International Journal of Applied Science and Engineering
2013. 11, 1: 41-49

Effects of Compression Ratio and EGR on Performance, Combustion and Emissions of Di Injection Diesel Engine

N. Ravi Kumar*, Y. M. C. Sekhar, and S. Adinarayana

Department of Mechanical Engineering MVGR College of Engineering, Vizianagaram, Andhra Pradesh, India

Abstract: The performance of a Diesel engine is influenced by various parameters like compression ratio, fuel air ratio, speed etc... The performance of a diesel engine increases with increase in compression ratio. Variable compression technologies in IC engines are used to increase fuel efficiency under variable loads. Cooled exhaust gas recirculation is a common way to control in-cylinder NO_x production and is used in most modern high speed direct injection diesel engines. However the effect of EGR on performance, combustion and emissions production at different compression ratios are difficult to depict. In the present work an attempt was made to study the effects of cooled exhaust gas recirculation on performance, combustion and emissions of a variable compression Diesel Engine. The test was conducted at different compression ratios with different loads (no load to full load) and for different EGR rates (0-10%).

Keywords: VCR diesel engine; EGR; emission analysis.

1. Introduction

The use of natural gas in Diesel engines has both economic and environmental advantages. Over past few years, stringent emission regulations have been imposed on NOx, smoke and particulate emissions emitted from automotive diesel engines worldwide. Diesel engines are typically characterized by low fuel consumption and very low CO emissions. However, the NOx emissions from diesel engines still remain high. Hence, in order to meet the environmental regulations, it is highly desirable to reduce the amount of NOx in the exhaust gas. Diesel engines are predominantly used to steer tractors, heavy lorries and trucks. Owing to their low fuel consumption, they have become increasingly attractive for smaller lorries and passenger cars also. But higher NOx emissions from diesel engine remain a major problem in the pollution aspect. In order to reduce emission levels, some external engine features can be applied, such as EGR or after-treatment systems. Cooled EGR systems have been used to reduce emissions of nitrogen oxides (NO_x) from diesel engines. Depending on the engine operating conditions, these systems divert 5-30% of an engine exhaust stream through a cooler then back to the combustion chamber. The percentage of exhaust gas recirculation is defined as volume of the EGR to total intake charge into the cylinder.

* Corresponding author; e-mail: naradasuravi@gmail.com

Received 2 December 2011
Revised 29 May 2012
Accepted 27 August 2012

$$\%EGR = \frac{Volume\ of\ EGR}{Total\ \mathrm{int}ake\ Ch\mathrm{arg}e\ to\ the\ Cylinder} \times 100$$

The optimization of the piston bowl and injector design may also bring significant improvements on NO_x and soot reduction. Piston bowl profile, injector nozzle diameter and angle, injector position on combustion chamber, and calibration variables (injection start, fuel mass, etc.) are some of the parameters that can be set for this purpose. NO and NO_2 together is called NO_x emissions. NO is formed during the post flame combustion process in a high temperature region. The principal source of NO formation is the oxidation of the nitrogen present in atmospheric air. The nitric oxide formation chain reactions are initiated by atomic oxygen, which forms from the dissociation of oxygen molecules at the high temperatures reached during the combustion process.

Machacon.*et.al* [1] studied the effect of EGR with O_2 enrichment on the exhaust emissions of Diesel engine. They concluded that higher EGR with O_2 enrichment gives lower NO_x emissions and smoke. Avinash kumar.*et.al* [2] studied the effect of EGR on exhaust gas temperature and exhaust opacity in CI engines. They found that that the exhaust gas temperatures reduce drastically by employing EGR. Thermal efficiency and brake specific fuel consumption are not affected significantly by EGR. However particulate matter emission in the exhaust increases, as evident from smoke opacity observations. Shahadat.*et.al* [3] studied the combined effect of EGR and inlet air preheating on engine performance in diesel engine. They found that at medium load conditions, oxides of nitrogen(NOx), carbon monoxide (CO), engine noise, and brake specific fuel consumption decreased when inlet air preheating and EGR were applied together as compared to those during normal operations of the engine. Ghazikhani.*et.al* [4] studied the effect of EGR and engine speed on CO and HC emissions of dual fuel HCCI engine. They observed that increasing engine speed at a constant EGR rate leads to increase in CO and UHC emissions due to the incomplete combustion caused by shorter combustion duration and less homogeneous mixture. Results also show that increasing EGR reduces the amount of oxygen and leads to incomplete combustion and therefore increases CO emission due to lower combustion temperature. HC emission also increases as a result of lower combustion temperatures.

