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Experimental investigation to evaluate the performance and emission characteristics of CI engine equipped with Exhaust Gas recirculation system.

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ABSTRACT
The presented study aims to experimentally investigate the sources of influence of exhaust gas recirculation on the tendency toward knock in the spark ignition engine. The three main sources of influence of exhaust gas recirculation on the engine tendency towards knock are known. The influence on flame propagation changes the profile of combustion and therefore the end-gas pressure and temperature profile. The thermal influence changes the thermal properties of the end-gas mixture and consequently its temperature profile, while the chemical influence changes the kinetic behavior of the end-gas mixture. The study is based on the results from experimental setup with spark ignition engine that uses cooled exhaust gas recirculation system and air heater installed into the intake manifold. Experimental tests that employ a new approach were performed, where intake temperature is varied by air heater when engine is operated with different levels of exhaust gas recirculation. In this way the end-gas temperature and exhaust gas recirculation percentage were varied while the influence on flame propagation was partially compensated by the change of spark timing. The obtained results show that there is no clear chemical influence of the exhaust gases on the tendency towards knock as the cases with low and high levels of exhaust gas recirculation are all mixed when the temperature of the end-gas is set to the same values. This leads to the overall conclusion that the predominant factor in a tendency towards knock is the end-gas temperature profile.
Keywords- Brake Power, C.I. engine, Electronic Control Machine, Exhaust Gas Circulation, NOx emission

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I. INTRODUCTION

All internal combustion engines generate power by creating explosions using fuel and air. These explosions occur inside the engine's cylinders and push the pistons down, which turns the crankshaft. Some of the power thus produced is used to prepare the cylinders for the next explosion by forcing the exhaust gases out of the cylinder, drawing in air (or fuel-air mixture in non-diesel engines), and compressing the air or fuel-air mixture before the fuel is ignited.

There are several differences between diesel engines and non-diesel engines. Non-diesel engines combine a fuel mist with air before the mixture is taken into the cylinder, while diesel engines inject fuel into the cylinder after the air is taken in and compressed. Non-diesel engines use a spark plug to ignite the fuel-air mixture, while diesel engines use the heat created by compressing the air in the cylinder to ignite the fuel, which is injected into the hot air after compression.

In order to create the high temperatures needed to ignite diesel fuel, diesel engines have much higher compression ratios than gasoline engines. Because diesel fuel is made of larger molecules than gasoline, burning diesel fuel produces more energy than burning the same volume of gasoline. The higher compression ratio in a diesel engine and the higher energy content of diesel fuel allow diesel engines to be more efficient than gasoline engines

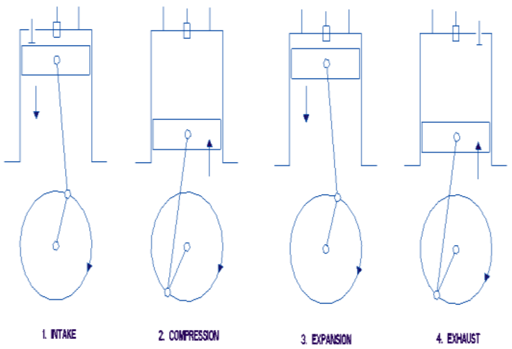

Fig. 1: Working of four stroke engine.

1.1. Formation of Nitrogen Oxides (NO_X)

The factors responsible for diesel engines to run more efficiently than gasoline engines also cause them to run at a higher temperature. This leads to a pollution problem, the creation of nitrogen oxides (NOx). You see, fuel in any engine is burned with extra air, which helps eliminate unburned fuel from the exhaust. This air is approximately 79% nitrogen and 21% oxygen.

When air is compressed inside the cylinder of the diesel engine, the temperature of the air is increased enough to ignite diesel fuel after it is ignited in the cylinder. When the diesel fuel ignites, the temperature of the air increases to more than 1500°F and the air expands pushing the piston down and rotating the crankshaft.

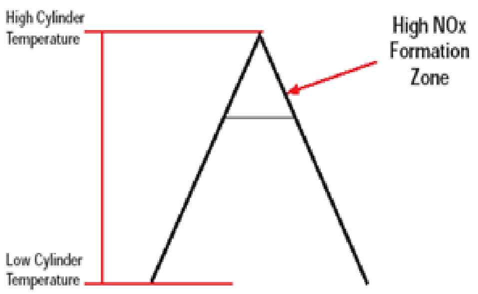

Fig 1.1.1: NOx formation zone.

Generally the higher the temperature, the more efficient is the engine which results into good performance and economy of the engine.

