A Study on Emission Effect of Exhaust Gas Recirculator on Single Cylinder 4-Stroke CI-DI Engine

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Abstract*- Exhaust gas recirculation (EGR) is a widely used technique in CI engines to reduce the exhaust emissions, particularly NOx. At higher temperatures, the nitrogen and oxygen in the combustion chamber of an engine chemically combine to form NOx. EGR controls the NOx because it lowers oxygen concentration and flame temperature of the working fluid in the combustion chamber The EGR system recirculates some fraction of exhaust gases back to the engine through the intake manifold where it mixes with the fresh incoming charge. By diluting the air-fuel ratio, peak combustion temperatures and pressures are reduced resulting in a reduction of NOx concentration. In this paper an experimental study is conducted on a single cylinder four stroke CI-DI engine to determine the influence of EGR on engine performance and NOx emissions.*

Keywords- EGR, NOx, CI engine

Nomenclature

EGR: Exhaust Gas Recirculation
NOx: Oxides of Nitrogen
CI : Compression Ignition
BTE: Brake Thermal Efficiency
BSFC: Brake Specific Fuel Consumption
PM:Particulate Matter
CO: Carbon Monoxide
HC: Hydrocarbon
CO_2: Carbon Dioxide
H_2O :Water Vapor
O_2:Oxygen
NO_2: Nitrogen Dioxide
NO: Nitric Oxide

I. INTRODUCTION

CI engines are preferred prime movers due to their excellent drivability and higher thermal efficiency. CI engines produce the lower amount of emissions so they are considered as a good replacement to gasoline engines. On the contrary, higher emissions of PM, NOx have been determined as major problems. Although, major constituents of diesel exhaust include CO_2, H_2O, O_2, CO, NOx, HC & PM are smaller in quantity but environmentally significant. CO_2, H_2O, N_2, O_2 in modern diesel engines are normally consist of more than 99% exhaust, while CO, HC, NOx, PM (the harmful pollutants) make for less than 1% exhaust. NOx encompasses of NO_2 & NO also both are considered to be destroying to humans moreover environmental health. NO_2 is noticed as more toxic in comparison to NO. It affects human health directly and is forerunner to formation of ozone and it is main doer of formation of smog. The NO_2 and NO ratio in CI engine exhaust is absolutely small, although NO gets instantly oxidized in the environment, forming NO_2. Because of the incomplete burning of the air-fuel mixture in the combustion chamber pollutants are produced. The dominant pollutants exhaled from the exhaust in behalf of incomplete combustion are,

1) NOx
2) CO
3) HC

As combustion is complete, the only products being dive out from exhaust would be water vapour which is innocuous and carbon dioxide, which is an inert gas and as such it is not directly harmful to humans. Despite their advantages they produce higher levels of NOx and smoke emissions which are more harmful to human health. Hence stringent emission norms have been imposed. In order to meet the emission norms and also the fast depletion of petroleum oil reserves lead to the research for alternative fuels for CI engines. Biodiesel from vegetable oils are alternative to diesel fuel for diesel engines. The use of biodiesel in CI engines does not require any engine modification. Biodiesel gives considerably lower emissions of PM, CO and HC without any fuel consumption or engine performance penalties. Many researchers have found that with biodiesel fueled engine produces higher NOx emissions compared to diesel [13-15]. 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 [14]. So, to reduce the NOx emission levels in the exhaust, it is necessary to keep the combustion temperature under control. Exhaust gas recirculation is one of the most effective techniques for NOx reduction

