

**PERFORMANCE ANALYSIS AND RECIRCULATION OF DIESEL ENGINE
EXHAUST GASES**

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ABSTRACT

A diesel engine is an internal combustion engine that sparks a fuel spray at the starting of compression stroke by using highly compressed air. Diesel engine emission consists of gases such as Oxygen (O₂), Carbon Monoxide (CO), Carbon Dioxide (CO₂), Nitrogen Oxide (NO), Nitrogen Dioxide (NO₂), and Hydrocarbons (HC's). An exhaust gas analyzer can measure these parameters in percentage or ppm. Diesel fuel is a mixture of hydrocarbons which would produce only carbon dioxide (CO₂) and water vapor (H₂O). Also, diesel exhaust gases are primarily composed of CO₂, H₂O and the unused portion of engine charge air. The objective of this paper is to do analysis of engine performance and emissions analysis of the exhausted gases of diesel engines with Exhaust gas analyzer and recirculate them with EGR.

Keywords: Analysis, Diesel Engine Emission, Gas analyzer

INTRODUCTION

During this century, the world was facing environmental problems; air pollution is one of them. Air pollution leads to global environment problem. The combustion of fossil fuels i.e. petroleum, coal, natural gas etc. results in global environment problems, involves global warming, acid rain, climate change and ozone layer depletion.[1]

A diesel engine is a type of internal combustion engine. The meaning of word internal is inside and combustion means burning, thus an internal combustion engine is one where the fuel is burned inside the main part of the engine (the cylinders) and power is produced.

The diesel engine is the most efficient engine among all known types of internal combustion engines. Heavy trucks, urban buses, and industrial equipment are powered almost exclusively by diesel engines all over the world and diesel powered passenger cars are also increasingly popular. For the foreseeable future, the world's transportation needs will continue to rely on the diesel engine and its gasoline counterpart. However, both engine technologies are evolving at an ever increasing pace to meet two major challenges: lower emissions and increased energy efficiency.

The exhaust gases from internal combustion engines are complex mixtures consisting oxidants of sulphur and nitrogen, products of complete of complete

combustion and derived compounds of fuel and lubricants. [2]

In the world most of the energy needs are fulfilled through petro-chemical sources, coal and natural gases, but these sources are finite and according to the current usage rates, they will be consumed shortly. Diesel fuels have an important function in the industrial transports and agricultural goods due to its low cost and high thermal efficiency. The largest producer of CO₂ emissions are fossil fuels and the significant use of fossil fuels is broaden the CO₂ blanket over the Earth. This blanket subterfuge ultra-violet (UV) rays that has been originally received by the Earth from the Sun. With the increasing advances in technology, requirement of energy is changing accordingly. It is necessary to improve the efficiency with the consumption of natural resources, and enhance renewable alternatives to protect resources on which the requirements of present and future generations depend. The diesel industry is facing problems regarding particulate emission and to find methods to reduce particulate matter, such as NO_x, smoke, HC and CO emissions.

The reason behind increasing popularity of diesel engine vehicles is better fuel economy and higher power with lower maintenance cost. [3]. The exhorting anticipation of additional improvements in diesel fuel and diesel vehicle sales in future have forced diesel engine manufacturers to upgrade the

technology in terms of power, fuel economy and emissions. Diesel emissions are categorized as carcinogenic [4]. The stringent emission legislations are compelling engine manufacturers to develop technologies to combat exhaust emissions. To meet these emission regulations with competitive fuel economy, exhaust gas after-treatment and optimized combustion are necessary. However, it is still unresolved which concept will succeed considering production and economic feasibility [5]. Diesel engines are very popular power plants for decentralized power production in rural areas all over the world as well as for powering the farm equipment due to their fuel economy, ease of maintenance and robustness due to the reason that diesel engine possesses high efficiency, durability and reliability at lower cost.[6]

1.1 AN OUTLOOK TO INDIAN AND GLOBAL SCENARIO OF DIESEL FUEL

1.1.1 INDIAN SCENARIO

India only produces diesel, which is designated as High Speed Diesel (HSD). The growth of the Indian economy has led to increasing demand for energy for transportation and industry since the recent 10-15 years. As India is predominantly a diesel based economy, the demand for diesel has been increasing at a quick pace. India's consumption of High Speed Diesel in 2008-09 is estimated to be 15.9 billion gallons in 2008-09, which is up by 30% from 2004-05 consumption of 12.2 billion gallons. High Speed Diesel exports from India have grown substantially, with it jumping from 2.6 billion gallons in 2005-06 to 4.2 billion gallons in 2008-09, representing an increase of above 60%, exposing the exporting Indian refineries to the huge volatility in global prices.

