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A Review Study of the effect of Exhaust Gas Recirculation (EGR) on performance and emission characteristics of diesel engine

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Abstract- Now-a-days, the use of diesel engines increases compared to gasoline engines because of the decrease in the cost of diesel engine and the efficiency of the diesel engine. But in other side NOx emissions from diesel engine are high. So there is a need for a technique which could reduce the emissions without affecting the performance of engine. One of such technique is Exhaust gas recirculation (EGR). EGR reduces oxygen concentration and flame temperature of the working fluid in the combustion chamber which result in reduction in NOx emission. As the use of EGR tends to a trade-off in terms of soot emissions moreover it exhausted more unburned hydrocarbons (20-30%) than conventional engines. For attaining minimum emission levels, Partial recirculation of exhaust gas becomes more essential. The modification of EGR valves and improvements in electronic controls allows better EGR accuracy and shorter response time in transient condition. Present paper aims to find the effect of Exhaust Gas Recirculation (EGR) on emission characteristics and performance of diesel engine.

Key words -: EGR, Engine performance, Staged combustion, Efficiency, Emissions and NOx

1. INTRODUCTION

The better fuel economy and high power with low maintenance cost increases the popularity of diesel engine vehicles increases rapidly. Diesel engines are applicable for powering equipment, bulk movement of goods and to generate electricity more economically comparatively others. The diesel engine manufacturer upgrades the technology in terms of power, fuel economy and emissions for the diesel vehicle sales in future. Diesel emissions are belonging to carcinogenic. The demanding emission prescriptions are enthralling engine manufacturers to develop technologies to antagonistic exhaust emissions. To fulfill these emission regulations with competitive fuel economy, exhaust gas after-treatment and optimized combustion are necessary.

In diesel engines, a highly temperature dependent phenomenon is NOx formation and it takes place when the temperature in the combustion chamber exceeds 2000 K. Therefore in order to reduce NOx emissions in the exhaust it is necessary to keep peak combustion temperatures under control. the late injection of fuel into the combustion chamber in diesel engine reduces the NOx emission which is the simple method. But this technique increases fuel consumption by 10% - 15%. So this necessitates the use of exhaust gas recirculation (EGR) which is more effective NOx reducing technique. When exhaust gas is recirculated, it is important to investigate the effect on characteristics of engine performance as well.

Diesel engines are produces the lower amount of emissions so they are considered as a good replacement to gasoline engines. On the contrary, higher emissions of particulate matter (PM), oxides of nitrogen (NOx) have been determined as major problems. Although, major constituents of diesel exhaust include carbon dioxide (CO_2), nitrogen (N_2), water vapor (H_2O), oxygen (O_2); carbon monoxide (CO), oxides of nitrogen (NOx), hydrocarbons (HC), and particulate matter (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 nitrogen dioxide (NO_2) and nitric oxide (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 diesel engine exhaust is absolutely small, although NO gets instantly oxidized in the environment, forming NO_2. After all diesel engines chiefly emit NO thus scrutiny has been given to reduce the NO formation.

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) Oxides of nitrogen (NOx)
2) Carbon monoxide (CO)
3) Hydrocarbons (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.

1.1 Exhaust Gas Recirculation

Exhaust Gas Recirculation is an adequate method for NOx control. The exhaust gases primarily amount to nitrogen, carbon dioxide etc. and the mixture has higher specific heat in comparison to atmospheric air. Re-circulated exhaust gas uproot fresh air entering the combustion chamber with carbon dioxide and water vapor present in engine exhaust. As aftermath of this air displacement, lower amount of oxygen in the intake mixture is accessible for combustion. Reduced oxygen available for combustion curtailed the effective air–fuel ratio. This effective reduction in air–fuel ratio influences exhaust emissions appreciably. Auxiliary 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 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).

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

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. Diesel 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. Withal 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. Withal application of EGR also give rise to modifications. In case of diesel engines, these modifications build higher specific fuel consumption and particulate matter emissions. Effectively, a tradeoff between NOx and soot is observed with the usage EGR. 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.

2. SPECIFICATIONS

The engine and the coupled alternator specifications were tabulated in Tables 1 and 2.