Exhaust gas recirculation (EGR) is an emission control technology which allows significant NOx emission reductions from most types of diesel engines. While the application of EGR for NOx reduction is the most common reason for applying EGR to modern commercial diesel engines, its potential application extents to other purposes as well. Some of these include: imparting knock resistance and reducing the need for high load fuel enrichment, aiding vaporization of liquid fuels engines or for improving the ignition quality of difficult-to-ignite fuels in diesel engines. The amount of EGR that can be used is limited by different factors. One of them is the need for delivering enough fresh air for the combustion to take place; another is the decrease of engine efficiency that can be caused by high amounts of EGR. The mixing of exhaust gases with intake air raises specific heat of intake mixture, which sequels in the reduction of flame temperature. Hence combination of minor oxygen quantity in the intake air and reduced flame temperature lowers the rate of formation of NOx reactions. The EGR (%) is termed as the mass percent of the recirculated exhaust (MEGR) in the total intake
mixture (Mi).

$$\text{EGR}=\frac{MEGR}{Mi}*100$$

The engines using EGR emit lower quantity of exhaust gases than non-EGR engines because a bit of the exhaust gas is re-circulated. Thus in spite of the concentration of toxic substances in the exhaust gas leftover unchanged, the total multitude of emission of toxic substances lower for the same volumetric concentration. CI engines manipulating at little loads and generally tolerate a higher EGR ratio after all re-circulating exhaust gases encompasses high concentration of oxygen and low concentration of carbon dioxide and water vapors. At higher loads, the oxygen in exhaust gas becomes sparse and the inert components initiate dominating furthermore raised exhaust temperature. Hence as load raises, diesel engines tend to develop farther smoke because of shortened availability of oxygen. At very high EGR rate (around 44%), PM emission decreased pointedly with a continuous drop in NOx emission yet this high EGR rate significantly affect the fuel economy. A pertinent volume of EGR boosts fuel economy and HC emissions. This aspect was probably due to the intake temperature raise by EGR, which improved the flame propagation in the relatively lanky region of the air– fuel mixture, which is non-uniformly divided. EGR was found to be a process of improving engine performance and emissions of spark ignition engines. In case of CI engines, these modifications build higher specific fuel consumption and particulate matter emissions. The rate of soot oxidation/reburning reduces due to reduction in flame temperature. As a result, in EGR system, more soot is produced during combustion and it leftover un-oxidized and eventually arrive in the exhaust. The increase in smoke (soot) level of engine exhaust due to EGR affects the engine performance in various approaches. Increased soot level accounts substantial raise in the carbon deposits and wear of the various important engine parts being cylinder liner, piston rings, valve train and bearings. Chemical reactions breeze on the surface (adsorption and corrosion) or to abrasion of material or rupture of anti-wear film by soot leads to wear of the materials. An increase in inlet charge temperature always results in shorter ignition delay and may upgrade thermal efficiency. If the exhaust gas is cooled ahead recirculation to combustion chamber, then it is called cooled EGR. Cooling of EGR give rise to increase in the charge density hence enhances volumetric efficiency of the engine. Also, it implements additional aids by lowering NOx emissions to a greater limit. Withal condensation of moisture present in the exhaust raises corrosion in combustion chamber. N.K.Miller Jothi**:** Studied the effect of Exhaust Gas Recirculation (EGR) on homogeneous charge ignition engine. A stationary four stroke, single cylinder, direct injection (DI) diesel engine capable of developing 3.7 kW at 1500 rpm was modified to operate in Homogeneous Charge Compression Ignition mode. In the present work the diesel engine was operated on 100% Liquified Petroleum Gas. Deepak Agarwal investigated the effect of EGR on soot deposits, and wear of vital engine parts, especially piston rings, apart from performance and emissions in a two cylinder, air cooled, constant speed direct injection diesel engine, which is typically used in agricultural farm machinery and decentralized captive power generation. Such engines are normally not operated with EGR. The experiments were carried out to experimentally evaluate the performance and emissions for different EGR rates of the engine. Emissions of HC, NO_X, CO, exhaust gas temperature and smoke capacity of the exhaust gas etc. were measured. Performance parameters such as thermal efficiency, brake specific fuel consumption BSFC were calculated. Reductions in NO_X and exhaust gas temperature were observed but emissions of PM, HC and CO were found to have increased with usage of EGR. The engine was operated for 96 hr in normal running conditions and the deposits on vital engine parts were assessed. The engine was again operated for 96 h with EGR and similar observations were recorded. N. Saravanan: Used hydrogen-enriched air as intake charge in a diesel engine adopting exhaust gas recirculation (EGR) technique with hydrogen flow rate at 20 l/min. Experiments are conducted in a single cylinder, four stroke, water-cooled, direct-injection diesel engine coupled to an electrical generator. Performance parameters such as specific energy consumption, brake thermal efficiency are determined and emissions such as oxides of nitrogen, hydrocarbon, carbon monoxide, particulate matter, smoke and exhaust gas temperature are measured. Usage of hydrogen in dual fuel mode with EGR technique results in lowered smoke level, particulate and NO_X emissions. H.E.Saleh: Studied Jojoba methyl ester has been used as a renewable fuel in numerous studies evaluating its potential use in diesel engines. These studies showed that this fuel is good gas oil substitute but an increase in the nitrogenous oxides emissions was observed at all operating conditions. The aim of this study mainly was to quantify the efficiency of exhaust gas recirculation (EGR) when using Jojoba methyl ester fuel in a fully instrumented, two-cylinder, naturally aspirated, four-stroke direct injection diesel engine. The tests were carried out in three sections.