1.1.2 GLOBAL SCENARIO

Globally, more than three-fourths of the distillate sales, as diesel are for transportation and only a little more than 10% is used for residential heating. US is the largest refiner of crude oil holding 20% of the total world refining capacity of 87,700 kilo barrels per calendar day, followed by China (8.9%), Former Soviet Union (8.8%), Japan (5.3%) and India (4.1%). However, the production of heating oil or diesel in any country depends on the type of economy it follows. For eg, while US has adopted a gasoline based economy, India is largely a diesel based economy, leading to more production and consumption of gasoline in US and High-Speed Diesel (HSD) in India.

1.2 BASICS OF EMISSION ANALYSIS

While running any internal combustion undesirable emissions are generated during the combustion process emphasis is given on reducing the emission coming out of an engine. The emissions which are exhausted into the surrounding pollute the atmosphere and causes various problems like global

warming, acid rain, smog, odours and respiratory hazards. Usually running an engine with diesel as fuel emission parameters are not specifically ideal that results in more emission of unburnt hydrocarbon HC and carbon monoxide CO and oxide of nitrogen NOx .

Retarded injection is an effective method employed in diesel engines for NOx control. However, this method leads to increased fuel consumption, reduced power, increased HC emissions and smoke. Water injection is another method for NOx control however this method enhances corrosion of vital engine components. In addition, it adds to the weight of the engine system because of requirement of a water storage tank. It is also difficult to retain water at a desired temperature during cold climate [7].

1.3 GAS ANALYZER

Gas analyzer is an instrument which is capable of analyzing the species of chemical gases is present in the sample. Not only it identifies the species but it also has capability to give measurement value of the quantity which it displays either in numerical form. [8]

In various engine types, exhaust gas levels are analyzed at the tailpipe and indicate unburned Oxygen, hydrocarbon, carbon monoxide, oxides of nitrogen, oxides of sulphur and represent a lean air/fuel mixture. The measurement of these gases is represented either in terms of ppm (parts per million) or percentage (%). Modern automobiles in good running order frequently show 10ppm or less. The level of CO₂ as indicated in analyzer is a product of combustion and represents the amount of fully burned fuel. Thus, a higher level of CO₂ indicates higher engine efficiency.

1.4 Exhaust Gas Recirculation

Exhaust Gas Recirculation (EGR) is being used widely to reduce and control the oxides of nitrogen (NOx) emission from diesel engines. EGR controls the NOx because it lowers oxygen concentration and flame temperature of the working fluid in the combustion chamber. However, the use of EGR leads to a trade-off in terms of soot emissions moreover it exhausted more unburned hydrocarbons (20-30%) compared to conventional engines. Present experimental study has been carried out to investigate the effect of EGR on performance and emissions in a three cylinders, air cooled and constant speed direct injection diesel engine, which is typically used in agricultural farm machinery. 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 hydrocarbons (HC), NOx, carbon monoxide (CO), exhaust gas temperature, and smoke opacity 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 particulate matter (PM), HC, and CO were found to have increased with usage of EGR. The engine was operated for normal running conditions with EGR and the performance and emission readings were observed.

Exhaust Gas Recirculation is an effective method for NO_x control. The exhaust gases mainly consist of carbon dioxide, nitrogen, etc. and the mixture has higher specific heat compared to atmospheric air. Re-circulated exhaust gas displaces fresh air entering the combustion chamber with carbon dioxide and water vapor present in engine exhaust. As a consequence of this air displacement, lower amount of oxygen in the intake mixture is available for combustion. Reduced oxygen available for combustion lowers the effective air-fuel ratio. This effective reduction in air-fuel ratio affects exhaust emissions substantially. In addition, mixing of exhaust gases with intake air increases specific heat of intake mixture, which results in the reduction of flame temperature. Thus combination of lower oxygen quantity in the intake air and reduced flame temperature reduces rate of NO_x formation reactions [9] and [10]. The EGR (%) is defined as the mass percent of the recirculated exhaust (MEGR) in the total intake mixture (Mi).