2.1 Experimental setup and methodology

Jaffar Hussain, K. Palaniradja, N. Alagumurthi, R. Manimaran operated three-cylinder constant speed direct injection diesel engine generator set chosen to study the effect of EGR on the performance and emissions, carbon deposits, and wear of diesel engine components. The specifications of engine are given in

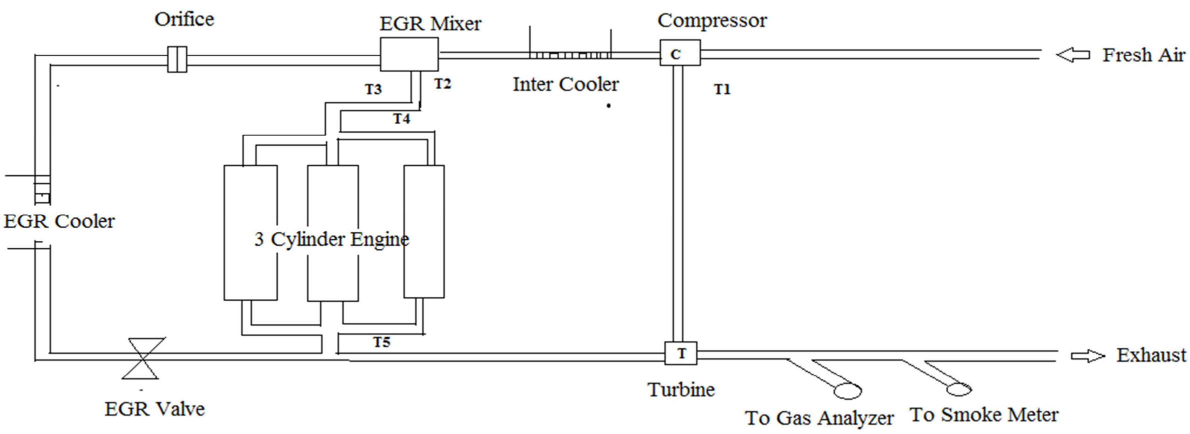

Fig. 1- The Schematic Diagram of Engine Setup

Section 2. The engine is driven by AC generator and the current generated is used by a resistive load

Table1 Specification of the Engine

Make	Kirloskar Engine
Model	HA 394
No. of cylinders	3
No. of strokes	4
Bore and Stroke	100mm*120mm
BHP/BP	32.5/20KW
Rated power	25KVA
Displacement	2826cc
Types of cooling	Air cooled
Fuel consumption at90% load	5L/h
Firing order	1.3,2
Aspiration	Natural
Speed	1500
Compression ratio	17:1

Table2 Specification of the alternator

Model	Genset
Rating	215KVA
Current	34.8A
Voltage	380/415V
RPM/frequency	1500/50Hz
No. of phases	3
Power factor	0.8

bank, thus in-turn loading the engine. The generator is calibrated and all losses in the generator such as copper losses, armature current losses and friction and windage losses (unaccounted losses) are accounted while analyzing the data. For recirculation of the exhaust gas, appropriate plumbing was done. The pipe line was not insulated hence allowing the re-circulated exhaust gases to cool down partially. The simplified diagram of the engine setup is shown in Fig. 1. The quantity of EGR can be controlled by a control valve installed in the EGR loop. An EGR Mixer was provided in EGR loop to dampen the fluctuations of the pulsating exhaust. An orifice was installed in the EGR loop to measure the discharge i. e. flow rate of re-circulated exhaust gas. Orifice meter was installed to measure the intake Exhaust flow rate. For measurement of temperatures at several locations, suitable instrumentation was done. Gravitational manometer was used to measure the fuel consumption. Oxygen, CO, NOx, and CO_2 were measured using manual Orsat apparatus. To achieve the aim of the study, engine was run under normal operating condition and at different EGR rates. The data for HC, NOx, CO, smoke opacity, exhaust gas temperature, and fuel consumption were recorded. Then, engine performance as well as emission patterns were compared. Optimum EGR rate was found on the basis of performance and emissions characteristics of the engine. Then, the engine was run with and without EGR and also with staged combustion for total 6 hrs in each phase using a fixed test cycle shown in Table 3

3. PERFORMANCE ANALYSIS OF THE ENGINE

The following equations were used in analysis of the collected data.