Some of the oxygen is used to burn the fuel, but the extra is supposed to just pass through the engine without reacted. The nitrogen, since it does not participate in the combustion reaction, also passes unchanged through the engine. When the peak temperatures are high enough for long periods of time, the nitrogen and oxygen in the air combines to form new compounds, primarily NO and NO_2. These are normally collectively referred to as "NOx".

1.2. Problems of NO_x

Nitrogen oxides are one of the main pollutants emitted by vehicle engines. Once they enter into the atmosphere, they are spread over a large area by the wind. When it rains, water then combines with the nitrogen oxides to form acid rain. This has been known to damage buildings and have an adverse effect on ecological systems. Too much NOx in the atmosphere also contributes to the production of SMOG (mixture of smoke and fog). When the sunrays hit these pollutants SMOG is formed. NOx also causes breathing illness to the human lungs.

1.3. Reduction of NO_x

Since higher cylinder temperatures cause NOx, it can be reduced by lowering cylinder temperatures. Charge air coolers are already commonly used for this reason. Reduced cylinder temperatures can be achieved in three ways.

a. Enriching the air fuel (A/F) mixture.
b. Lowering the compression ratio and retarding ignition timing.
c. Reducing the amount of Oxygen in the cylinder.

Enriching the air fuel (A/F) mixture results in reduce combustion temperatures. However, this increases HC and carbon monoxide (CO) emissions. Also Lowering the compression ratio and retarded Ignition Timing make the combustion process start at a less than the optimum point and reduces the efficiency of combustion.

These techniques lowers the cylinder temperature, reducing NOx, but it also reduces fuel economy and performance, and creates excess soot, which results in more frequent oil changes. So, the best way is to limit the amount of Oxygen in the cylinder. Reduced oxygen results in lower cylinder temperatures. This is done by circulating some exhaust gas and mixing it into the engine inlet air. This process is known as Exhaust Gas Recirculation

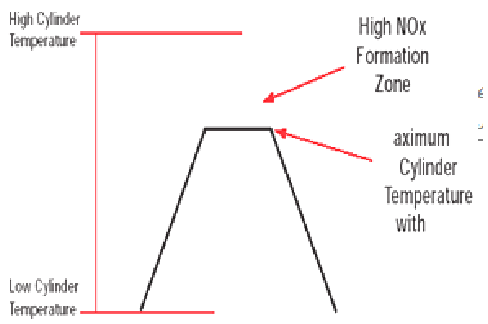

Fig 1.3.1: NOx reduction by lowering the temp..

II. EXHAUST GAS RECIRCULATION

Exhaust Gas Recirculation is an efficient method to reduce NOx emissions from the engine. It works by recirculating a quantity of exhaust gas back to the engine cylinders. Intermixing the recirculated gas with incoming air reduces the amount of available O_2 to the combustion and lowers the peak temperature of combustion. Recirculation is usually achieved by piping a route from the exhaust manifold to the intake manifold. A control valve within the circuit regulates and times the gas flow.

2.1. Uses of Exhaust Gas Recirculation

First, exhaust gas recirculation reduces the concentration of oxygen in the fuel-air mixture. By replacing some of the oxygen-rich inlet air with relatively oxygen-poor exhaust gas, there is less oxygen available for the combustion reaction to proceed. Since the rate of a reaction is always dependent to some degree on the concentration of its reactants in the pre- reaction mix, the NOx-producing reactions proceed more slowly, which means that less NOx is formed. In addition, since there is less oxygen available, the engine must be adjusted to inject less fuel before each power stroke. Since we are now burning less fuel, there is less heat available to heat the fluids taking place in the reaction. The combustion reaction therefore occurs at lower temperature. Since the temperature is lower, and since the rate of the NOx-forming reaction is lower at lower temperatures, less NOx is formed.

2.2. Basic parts of EGR

There are 3 basic parts of EGR

1. EGR Valve
2. EGR Cooler
3. EGR Transfer Pipe

When EGR is required engine electronic controls open the EGR valve. The exhaust gas then flows through the pipe to the cooler. The exhaust gases are cooled by water from the truck cooling system. The cooled exhaust gas then flow through the EGR transfer pipe to the intake manifold.