$$\text{EGR (\%)} = \frac{\text{MEGR}}{M_i} \times 100$$

Desantes et al. used Non-Dispersive Infrared Detector (NDIR)-based CO₂ concentration measurement at the intake ([CO₂]_{int}) and exhaust manifold ([CO₂]_{exh}) for the determination of EGR rate [11].

$$\text{EGR} = \frac{[\text{CO}_2]_{\text{int}} - [\text{CO}_2]_{\text{atm}}}{[\text{CO}_2]_{\text{exh}} - [\text{CO}_2]_{\text{atm}}}$$

The engines using EGR emit lower quantity of exhaust gases compared to non-EGR engines because part of the exhaust gas is re-circulated.

In the process of exhaust gas recirculation, a portion of exhaust gases is passes through an EGR control valve and to EGR cooler, which is then proceeds to a throttle valve assembly where mixing of filtered, high pressure, fresh combustion air and exhaust gases takes place. This mixture is then enters in the engine through the Inlet valve. [12]

PROPOSED WORK

2.1 PROJECT OBJECTIVES

The project objectives includes-

- To analyze different gases emitted from diesel engine. The exhaust gases from internal combustion engines are complex mixtures consisting oxidants of sulphur and nitrogen, unburnt products of complete

combustion and derived compounds of fuel and lubricants.

- To study and done the evaluation of the performance on characteristics curves after recirculation of exhaust gases.

MATERIALS AND METHODS

3.1 PERFORMANCE PARAMETERS [13]

3.1.1 INDICATED POWER (I.P.)

Indicated Power is the amount of fuel consumed for each unit of brake power per hour. It indicates the efficiency with which the engine develops the power from fuel. It is used to compare performance of different engines.

$$IP = \frac{(p_{im})LANK}{60 \times 1000}$$

Where, IP = indicated power (kW)

p_{im} = indicated mean effective pressure (N/m²)

L = length of stroke (m)

A = cross-sectional area of piston (m²)

n = number of power strokes

n=N/2 for four strokes, and n=N for two-stroke

N = crankshaft speed (revolutions per minute)

K = number of cylinders

3.1.2 BRAKE POWER (B.P.)

Brake power is the output power measured at the engine crankshaft. Brake power is also termed as Shaft power or Delivered power.

$$BP = \frac{(p_{bm})LANK}{60 \times 1000}$$

Where, BP = Brake power (kW)

p_{bm} = brake mean effective pressure (N/m²)

L = length of stroke (m)

A = cross-sectional area of piston (m²)

n = number of power strokes

n=N/2 for four strokes, and n=N for two-stroke

N = crankshaft speed (revolutions per minute)

K = number of cylinders

3.1.3 HEAT SUPPLIED BY FUEL

It is the thermal power released by burning fuel inside the engine. It is the product of mass of fuel burned per second and calorific value of the fuel.

$$h = \dot{m}_f \times CV$$

3.1.4 SPECIFIC FUEL CONSUMPTION (ISFC)

3.1.4(a) INDICATED SPECIFIC FUEL CONSUMPTION (ISFC)

3.1.4(b) BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)

Specific fuel consumption is defined as fuel flow rate per unit power output. It is the measure of how efficiently the fuel supplied to the engine is used to produce power. Since for a given power level, less fuel is consumed, thus low value of specific fuel consumption is desirable.

$$sfc = \frac{\dot{m}_f}{P}$$

In case of Indicated power, Indicated specific fuel consumption is given by,

$$isfc = \frac{\dot{m}_f}{IP}$$

In case of Brake power, brake specific fuel consumption is given by,

$$bsfc = \frac{\dot{m}_f}{BP}$$

3.1.5 INDICATED THERMAL EFFICIENCY (n_{ith})

Indicated thermal efficiency is the ratio of energy in the indicated power to the input fuel energy in appropriate units.

$$n_{ith} = \frac{ip}{h}$$

Where, ip= indicated power (kJ/s)

h=heat supplied by fuel or Energy in fuel (kJ/s)