Engine brake horse power:

$$P.\ S. = \frac{W*N}{1000} \quad (1)$$

Where P.S = brake horse power in Watt,
W = Torque in Kg
N = speed in RPM

Specific fuel consumption:

$$SFC = \frac{\dot{m}f}{W} \quad (2)$$

Where SFC = specific fuel consumption in Kg/hr,

ṁf = mass flow rate of fuel in Kg/hr and
W = engine power in Watt.

Brake specific fuel consumption:

$$BSFC = \frac{\dot{m}f}{Wb} \qquad (3)$$

Where BSFC = brake specific fuel consumption in Kg/hr,
ṁf = mass flow rate of fuel in Kg/hr and
Wb = brake power in Watt.

Thermal efficiency:

$$\eta th = \frac{W*\dot{m}f}{CV} \qquad (4)$$

Where η_{th}= thermal efficiency,
W = engine power in Watt,
ṁf = mass flow rate of fuel in Kg/hr and
CV = calorific value of fuel in KJ/KgK.

Brake thermal efficiency:

$$\eta bth = \frac{Wb}{\dot{m}f*CV} \qquad (5)$$

Where η_{bth} = brake thermal efficiency,
Wb = brake power in Watt,
ṁf = mass flow rate of fuel in Kg/hr and
CV = calorific value of fuel in KJ/KgK.

Percentage of exhaust gas recirculation:

$$\%EGR = \frac{volume\ of\ EGR}{total\ intake\ charge\ to\ the\ cylinder} * 100 \qquad (6)$$

4. RESULTS AND DISCUSSION

The following results were recorded by Jaffar Hussain, K. Palaniradja, N. Alagumurthi, R. Manimaran .Different load tests were performed at 1500 rpm with different EGR rates (from 0% to 25%)

Table3 Engine test cycle for endurance test

Load	Duration(mm)
No load	20
100% load	30
50% load	120
No load	20
75% load	60
No load	20
100% load	30
75% load	60
Total	360(6 h)

to investigate the effect of EGR on the engine performance and emissions. The performance and emission data including thermal efficiency, HC, CO, NOx emission, BSFC, exhaust gas temperature, and smoke capacity was analyzed and presented on the graph.

4.1 Engine performance analysis

The trends of thermal efficiency are shown in Fig. 2. Thermal efficiency is slightly increased with EGR at lower engine loads. This is because of re-burning of hydrocarbons that enter the combustion chamber with the re-circulated exhaust gas. For part load engine, exhaust gas has less CO_2 and fairly high amount of O_2. Also, partly-cooled EGR acts like a pre-heater of the intake mixture. When this exhaust

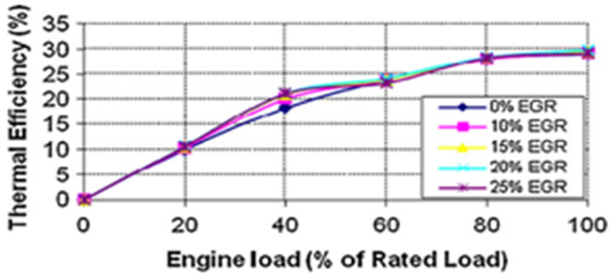

Fig. 2- Thermal Efficiency for Different EGR Rates

gas is circulated again in the cylinder, the unburned HC in exhaust gas burns, since sufficient O_2 available in combustion chamber and reasonably high intake temperatures. Excess of unburned hydrocarbons utilized with reduced fueling rates in staged combustion at higher engine loads, the thermal efficiency remains unaffected by EGR. Exhaust gas has higher amount of CO_2 at higher load, which decreases maximum temperature in combustion chamber along with oxygen availability therefore re-burning of HC is not significant.

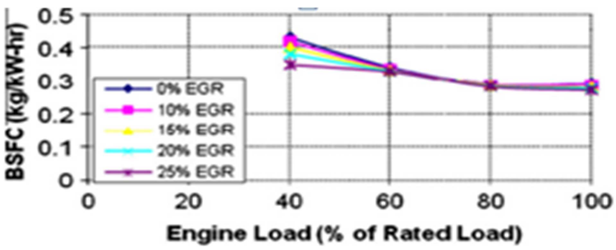

Fig. 3-Brakes Specific Fuel Consumption for Different EGR Rates

Fig. 3 represents variation of BSFC with engine load. The BSFC increases EGR rate increases and diesel without EGR as lower specific fuel consumption. At higher loads, amount of fuel supplied to the cylinder get increased and oxygen required for combustion gets reduced. Thus, air fuel ratio get changed and this increases the BSFC.

