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"Optimization of EGR Rate on multi cylinders 4-stroke diesel engine."

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Abstract

The objective of this project is to check the effects of Exhaust Gas Recirculation on the performance & emissions of a diesel engine .This paper investigates the effects of Exhaust Gas Recirculation on the performance of a diesel engine in terms of fuel consumption, thermal efficiency, as well as HC, CO, and NO_x emissions. For this aim, a naturally aspirated four-stroke direct injection diesel engine was tested with diesel fuel, at different loading conditions from no load to full load condition at the constant speed1500 rpm and at different EGR Rates from 10% to 40%. The evaluation of experimental data showed that NO_x emission was reduced by about 80% because of EGR. However, it was observed that emissions of CO & HC were higher than those in the operations with diesel fuel, without EGR. A slight decrease in brake thermal efficiency was also noticed because of EGR. This study reveals that Exhaust Gas Recirculation is an effective way to reduce NO_x emission if used with proper after treatment of exhaust gas to limit the drawbacks associated with EGR.

1. Introduction

The diesel engine is well known as the most efficient internal combustion engine. It also appears that in the near future more and more diesel engines will be used for propulsion applications because of their high durability, performance and efficiency. Carbon dioxide (CO_2) is one of the main products of combustion of internal combustion (IC) engine that has a significant share on green house effect as well as on global warming. The emission of CO_2 is directly proportional to the fuel consumption. Fuel consumption and CO_2 emission from diesel engines are 20-30% less than that of gasoline engines and a reason of increasing diesel engine vehicles worldwide. However, higher particulate matters (PM) and oxides of nitrogen (NO_x) are the main disadvantages. During the combustion process the chemical energy in the diesel fuel is transformed in mechanical energy with the formation of reaction products, which leave the engine through the exhaust into the atmosphere. The most important ones are carbon dioxide (CO_2), carbon monoxide (CO), nitric oxides (NO_x), hydrocarbons (HC), water (H_2O) and particulate matter (PM). Because some of these emissions are toxic and harmful for humans and/or the environment, it is clear that regulations are presented by the authorities. These regulations will become stricter in the near future. Therefore engine manufacturers are required to do research and development of emission reducing techniques in order to meet the upcoming required emission standards.

The main focus of this article is on the development of an **exhaust gas recirculation (EGR)** system on 4-stroke 4-cylinders diesel engine in order to lower the NO_x emission significantly. The introduction of inert gases into the cylinder charge can dilute the oxygen concentration, chemically retard ignition, and ultimately lower combustion temperatures and hence NO_x emission as NO_x emission is directly proportional to combustion temperature. A readily available source for gases mostly depleted of oxygen is the exhaust. A portion of exhausted gases can be re-burned in the engine – a method well known as **exhaust gas recirculation**. Emission and performance test is carried out at different EGR rates

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and at varying load condition keeping engine speed constant i.e. 1500 RPM.

2. Experimental Work

2.1 Engine Specifications

Manufacturer	Tata motors Limited
Engine type	4-Cylinders 4 Stroke Diesel Engine
Bore	75 mm
Stroke	79 mm
Swept volume	1405 cc
Compression ratio	22:1
Brake Power and speed	20 hp and 2700 rpm
Fuel Injection Pressure	185 kg/cm^2
Specific fuel consumption	251 g/kwh

