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EXPERIMENTAL INVESTIGATION OF EFFECT ON EXHAUST GAS RECIRCULATION ON REDUCTION OF DIESEL ENGINE EMISSIONS AND ITS ANALYSIS AT VARIOUS COOLING RATES

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Abstract:

Diesel engine exhaust emits particulate matter (PM) and gaseous emissions and has been regarded as one of the main air pollution source, particularly in the cities; they are the source of serious problem. There are so many researches in this field for reduction of these pollutants since diesel engines play major role in transport sector were done. Common emissions from a diesel engine are NOx, CO and HC. Among them NOx is considered as the major pollutant. There are various methods to reduce these emissions. The Exhaust Gas Recirculation (EGR) is considered as one of the effective methods. 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. 12%, 17% and 24% at various cooling rates of 3LPM, 5LPM and 7LPM. Effect of EGR on NOx and other emissions were studied. Performance parameters such as break power, break thermal efficiency, mechanical efficiency, specific fuel consumption and NOx were investigated.

Key Words: Four Stroke Diesel Engine & EGR

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 nitrogen oxides (NOx), particulate matter (PM), hydrocarbons (HC), carbon monoxide (CO) and water vapour are contained in engine exhaust gases. All of these are considered environmentally harmful except the water vapour. 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. Literature Review:

Mechanism of Formation of Exhaust Emissions:

During combustion of Diesel, many toxic and non-toxic gases are formed. The non-toxic parts may be are carbon dioxide and water. Then water is completely unproblematic, but the CO2 emission has negative impacts on the environment. CO2 is believed to be the main cause of global warming and therefore, its emission has to be reduced. The formation of CO2 is directly proportional to the fuel consumption of an engine, if fossil fuel is burned. This means, that for a reduction of CO2, the fuel consumption has to be reduced. The two most problematic emissions in diesel engines are nitrogen oxides and soot particles. HC and CO emissions are quite low and can be removed fairly easy from the exhaust with the help of an oxidation catalyst

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. Therefore, they are only fast enough to form significant amounts of NOx if the temperatures are above 2200 K.

$$N2 + O \rightarrow NO + N$$
$$N + O2 \rightarrow NO + O$$
$$N + OH \rightarrow NO + H$$

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

$$NO + HO2 \rightarrow NO2 + OH$$
$$NO2 + O \rightarrow NO + O2$$

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. Hence any technique, that can keep the instantaneous local temperature in the combustion chamber below 2000 K, will be able to reduce NOx formation.

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3. Control of Oxides of Nitrogen (NOX):

Many theoretical and experimental investigation shows that the concentration of NOx in the exhaust gas is closely related to the peak cycle temperature and available amount of oxygen in the combustion chamber. Any process to reduce cylinder peak temperature and concentration of oxygen will reduce the oxides of nitrogen. This suggests a number of methods for reducing the level of nitrogen oxides. Among these the dilution of fuel-air mixture entering the engine cylinder with an inert or non-combustible substance is one which absorbs a portion energy released during the combustion, thereby affecting an overall reduction in the combustion temperature and consequently in the NOx emission level. The following are the three methods for reducing peak cycle temperature and thereby reducing NOx emission.

- ✓ Water Injection
- ✓ Catalyst
- ✓ Exhaust Gas Recirculation (EGR)

4. Materials and Methods:

The engine specification and EGR are discussed here:

Engine Specification: The performance characteristics were carried out on variable compression diesel engine

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

Specifications of the Engine:

Exhaust gas recirculation (EGR) EGR is commonly used to reduce NOx in S.I. engines as well as C.I. engines. Fig shows the arrangement of exhaust gas recirculation (EGR) system. The principle of EGR is to recirculate about 10% to 30% of the exhaust gases back into the inlet manifold where it mixes with the fresh air and this will reduces the quantity of O2 available for combustion. This reduces the O2 concentration and dilutes the intake charge, and reduces the peak combustion temperature inside the combustion chamber which will simultaneously reduce the NOx formation. About 15% recycle of exhaust gas will reduce NOx emission by about 80%. It should be noted that most of the NOx emission occurs during lean mixture limits when exhaust gas recirculation is least effective.