Selim [5] studied the Effect of exhaust gas recirculation on combustion characteristics of dual fuel engine. He found that the combustion noise and thermal efficiency of the dual fuel engine are affected when EGR is used in the dual fuel engine. Mahla [6] studied the effect of EGR on Performance and emission characteristics of natural gas Fueled Diesel Engine. His experimental results show that the application of EGR reduces substantially NOx, CO and smoke. Rajan and Senthil kumar [7] studied the effect of EGR on the performance and emission characteristics of Diesel Engine with Sunflower Oil Methyl Ester. They observed that B20 SFME with 15% EGR rate produce 25% less NOx emissions compared to diesel fuel for the same level smoke emissions. Arjun Krishnan et.al [8] studied the Prediction of NO_x reduction with EGR using the flame temperature correlation technique. They developed a procedure to calculate the reduction in NO_x levels due to EGR, given only engine base-data. This approach utilised the flame temperature correlation technique to obtain NO_x predictions with sufficient accuracy – 6.5% at part loads. In the current study we done experimentation on variable compression Diesel engine by varying compression ratio, load on the engine and percentage of exhaust gas re circulated. The output parameters found from the study are specific fuel consumption, brake thermal efficiency, heat release rate, mass fraction burnt and composition of exhaust emissions.

2. Experimental setup

The experiments are conducted on a single cylinder, direct injection, variable compression, high speed diesel engine. Specifications of the engine are given in Table 1. At the rated speed (1500 RPM), the engine develops approximately 4 kW power output. The engine is coupled to an eddy current dynamometer. A mass flow sensor is used to find the mass flow rate of air enter into the cylinder. A non-contact PNP sensor is used to measure the engine RPM. A PNP sensor gives a pulse output for each revolution of the crankshaft. The frequency of the pulses is converted into voltage output and connected to the computer. Torque is measured using a load cell transducer. The transducer is a strain gauge base. The output of the load cell is connected to the load cell transmitter. The output of the load cell transmitter is connected to the USB port through interface card.The fuel consumption is measured with the help of optical sensors. These optical sensors are capable of detecting any liquid and give an output in type of signals. The system consists of a burette fitted with two optical sensors one at the high level and the other at the low level. As the liquid passes through the higher-level optical sensor, the sensor gives a signal to the computer to start the time. Once the liquid reaches the lower level optical sensor, the sensor gives a signal to the computer to stop the time and refill the burette. The time taken for consumption of fuel for a fixed volume is calculated. The cylinder pressure is calculated using piezoelectric transducer. The temperature of gases and water at various points are calculated using ‘K’ type thermocouples.An AVL 437C smoke-meter is used to measure the smoke opacity of the exhaust gas. AVL 444 - 5 Gas Analyser is used to measure NO, CO, HC, CO_2, O_2. Experimentation is done at different compression ratios with different loads (no load to full load) and different EGR rates (0%, 5% &10%).

Table 1. Specifications of the engine

Bore and Stroke (mm) = 80x110
BHP = 5
Speed (rpm) = 1500
Loading = Eddy current dynamometer
Compression ratio = 5 to 20
Type of injection = Direct injection
Injection pressure = 200 bar
Injection timing = 23^0 btdc
Load measurement = strain gauge
Fuel measurement = optical sensors
Emission measurement =AVL 444 5-gas analyser
Smoke measurement – AVL 437C smoke meter

