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Improving The Emission Characteristics of Diesel Engine by Using EGR at Different Cooling Rates

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Abstract - *Diesel engines exhausts gaseous emissions and particulate matter (PM) have been regarded as one of the main air pollution source, particularly in cities, and have been a source of serious public problem for a long time. There are so many researches in the field of reduction of these pollutants since diesel engines came to major use. Common emissions from a diesel engine are NOx, HC and CO. Among them NOx is considered as the major pollutant. There are various methods to reduce these emissions and Exhaust Gas Recirculation (EGR) is considered as the most effective method.*

In this project experiments were conducted on twin cylinder, water cooled diesel engine. Exhaust gas recirculation system was tested with different EGR percentages i.e. 13%, 18% and 25% at various cooling rates of 3LPM, 5LPM and 7LPM. Effect of EGR on NOx and other emissions were studied. Performance parameters like break power, break thermal efficiency, mechanical efficiency and specific fuel consumption were calculated.

Key Words: **Emissions, Nitrogen Oxides (NOx), Particulate Matter (PM), EGR, cooling rates.**

1. INTRODUCTION

An important task in the development of internal combustion engines is the reduction of emissions. As the individual mobility in the world is increasing and the transportation sector is growing, it is important to limit the impact of traffic on both the environment and the health of the population. The main combustion products that are contained in engine exhaust gases are water vapour, nitrogen oxides (NOx), particulate matter (PM), hydrocarbons (HC) and carbon monoxide (CO). All of these, except for the water vapour, are considered environmentally harmful. This is also reflected in the fact that governments all over the world enact limits for the emission of these gases. Therefore, engine developers work on diminishing these emissions.

A way to reduce the formation of NOx in diesel engines is the use of EGR, re circulated exhaust gas. Part of the exhaust gas is rerouted into the combustion chamber, where it helps to attenuate the formation of NOx by reducing the local reaction temperature.

2. MECHANISM OF FORMATION OF EXHAUST EMISSIONS

A. Nitrogen Oxides (NOx)

Nitrogen oxides, NO and NO2, are referred to as NOX. They are harmful for the lungs when local concentrations get too high. They also contribute to acid rain and form smog in combination with hydrocarbons.
NOx formation takes place in combustion zones with high oxygen concentration and high combustion temperatures. The most important mechanism for NOx formation in internal combustion engines are thermal NOx and prompt NOx. A theoretical approach to the thermal NO formation is the extended Zeldovich mechanism. It consists of three chemical reactions that form NO.The triple-bond in the N2 molecules makes a high energy necessary to activate these reactions.

$$N_2 + O \rightarrow NO + N,$$
$$N + O_2 \rightarrow NO + O,$$
$$N + OH \rightarrow NO + H.$$

Chemical equilibrium indicates that for burnt gases at typical flame temperatures, NO2=NO ratios should be negligibly very small. While experimental data show that this is true for SI engines, in diesels, NO2 can be 10 to 30% of total exhaust emissions of (NOx). A real mechanism for the persistence of NO2 is as follows. After this NO formed in the flame zone can be rapidly converted to NO2 via reactions such as

$$NO + HO_2 \rightarrow NO_2 + OH$$
$$NO_2 + O \rightarrow NO + O_2$$

The local atomic oxygen concentration depends on molecular oxygen concentration as well as local temperatures. Formation of NOx is almost absent at temperatures below 2000 K. So any technique, that can maintain the instantaneous local temperature in the chamber below 2000 K, will be able to decrese NOx formation.

B. Hydrocarbons (HC)

The construction of HC is usually not a main problem in diesel engines. It happens when combustion is not completed which can occur when there is a lack of oxygen or near to cool walls. Another phenomenon that leads to HC formation is caused by the injector sac volume. In this volume, a small fuel portion is left at the end of injection. It is evaporated by the combustion heat and enters the combustion chamber with a low pressure. This leads to a slow mixing with air and thus some fuel can escape the combustion. HC is suspected to be highly carcinogenic and is one of the causes of smog.

C. Carbon Monoxide (CO)

The formation of CO is an intermediate step in the combustion of hydrocarbons. The next step, the complete oxidation to CO2, is mainly done with the help of OH-radicals. For this process, temperatures above 1200 K and sufficient available oxygen are needed. The oxidization of CO can locally minimizes due to non mixing and due to low temperatures close to cylinder walls.