The exhaust gas which is sent into the combustion chamber has to be cooled so that the volumetric efficiency of the engine can be increased. EGR ratio is defined as the ratio of mass of recycled gases to the mass of engine intake. Also %EGR is From above three methods, EGR is the most efficient and widely used system to control the formation of oxides of nitrogen inside the combustion chamber of I.C. engine. The exhaust gas for recirculation is taken through an orifice and passed through control valves for regulation of the quantity of recirculation. Normally exhaust gas recirculation is shut off during idle to prevent rough engine operation. EGR is a very useful technique for reducing the NOx emission. EGR displaces oxygen in the intake air and dilute the intake charge by exhaust gas recirculated to the combustion chamber.

Recirculated exhaust gas lower the oxygen concentration in combustion chamber and increase the specific heat of the intake air mixture, which results in lower flame temperatures. It was observed that 15% EGR rate is found to be effective to reduce NOx emission substantially without deteriorating engine performance in terms of thermal efficiency, bsfc and emissions. Thus, it higher rate of EGR can be applied at lower loads and lower rate of EGR can be applied at higher load. EGR can be applied to diesel engine fueled with diesel oil, biodiesel, LPG, hydrogen, etc without sacrificing its efficiency and fuel economy and NOx reduction can thus be achieved. EGR is a useful technique for reducing NOx formation in the combustion chamber. Exhaust consists of CO2; N2 and water vapors mainly. When a part of this exhaust gas is re-circulated to the cylinder, it acts as diluent to the combusting mixture. This also reduces the O2 concentration in the combustion chamber. The specific heat of the 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.

$$\%EGR = (\text{volume of EGR/ total intake charge into the cylinder}) * 100$$

5. Experimental Setup and Procedure:

A. Experimental Setup: Experiment is 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.

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Coupling is 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 volumetric flask with a fuel distributor is provided for measurement and directing the fuel to the engine respectively.

B. Testing Procedure: First the experimentation is performed with diesel without using EGR (for getting the base line data of the engine) and then EGR at 13%, 18% and 25% is implemented. The performance of the engine is evaluated in terms of brake thermal efficiency, brake specific energy consumption, exhaust gas temperature, and emission of the engine is analyzed in relation with HC, CO and NOx.

The experimentation has done for the different cooling rates 3LPM, 5LPM, 7LPM and at different applied loads of 0,2,4 kg respectively . On changing the cooling rates for different loads the performance of the diesel engine is analyzed whether the efficiency of the engine increases or decreases, then the same is performed implementing EGR with 13%, 18% and 25%.

- ✓ Performance of diesel engine at 0, 2, 4, kg loads on 3LPM cooling rate.
- ✓ Performance of the same at similar loads at 4, 5, 6, 7, 8 LPM cooling is tested with exhaust analysis.

Connect the cooling water inlet to a constant head water sources. Set zero by presenting the arrow button at digital water flow indicator first and open the inlet gate valves of the engine jacket to suitable flow rate by adjusting the gate valve which is provided before the flow meter. Connect the instrumentation power input plug to a 230V, single phase power source. Now the digital temperature indicator displays the respective readings. Set zero by pressing the arrow button at digital fuel flow indicator first and fill up the diesel into the tank.

Check the lubricating oil level in the sump with the dipstick provided. Ensure that the Engine is in the no load condition Open the diesel cock provided from the Diesel tank. Set the fuel flow indicator, water flow indicator & Air flow indicator to zero by pressing the arrow button. Insert the starting handle and Crank the engine slowly by rotating in clockwise and ascertain proper flow of fuel into the pump and in turn through the nozzle into the engine cylinder when maximum cranking speed is attained, pull down the decompression lever now the engine starts. Allow the engine to run and stabilize. The engine is a constant speed engine fitted with centrifugal governor. Now turn the knob of eddy current drive provided at the panel gradually to load the engine through eddy current dynamometer. The torque 'T' is indicated on a digital indicator. Now rotate the knob of eddy current drive in clockwise and set the load to 1/4 of the full load. Before taking the reading allow the engine to run at the set load and speed for few minutes. Note down the readings. Time for10cc of fuel consumption and load on the Engine and difference of water column level in manometer for finding volumetric efficiency. Then increase the load and repeat the same procedure