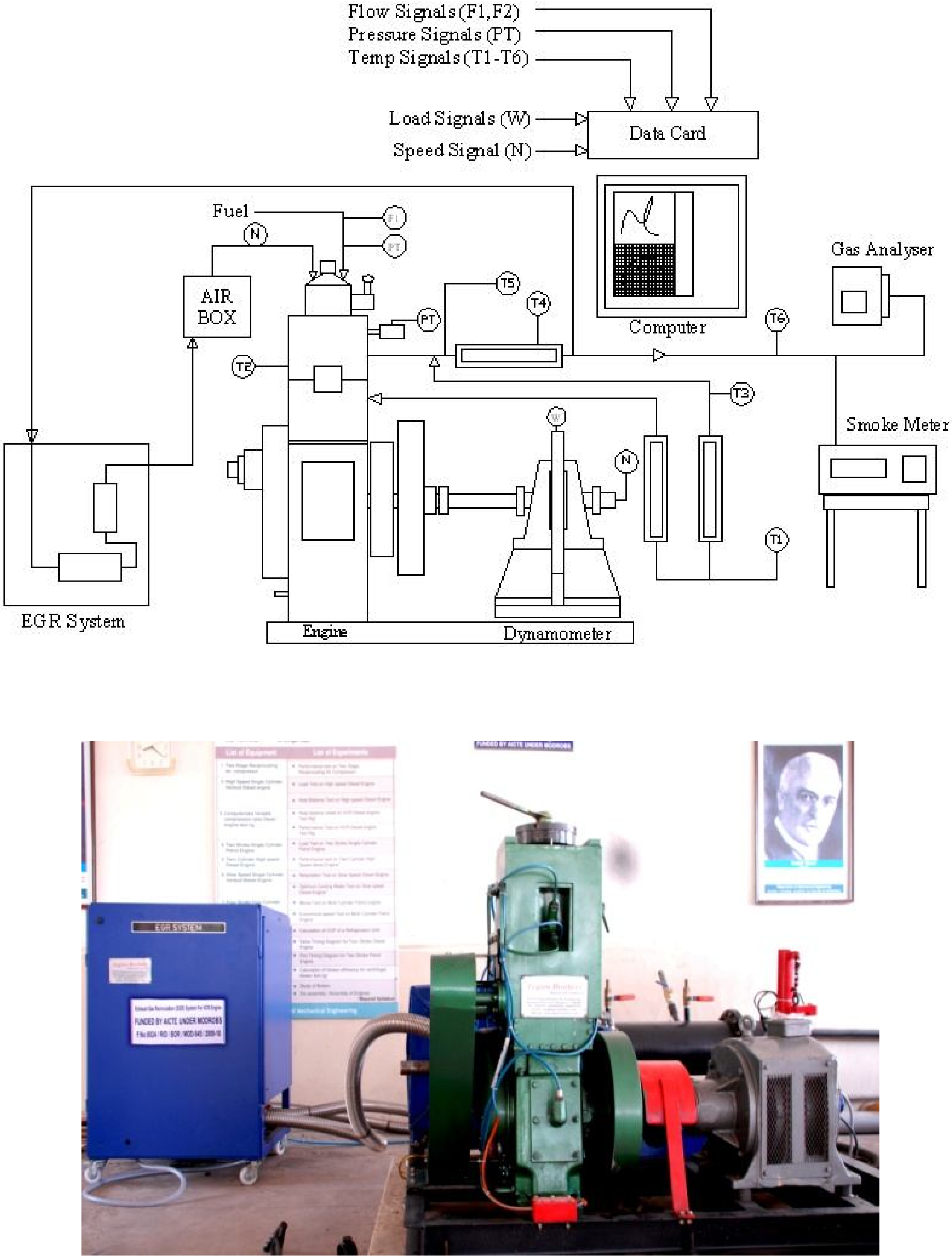

Figure 1. Experimental setup of VCR Diesel engine

3. Results and discussion

The experimentation is done at constant speed and different loads by varying the compression ratios. The data related to performance, combustion and emissions is simultaneously taken at a time. Initially tests are carried out without exhaust gas recirculation; later at different percentages of EGR (0%, 5% &10%) experimentation was done. The results obtained from experimentation is plotted and explained in this section.

