suction with the re-circulated exhaust gases. At full load operation the brake thermal efficiency marginally decreases.

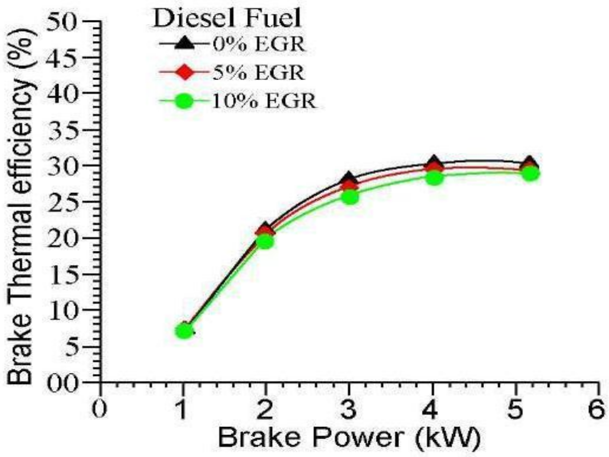


Fig.2: Variation of brake thermal efficiency with brake power

1. Specific fuel consumption

The bellow graph shows the variations of Specific fuel consumption with brake power for diesel engine at constant speed of the engine. The specific fuel consumptions are lower for diesel at all loading conditions when operated with EGR, However, at higher loads of the engine, Specific fuel consumption with 10% EGR is almost same to that of without EGR for diesel fuel.

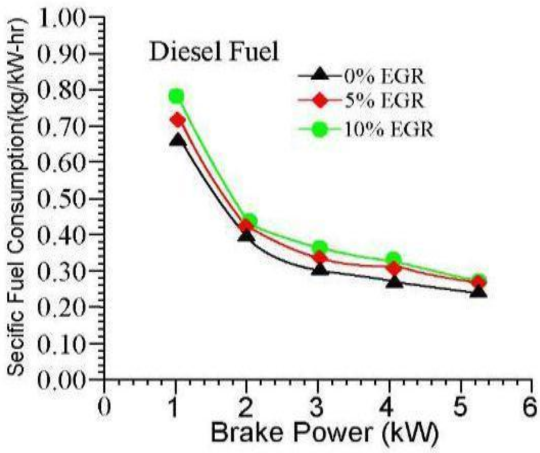
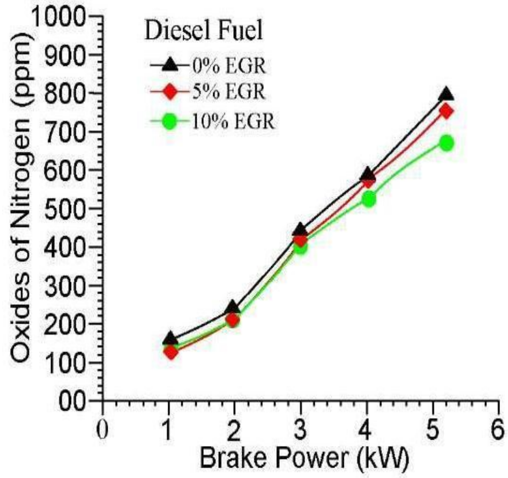


Fig.3: Variation of Specific Fuel Consumption with Brake Power

1. Oxides of nitrogen emission (NOx)

The variations of NOx emissions with brake power of diesel fuel are shown bellow at constant speed of the engine. The emission of NOx tends to decrease significantly with the increase of EGR rate for all loading conditions due to reduction of oxygen concentration for the presence of inert gases that decreased the flame temperatures in the combustion chamber. From the figure it is observed that maximum NOx reduction occurs with 10% EGR.



VI. Conclusion

It can be concluded from the measured results the effect of EGR on the performance and exhaust emissions of the diesel engine were analyzed. The results of this study may be concluded as follows:

[1] Brake thermal efficiencies are increased with increase in load with or without EGR at lower load.

[2] The specific fuel consumptions are lower for diesel at all loading conditions when operated with EGR and vice versa.

[3] The increase of EGR flow rates resulted in considerable rise in smoke and HC emissions for both net diesel fuel.

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