II. EXPERIMENTAL SET UP AND PROCEDURE

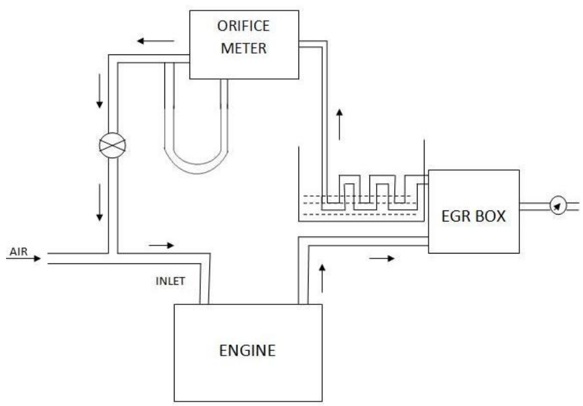

Fig 2.1 Layout of EGR with engine

The exhaust gas coming from engine is made to collected in EGR box. By operating the valves provided in the system, different percent of exhaust gas is enter into the inlet with the help of orifice meter. This exhaust gas is made to pass through the cooling system placed after the EGR box. This reduces the temperature of engine and also provides better combustion. Hence reduces the NO_x emission. The exhaust gas entering into cylinder at high temperature contains unburnt fuel & some hydro carbon gases, which decreases the mass of air fuel mixture into cylinder and decreases amount of oxygen in cylinder to reduce the combustion temperature in cylinder. As the cylinder temperature reduces, NOx formation is also reduced.

Fig 2.2 Experimental Setup

Tests are conducted for normal condition of an engine without EGR. Water flow rate is kept constant at 200lit/hr in rotameter. NOx content in exhaust gas is measured using Exhaust Gas Analyser. Inserting the analyzer pipe into exhaust and note down the NOx content from analyzer. In this way procedure is repeated for different loads. Conduct the experiment with EGR. The exhaust gas valve on the box is kept closing till the manometer reading is stable and the valve is kept undisturbed. The exhaust gas coming from the EGR box passes through the cooling system which is maintained in the tray, the gas passing through this system is cooled slightly and later gas moves to the orifice meter where the flow rate is varied and change in head is noticed in the differential manometer and this gas is passes through EGR valve into the engine cylinder The EGR valve is opened using the knob and head for 5% of exhaust gas calculated is maintained in the manometer and for same head all readings are noted. Later the similar procedure is carried for 10% and 15% of exhaust gas by varying the EGR valve. Mechanical efficiency, thermal efficiency and all the different performance parameters are calculated and graphs are plotted for the same.

