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"Experimental Investigation on Engine Performance and Emissions of A Four Cylinder Diesel Engine using Hot and Cooled Exhaust Gas Recirculation."

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***Abstract*:- The aim of this work is to study the potential of exhaust gas recirculation (EGR) to reduce the exhaust emissions, particularly NO_x, and PM. The work describes the application of Exhaust Gas recirculation technique for diesel engines for reduction in engine emissions and to upgrade the engine from current emission norms to much better one. The detailed analysis of various configurations of the EGRs (with and without EGR cooler) were studied and then these EGRs were tested and suitable EGR was suggested. From the analysis it was found that the dual requirement of drastic reduction in NO_x emissions and improved fuel consumption, it is clearly found that Exhaust Gas recirculation(EGR) promises to be a good alternative capable of having relatively high effect on the NO_x reduction. It was also found that cooling the exhaust gas further proves to be more beneficial and is to believed to be most effective in improving exhaust emissions.**

INTRODUCTION:

The diesel engine has been in use for over a hundred and twenty years. Since then the progress of diesel engines for commercial vehicle was impressive, as being the most efficient internal combustion engines. The rise in population of the diesel engine in light-duty applications has invariably raised public awareness and led to increase concerns about its pollutant emissions, particularly nitric oxides (NO_x) and Particulate Matter (PM) emissions. After relaxed limits imposed on diesel in the early 2000s, the European commission, as well as the environmental Protection Agency (EPA), are now imposing much stricter limits for light duty applications through EURO 5/6.

It has been most difficult and challenging task for engineers and manufacturers of diesel engine the control and reduction of these pollutants to acceptable limits as the norms getting more stringent day by day. There has been significant improvement in diesel engine pollutants control since past decades but at the same time more stringent norms are imposed by relevant legislations as in EURO-V. Diesel engines are widely used for transport applications in addition to it in stand-by power applications, electrical power generation which has led to tremendous increase in air pollution and other ill effects such as Los Angeles smog problem. These exhaust emissions affect both ecology and human health and reduction of emissions from these engines is necessary for better future.

There are very advanced combustion technologies and/or after treatment such as turbo charging and inter-cooling, high pressure fuel injection, electronic timing and fuel control, water injection, catalytic conversion but each having some pros and cons. The only possibility to meet stringent norms and for attaining lower emission levels is to combine available technologies and Exhaust gas recirculation [1]. Exhaust gas recirculation promises to be a good alternative capable of having relatively high effect on the NO_x reduction [2].

An experimental analysis has therefore been carried out in this work in order to access Exhaust gas recirculation potential for a diesel engine.

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EXHAUST GAS RECIRCULATION AND NO_X FORMATION:

Exhaust gas recirculation has been widely applied in diesel engines for reduction of NO_x formation. The exhaust gas recirculation refers to introduction of exhaust gas into engine along with fresh inlet air. The addition of diluents to the intake charge decreases peak combustion temperature and NO_x formation. The heat capacity of exhaust gas is higher than air as it contains significant amount of tri-atomic gases such as CO_2 and water vapors. Dilution of fresh intake charge by EGR combined with exhaust residual gases left in the cylinder form previous cycle decreases the combustion temperatures. Burnt gas temperatures are further reduced due to lower combustion rates resulting with addition of exhaust gas to intake charge. Use of EGR also reduces mass fraction of O_2 in the cylinder as the exhaust gas replaces part of air. All these factors cause reduction in NO formation.

NOx FORMATION:

While nitric oxide (NO) and nitrogen dioxide (NO_2) are usually grouped together as NO_x emission, nitric oxide is the predominant oxide of Nitrogen produced inside the engine cylinder. The principal source of NO is the oxidation of atmospheric (molecular) Nitrogen. However if the fuel contains significant nitrogen, the oxidation of the fuel nitrogen containing compounds is an additional source of NO.

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Four different mechanisms lead to the formation of nitrogen oxide in combustion system.

(1) *Thermal NO*: Is formed at high temperature under slightly lean conditions within the burned products. The involved nitrogen and oxygen come from the combustion air.

(2) *Prompt NO*: This describes the reaction of N_2 from combustion air with hydrocarbon radicals in fuel rich regions. Because of the need of the HC radicals this path is followed directly within the reaction zone.

(3) *Fuel NO*: This refer to the formation of NO from fuel bound nitrogen

(4) *Nitrogen Intermediate*: This route is activated at lower temperatures than the thermal NO in a fuel lean and high-pressure environment. (Important for gas turbine and minor effect on diesel combustion)

It is widely accepted that within diesel engine the major fraction of NO is formed via thermal path. The prompt NO, fuel NO and intermediate N_2O are hardly accounted for in combustion engine modeling, because they only contribute to negligible amounts of Nitrogen Oxides anyway.