Table 2.1 Specification of test engine

2.2 Block Diagram & Actual Photographs of Experimental Set up

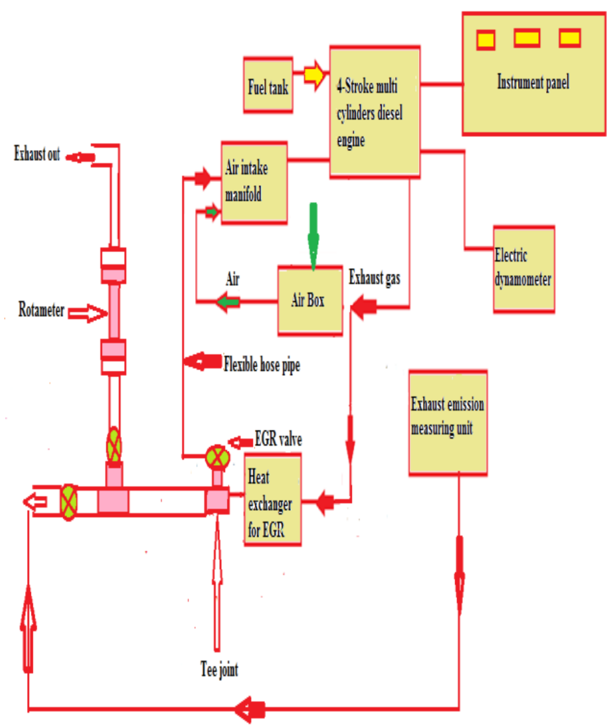

Fig.2.1 Block Diagram for Experimental Setup

Fig.2.2 Actual photographs of experimental set up

2.3 Experiment Procedure

The aim of the experiment is to observe the effect of EGR Rate on the performance and emission of a 4-stroke 4-cylinders diesel engine. For this following procedure has been carried out:

- The naturally aspirated 4 cylinders 4-stroke diesel engine was first modified to run it with EGR.
- Engine performance and emission was tested at varying EGR Rate (0-40%) and optimum EGR Rate for the naturally aspirated engine is found out by taking the performance and emission readings at varying load conditions (0-120%) and at constant speed i.e. 1500 RPM.

- Here, brake power was measured with electric dynamometer, exhaust emission was measured with a five gas analyzer while EGR Rate was controlled using exhaust gas rotameter and valves.
- Performance & emission results are plotted on the graphs & are analyzed to find out the optimum EGR Rate for each load condition.

3. Results and Discussions

3.1 Engine Performance Graphs and Discussion

(a) Fuel consumption

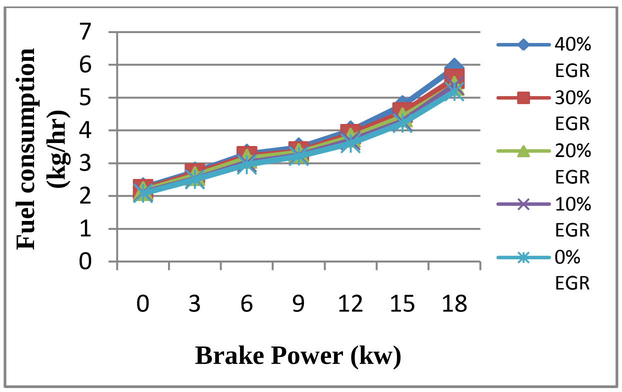

Fig.3.1 Brake power vs. Fuel consumption.

Fig. 3.1 shows graph for variation of fuel consumption with respect to brake power, without and with different EGR Rates for naturally aspirated engine. For all the cases tested, fuel consumption is found to increase with increase in the brake power. It can be seen that as the load increases, fuel consumption increases to the maximum at full load (15 kw) for all the cases tested i.e. without and with different EGR Rates. A slight increase in fuel consumption is found due to the introduction of EGR which reduces the availability of fresh charge. At 10% EGR rate, average fuel consumption increases only about 1.5%. At 20% EGR rate, average fuel consumption increase is about 4% .At 30% EGR rate, average fuel consumption increase is about 6% and at 40% EGR Rate average fuel consumption increase is about 11% than that of without EGR.

(b) Brake thermal efficiency

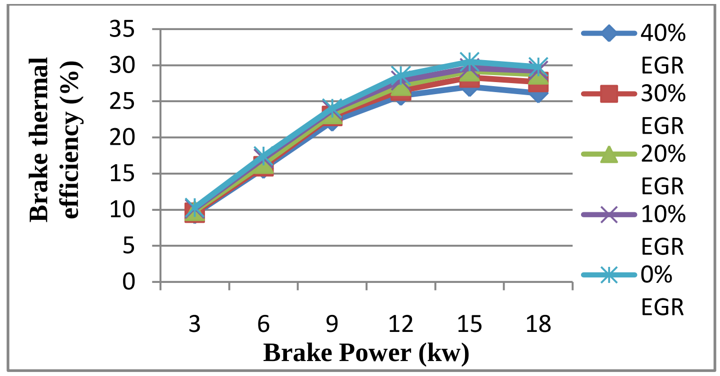

Fig.3.2 Brake power vs. Brake thermal efficiency.

