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Reduction of Diesel Engine Emissions and Its Analysis by Using Exhaust Gas Recirculation at Various Cooling Rates

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Abstract: - The cooling rate of an IC engine stands one of important parameters that govern the performance and emissions. In our present experimental investigation emissions of a Kirloskar AV-1 single cylinder, water cooled, diesel engine was observed at various cooling rates and compared with that of operated under Exhaust Gas recirculation(EGR). Experiment was conducted in various cycles by varying loads, cooling rates and recirculation of exhaust gas. Exhaust Gas recirculation was done by provision in the test rig that is provided with a valve for managing flow and a U-tube manometer for measurement of the EGR flow. The EGR proportion of 18% was maintained as this proportion of EGR substitution was the maximum that did not detoriate the performance of engine further substitution had led to slow down of engine. The emissions NO_x in PPM, CO in %vol, CO_2 %vol, HC in PPM & un reacted O_2 in %vol was measured using MN-05 multi gas analyzer.

Keywords: **Analyzer, Emissions, EGR, Oxides.**

I. INTRODUCTION

Air pollution is referred addition harmful foreign particles or additives to the atmospheric air. The most of air pollution to the atmospheric is contributed by automobile engine emissions. The main emissions from the auto motive engine are oxides of nitrogen, oxides of sulphur, carbon dioxide, carbon monoxide, suspended or particulate matter, unused oxygen, and un burnt hydro carbons. Each of these pollutants has their own evil effect on the environment. Hence many efforts are made and many researches have been conducting to reduce these emissions without affecting the performance of the engine. Cooling rate of an IC engine has an adverse effect on emission and performance of the engine. An optimum cooling rate of an engine can attain reduced emissions and increased performance. Ki-Hyung Lee *et al* in his journal "Investigation of emission characteristics affected by new cooling system in a diesel engine" concluded that At partial load conditions of NEDC drive cycle, HC and CO were reduced by approximately 10 % and 4%, respectively. In the case of decreasing coolant flow, HC and CO were reduced down to 20% during NEDC drive cycle.

II. MECHANNISM OF FORMATION OF POLLUTANT

A. Mechanism of formation of Carbon Monoxide (CO)

Carbon monoxide is a colourless poisonous gas. Small amounts of CO concentrations, when breathed in, slow down physical and mental activity and produces headaches, while large concentration will kill. CO is generally formed when the mixture is rich in fuel. The amount of CO formation increases as the mixture becomes more and more rich in fuel. A small amount of CO will come out of the exhaust even when the mixture is slightly lean in fuel because air- fuel mixture is not homogenous and equilibrium is not established when the products pass to the exhaust. At the high temperature developed during the combustion, the products formed are unstable and following reactions take place before the equilibrium is established [2].

$$2C+O2 = 2CO$$

As the products cool down to exhaust temperature, major part of CO reacts with oxygen to form CO2. However, a relatively small amount of CO will remain in exhaust.

B. Mechanism of formation of Hydrocarbons (HC)

Hydrocarbons, derived from unburnt fuel emitted by exhausts, engine crankcase fumes and vapour escaping from the carburetor are also harmful to health. Hydrocarbons appears in exhaust gas due to local rich mixture pockets at much lower temperature than the combustion chamber and due to flame quenching near the metallic walls. A significant of this unburnt HC may burn during expansion and exhaust strokes if oxygen concentration and exhaust temperature is suitable for complete oxidation [2]. C. Mechanism of formation of nitric oxide (NO) of nitrogen is produced in very small quantities can cause pollution. While prolonged exposure of oxides of nitrogen is dangerous to health. Oxides of nitrogen which occurs only in the engine exhaust are a combination of nitric oxide (NO) and nitrogen dioxide (NO2). Nitrogen and oxygen react at relatively high temperature. NO is formed inside the combustion chamber in post-flame combustion process in the high temperature region. The high peak combustion temperature and availability of oxygen are the main reasons for the formation of NOx. In the present of oxygen inside the combustion chamber at high combustion temperatures the following chemical reactions will takes place behind the flame [2].

$$N_2+O_2 = 2NO$$

$$N_2+2H_2O = 2NO+H_2$$

Calculation of chemical equilibrium shows that a significant amount of NO will be formed at the end of combustion. The majority of NO formed will however decompose at the low temperatures of exhaust. But, due to very low reaction rate at the exhaust temperature, a part of NO formed remains inexhaust. The NO formation will be less in rich mixtures than in lean mixtures [1, 2]. The concentration of oxides of nitrogen in the exhaust is closely related peak combustion temperature inside the combustion chamber.

