Experimental Investigation of Emission Characteristic of a CI Engine Using Exhaust Gas Recirculation System

B. Pattanayak, S. S. Mohapatra, U. K. Patel
Department of Mechanical Engineering, S 'O' A University, India

***Abstract* - Fossil fuels are used throughout the globe to supply the energy needs of transportation sector. Among the fossil fuels diesel is the main fuel used in the transportation sector throughout India. Nitrogen Oxide (NO_x), Carbon Monoxide (CO), Unburnt Hydrocarbons (HC) etc. are harmful gases emitted by combustion of diesel. The engine system has to be modified to reduce the emission of these harmful gases. In the present work Exhaust Gas Recirculation (EGR) technique is used to reduce NO_x emission. This system uses mixture of fresh air and exhaust gas as suction air in the induction pipe. The current article deals with the experimental analysis of engine emission using EGR system in a single cylinder CI engine.**

Key words - Exhaust Gas Recirculation (EGR), Nitrogen Oxide (NO_x), Carbon Monoxide (CO_2), Unburnt Hydrocarbons (HC). CI Engine.

I. INTRODUCTION

Requirement of petroleum fuels are one of the major energy sources throughout the world. However, the world energy demand is increasing rapidly leading to excessive use of fossil fuel. Unfortunately 100% combustion of fossil fuel is not possible leading to harmful exhaust emissions. Exhaust emissions include CO, HC, smoke etc. In addition an unwanted chemical reaction occurs between nitrogen and oxygen in the combustion chamber due to high temperature. This results in formation of NO_x as harmful emission. Some standards are made by different countries to regulate the engine exhaust emissions.

EGR is a useful technique for reducing NO_x formation in the combustion chamber. When a part of this exhaust gas is re-circulated to the cylinder it acts as dilutant to the combusting mixture. Exhaust gases lower the oxygen concentration in combustion chamber and increase the specific heat of the intake air mixture. This results in lower flame temperatures (Agarwal et al. 2011). Tsolakis et al. (2007) found that with the use of EGR, NO_x formation decreases. The reduced availability of oxygen for combustion and reduced flame temperature decreases NO_x formation.

EGR systems are classified as HOT EGR system, Fully Cooled system and Partially Cooled EGR system (Agarwal et al. 2004). In the present experiment Partially Cooled EGR system is used where natural convection is used for exhaust gas cooling.

II. EXPERIMENTAL PROCEDURE

To carry out the present study the experiment has been conducted on a 5 hp diesel engine coupled with a hydraulic dynamometer was selected. The engine was a single cylinder, direct injection and water cooled diesel engine with a rated speed of 1500 rpm. Engine specification is given in table 1.

Table 1: General Specification of Engine test rig

Make	Kirloskar
Engine Type	Single cylinder, Vertical, Direct injection, Water Cooled
Bore	80 mm
Stroke Length	110 mm
Cubic Capacity	553 cc
RPM	1500
BHP	5hp
Compression Ratio	16.5 : 1
No.of strokes	4 strokes

An EGR loop constituting a flow regulator, EGR filter, surge tank was connected from the engine exhaust to the air suction pipe. Fig. 1. shows the engine layout diagram.

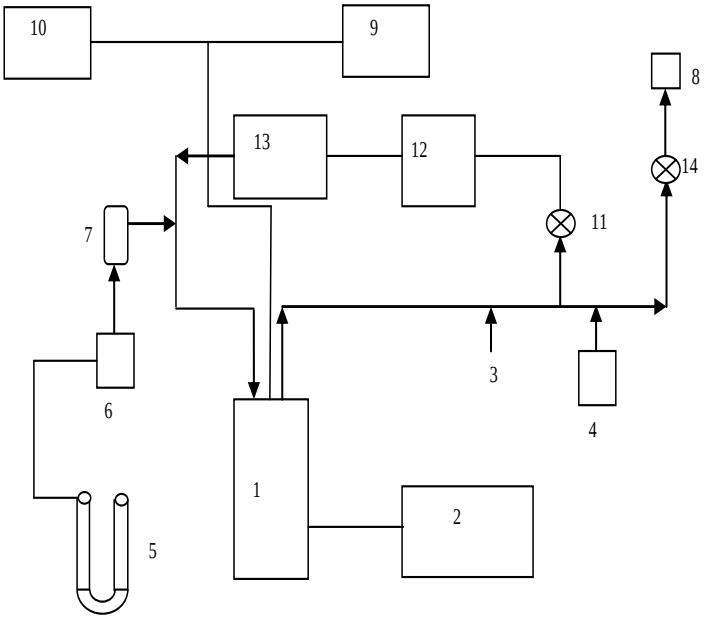

Fig. 1. Engine layout diagram with EGR system

1. Engine
2. Dynamometer
3. Exhaust gas pipe
4. Exhaust gas analyser
5. U-tube manometer
6. Air box
7. Air filter
8. Muffler
9. Diesel fuel tank
10. Biodiesel fuel tank
11. EGR control valve
12. Exhaust gas particulate valve
13. Surge tank
14. Back Pressure Valve