Figure 1: Shows Photography view of experimental setup

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6. Results and Discussions:

Change in brake thermal efficiency with respect to change in load

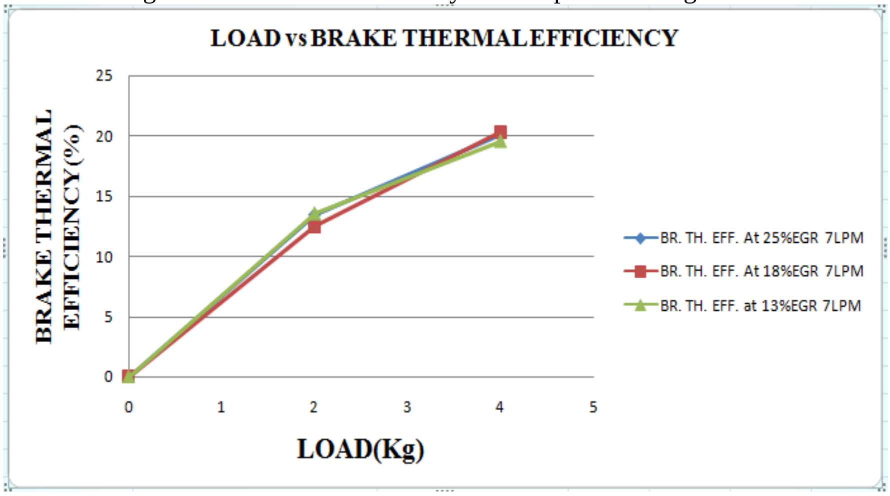

Figure 2: Change in brake thermal efficiency with respect to change in load

At no load condition, brake thermal efficiency at 12% EGR, 19% EGR and 23%EGR diesel is same. As the load on the engine increases, brake thermal efficiency increases because brake thermal efficiency is the function of brake power and brake power increases as the load on the engine increases. The reason for increase in BTE with EGR is due to re-burning of HC that enters combustion chamber with the recirculation of exhaust gases and also EGR increases intake charge temperature which increases the rate of combustion. The value at 12% EGR is 19.5%, at 17.5% EGR is 20.12% and at 24% EGR is 20%.

Mechanical Efficiency:

Change in Mechanical efficiency of diesel with 12.5%EGR, 18%EGR, and 24% EGR with respect to change in load is shown in the following figures.

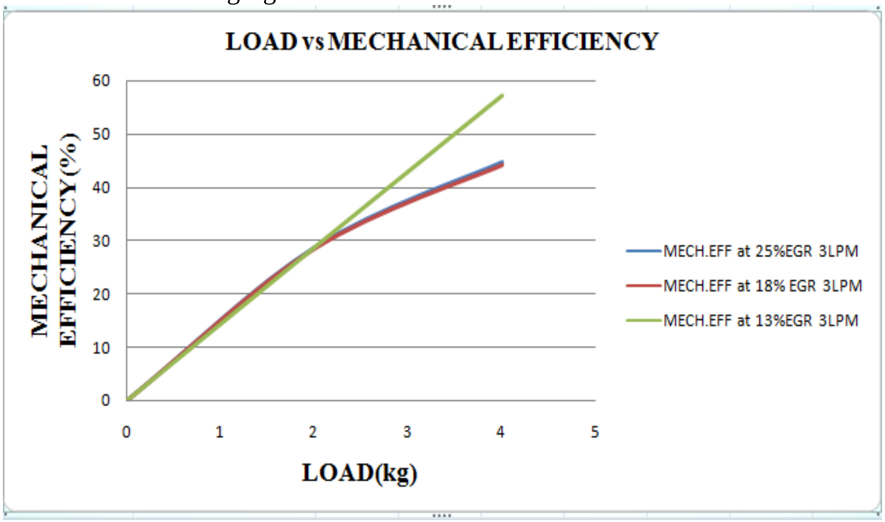

Figure 3: Change in mechanical efficiency with respect to change in load

At no load condition, mechanical efficiency 13% EGR, 18% EGR and 25% EGR is same. As the load on the engine increases, mechanical efficiency increases because brake power increases and speed decreases as the load on the engine increases. At full load conditions, mechanical efficiency at13% EGR is more compared to other rates. The mechanical efficiency at 13% EGR is 57% at 18% EGR is 44.25% and at 13% EGR is 44.7%.