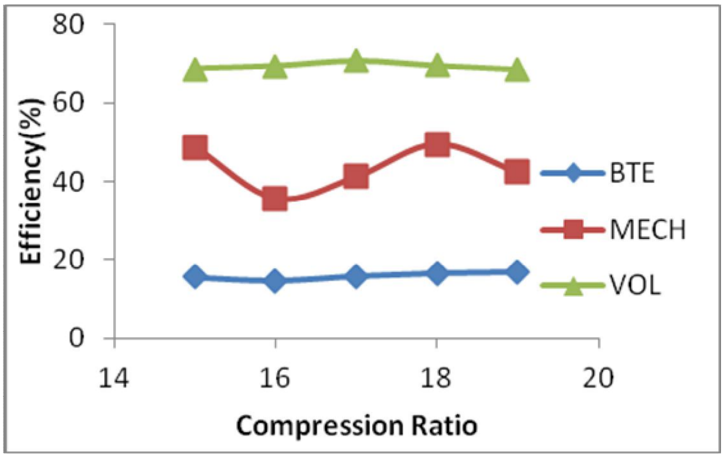

Figure 2. Effect of Compression ratio on brake thermal, mechanical and volumetric efficiency at ¼ load

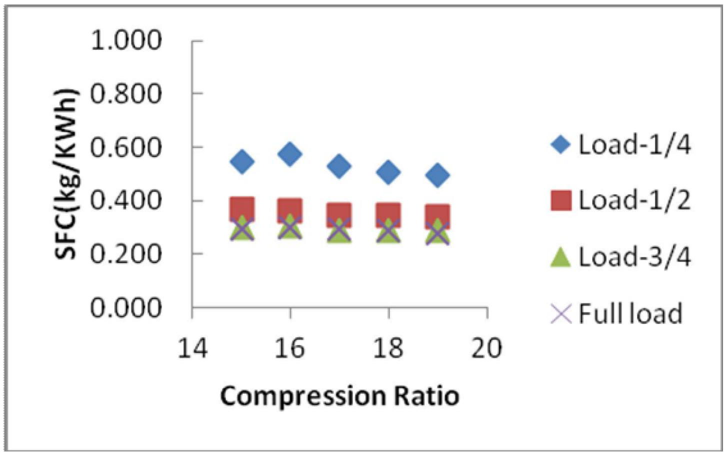

Figure 3. Effect of Compression ratio on Specific fuel consumption at different loads

Figure 2 describes the effect of compression ratio on brake thermal efficiency, volumetric efficiency and mechanical efficiency. It is observed that irrespective of the compression ratio the volumetric efficiency of the engine is almost constant but the mechanical efficiency decreases between compression ratios 15 and 16 due to more friction power. At CR 19 the brake thermal efficiency reached maximum value of 17%. The brake thermal efficiency of the engine is low at CR 16 and later it slightly increases. The specific fuel consumption at various loads and compression ratios are presented in Figure3. Overall with increase in compression ratio the specific fuel consumption decreases irrespective of the load except at compression ratio 16 due to less ignition delay and more combustion duration.

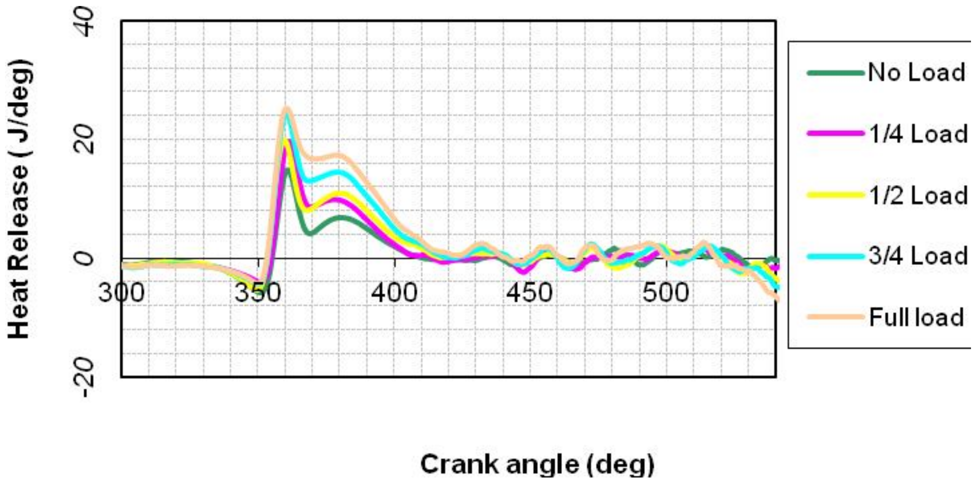

Figure 4. Effect of load on rate of heat release with repect to cran kangle at 5% EGR

Figure 4 shows the effect of various loads on rate of heat release with 5% exhaust gas recirculation. At 1/4 laod condition with 5% EGR the combustion duration is only 37^0 of crank angle rotation. With increase in load the combustion duration also increased gradually 39^0 at ½ load 42^0 at ¾ laod and 46^0 at full load. With increase in duration of combustion the heat release rate also increased due to possibility of complete combustion.