*Thermal NO***:** The thermal formation of nitric oxide is described by the so-called extended Zeldovich mechanism. It describes the breakup of nitrogen molecule by an oxygen atom and subsequent oxidation of the Nitrogen atoms.

$$N_2 + O = NO + N \qquad \textit{Eq. 3.1}$$

$$N + O_2 = NO + O \qquad \textit{Eq. 3.2}$$

$$N + OH = NO + H \qquad \textit{Eq.3.3}$$

EGR EFFECT ON COMBUSTION AND NOx CONTROL THEORY:

The decrease in NOx emission is result of following effects of EGR:

- The thermal effect: Increase of inlet heat capacity due to higher specific heat capacity of recirculated CO_2 and H_2O compared with O_2 and N_2 (at constant boost pressure) resulting in lower gas temperatures during combustion, and particularly in a lower flame temperature .
- The dilution effect Decrease of inlet O_2 concentration, whose principal consequence is the deceleration of the mixing between O_2 and fuel resulting in the extension of flame region. Thus, the gas quantity that absorbs the heat release is increasing, resulting in a lower flame temperature
- The chemical effect: The recirculated water vapor and CO_2 are dissociated during combustion, modifying the combustion process and the NO_x formation. In particular, the endothermic dissociation of H_2O results in a decrease of the flame temperature.

An increase of the ignition delay: is generally observed, so that the premixed part of combustion is higher; without EGR, it may increase NO_x emissions, but, in the presence of EGR, the rate of heat release (ROHR) premixed peak is lower, so that it would reduce NO_x emissions [3].

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NOx REDUCTION THEORY:

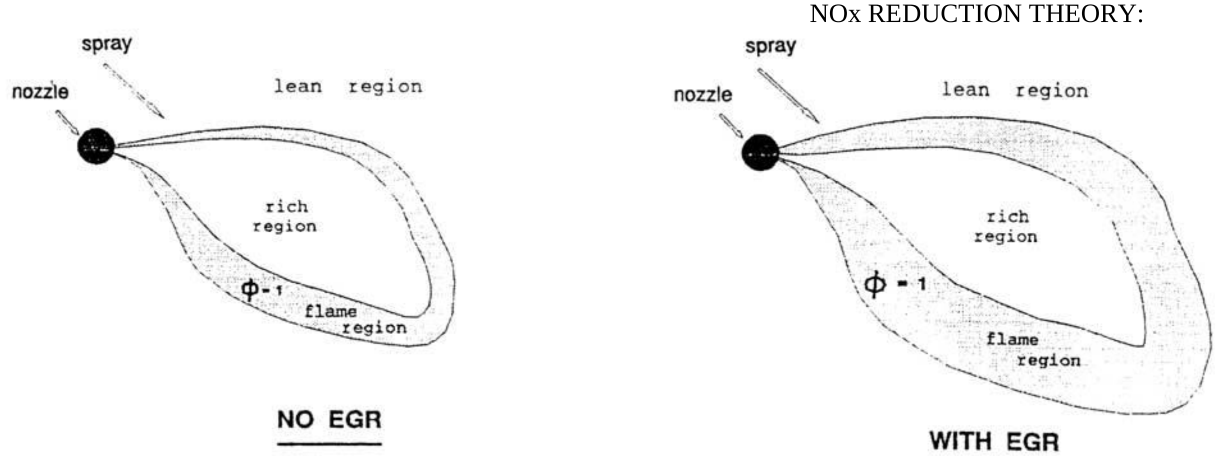

Figure 1: Theory of NO_x reduction by EGR

A possible explanation for NO_x reduction can be given by previous studies [1, 5]. Firstly, the assumption is made that the combustion takes place in regions where the air fuel ratio is at stoichiometric proportions, as shown in above figure. On using EGR, some of the O2 in the cylinder contents is replaced by CO2, and the local O2 concentration in the cylinder becomes lower. With the local O2 concentration reduced, given amount of fuel will have to diffuse over a wider area before sufficient O2 concentration is encountered for a stoichiometric mixture to be formed. Now for a given amount of fuel, this larger region of stoichiometric mixture contains not only the stoichiometric mixture but also additional quantity of CO2, H2O and N2. The addition amount of these gases absorb energy released by combustion, leading to lower flame temperature and lower NO_x generation.