A. Engine exhaust modification

For exhaust gas recirculation appropriate plumbing is done. A T-joint is connected in the exhaust gas pipe line to trap some amount of exhaust gas from the pipeline. An EGR valve is used to regulate the flow rate of exhaust gas. After the EGR valve one diesel particulate filter is used to remove the particulate matter from the engine exhaust gas. Then the gas is passed into a surge tank which is basically used to control the fluctuating flow of exhaust gas. The gas coming out of surge tank is mixed with fresh air in the air suction pipe. The length of air suction pipe is increased to ensure proper mixing of exhaust gas and fresh air. Here in this experimental work partially cooled EGR is used. Various methods are proposed by researchers to determine the EGR percentage. Sherma and Pradeep (2007) proposed a method to calculate EGR percentage by calculating the mass flow rate of fresh air with and without EGR mode. They determined EGR percentage using the following method:

$$\%\ EGR = \frac{\text{Mass of air admitted without EGR} - \text{Mass of air admitted with EGR}}{\text{Mass of air admitted without EGR}} \times 100\,\% \quad (1)$$

NDIR-based CO_2 concentration measurement at the intake ($[CO_2]_{int}$) and exhaust manifold ($[CO_2]_{exh}$) was used by Desantes et al. (2010) for the determination of EGR percentage.

$$\%\ EGR = \frac{[CO_2]_{int} - [CO_2]_{atm}}{[CO_2]_{exh} - [CO_2]_{atm}} \times 100 \quad (2)$$

Agarwal et al. (2004) proposed a volume based method to calculate the EGR percentage. They had calculated the EGR rate using the following expression:

$$\%\ EGR = \frac{Volume\ of\ EGR}{total\ intake\ charge\ into\ cylinder} \times 100 \quad (3)$$

Here volume flow of EGR was measured with the help of an orifice meter. In the current work EGR percentage is calculated by using the following method:

$$\%\ EGR = \frac{\text{Volume of air admitted without EGR} - \text{Volume of air admitted with EGR}}{\text{Volume of air admitted without EGR}} \times 100 \quad (4)$$

The modified engine layout diagram is represented in fig. 1.

B. Methods of emission measurement

In the current work volume flow rate of air is measured by air box method where in height of water column in the manometer is measured and volume flow rate of air is calculated. Emission measurement is done with the help of a Multi gas analyzer which is of AVL (digas 444) make. The reading of CO is measured in % by volume where as NO_x and HC were measured in ppm using gas analyzer

III. RESULT AND DISCUSSION

A. CO emission

CO emission comparison for diesel fuel with and without EGR is represented in fig. 2. CO emission increases with the increase in EGR percentage. EGR replaces fresh air with exhaust gas. So availability of oxygen for combustion is reduced and proper combustion of fuel does not occur. Since proper combustion of the fuel does not occur, CO emission increases.

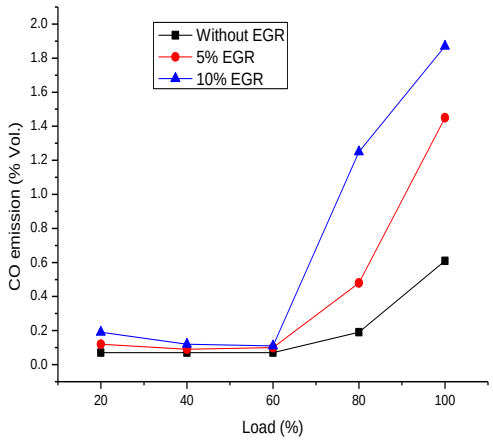

Fig. 2. CO emission vs Load characteristic

B. HC emission

Fig. 3 represents the comparison of HC emission variation with different loading conditions with different EGR rates diesel fuel. With increase in EGR percentage HC emission increases as oxygen availability is reduces. With increase in exhaust gas less amount of fresh air is sucked into the engine which ultimately leads to improper combustion and more HC emission. Minimum HC emission is found for neat diesel fuel without EGR.