Specific Fuel Consumption:

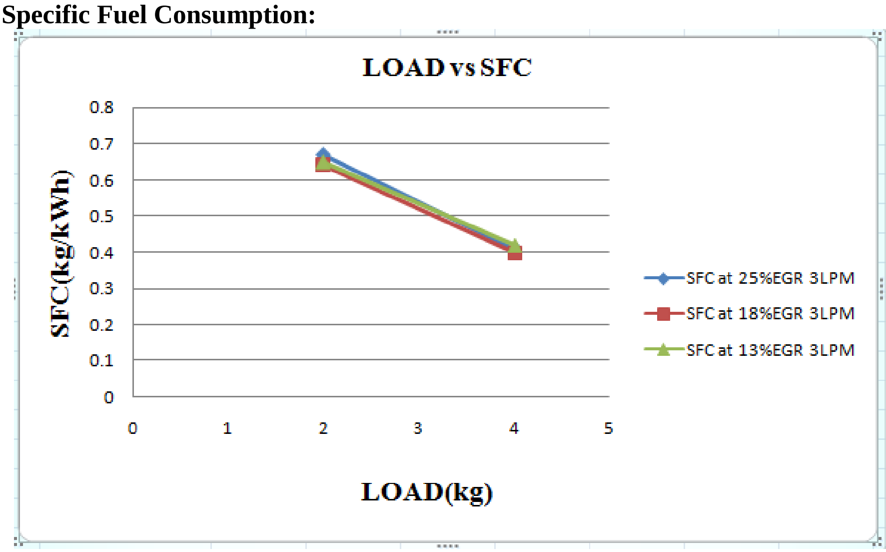

Figure 4: Shows change in SFC of diesel with 13%EGR, 18%EGR, and 25% EGR with respect to change in load is shown in the following figures.

After that the specific fuel consumption decreases continuously with increase in load. At 2 kg load conditions, SFC of diesel is high. The decrease in SFC with EGR is due to increase in intake charge temperature which increases the rate of combustion of the fuel, hence causing a decrease in SFC. The maximum value is 0.67kg/kwhr and the minimum value is 0.42kg/kwhr.

Emission Results:

NOx Emissions:

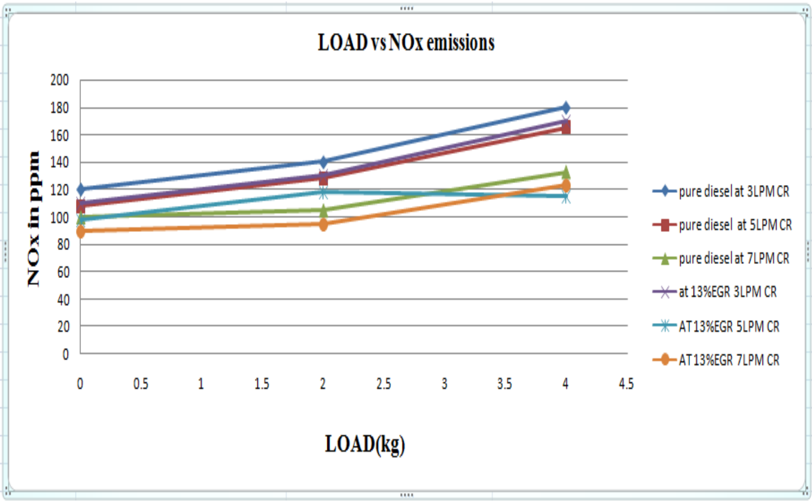

Figure 5: Change in quantity of Nox with load variations

The above graph shows that increasing of cooling rate decreases 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 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.