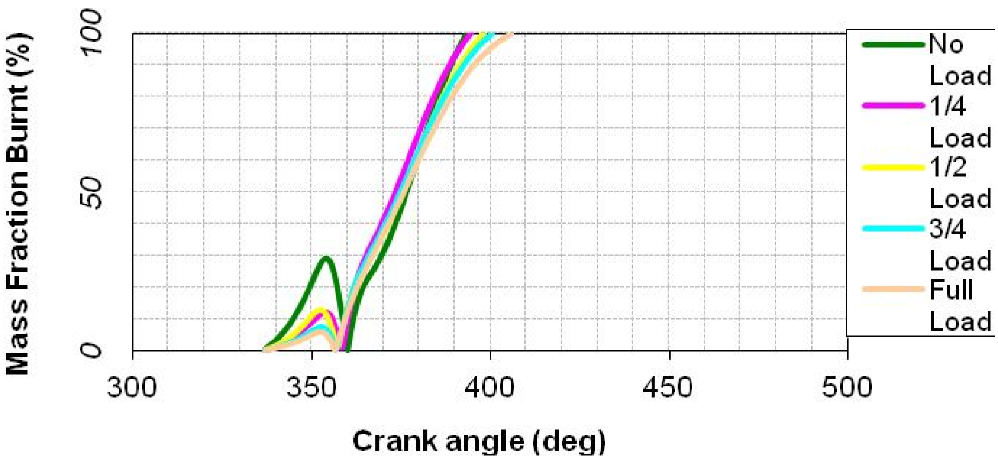

Figure 5. Mass fraction burnt percentage with respect to the crank angle at 0% EGR

Figure 5 shows the percentage amount of charge burned (mass fraction burnt) with respect to the crank angle. From the diagram it is observed that at no laod the combustion is started at crank angle of 361^0 and completed at 393^0 with total combustion duration of 32^0. With incraese in load the combustion duration is slightly increased. Around 70% of the total charge is burnt in the first 20^0 of the crank angle rotation and remaining 30% charge is burnt for furher rotation of the crank angle.