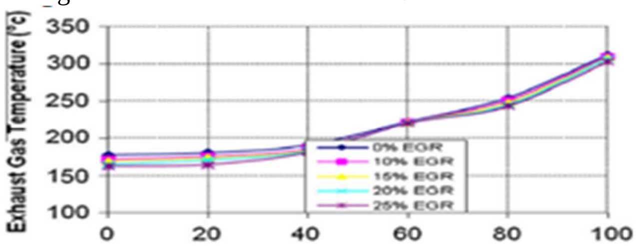

Fig. 4- Exhaust Gas Temperatures for Various EGR Rates

Fig. 4 represents change in exhaust gas temperature with load. It is clear that extremely high temperature in the combustion chamber causes the formation of NOx. The graph indicates that as EGR rate increases, the exhaust gas temperature reduces.

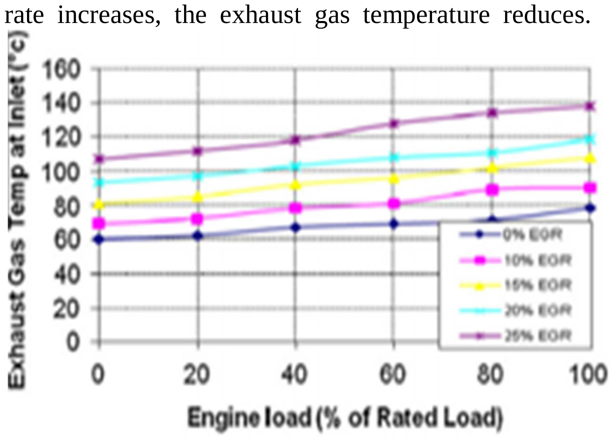

Fig. 5-Exhaust Gas Temperature at the Inlet of Manifold for different EGR Rates

Fig. 5 represents the change in exhaust gas temperature at the entry to the inlet manifold for different EGR rates. The above graph shows that exhaust gas temperature at entry to inlet manifold is not too high since exhaust gases are partly cooled before mixing with fresh air at atmospheric temperature. When load and EGR rates are increased, the exhaust gas temperature at the entry to the inlet manifold becomes higher than atmospheric temperature and hence EGR acts as a pre-heater to fresh intake air.

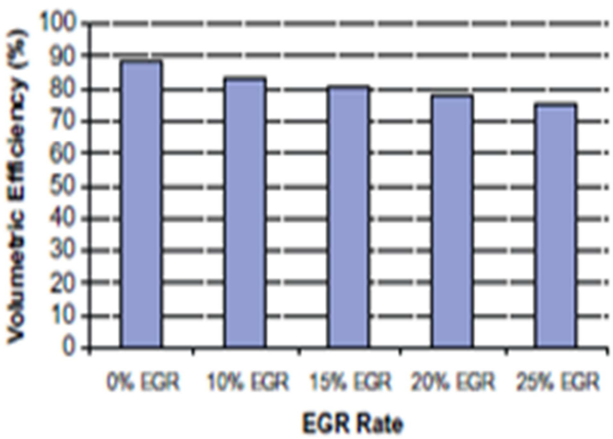

Fig. 6- Volumetric Efficiency for different EGR Rates

Fig. 6 shows volumetric efficiency for different EGR rates. It is clear that the EGR rate increases with decrease in volumetric efficiency. The mass flow rate of intake air reduces because of EGR implementation, i. e. volumetric efficiency drops.