3.1.6 BRAKE THERMAL EFFICIENCY (n_{bth})

Brake thermal efficiency is the ratio of energy in the brake power to the input fuel energy in appropriate units.

$$n_{bth} = \frac{bp}{h}$$

Where, bp= brake power (kJ/s)

h=heat supplied by fuel or Energy in fuel (kJ/s)

3.1.7 MECHANICAL EFFICIENCY

Mechanical efficiency is defined as the ratio of brake power (delivered power) to the indicated power (power provided by piston).

$$n_m = \frac{bp}{ip} = \frac{bp}{bp + fp}$$

Where, fp = frictional power = ip - bp

3.1.8 VOLUMETRIC EFFICIENCY

Volumetric efficiency is defined as the ratio of actual volume flow rate of air into the intake system to the rate at which the volume is displaced by the system.

$$n_v = \frac{\dot{m}_a}{\rho_a * n * V_s}$$

Where, ρ_a = density at inlet

n= number of intake stroke per minute

=N/2 (for four- stroke engine)

N= speed of the engine (rev/min)

V_s = Swept volume

3.1.9 SWEPT VOLUME

$$V_s = \frac{\pi}{4} * D^2 * L * \frac{n}{60} * K$$

Where, D= diameter of bore of engine

L= stroke of engine

n= n = number of power strokes

n=N/2 for four strokes, and n=N for two-stroke

N = crankshaft speed (revolutions per minute)

K = number of cylinders

3.1.10 TORQUE

$$\tau = \frac{9.5488 * P}{N}$$

Where, τ = Torque (N-m)

P= power (kW)

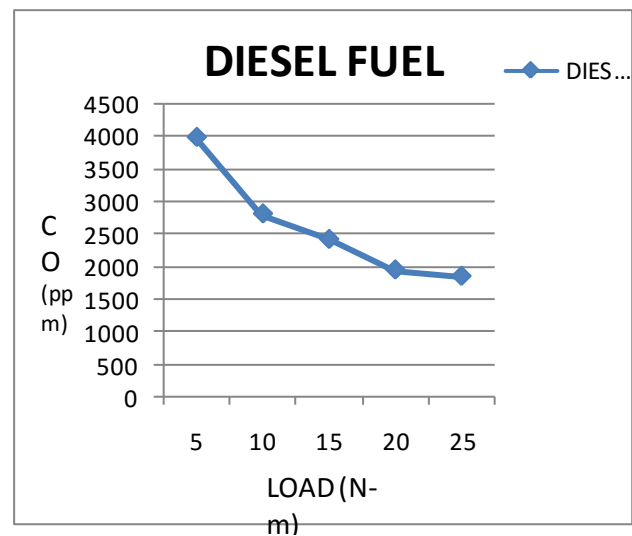
N= speed of crankshaft (rpm)

4. RESULTS AND CONCLUSION

4.1 PERFORMANCE CURVES

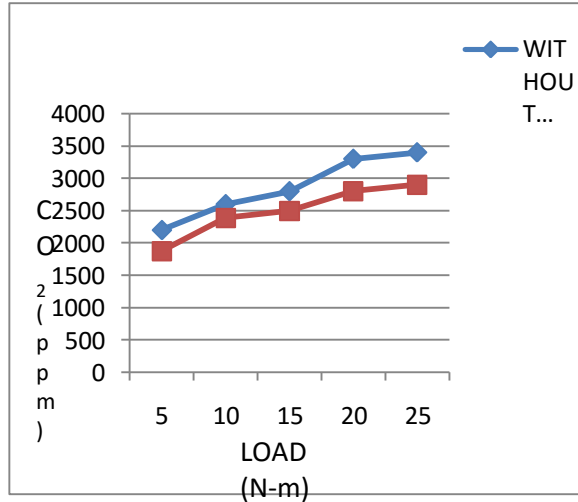
4.1.1 Carbon Monoxide (CO) Emissions-

The variations of carbon monoxide emissions at different loads are shown below. With increase in loads, reduction in emission of carbon monoxide can be observed.