Fig. 3.2 shows graph for variation of brake thermal efficiency with respect to brake power, without and with different EGR Rates for naturally aspirated engine. For all the cases tested, brake thermal efficiency is found to increase with increase in the brake power. It can be seen that as the load increases, brake thermal efficiency increases to the maximum at full load (15 kw) and then decreases at overload for all the cases tested i.e. without and with different EGR Rates. A slight decrease in brake thermal efficiency is found due to the introduction of EGR which reduces the availability of fresh charge. At 10% EGR rate, average brake thermal efficiency decreases only about 1.5%. At 20% EGR rate, average brake thermal efficiency decrease is about 4%. At 30% EGR rate, average brake thermal efficiency decrease is about 6% and at 40% EGR rate, average brake thermal efficiency decrease is about 9 % than that of without EGR.

3.2 Engine Emission Graphs and Discussion

(a) Nitrogen oxides (NO_x)

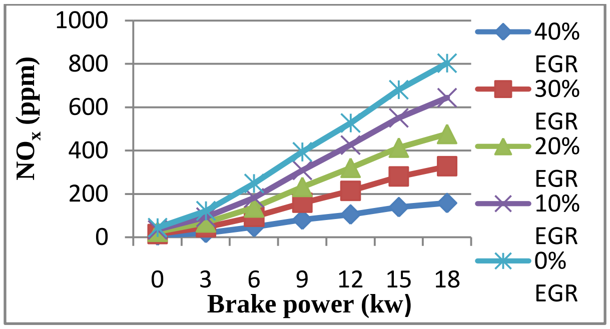

Fig.3.3 Brake power vs. NO_x.

Fig. 3.3 shows graph for variation in NO_x emission with respect to brake power, without and with different EGR Rates for naturally aspirated engine. It shows that the NO_x emission has the tendency to increase with increase in brake power for all the cases tested. NO_x formation is a strong function of temperature. Higher the temperature, higher is the NO_x formation. The presence of high gas temperature inside cylinder will create a conductive ambient for reaction of atmospheric nitrogen with oxygen. This is the major reason for higher NO_x emission at higher load range. However, NO_x emission reduces drastically with the introduction of EGR. This is due to the fact that EGR admits the inert gases in the chamber which have specific heat higher than that of air so they absorb the heat of combustion and also dilute the fresh air which increases the ignition delay and hence reduce the heat of combustion which ultimately result in lower exhaust gas temperature and lower NO_x emission. At 10% EGR rate, NO_x reduction is 19-22% depending on engine loads. The average NO_x reduction is about 20%. At 20% EGR rate, NO_x reduction is about 39-42% and average NOx reduction is about 40%. At 30% EGR rate, NO_x reduction is about 58-66% and average NOx reduction is about 62%. At 40% EGR rate, NO_x reduction is about 76-82% and average NOx reduction is about 79%.

It is to be noted that NO_x limit for passenger cars is 200 ppm according to Euro V and optimization of EGR Rate can be made from this limiting value. It can be seen from the graph that up to 20% load i.e. 3 kw brake power, NO_x emission is within acceptable limit and hence EGR can be eliminated up to 20% load. At 40% load i.e. 6 kw brake power, 10% EGR Rate will give satisfactory result for the naturally aspirated engine. At 60% load i.e. 9 kw brake power, 20% EGR Rate will give satisfactory result for naturally aspirated engine. At 80% load i.e. 12 kw brake power, 30% EGR Rate will give satisfactory result for naturally aspirated engine. At rated power i.e. 15 kw where NO_x emission is maximum, 40% EGR Rate would be required to bring NO_x emission within acceptable limit.

(b) Carbon monoxide (CO)

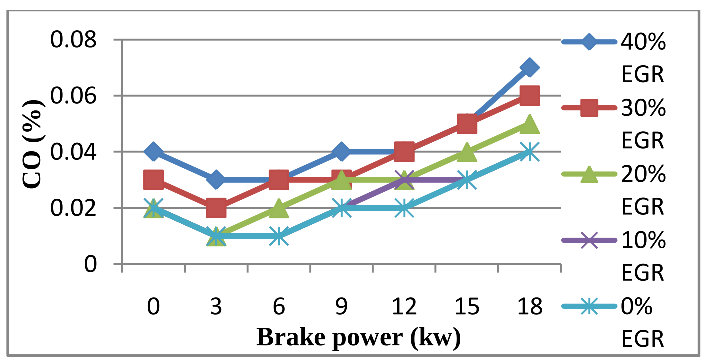

Fig. 3.4 Brake power vs. CO.