4.2 Engine emission analysis

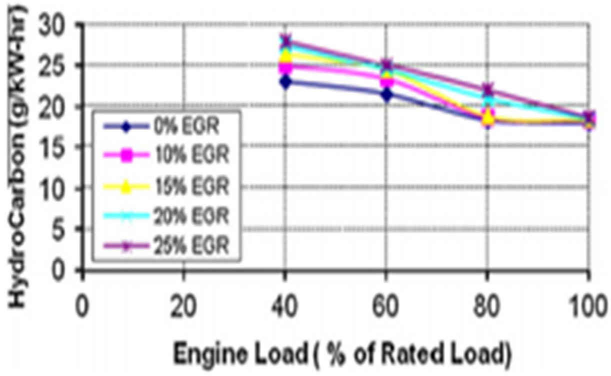

Fig.7-Hydrocarbons for Different EGR rates

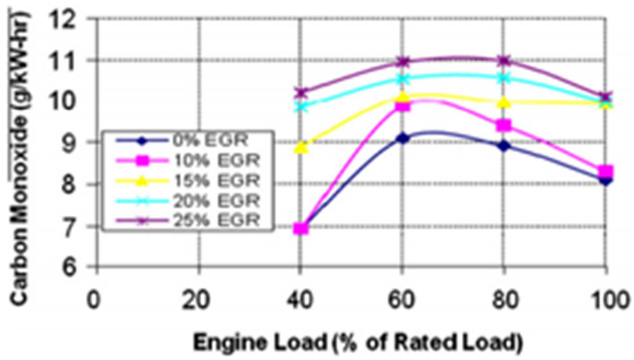

Fig. 8- Carbon Monoxides for different EGR Rates

Effect of EGR on carbon monoxide (CO) and unburned hydrocarbon (HC) are shown in Figs. 7 and 8, respectively. The above graph shows that HC and CO emissions increase with increase in EGR rate. This is because of decrease in available oxygen to combine with carbon.

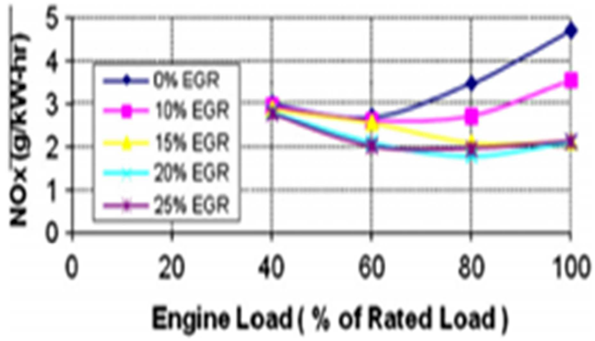

Fig. 9 - NOx for Different EGR Rates

Fig. 9 represents the main benefit of EGR in decreasing NOx emissions from diesel engine. The reasons for reduction in NOx by implementation of

In diesel engines EGR decreases oxygen concentration as well as flame temperatures in the combustible mixture. At the part load, sufficient amount of O_2 is available but at high loads, O_2 reduces drastically. Hence NOx emission reduction occurs more in at higher load than part load.

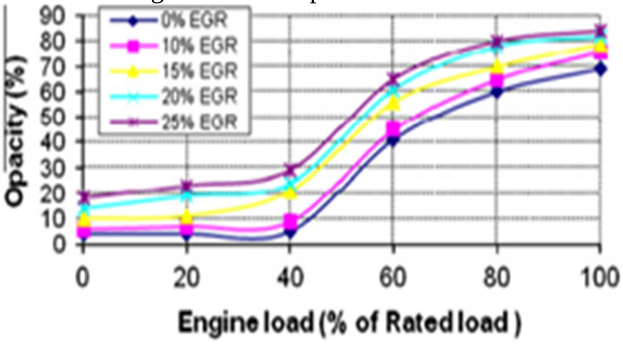

Fig. 10-smoke Capacity for Different EGR Rates

To express the quantity of the particulate matter present in the exhaust gas, the smoke capacity of the exhaust gas is measured. The smoke capacity is as shown in Fig. 10. Higher smoke in the exhaust is obtained when the engine is operated with EGR than without EGR. The EGR decreases availability of oxygen for combustion of fuel, which results in relatively incomplete combustion and increased formation of particulate matter. Higher soot formation takes place in EGR system because of higher carbon deposits.

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5 Conclusions

a) For reduction of NOx emission 15% EGR ate is very useful without deteriorating engine performance.
b) EGR increases efficiency of diesel engine slightly but decreases BSFC at lower load.
c) Smoke increases slightly with increase in percentage of EGR.
d) There is slight increase in CO and HC emissions because of implementation of EGR.

Thus by taking all the results into consideration from the present experiment, we conclude that for optimum engine performance as well as reduction of emissions, EGR is very useful.

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