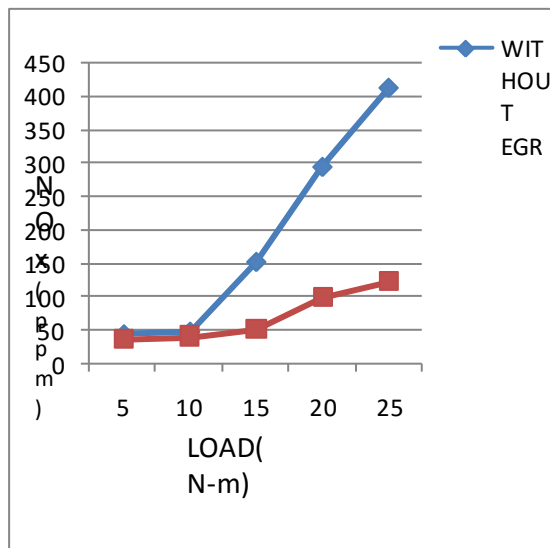
4.1.2 Carbon dioxide (CO₂) Emissions-

The variation of carbon dioxide emissions at different loads are shown below. It is observed that emission increases with increase in loads. After recirculation of gases exhausted after combustion, emission of carbon dioxide is somewhat decreases.



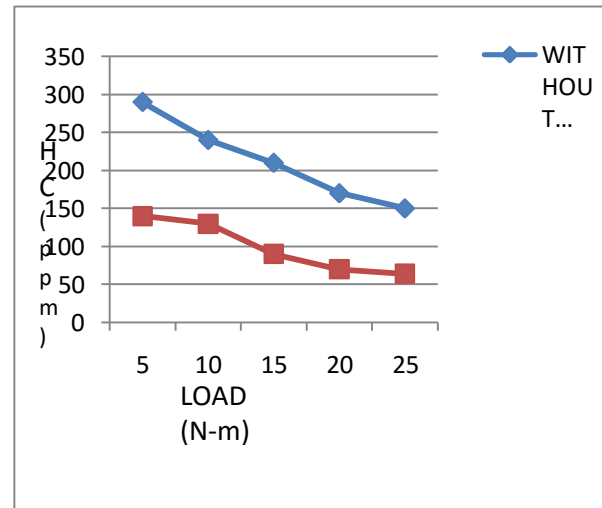
4.1.3 Oxides of Nitrogen (NO_x) Emissions-

Characteristic curve shown below indicates the variation in oxides of nitrogen (NO_x) emission with varying loads. After recirculation of exhaust gases, sudden decrement in emission of oxides of nitrogen is observed at higher loads.



4.1.4 Hydrocarbon (HC) Emissions-

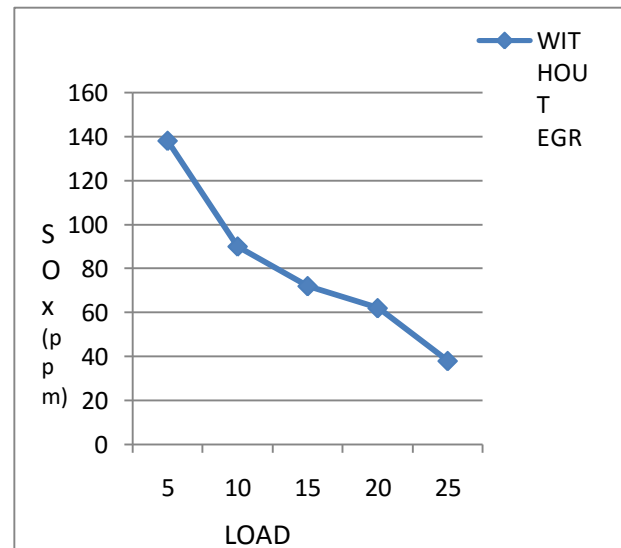
The variation of hydrocarbon can be seen in the following characteristic curve at different loads. The value of unburnt hydrocarbon decreases significantly from 290ppm to 140ppm at initial load condition as a result of cooling of exhaust gases in recirculation system.