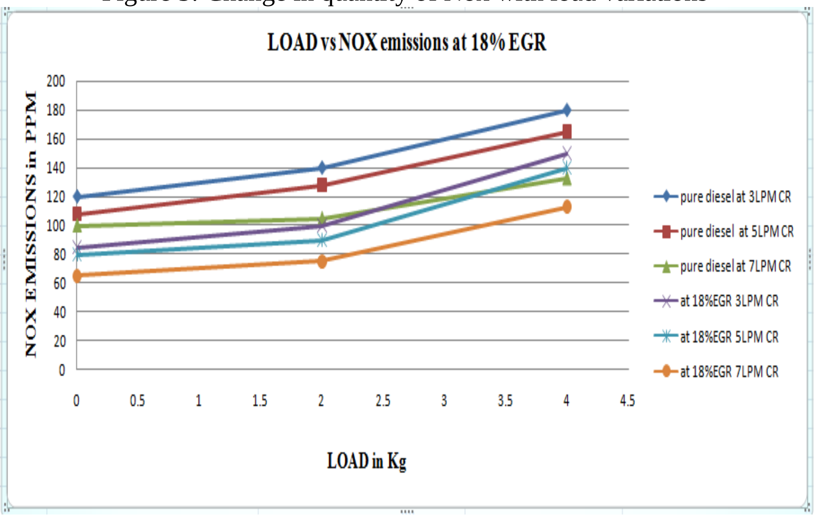

Figure 6: Change in quantity of NOx with load variations

The above graph shows that increasing of cooling rate decreases NOx emissions relatively at all loads. This is due to the excess cooling rate bringing down the peak temperatures and thereby decreasing NOx emissions. Induction of 18% 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

HC Emissions:

The following figures show the variation in the quantity of un burnt hydrocarbons with change in load (in kg.) at 13% EGR, 17% EGR and 24% EGR at various cooling rates

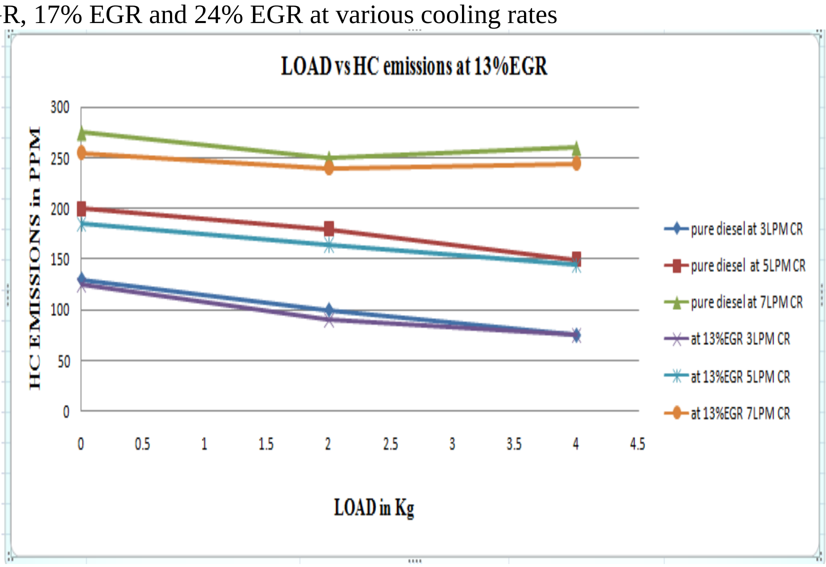

Figure 7: Change in quantity of unburnt hydrocarbons with load variations

From the above graph it is inferred that increased cooling rates has increased the HC formation due to reduced engine temperature result in improper or reduced burning potency of the hydro carbons which is left as emission. Inducing of EGR into the has increased the temperature inside the combustion chamber and also complete burning of HCs which was sent out as exhaust hence reducing the HC emissions to some extent.