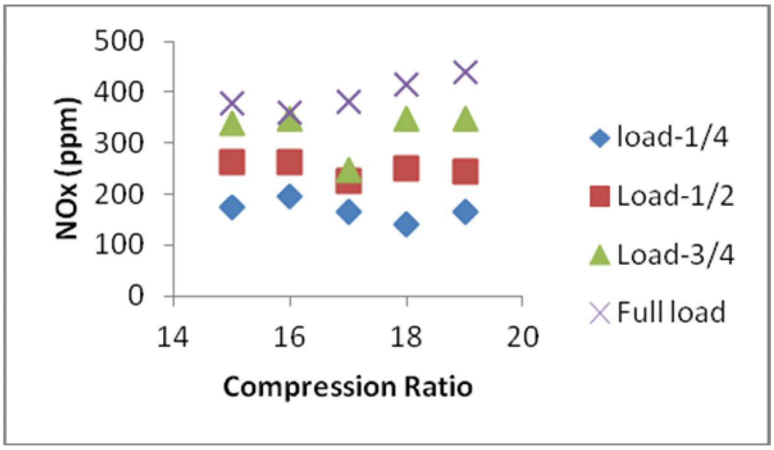

Figure 6. Effect of Compression ratio on Nox

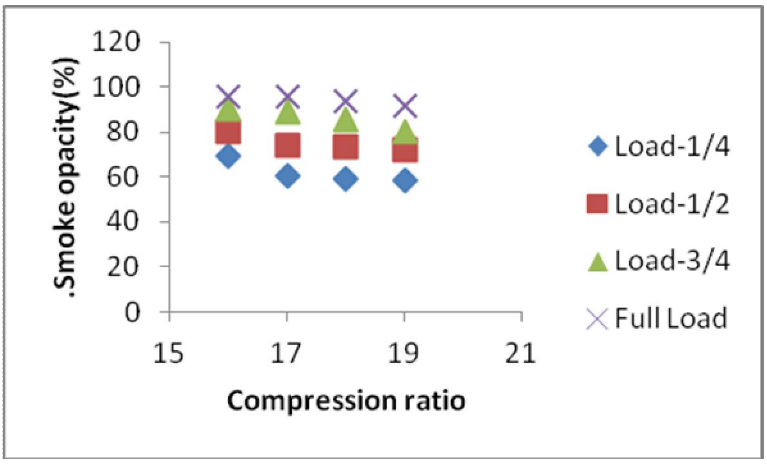

Figure 7. Effect of compression ratio on smoke opacity

Figure 6 and 7 analyses the effect NOx and smoke opacity at different loads and compression ratios. With increase in load the NOx value also increased due to more heat release and caused for dissociation of gases. The smoke opacity is continuously increasing with respect to all loads and compression ratios due to more amount of fuel injected in the cylinder.

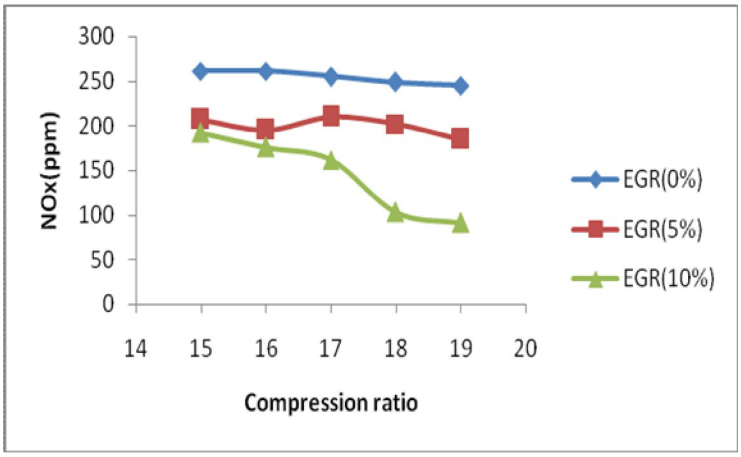

Figure 8. Effect of EGR on NOx emissions

Figure 8 shows the effect of exhaust gas recirculation (EGR) on NOx emissions. It is observed from the figure that with increase in percentage of EGR the NOx emissions are reduced. These are mainly due to low peak temperatures and complete combustion of re circulated gases in the cylinder. At compression ratio 15 and 10% EGR the percentage reduction of NO_x was 26.5% and at full load it was 62.5%.

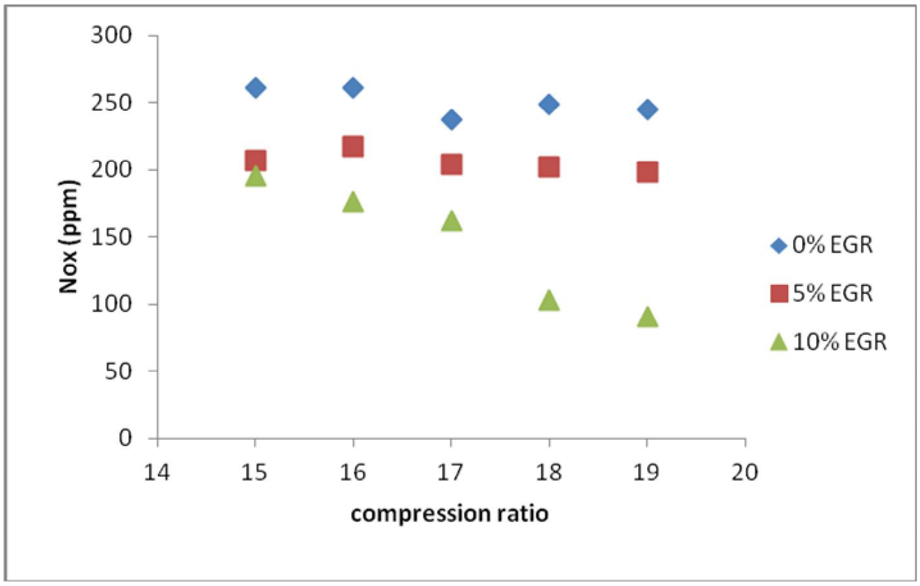

Figure 9. Effect of EGR on NO_x emissions

Figure 9 discussed about the effect of EGR on NOx emissions at different compression ratios. It is observed that with increase in percentage of exhaust gas recirculation the amount of NOx emissions are gradually decreased. This is mainly due to low flame temperature and less oxygen concentration of the working fluid in the combustion chamber.