3. CONTROL OF OXIDES OF NITROGEN (NOX)

Many theoretical and experimental analysis shows that the concentration of NOx in the exhaust gas is closely related to the peak cycle temperature and available amount of O2 in the combustion chamber. Any process to reduce cylinder high temperature and concentration of oxygen will minimize the oxides of nitrogen. This denotes a number of methods for minimizing the strength of nitrogen oxides. The following are few methods for minimizing peak cycle temperature and thereby minimizing NOx emission.

- Water injection.
- Catalyst
- Exhaust gas recirculation (EGR)

A. Water injection

Minimization of Nitrogen oxides NOx is a function of injection rate of water. NOx emission minimizes with increase in water injection rate per kg of fuel. The fuel consumption reduces a few percent at medium water injection rate. The water injection system is used as a process for controlling the NOx emission from the engine exhaust pollution.

B. Catalyst

A copper catalyst has used to reduce the NOx emission from engine in the presence of CO. Catalytic converter is used to control the emissions of various pollutants by modifying the chemical characteristics of the exhaust gases. Catalyst materials such as platinum and palladium are applied to a ceramic support which has been treated with an aluminium oxide wash coat. This results in as extremely porous structure providing a large surface area to stimulate the combination of oxygen with HC and CO. This oxidation process makes most of these compounds to water vapor and CO_2.

C. Exhaust gas recirculation (EGR)

EGR is used to reduce NOx in S.I. engines as well as C.I. engines. The working of EGR is to recirculate about 10% to 30% of the exhaust gases return into the inlet manifold where it mixes with the fresh air and the mixture will reduces the quantity of O2 available for combustion . This minimizes the O2 concentration and reduces the peak combustion temperature inside the combustion chamber which will reduce the NOx formation. Nearly 15% recycle of exhaust gas will minimize NOx emission by about 80%. It can be noted that maximum NOx emission producing during lean mixture limits when exhaust gas recirculation is least effective. The exhaust gas while going back into the combustion chamber has to cool, so that the volumetric efficiency of the engine will be improved.

% EGR = [volume of EGR/ total intake charge into the cylinder] *100

EGR is, the ratio of mass of recycled gases to the mass of engine intake. Also EGR is the best efficient and widely used method to control the production of oxides of nitrogen inside the I.C. engine combustion chamber compared to the above methods .

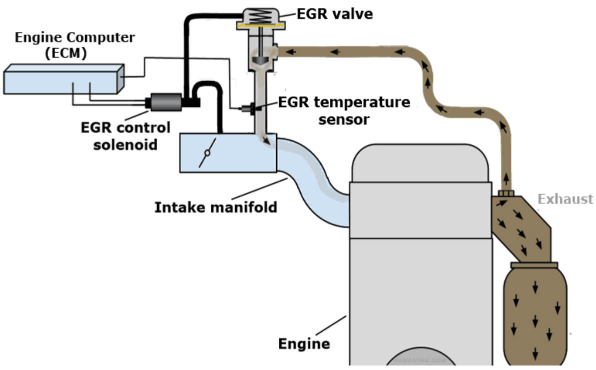


Fig -1: EGR-diagram

The exhaust gases for recirculation is taken through an orifice and sends through control valves for regulation of the quantity of recirculation. Normally EGR is shut off during idle to prevent rough engine operation. EGR sends oxygen in the intake air and mixes the intake charge by exhaust gas recirculate. Exhaust gas which is recirculated to the engine chamber minimizes the oxygen percentage and increases the specific heat of the intake fresh air mixture, which gives in minimum flame temperatures. Finally it says that, its high rate of EGR can be applied at minimum loads and minimum rate of EGR can be applied at higher load.with the above discussion we can say that EGR cab be used to diesel engine fueled with diesel oil, biodiesel, LPG, hydrogen, etc without losing its efficiency and fuel economy and NOx reduction can thus be achieved. EGR is a best technique for minimizing NOx formation in the combustion chamber. The specific heat of the recalculated gas is much higher than fresh air, hence EGR maximizes the specific heat of the intake charge, thus minimizing the temperature rise for the same heat release in the combustion chamber.