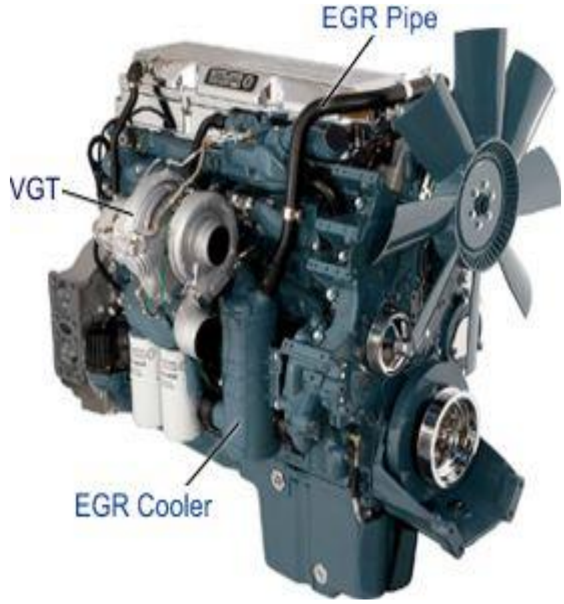

Fig**. 2.2.1:** Typical Four Stroke Diesel Engine with Basic Parts of EGR

2.3 EGR operating conditions

There are three operating conditions. The EGR flow should match the conditions

1. High EGR flow is necessary during cruising and midrange acceleration
2. Low EGR flow is needed during low speed and light load.
3. No EGR flow should occur during conditions when EGR flow could adversely affect the engine operating efficiency or vehicle drivability i.e., during engine warm up, idle, wide open throttle, etc.

2.4. EGR impact on ECS.

The ECM (Electronic Control Machine) considers the EGR system as an integral part of the entire ECS. Therefore the ECM is capable of neutralizing the negative aspects of EGR by programming additional spark advance and decreased fuel injection duration during periods of high EGR flow. By integrating the fuel and spark control with the EGR metering system, engine performance and the fuel economy can actually be enhanced when the EGR system is functioning as designed.

2.5. EGR theory of operation

The purpose of the EGR system is to precisely regulate the flow under different operating conditions. The precise amount of exhaust gas must be metered into the intake manifold and it varies significantly as the engine load changes. By integrating the fuel and spark control with the EGR metering system, engine performance and the fuel economy can be enhanced. For this an ECM (Electronic Control Machine) is used to regulate the

EGR flow. When EGR is required ECM opens the EGR valve.The ECM is capable of neutralizing the negative aspects of EGR by programming additional spark advance and decreased fuel injection duration during periods EGR flow The exhaust gas then flows through the pipe to the cooler. The exhaust gases are cooled by water from the vehicle's cooling system. The cooled exhaust gas then flow through the EGR transfer pipe to the intake manifold.

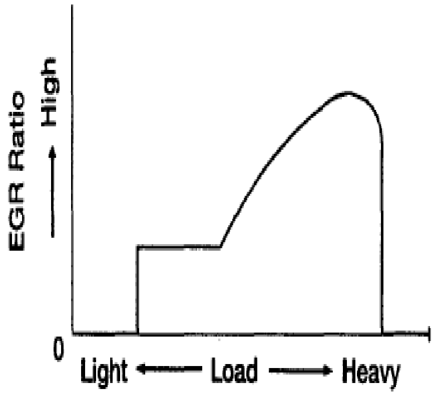

Fig. 2.5.1: Relationship between EGR Ratio and Load

III. EXPERIMENTAL ANALYSIS WITHOUT EGR SYSTEM

The experiment was carried out on a single cylinder, air cooled, and four stroke diesel engines. Engine was first started and kept in running condition up to 10 minutes. After that we set the speed of engine as 800 rpm (Tachometer was used). Once rpm was set we observed time (by stopwatch) required by engine to consumed 20 ml of fuel (Diesel) and then Temperature at Exhaust 8 manifold was measured (with the help of infrared Thermometer and thermocouple). Calculations for different parameters (BP, FC, SFC, BSFC, BTE, etc.) were calculated by obtained time and temperature.

Calculation without EGR System:-

Data: Speed of Engine, N = 800 RPM

Weight, W = 3 kg = 3 × 9.81 = 29.43 N

Time (time required by an engine to consume 20 ml of fuel at particular rpm of diesel) = 85 sec.