The exhaust gas entering into cylinder at high temperature contains unburnt fuel and some hydro carbon gases this decreases the mass of air fuel mixture into cylinder and this decreases amount of oxygen in cylinder and this reduces the combustion temperature in cylinder. As the cylinder temperature reduces, the formation of NO_x is also reduced in the cylinder.

Engine Specifications:-Table 2.1

1)	Engine type	AV1 Kirloskar Diesel Engine
2)	No. Of Strokes	4 Strokes
3)	No. Of Cylinders	Single Cylinder
4)	Bore	80mm
5)	Stroke	110mm
6)	Compression Ratio	16.5:1
7)	Rated Output	3.7KW at 1500rpm
8)	Load on engine	Lamp Load

III. RESULTS AND DISCUSSION

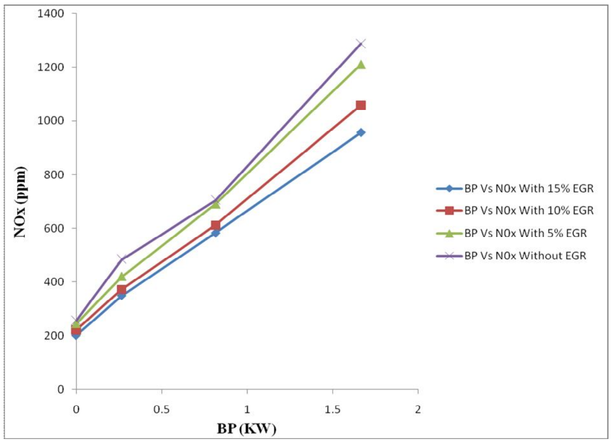

Fig 3.1 BP v/s NO_x

In the figure 3.1 graph is plotted for BP against NOx formation without EGR system along with 5%, 10% and 15% of EGR System. It is observed that as the Percentage of exhaust gas recirculation to the Engine increases, the formation of NO_x also reduces.

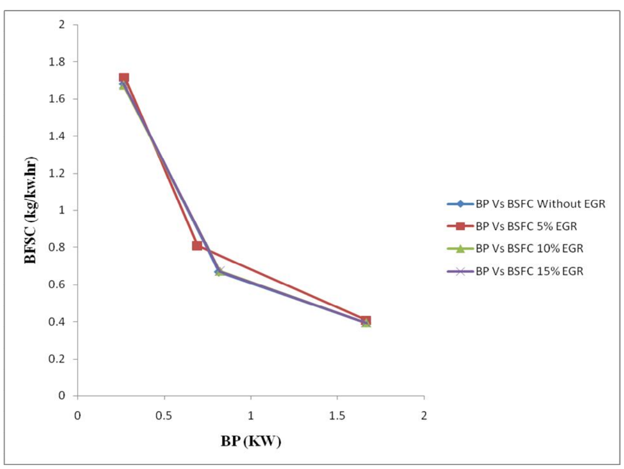

Fig 3.2 BP v/s BSFC

In the figure 3.2 graph is plotted for BP against BSFC without EGR system along with 5%, 10% and 15% of EGR system. The BSFC is same for without EGR system and with 5% EGR system. Also, the BSFC is same for 10% and 15% EGR system. This is slightly lesser than without EGR and with 5% EGR system. So, as percentage of exhaust gas recirculation to the engine is increases the EGR is goes on decreases.

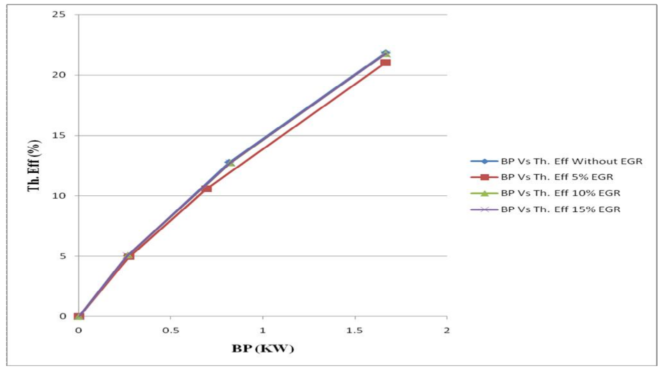

Fig 3.3 BP v/s Thermal efficiency

In the figure 3.3 graph is plotted for BP against Thermal Efficiency without EGR System along with 5%, 10% and 15% of EGR System. It is seen that, the thermal efficiency is almost same for without EGR and with EGR System. So, the exhaust gas recirculation to the engine will not have more effect on thermal efficiency.