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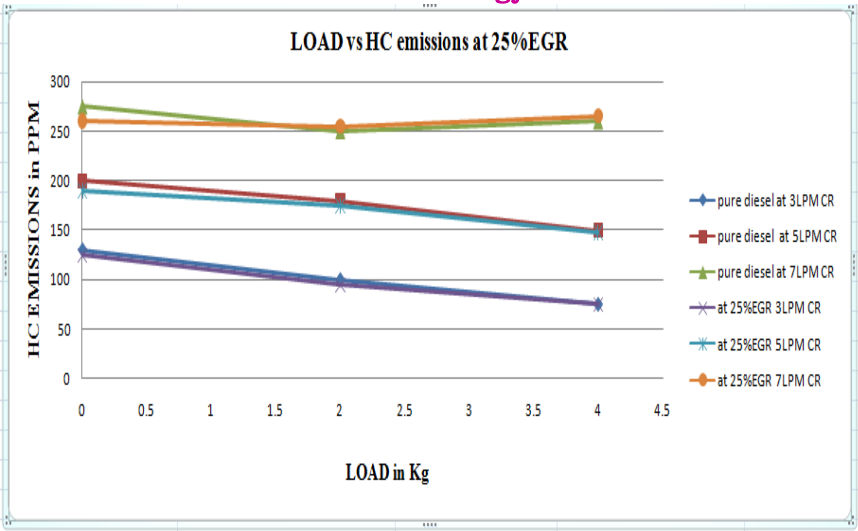

Figure 8: Change in quantity of unburnt hydrocarbons with load variations

From the above graph it is inferred that increased cooling rates has increased the HC formation due to reduced engine temperature result in improper or reduced burning potency of the hydro carbons which is left as emission. Inducing of EGR into the has increased the temperature inside the combustion chamber and also complete burning of HCs which was sent out as exhaust hence reducing the HC emissions to some extent.

CO Emissions:

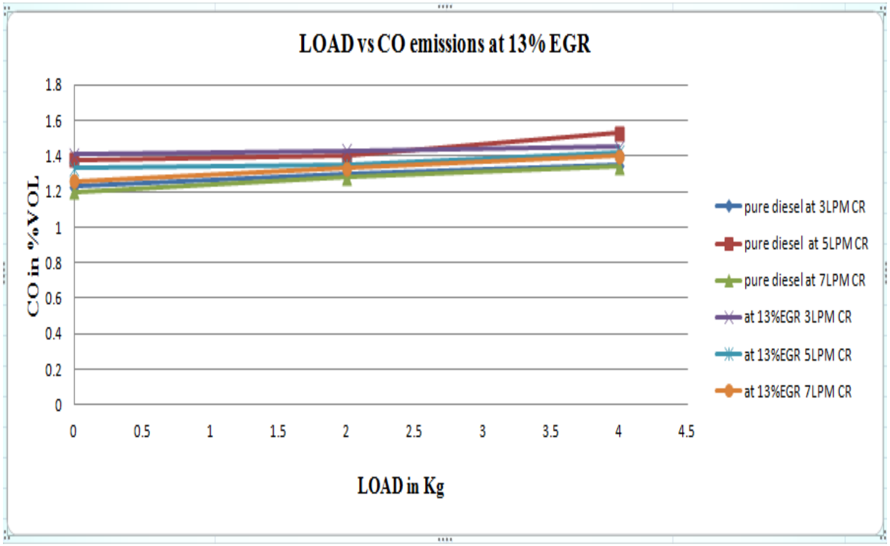

Figure 9: Change in quantity of CO with load variations

Carbon monoxide formation is due to carbon particles which are not totally oxidized. Induction EGR has decreased oxygen content in the combustion chamber there by reducing the oxidation of carbon flakes and increases the formation of CO. But as seen from 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.