III. 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 reducethe 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 [1, 2].

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

A. Water injection

Nitrogen oxides NOx reduction is a function of water injection rate. NOx emission reduces with increase in water injection rate per kg of fuel. The specific fuel consumption decreases a few percent at medium water injection rate. The water injection system isused as a device for controlling the NOx emission from the engine exhaust.

B. Catalyst

A copper catalyst has been used to reduce the NOx emission from engine in the presence of CO. Catalytic converter package is use to control the emission levels of various pollutants by changing 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 converts most of these compounds to water vapour and carbon dioxide.

C. Exhaust gas recirculation (EGR)

EGR is commonly used to reduce NOx in S.I. engines as well as C.I. engines. Fig (1) 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 O_2 available for combustion [1,12]. This reduces the O_2 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 [3]. 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.[3] EGR is a useful technique for reducing NOx formation in the combustion chamber. Exhaust consists of CO_2;N_2 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 O_2 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.[5]

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%EGR = (volume of EGR/ total intake charge into the cylinder) *100

Type	Four- stroke, single cylinder, Compression ignition engine, with variable compression ratio.
Make	Kirloskar AV-1
Rated power	3.7 KW, 1500 RPM
Bore and stroke	80mm×110mm
Compression ratio	16.09:1, variable from 13.51 to 19.69
Cylinder capacity	553cc
Dynamometer	Electrical-AC Alternator
Orifice diameter	20 mm
Fuel	Diesel and Biodiesel
Calorimeter	Exhaust gar calorimeter
Cooling	Water cooled engine
Starting	Hand cranking and auto start also provided

Table 1. Engine specifications

IV. EXPERIMENTAL PROCEDURE

Series of several experimental cycles were conducted with varying conditions of cooling rates and iterations were done with varying EGR substitutions and the results were compared. The exhaust gas analyzer used is MN-05 multi gas analyzer (4 gas version) is based on infrared spectroscopy technology with signal inputs from an electrochemical cell. Non-dispersive infrared measurement techniques use for CO, CO2, and HC gases. Each individual gas absorbs infrared radiation absorbed can be used to calculate the concentration of sample gas. Analyzer uses an electrochemical cell to measure oxygen concentration. It consists of two electrodes separated by an electrically conducted liquid or cell. The cell is mounted behind a poly tetrafluorethene membrane through which oxygen can diffuse. The Device therefore measures oxygen partial pressure. If a polarizing voltage is applied between the electrodes the resultant current is proportional to the oxygen partial pressure. The engine used in the present study is a Kirloskar AV-1, single cylinder direct injection, Water cooled diesel engine with the specifications given in Table 1. Diesel injected with a nozzle hole of size 0.15mm.the engine is coupled to a dc dynamometer. Engine exhaust emission is measured. Load was varied from 1 kilo watt to 3kilo watts. The amount of exhaust gas sent to the inlet of the engine is varied. At each cycle, the engine was operated at varying load and the emissions were noted. The experiment is carried out by keeping the compression ratio constant i.e., 16.09:1.

AB-air box ,E-exhaust gas recirculation provision-measurement of air by mano meter , Fw-fly wheel, ADM-alternator dynamometer, i-fuel injector,C-computer for P-θ interface,v-valve for fuel control, EGA-exhaust gas analyzer, s-piezo electric sensor for p-θ interfacing,PB-panel board, EP-exhaust gas probe, FT-fuel tank.

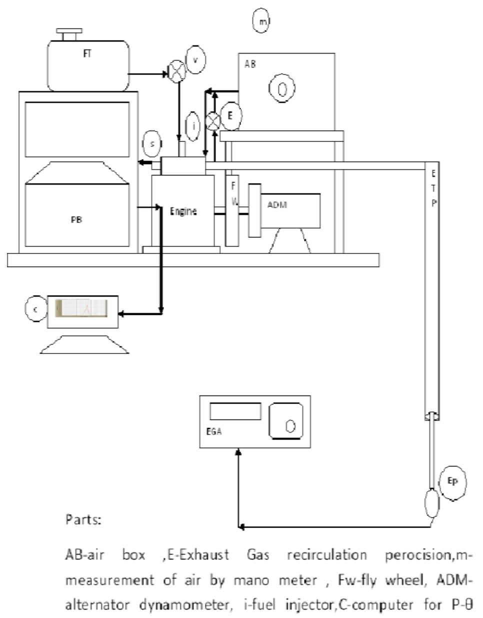

Fig: 1 block diagram of experimental set up

Nomenclature:

NO_X	Oxides of nitrogen
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Unburnt hydro carbons
PPM	Parts per million
CR	Cooling rate in LPM
%vol	Percentage of volume

Table2: Nomenclature

V. RESULTS

Significant results were obtained after conducting of several experimental cycles with varying cooling rates and blends at different loads.