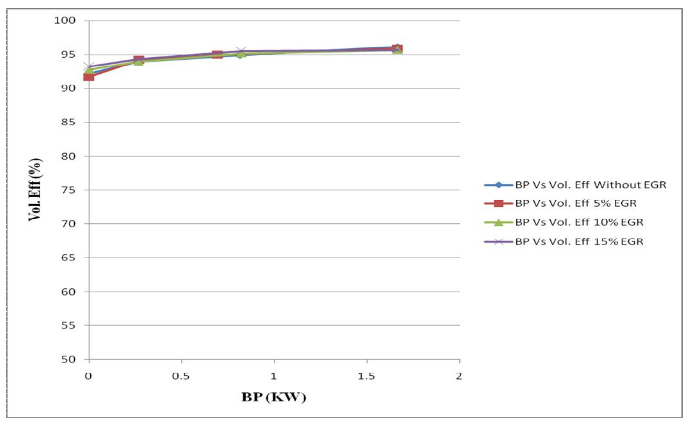

Fig 3.4 BP v/s Volumetric efficiency

In the figure 3.4 graph is plotted for BP against Volumetric Efficiency without EGR System along with 5%, 10% and 15% of EGR System. It can be concluded that as percentage of exhaust gas recirculation to the engine increases, the volumetric efficiency will remain constant. So, EGR will not have much effect on volumetric efficiency.

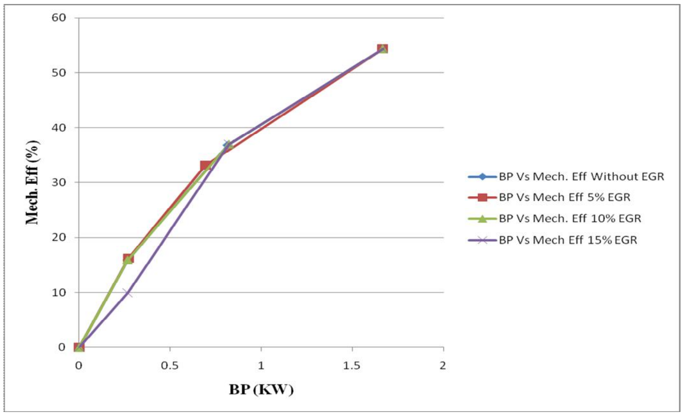

Fig 3.5 BP v/s Mechanical efficiency

In the figure 3.5 graph is plotted for BP against volumetric efficiency without EGR System along with 5%, 10% and 15% of EGR System. It is observed that as percentage of exhaust gas recirculation to the engine increases, there is reduction in mechanical Efficiency.

IV. CONCLUSIONS

The conclusions drawn from present experimental investigation are as follows.

1. With increase in percentage of the EGR, BTE increases initially and BSFC decreases initially and then increases. The optimum EGR for maximum BTE and minimum BSFC is found to be around 15%.
2. Recycled exhaust gas lowers the oxygen concentration in the combustion chamber and increases the specific heat of intake charge which results in lower flame temperature and reduction in NOx formation.
3. The formation of NOx is reduced by 40% at 15% of EGR as compared to without EGR at same loading condition.
4. EGR is proved to be one of the most efficient methods of NOx reduction in diesel engines. The increase in particulate matter emissions due to EGR can be taken care by employing particulate traps and adequate regeneration techniques

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