4. EXPERIMENTAL SETUP

Many experiment are performed on the 4 stroke diesel engine. The diesel engine is equipped with cooling water for cooling of the cylinders. The cooling water is in and out system not a circulatory one to provide the maximum effect of cooling. Flow of cooling water is regulated with using a gate valve. Gate valve is used so that flow can be adjusted according to the required rate. The cooling water pipes are checked for the leakages and minimum water flow is adjusted so that required amount of cooling is provided to the engine. Engine should be operated at different loads for measuring the parameters required. So the engine is provided with dynamometer which is connected to the fly wheel of the engine with help of a coupling. Coupling is

Table 1. Engine specifications

Make	Kirloskar
Bhp	14 hp
Speed	1500 rpm
Compression ratio	17.5:1
Bore	87.5 mm
Stroke	110 mm
Orifice diameter	20 mm
Type of ignition	Compression ignition
Method of starting	Crank shaft
Method of cooling	Water cooled
Method of Loading	Hydraulic Dynamometer

provided so in case of excess load or wreckage no damage is occurred to the engine.

Dynamometer is operated by fluid force acting on it. Water is used in present case for applying of the load. Two gate valves are used to control the flow of the water that is effecting the rotation of dynamometer. Oil levels of the engine are also checked using the oil gauge rod at the side of the engine. Oil should be at least above the minimum level required so that no damage is occurred to the engine parts. The standard oil of SAE-40 is used so that enough lubrication occurs. The fuel should be pure and clean so that no distraction in the experiment should occur.

To achieve this fuel tank is depleted after every iteration of the experiment and cleaned. The pressure pump of the engine is also cleaned at every iteration of the experiment. Exhaust gas pipes are also provided with insulation so that accidents can be prevented. The sensors of the engine are also checked so that no error can be occurred. This is done by basic thermometer operation of room temperature to the sensor temperature. Power supply to the electronic board is checked so that all devices should perform accordingly. At last water is checked so that continuous supply is arranged.

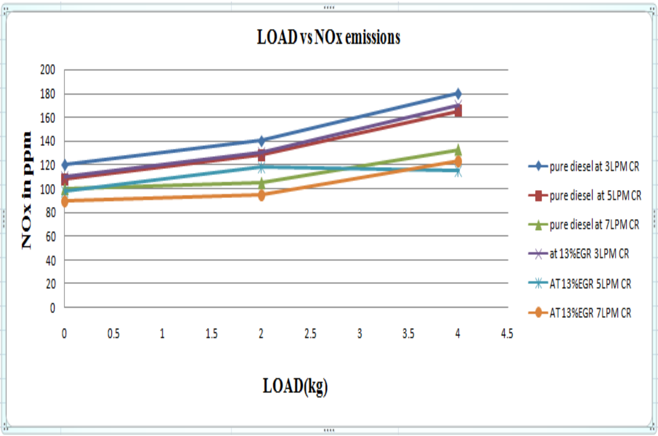
The test Ring consists of Four-Stroke Diesel Engine, to be tested for performance, is connected to hydraulic Dynamometer. The equipment consists of KIRLOSKAR Diesel Engine (Crank started) and is water cooled. The engine is coupled to a Hydraulic Dynamometer for loading purposes coupling is done by an extension shaft in a separate bearing house. The dynamometer is connected to the spring load assembly for varying the load Thermocouples are provided at appropriate positions and are read by a digital temperature indicator with channel selector to select the position Engine speed and the load applied at various conditions is determined by a Digital RPM Indicator and spring balance reading. A new device called, volumetric flask with a fuel distributor is provided. Which is used to measure and direct the fuel to the engine.

Fig -2: Twin cylinder 4 stroke diesel engine test rig with hydraulic dynamometer loading.