Fig. 3.4 shows graph for variation in CO emission with respect to brake power, without and with different EGR Rates for naturally aspirated engine. It shows that the CO emission has the tendency to decrease slightly with increase in brake power initially and thereafter increases sharply near higher load conditions for all the cases tested i.e. without and with different EGR Rates. Drastic increase of CO emission at higher loads is due to rich mixture at higher loads than that of at lower loads. A drastic increase in CO emission is found due to the introduction of EGR which reduces the availability of fresh charge. The CO data supports the idea that at high EGR rates-high loadings, the combustion becomes incomplete producing much higher CO in exhaust gases. At 10% EGR rate, CO increases 0-50% depending on engine loads. The average CO increase is about 8% only. At 20% EGR rate, CO increases 0-100% and average CO increase is about 37%. At 30% EGR rate, CO increases 0-100% and average CO increase is about 65%.At 40% EGR rate, CO increases 66-200% ,average CO increase is about 127% while CO increase at full load is about 67% than that of without EGR.

(c) Hydrocarbons (HC)

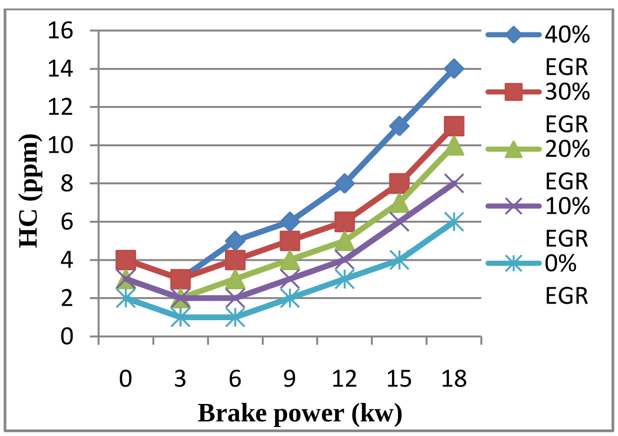

Fig. 3.5 Brake power vs. HC.

There are normally some regions within the combustion chamber of an engine fuelled with diesel where the mixture is either too lean or too rich to ignite the partially decomposed and oxidized fuel in the exhaust. These unburnt species are collectively known as unburnt hydrocarbon emissions.

Fig. 3.5 shows graph for variation in HC emission with respect to brake power, without and with different EGR Rates for naturally aspirated engine. It shows that the HC emission has the tendency to decrease slightly with increase in brake power initially and thereafter increases sharply near higher load conditions for all the cases tested i.e. without and with different EGR Rates. Drastic increase of HC emission at higher loads is due to rich mixture at higher loads than that of at lower loads .A drastic increase in HC emission is found due to the introduction of EGR which reduces the availability of fresh charge. The HC data supports the idea that at high EGR rates-high loadings, the combustion becomes incomplete producing much higher HC in exhaust gases. At 10% EGR rate, HC increases 33-50% depending on engine loads. The average HC increase is about 40%. At 20% EGR rate, HC increases 40-75% and average HC increase is about 55%. At 30% EGR rate, average HC increase is about 100%.At 40% EGR rate, HC increases 133-200% ,average HC increase is about 170% while HC increase at full load is about 175% than that of without EGR.

(d) Oxygen (O_2)

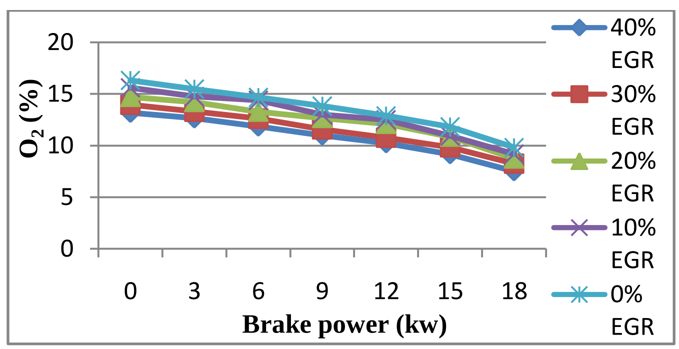

Fig. 3.6 Brake power vs. O_2.