4.1.5

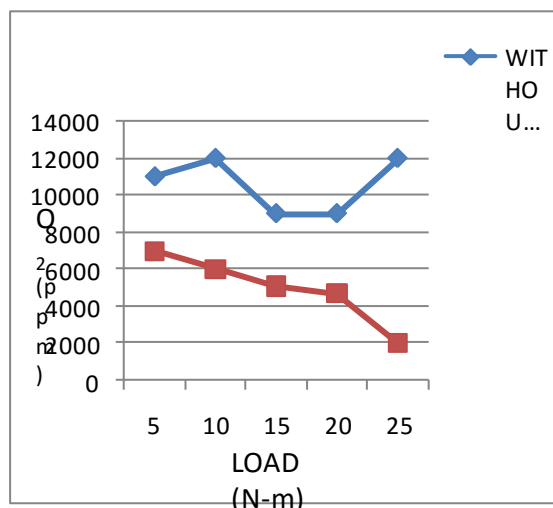
Oxides of Sulphur (SO_x) Emissions-

Characteristic curve shown below indicates the variation in oxides of sulphur (SO_x) emission with varying loads. However, emission decreases from 138 ppm to 38 ppm with increase in load from 5 N-m to 25 N-m, but this range of oxides of sulphur in diesel are harmful for the environment because they prevent the use of catalytic diesel particulate filters to control diesel particulate emissions.



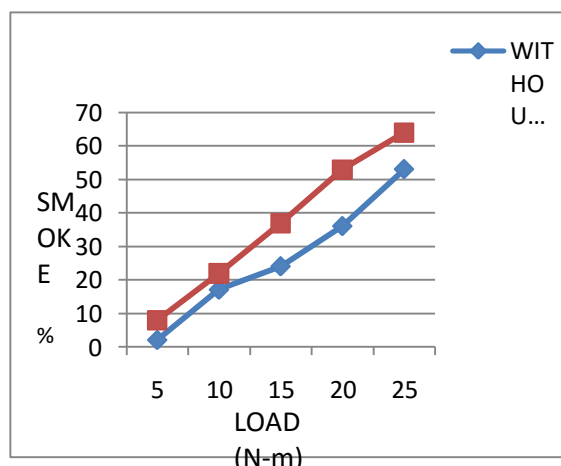
4.1.6 Oxygen (O₂) Emissions-

The variation of oxygen can be seen in the following characteristic curve at different loads. After recirculation it is observed that emission of oxygen is somewhat decreases.



4.1.7 Smoke Density-

The variations of smoke density for different rated loads are shown in the following curve. The smoke density is increasing with increase of load. After recirculation percentage of smoke emitted is increased from 53% to 64%, which is considerable.



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REFERENCES

1. U.S.Jyoti, K.Vijaya Kumar Reddy, "Effect on Performance, Combustion and Emissions of Diesel Engine with Varied Piston Bowl Geometry", International Journal of Research in Mechanical Engineering, Volume 3, Issue 5, September-October, 2015, pp. 22-27
2. Martin A. Elliott, Gerge J.Nebel and Fred G. Rounds, "The Composition of exhaust gases from Diesel, Gasoline and Propane

Powered Motor Coaches" 48 Annual Meeting of the air pollution control Association, Detroit, Michigan, May 22-26, 1955, pp.103-108

3. Yalavarthi Sateesh 1, Chintalapudi Anil Kumar 2 and Dev Satya, "Performance and Emission Analysis of Diesel Engine Using Oxygenated compounds", International Journal of Advanced Science and Technology Vol.61, (2013), pp.9-16
4. Stewart K.M., Health effects of diesel exhaust. Report from American Lung Association of Pennsylvania, 2001.
5. Moser F.X., Sams T., Cartellieri W., "Impact of future exhaust gas emission legislation on the heavy duty truck engine", JSAE 2001-01-0186, 2001.
6. Resitoglu Ibrahim Aslan, Altinisik Kemal, Keskin Ali, "The pollutant emissions from diesel engine vehicles and exhaust aftertreatment system", Springerlink.com, 11 June, 2014.
7. Pradeep V., Sharma R.P., "Use of hot EGR for NOx control in a compression ignition engine fuelled with bio-diesel from Jatropha Oil and Renewable Energy", 32 (7) (2007), pp. 1136-1154
8. Ury Allen B, "8 Advantages of Diesel Engines", <http://news.wyotech.edu/post/2012/03/8-advantages-of-diesel-engines/#.VsQcDLR95kg>, Mar 6, 2012
9. Thomas Sibul 1, Haider Nishi Shahnaj 2, "A Study on Basics of a Gas Analyzer", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (An ISO 3297: 2007 Certified Organization) Vol. 2, Issue 12, December 2013
10. Ladommatos N., Balian R., Horrocks R, Cooper L., "The effect of exhaust gas recirculation on soot formation in a high-speed direct-injection diesel engine", in: SAE 960841, 1996.
11. Abd-Alla G.H., "Using exhaust gas recirculation in internal combustion engines: a review", Energy Convers. Manage., 43 (2002), pp. 1027-1042
12. MAN, 2011. "Tier III Compliance - Low Speed Engines", MAN Diesel & Turbo, Copenhagen, Denmark, http://www.mandieselturbo.com/files/news/files/15014/5510-0088-00ppr_low.pdf
13. Ganeshan V., (2012) "Internal Combustion Engines", 4th edition, published by Tata McGraw Hill Education Private Limited.