5. EMISSION RESULTS

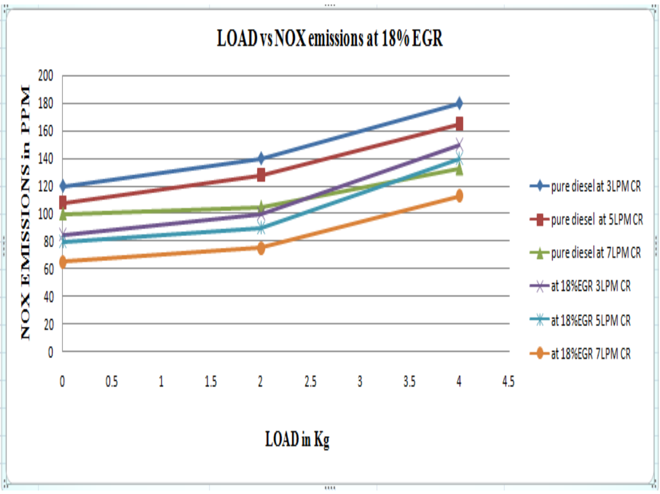
A. NOx Emissions:

The following Figures show variation in the quantity of nitrous oxides (in ppm) with change in load (in kg) at 13% EGR, 18% EGR and 25%EGR at various cooling rates.



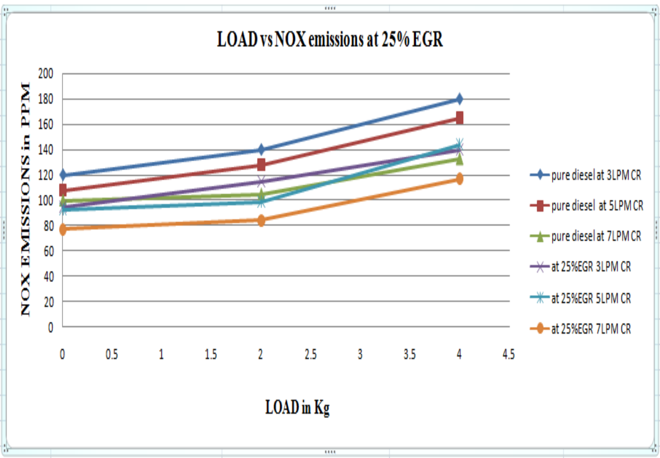
Graph-1: Change in quantity of Nox with load variations at 13% EGR

The above graph shows that increasing of cooling rate decreases NOx emissions relatively at all loads. Induction of 13% of EGR has decreased Nox than that of pure diesel. The reason behind this is, reduced oxygen concentration because of dilution of intake charge and decreased flame temperature.



Graph-2: Change in quantity of Nox with load variations at 18% EGR

The above graph shows that increasing of cooling rate decreases NOx emissions relatively at all loads. Induction of 18% of EGR has decreased Nox than that of pure diesel. Now the reason for this is, lowered oxygen concentration because of mixing of intake charge and decreased flame temperature.

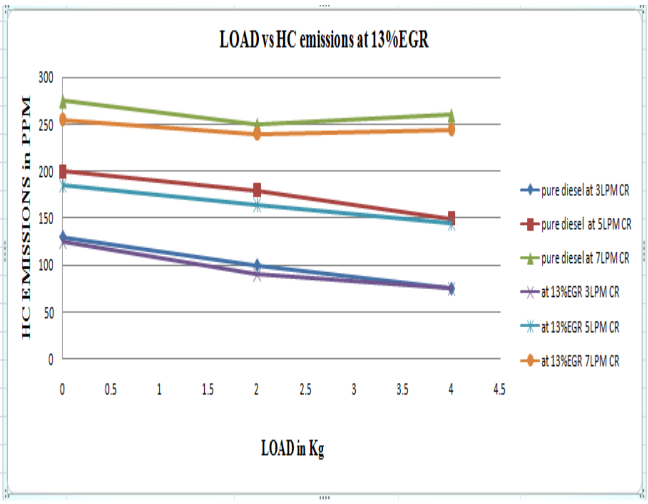


Graph-3: Change in quantity of Nox with load variations at 25% EGR

The above graph shows that increasing of cooling rate decreases NOx emissions relatively at all loads. Induction of 25% of EGR has decreased NOx than that of pure diesel. The reason behind this is, reduced oxygen concentration because of dilution of intake charge and decreased flame temperature.