NOx emissions

Graph 1 shows that increasing of cooling rate decreases NO_x emissions relatively at all loads. This is due to the excess cooling rate bring down the peak temperatures and there by decreasing NO_x emissions. Induction of 18% of EGR has decreased Nox by 20% of that of pure diesel.

Graph2 shows NO_x emissions at various cooling rates, from the graph it is quite obvious that increased cooling rate decreased the peak temperatures there by decreased NO_x by 18% and induction of 18% EGR reduced NO_x to 20% of that of only diesel.

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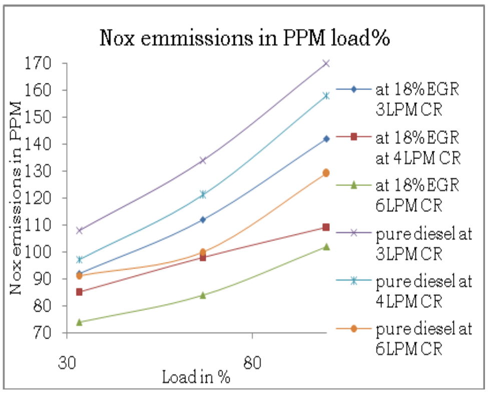
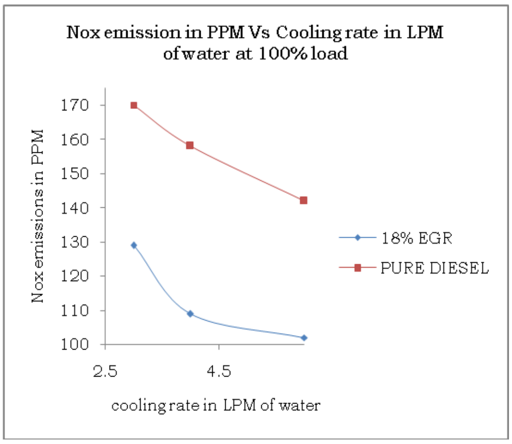


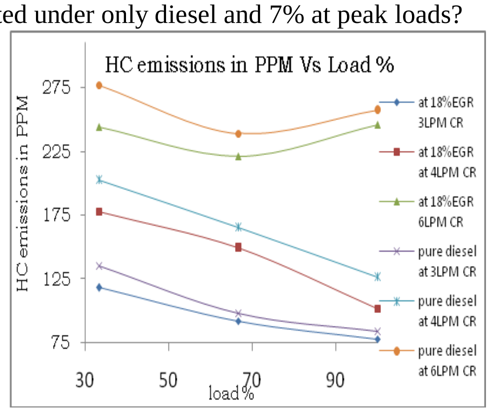
Graph1: Nox emissions in PPM load%



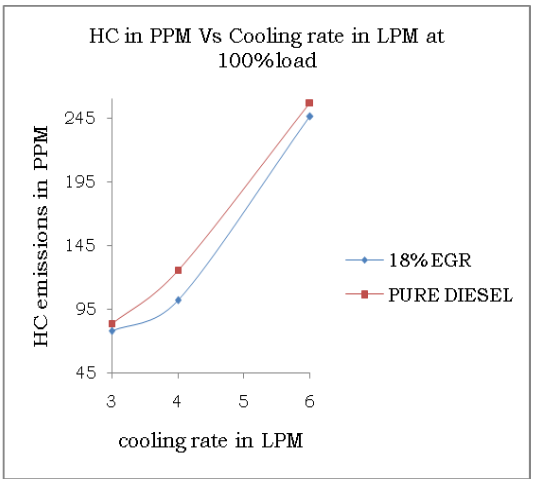
Graph2: Nox emission in PPM Vs cooling rate in LPM of water at 100% load.

VI. HC EMISSIONS

From graphs 3&4 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. At part load conditions decrease of Emissions was 15% to that of operated under only diesel and 7% at peak loads?