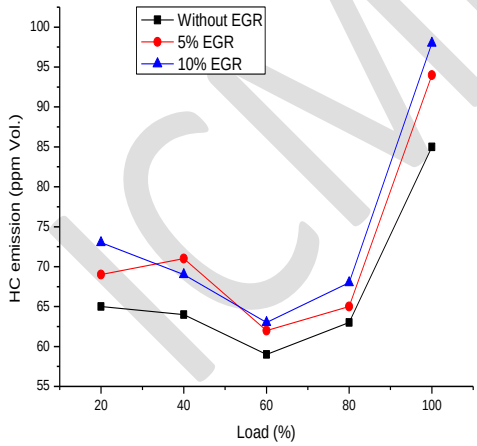

Fig. 3. HC emission vs Load Characteristic

C. NO_x emission

Fig. 4 represents the comparison of NO_x emission at different loading condition for different EGR percentage. The main advantage of use of EGR is NO_x reduction. With EGR use the availability of fresh oxygen for combustion reduces. Also the specific heat of exhaust gas in more than fresh air as exhaust gas contains more amount of CO_2 and water vapor which in turn reduces the flame temperature. With the use of EGR the NO_x emission reduces. Maximum reduction of NO_x emission occurs in case of 10% EGR.

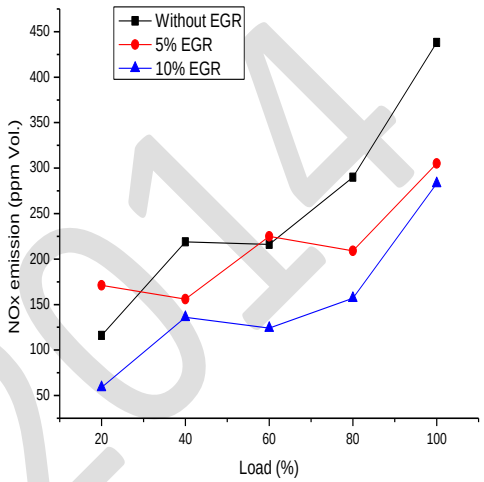

Fig. 4. NO_x emission vs Load Characteristic

CONCLUSION

The aim of our study was to use modify the air suction system of CI engine to circulate and mix exhaust air with fresh suction air to reduce the amount of exhaust gas to the atmosphere and to analyze the emission of various harmful gases from the engine in that condition. From the experiment following points are concluded:

1. As part of the exhaust gas is recirculated the amount of exhaust gas decreases.
2. With the use of EGR, CO and HC emission increased due to improper combustion of fuel in combustion chamber.
3. With the use of EGR, NO_x emission decreased as the use of exhaust gas reduced the flame temperature of combustion.
4. Only 10% of EGR could be recirculated as the increase in more EGR percentage resulted in more emission of black smoke from the engine.

Biodiesel is a possible alternate of the conventional diesel fuel. Researchers have tested that the use of biodiesel reduces the CO and HC emission but increases NO_x emission (Mustafa and Havva 2008, Lapuerta et al. 2008). So as a future work the combined use of biodiesel and EGR can be experimented to analyze their joint effects on engine performance and emission.

ACKNOWLEDGEMENT

The authors acknowledge the assistance M. K. Giri and K. C. Mohapatra, staff members of Internal Combustion Laboratory, Department of Mechanical Engineering, ITER, Bhubaneswar. Authors are also thankful to the SOA University management for financial support to conduct experiment with the engine setup.

REFERENCE

[1] Agarwal A K, Singh S K, Sinha S and Shukla M K. Effect of EGR on the exhaust gas temperature and exhaust opacity in compression ignition engines. 2004; 29 (3): 275–284

[2] Agarwal A K, Agarwal D and Singh S K. Effect of Exhaust Gas Recirculation (EGR) on performance, emissions, deposits and durability of a constant speed compression ignition engine. Applied Energy 2011; 88: 2900-2907.

[3] Desantes JM, Galindo J, Guardiola C, Dolz V. Air mass flow estimation in turbocharged diesel engine from in-cylinder pressure measurement. Exp Therm Fluid Sci 2010;34:37–47.

[4] Lapuerta M, Armas O and Rodrıguez-Fernandez J. Effect of biodiesel fuels on diesel engine emissions. Progress in Energy and Combustion Science. 2008; 34: 198-223.

[5] Mustafa B and Havva B. A critical review of bio-diesel as a vehicular fuel. Energy Conversion and Management. 2008; 49: 2727–2741.

[6] Sharma R P and Pradeep V. Use of HOT EGR for NO_x control in a compression ignition engine fuelled with bio-diesel from Jatropha oil. Renewable Energy 2007; 32: 1136-1154.

[7] Tsolakis, A., Megaritis, A., Wyszynski, M. L. and Thennoi, K. 'Engine performance and emissions of a diesel engine operating on diesel-RME (rapeseed methyl ester) blends with EGR (exhaust gas recirculation)', Energy, 2007; 32: 2072-2080.