B. HC Emissions:

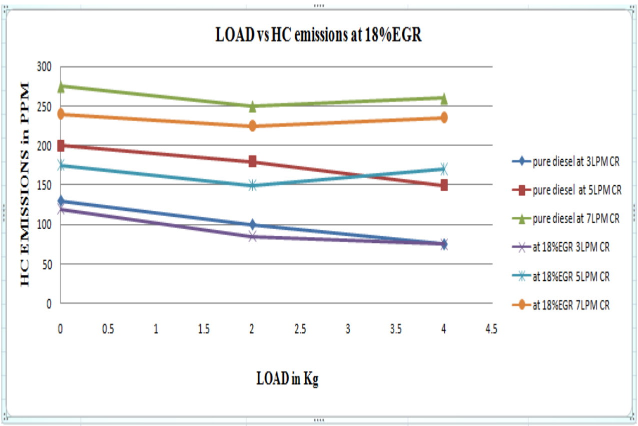
The following figures show the variation in the quantity of un burnt hydrocarbons with change in load (in kg.) at 13% EGR, 18% EGR and 25% EGR at various cooling rates



Graph-4: Change in quantity of unburnt hydrocarbons with load variations at 13% EGR

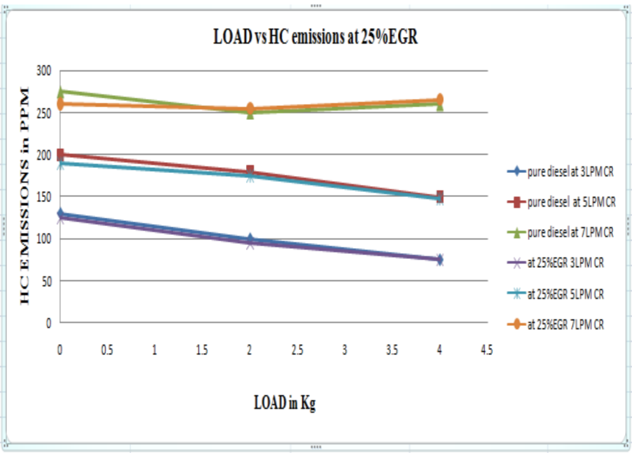
The above graph says that increased cooling rates has increased the HC formation due to minimized engine temperature result in improper or reduced burning potency of the hydro carbons which is left as emission. Usage of

13% EGR into the system has increased the combustion chamber temperature and also HCs complete burning, which was sent out as exhaust. Finally reducing the HC emissions to some extent.



Graph-5: Change in quantity of unburnt hydrocarbons with load variations at 18% EGR

Usage of 18% EGR into the system has increased the combustion chamber temperature and also HCs complete burning, which was sent out as exhaust. Finally reducing the HC emissions to some extent.

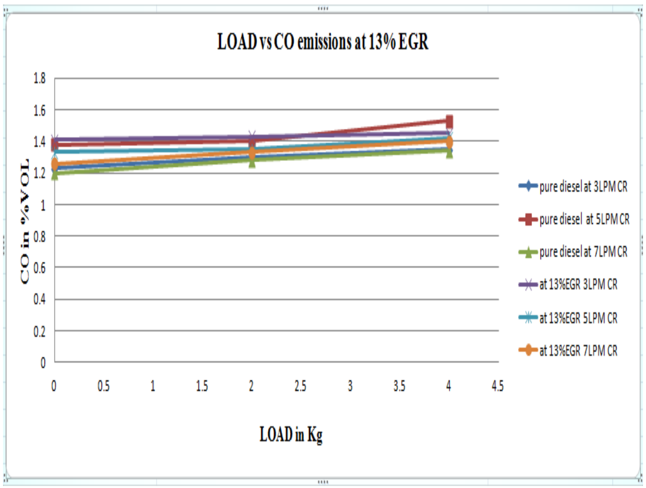


Graph-6: Change in quantity of unburnt hydrocarbons with load variations at 25% EGR

Usage of 25% EGR into the system has increased the combustion chamber temperature and also HCs complete burning, which was sent out as exhaust. Finally reducing the HC emissions to some extent.