Table I: Engine specifications

Engine	Diesel engine
Type	4 cylinder 4 stroke
Engine Speed	2000 rpm
Swept Volume (cc)	33490 cc
Cylinder Bore	80 mm
Stroke Length	100 mm
Compression Ratio	8:10

Table II: Summary of Experimental results at Loads

SPEED OF THE ENGINE (rpm)	LOAD/TORQUE (N-m)	CO (ppm)	CO ₂ (ppm) Without EGR	CO ₂ (ppm) With EGR	NO _x (ppm) Without EGR	NO _x (ppm) With EGR	HC (ppm) Without EGR	HC (ppm) With EGR	SO _x (ppm) Without EGR	O ₂ (ppm) Without EGR	O ₂ (ppm) With EGR	SMOKE (%) Without EGR	SMOKE (%) With EGR
2000	5	3989	2200	1875	43	36	290	140	138	11000	7000	2	8
2200	10	2804	2600	2390	47	40	240	130	90	12000	6000	17	22
2100	15	2409	2800	2500	152	51	210	90	72	9000	5100	24	37
2000	20	1936	3300	2800	295	99	170	70	62	9000	4700	36	53
2200	25	1837	3400	2900	414	122	150	64	38	12000	2000	53	64

Fig. 7.1 BLOCK DIAGRAM OF EXPERIMENTAL SETUP

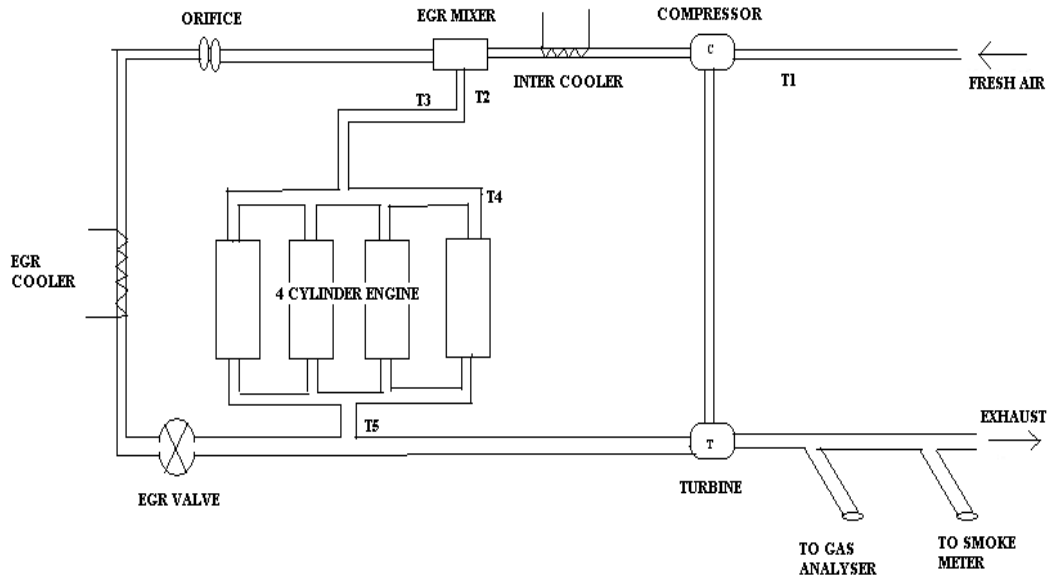


Fig.7.2 PHOTOGRAPHIC VIEW OF ENGINE SETUP



Fig.7.3 GAS ANALYZER KIT



Fig.7.4 EGR SYSTEM