Calorific value, CV = 43000 kJ / kg

Radius of flywheel of engine, r = 0.5 meter (m)

Specific gravity = 0.82

Torque, T = W × r = 29.43 × 0.5 = 14.715 N-m

1) Brake Power (B.P)

$$B.P = \frac{2\pi nt}{60} = 1232.76$$

2) Fuel consumption (F.C)

$$F.C = \frac{20}{t_f} x \frac{3600}{1000} \text{ x specific gravity}$$

F.C = 0.6945 kg/hr

3) Specific Fuel consumption (S.F.C)

$$S.F.C = \frac{F.C}{B.P}$$

S.F.C = 0.564 kg/kW hr

4) Brake specific Fuel consumption (B.S.F.C)

B.S.F.C = S.F.C X C.V

B.S.F.C = 24252 KJ/kw hr

5) Heat supplied by fuel (H.F)

H.F = F.C X C.V = 29885 KJ/KG

6) Brake Thermal Efficiency (B.T.E)

$$B.T.E = \frac{B.P \text{ in kwhr}}{H.F} X\ 100$$

= 14.85%

3.1. Characteristics performance graph without EGR system

From the graph of variation of Exhaust Gas Temperature of the engine without EGR system at various brakes Power it is observed that when Brake power of the engine increases, Exhaust Gas Temperature of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and respectively Exhaust Gas Temperature varies from 110 °C to 135 °C. From the graph of variation of fuel consumption of the engine without EGR system at various Brake Power.it can be stated that when Brake power of the engine increases, the fuel consumption of the engine is also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and fuel consumption varies from 0.6945 kg/hr to 0.984 kg/hr respectively. From the graph of variation of brake thermal efficiency of the engine without EGR system at various Brake Power it can be concluded that when Brake power of the engine increases, the Brake thermal efficiency of the engine is also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and respectively, brake thermal efficiency varies from 14.85 % to 20.96%