Fig. 3.6 shows graph for the variation in oxygen concentration with respect to brake power, without and with different EGR Rates for naturally aspirated engine. It shows that oxygen concentration decreases with increase in brake power for all the cases tested. This is due to the utilization of more air during the combustion at higher loads and hence formation of rich mixture at higher loads. The oxygen concentration reduces further because of the introduction of EGR as it admits inert gases which dilutes and reduces the entry of fresh air in successive cycles.

(e) Exhaust gas temperature

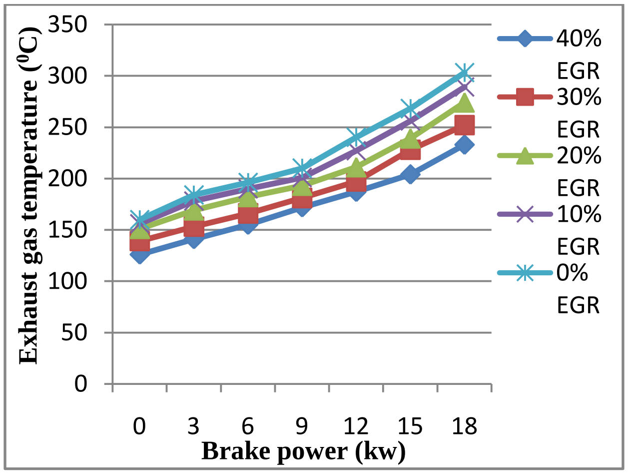

Fig. 3.7 Brake power vs. exhaust gas temperature.

Fig. 3.7 shows graph for the variation in exhaust gas temperature with respect to brake power, without and with different EGR Rates for naturally aspirated engine. It shows that exhaust gas temperature increases with increase in brake power as more fuel is oxidized to meet the requirement of higher power which results in higher heat release and hence higher combustion temperature which ultimately leads to higher exhaust gas temperature. However, the exhaust gas temperature is found to decrease with the introduction of EGR.This is due to the fact that EGR admits the inert gases in the chamber which have specific heat higher than that of air so they absorb the heat of combustion and also dilute the fresh air which increases the ignition delay and hence reduce the heat of combustion which ultimately result in lower exhaust gas temperature. At 10% EGR Rate, the average reduction in exhaust gas temperature is about 5%. At 20% EGR Rate, the average reduction in exhaust gas temperature is about 10%. At 30% EGR Rate, the average reduction in exhaust gas temperature is about 15% and at 40% EGR Rate, the average reduction in exhaust gas temperature is about 20% when compared that of without EGR.

4. Conclusions and future scope of work

4.1 Conclusions

Following are the conclusions based on the experimental results obtained while operating on multi cylinders 4-stroke diesel engine when modified to implement EGR in it.

- Engine can be run without any abnormality when modified to implement EGR in it.
- Exhaust gas recirculation (EGR) has been found a very effective way to reduce NO_x emission from the diesel engine. NO_x emission reduction of about 80% is achieved with 40% EGR rate.
- However, average fuel consumption is increased by about 11% and average CO emission is increased by about 67% with 40% EGR Rate which are the drawbacks of EGR.
- HC emission increases by about 170% because of 40% EGR Rate but the value still remains within the acceptable limits.
- It has been observed that up to 20% load i.e. 3 kw brake power, NO_x emission is within acceptable limit and hence EGR can be eliminated up to 20% load.
- At 40% load i.e. 6 kw brake power, 10% EGR Rate will give satisfactory result for the naturally aspirated diesel engine.
- At 60% load i.e. 9 kw brake power, 20% EGR Rate will give satisfactory result for the naturally aspirated diesel engine.

- At 80% load i.e. 12 kw brake power, 30% EGR Rate will give satisfactory result for the naturally aspirated diesel engine.
- At rated power i.e. 15 kw where NO_x emission is maximum, 40% EGR Rate would be required to bring NO_x emission within acceptable limit.

4.2 Future scope

- The test results for optimum EGR Rate can be utilized to develop a sophisticated electronically controlled EGR system.
- An after treatment of exhaust gas can be carried out to minimize the CO and HC emission increase because of EGR.
- A fuel reformer can be developed in the EGR loop to minimize the reduction in brake thermal efficiency due to the introduction of EGR.

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