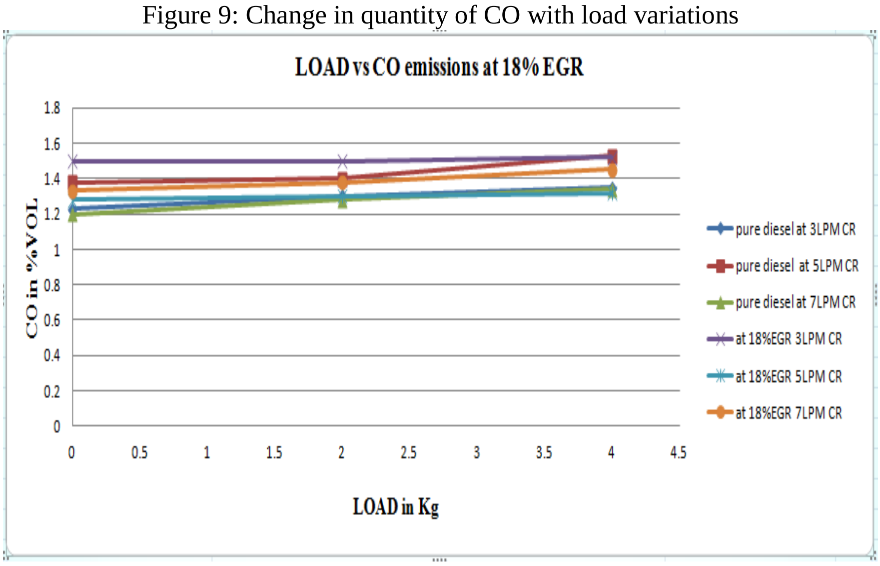

Figure 10: Change in quantity of CO with load variations

Carbon monoxide formation is due to carbon particles which are not totally oxidized. Induction EGR has decreased oxygen content in the combustion chamber there by reducing the oxidation of carbon flakes and increases the formation of CO. But as seen from graph 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.

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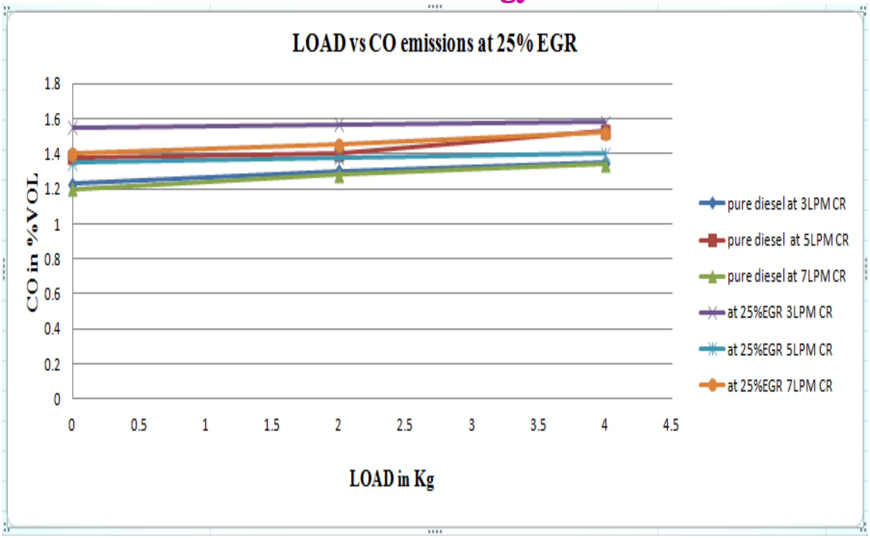

Figure 11: Change in quantity of CO with load variations

Carbon monoxide formation is due to carbon particles which are not totally oxidized. Induction EGR has decreased oxygen content in the combustion chamber there by reducing the oxidation of carbon flakes and increases the formation of CO. But as seen from graph 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.

Conclusion:

- ✓ Increasing of cooling rate decreased NOx emissions relatively at all loads. This is due to the excess cooling rate bringing 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.
- ✓ Increased cooling rates has increased the HC formation due to reduced engine temperature result in improper or reduced burning potency of the hydro carbons which is left as emission. Inducing of EGR 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 minimum 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.
- ✓ 15% EGR is found to be optimum, which improves the thermal efficiency as well as reduces the exhaust emissions. EGR upsurges the HC and CO 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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