EXPERIMENTAL SETUP:

The engine used for the experiment is four stroke, water cooled, four cylinder, direct injection diesel engine. The engine was tested for performance and emissions of the Exhaust gas recirculation system to generate the data required. An eddy current dyno was used for load application and accordingly it was varied as required. Various arrangements for temperature sensors for gas and water inlet and outlet temperatures were provided on the EGR routing piping. Similarly arrangements for water and gas pressure difference were made. The water used for cooling the engine was circulated through external heat exchanger. . A combustion air handling unit was used to maintain the test conditions as per ISO8178 test standards. A portable HORIBA emission analyzer was used to measure the NO_x emissions. PM emissions are measured by using AVL Smart Sampler system.

Table 1: Technical specifications of engine.

Engine Type	4-Cylinder, DI
Displacement	2596.00 CC
No. of cylinders	4
Aspiration	Without turbocharged
Maximum Power	61 HP @ 3200 RPM
Maximum Torque	158 NM @ 2000 - 2200 RPM

RESULTS AND CONCLUSIONS:

The experiment was carried out to experimentally evaluate the performance and emission parameters such as oxides of nitrogen, carbon monoxide, BSFC, reduction in air fuel ratio. The reading where taken on without EGR engine, with Hot EGR and with cooled EGR. The results of all three configurations were plotted on a single graph for comparison.

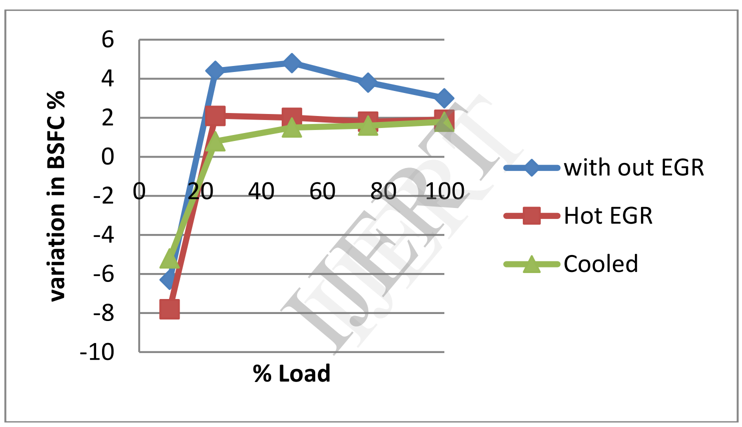

Figure 2: Variation in BSFC for without EGR, Hot EGR &Cooled EGR

Figure represents comparison of BSFC for all setups. It was found that the BSFC is lower at lower loads for engine operated with EGR compared to without EGR. Further cooling the EGR, the BSFC lowers a bit as compared to Hot EGR. However, at high engine loads, BSFC with EGR and cooled EGR approaches to similar value to that of without EGR. At high loads, amount of fuel supplied to the cylinder is increased at higher rate and Oxygen available for combustion gets reduced. Thus, air fuel ratio is changed and thus increases BSFC.

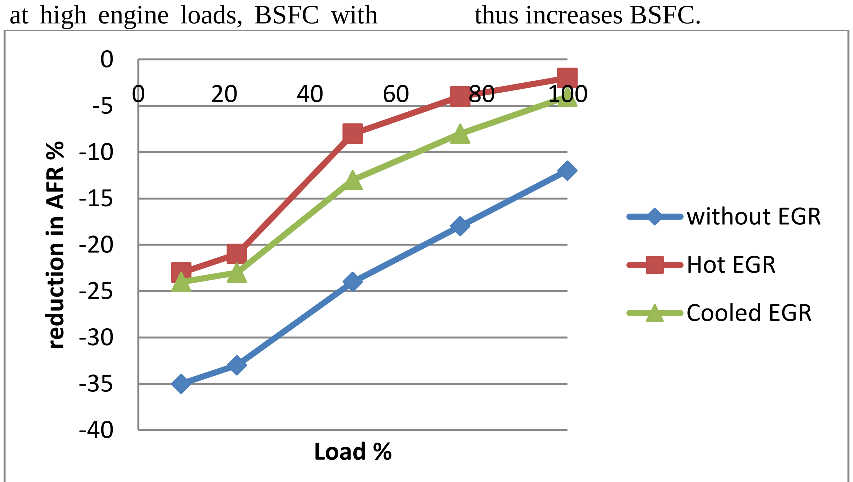

Figure 3: Reduction in Air Fuel ratio for without EGR, Hot EGR &Cooled EGR

Figure shows the variation in air fuel ratio, with the use of EGR there has been reduction in air fuel ratio as compared to with EGR system. It has been found that there is about 30% reduction in air fuel ratio when exhaust gas recirculation system is used. The Thus, air fuel ratio is changed and thus increases BSFC. There is not much reduction difference in air fuel ration between Hot and Cooled EGR. The difference value in this case is about 4% to 6 %.