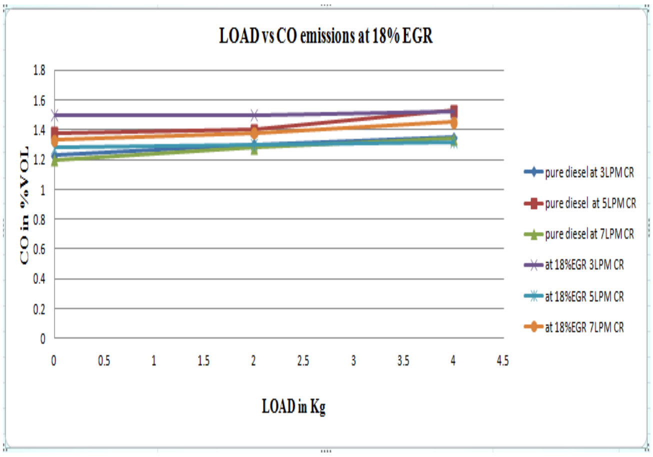
3. CO Emissions:

The following figures show variation in the quantity of carbon monoxide (in % of vol) change in load (in kg) at 13% EGR, 18% EGR and 25% EGR at various cooling rates.



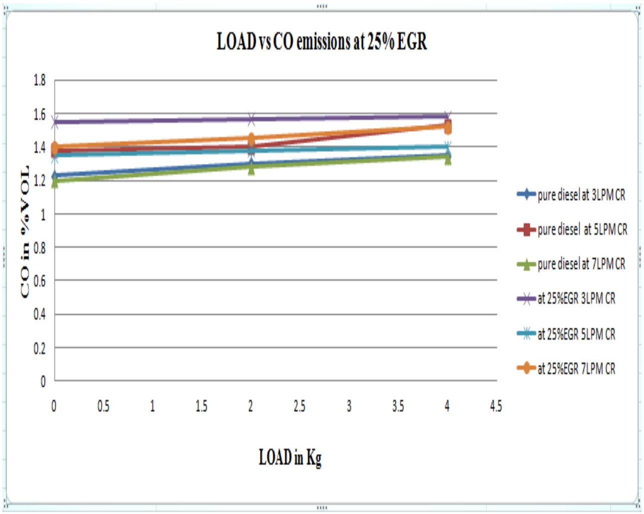
Graph-7: Change in quantity of CO with load variations at 13% EGR

Carbon monoxide formation is due to carbon particles which are not totally oxidized. Oxygen content in the combustion chamber is reduced due to the usage of EGR there by decreasing the oxidation of carbon flakes and increases the formation of CO. The graph increase in CO emissions due to 13%EGR induction was not so substantial and was not more than 2% of that of condition when operated with pure diesel. After using EGR, there is an increase in CO emission because of decreasing air-fuel ratio.



Graph-8: Change in quantity of CO with load variations at 18% EGR

From the above graph, it says that increase in CO emissions due to 18%EGR induction was not so substantial and was not more than 2% of that of condition when operated with pure diesel. After using EGR, there is an increase in CO emission because of decreasing air-fuel ratio.



Graph-9: Change in quantity of CO with load variations at 25% EGR

From the above graph, it says that increase in CO emissions due to 18%EGR induction was not so substantial and was not more than 2% of that of condition when operated with pure diesel. After using EGR, there is an increase in CO emission because of decreasing air-fuel ratio.

6. CONCLUSIONS

- Increasing of cooling medium rate results decreased NOx emissions relatively at all loads. This is due to the excess cooling rate bring down the peak temperatures and thereby decreasing NOx emissions. Induction of 18% of EGR has decreased NOx by a great extent of that of pure diesel when compared to 13% EGR and 25% EGR. NOx emissions at various cooling rates, from the graph it is quite obvious that increased cooling rate decreased the peak temperatures there by decreased NOx .

- HC formation is Increased due to increased cooling rates, then reduced engine temperature result in improper hydro carbons which is left as emission. I EGR which is induced into the combustion chamber has increased the temperature inside it and also complete burning of HCs which was sent out as exhaust. Among the different EGR rates HC emissions were lower at 18% EGR when compared to 13% EGR and 25% EGR.

- CO emissions increased with increase in EGR because of the lesser availability of the oxygen. CO emissions were maximum at 25% EGR when compared to other EGR rates.

- Out of the three percentages,15% EGR is found to be better, which increases the thermal efficiency as well as decreases the exhaust emissions.

- Therefore, it can be concluded that engine operation with various cooling rates while engaging EGR results in NOx reductions without compromising engine performance.

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