4. Conclusion

An experimental study was conducted on single cylinder variable compression diesel engine with different compression ratios, percentages of EGR and loads to estimate performance, combustion and emission characteristics of the engine.

It was found that with increase in compression ratio the brake thermal efficiency increases and specific fuel consumption decreases. It was observed that with raise in % of EGR the percentage increase in brake thermal was up to 13.5%.

The combustion duration was decreases by 2-3^0 with increase in compression ratio due to less ignition delay.

It was found that with raise in % EGR the NOx emissions was gradually decreases by 11% to 85% at different compression ratios due to less flame temperatures and low oxygen content in the combustion chamber.

It was also found that maximum amount of charge was burnt in the first 20^0 of crank angle rotation during combustion stage.

The smoke opacity is gradually decreases at all compression ratios. The decrease in percentage varies from 17% to 4% from no load to full load.

5. Nomenclature

BTE-Brake thermal efficiency
CR-Compression ratio
CO-Carbon monoxide
EGR-Exhaust gas recirculation
RHR-rate of heat release
sfc- specific fuel consumption

Acknowledgements

The authors are thankful to the All India Council for Technical Education (AICTE), New Delhi for their financial support vide project grant,File.NO:8204/RID/BOR/MOD-545/2009-10.

References

[1] Machacon, C., Seiichi, shiga., Takao, Karasawa, and Nakamura. 1997. Effect of EGR on the Particulate and Its Component Emissions in a D. I. Diesel Engine. *Bulletin of the M. E. S. J*, 25, 2: 77-83.
[2] Avinash, Kumar, Agrawal., Shrawan, Kumar, Singh., Shailendra, sinha., and Mritunjay, Kumar, shukla. 2004. Effect of EGR on the exhaust gas temperature and exhaust opacity in compression ignition engines. *Sadhana*, 29, 3: 275-284.
[3] Shahadat, M. M. Z., Nabi, M. N., Akhter, M. S., Tushar, M. S. H. K. 2008. Combined Effect of EGR and Inlet Air Preheating on Engine Performance in Diesel Engine. *International Energy Journal,* 9, 2.
[4] Ghazikhani, M., Kalateh, M. R., Toroghi, Y. K., and Dehnavi, M. 2009. An Experimental Study on the Effect of EGR and Engine Speed on CO and HC Emissions of Dual Fuel HCCI Engine. *World Academy of Science, Engineering and Technology.*
[5] Selim, M. Y. E. 2003. Effect of exhaust gas recirculation on some combustion characteristics of dual fuel engine. *Energy Conversion and Management*, 44: 707-721.
[6] Mahla, S. K., Das, L. M., Babu, M. K. G. 2010. Effect of EGR on Performance and Emission Characteristics of Natural Gas Fueled Diesel Engine. *Jordan Journal of Mechanical and Industrial Engineering*, 4, 4: 523-530.
[7] Rajan, K. and Senthilkumar, K. R. 2010. Effect of Exhaust Gas Recirculation (EGR) on the Performance and Emission Characteristics of Diesel Engine with Sunflower Oil Methyl Ester. *Jordan Journal of Mechanical and Industrial Engineering*, 3, 4: 306-311.
[8] Arjun Krishnan, and Sekar, V. C. 2006. Prediction of NOx reduction with Exhaust Gas Recirculation using the Flame Temperature Correlation Technique. *Proceedings of the National Conference on Advances in Mechanical Engineering*, Kota, India, March 18-19.
[9] Heywood, J. B. 1988. Pollutant formation and control. *Internal combustion engine fundamentals* Int. Edn, Mc-Graw Hill., New York.
[10] Ming Zheng, Graham, T., Reader, J., and Gary Hawley. 2004. Diesel engine exhaust gas recirculation-a review on advanced and novel concepts. *Energy Conversion and Management*, 45: 883-900.