Figure shows the main benefit of EGR that is reduction in NO_x compared to baseline diesel engine. It shows that reduction of NO_x at higher loads is higher. It has been found that the part load, O_2 is available in sufficient quantity but at high loads, O2 reduces drastically, therefore NO_x reduced more at higher loads compared to part load.

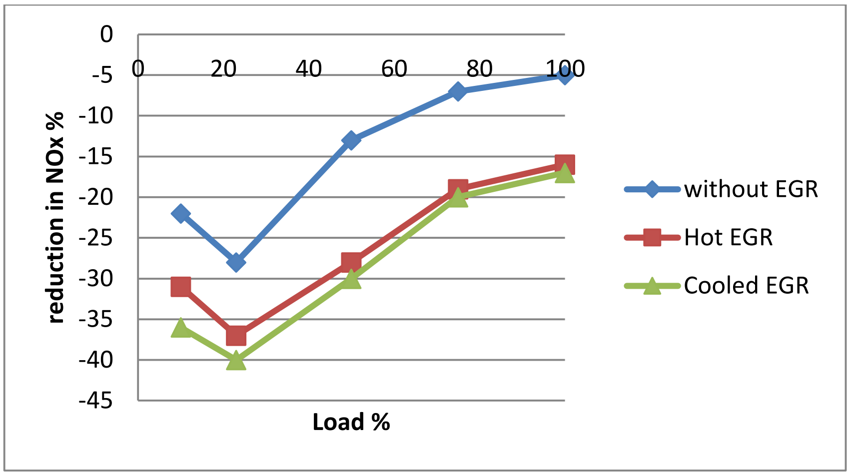

Figure 4: Reduction in NO_x without EGR, Hot EGR &Cooled EGR

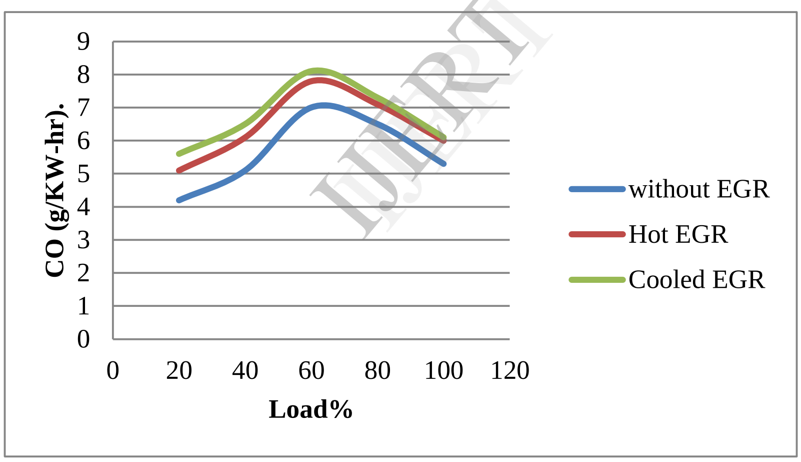

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Figure 5: Variation in CO for without EGR, Hot EGR &Cooled EGR

Effect of EGR on carbon monoxide (CO) are shown in Figs. These graphs show CO emissions increase with increasing EGR. Lower excess oxygen concentration results in rich air–fuel mixtures at different locations inside the combustion chamber. This heterogeneous mixture does not combust completely and results in higher hydrocarbons, and carbon monoxide emissions. At part loads, lean mixtures are harder to ignite because of heterogeneous mixture and produce higher amount of CO.

CONCLUSION:

In present research, experimental investigation were conducted to study the effect of EGR on performance and emissions on diesel engines. It has been found that EGR is a very useful and promising technique for reduction in NO_x emissions. The BSFC is decreased at lower loads with EGR compared to without EGR. But it approaches to similar value at high loads. There is reduction in the air fuel ratio with EGR as compared to without EGR. But not significant difference in reduction in air fuel ration between Hot and cooled EGR. With the use of EGR there has been rise in carbon monoxide level as compared to without EGR. At last, the most benefiting aspect of EGR is that reduction in NO_x. It has been found that there is drastic reduction in reduction in NO_x when the EGR system is used. It has also been found that reduction in NO_x at high loads is more as compared to part loads. Further cooling the exhaust gas effects more reduction in exhaust NO_x and proves to be a good technique to keep in control the in-cylinder NO_x production.

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