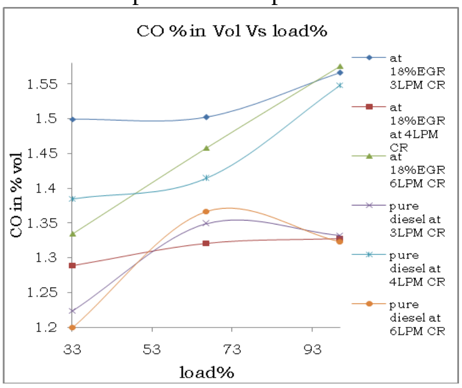
Graph3: HC emissions in PPM Vs Load%



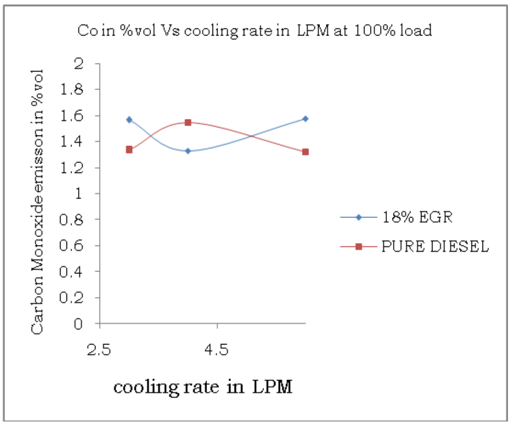
Graph4: HC in PPM Vs cooling rate in LPM at 100% load

VII. CO EMISSIONS

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 graphs 5 & 6the increase in CO emissions due to EGR induction was not so substantial and was not more than 4% of that of condition when operated with pure diesel.



Graph5: CO % in Vol Vs load%



Graph6: Co in %vol Vs cooling rate in LPM at 100% load

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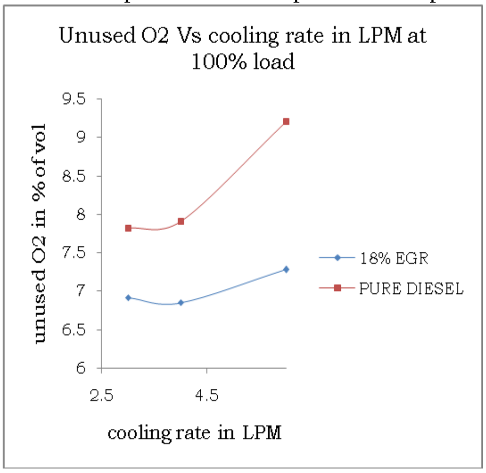
VIII. UNUSED OXYGEN

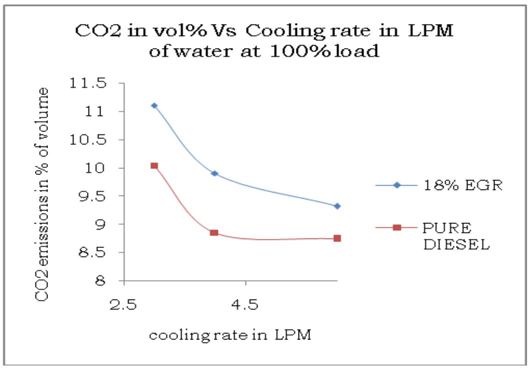
Induction of EGR clearly reduces the intake of oxygen and hence lading to reduction in out come of unused oxygen. Graph7 shows 26% reduction in un reacted oxygen when compared to that of pure diesel operation.



Graph7: Unused O2 Vs cooling rate in LPM at 100% load

IX. CO_2 EMISSIONS

Graph 8 shows that increase in the cooling rate of the engine any how decreased the CO_2 emissions by 20% but increase in 19% to that of operation of engine without EGR.



Graph8: CO2 in vol% Vs cooling rate in LPM of water at 100% load

X. RESULTS

Significant conclusions were drawn from after conducting of several experimental cycles with varying cooling rates and EGR substitutions at different loads and observing the results.

- Increasing of cooling rate decreased NOx emissions relatively at all loads. This is due to the excess cooling rate bring down the peak temperatures and there by decreasing NO_x emissions. Induction of 18% of EGR has decreased Nox by 20% of that of pure diesel. NO_x emissions at various cooling rates, from the graph it is quite obvious that increased cooling rate decreased the peak temperatures ther by decreased NO_x by 18% and induction of 18% EGR reduced NO_x to 20% of that of only diesel.
- 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. At part load conditions decrease of Emissions was 15% to that of operated under only diesel and 7% at peak loads?
- 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 graphs 5 & 6the increase in CO emissions due to EGR induction was not so substantial and was not more than 4% of that of condition when operated with pure diesel.
- Induction of EGR clearly reduces the intake of oxygen and hence lading to reduction in out come of unused oxygen. Graph7 shows 26% reduction in un reacted oxygen when compared to that of pure diesel operation.
- The increase in the cooling rate of the engine any how decreased the CO_2 emissions by 20% but increase in 19% to that of operation of engine without EGR.

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