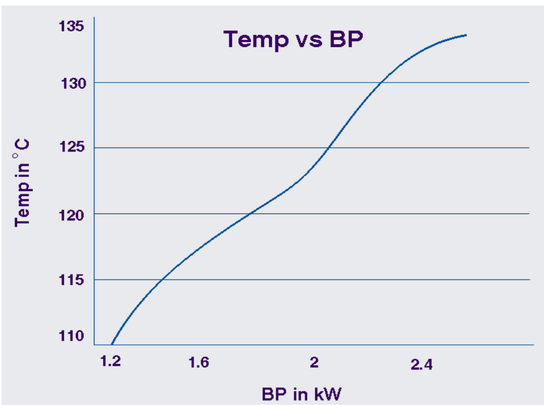

Fig. 3.1.1: Temp. vs BP

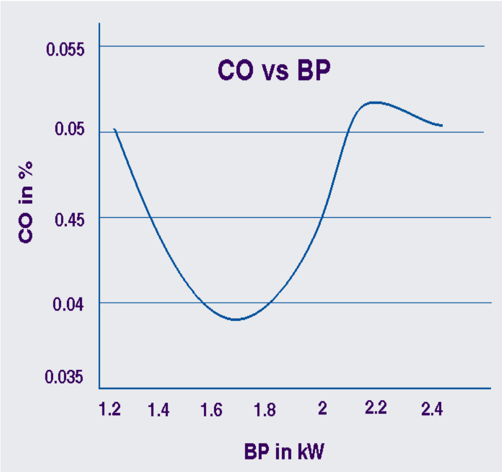

Fig. **3.1.2 :** % CO vs BP

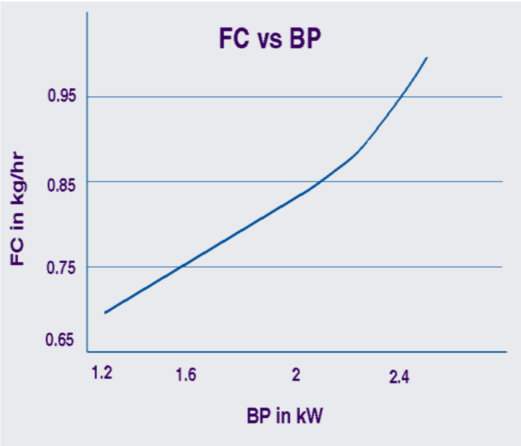

Fig. 3.1.3 : FC vs BP

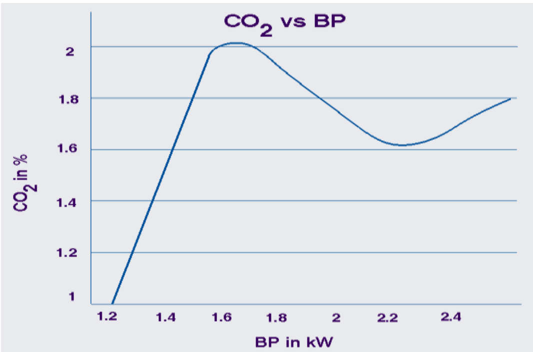

Fig. 3.1.4 : CO2 vs BP

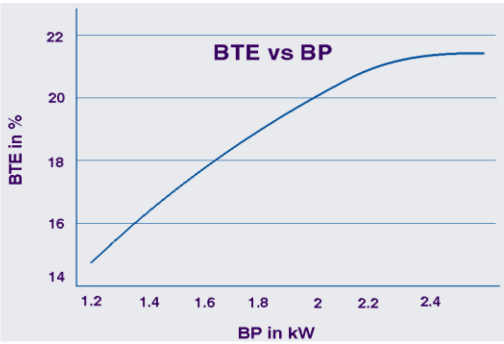

Fig. 3.1.5 : BTE vs BP

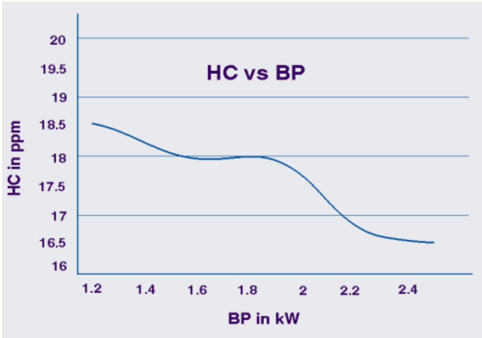

Fig**. 3.1.6** : HC vs BP

IV. EXPERIMENTAL ANALYSIS WITH EGR SYSTEM

The experiment was carried out on a single cylinder, air cooled, four stroke diesel engines. It was necessary to make some of modifications in the engine since the original engine had no EGR. It was necessary to connect the exhaust manifold with the air intake manifold. The experimental set-up and comprises a diesel particulate air filter, a heat exchanger, a liquid fuel metering systems, and an exhaust gases analysis system. It was necessary to connect the exhaust manifold with the air intake manifold. A tachometer is connected with engine; it is use for measuring RPM of the engine. The EGR pipe connected with exhaust manifold to the inlet of the engine. The EGR pipe also connected with intercooler and air filter the air filter is used for particulate reduction and supply of clean gas for

EGR. The intercooler is used as an exhaust cooler for cooling exhaust gas. Procedure for measurement and calculation of various parameters i.e. time (required by engine to consumed 20 ml of fuel at various rpm), temperature, BP, SFC, BSFC, BTE, etc. was same as that carried out for without EGR system.

Calculation with EGR System:-

Data: Speed of Engine, N = 800 RPM

Weight, W = 3 kg = 3 × 9.81 = 29.43 N

Time (time required by an engine to consume 20 ml of fuel at particular rpm of diesel) = 85 sec.

Calorific value, CV = 43000 kJ / kg

Radius of flywheel of engine, r = 0.5 meter (m)

Specific gravity = 0.82

Torque,

T = W × r = 29.43 × 0.5 = 14.715 N-m

1) Brake Power (B.P)

$$B.P = \frac{2\pi nt}{60} = 1232.76\ W$$

2) Fuel consumption (F.C)

$$F.C = \frac{20}{t_f} x \frac{3600}{1000}\ \text{x specific gravity}$$

F.C = 0.7288 kg/hr

3) Specific Fuel consumption (S.F.C)

S.F.C = $\frac{F.C}{B.P}$

S.F.C = 0.592 kg/kW hr

4) Brake specific Fuel consumption (B.S.F.C)

B.S.F.C = S.F.C X C.V = 25456 KJ/kw hr

5) Heat supplied by fuel (H.F)

H.F = F.C X C.V = 31347 KJ/KG

6) Brake Thermal Efficiency (B.T.E)

B.T.E = $\frac{B.P \text{ in kw hr}}{H.F}$ X 100

= 14.15%

4.1 Characteristics performance graph with EGR system

The graph of variation of Exhaust Gas Temperature of the engine with EGR system at various Brake Power indicates that when Brake power of the engine increases, Exhaust Gas Temperature of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and Exhaust Gas Temperature varies from 105 °C to 129 °C. From the graph of variation of fuel consumption of the engine with EGR system at various Brake Power it is concluded that when Brake power of the engine increases, fuel consumption of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and fuel consumption varies from 0.7288 kg/hr to1.1808 kg/hr. It is observed from the graph of the variation of the brake thermal efficiency of the engine with EGR system at various Brake Power that when Brake power of the engine increases, Brake thermal efficiency of the engine also increases. The brake power of the engine varies from 1.232 kW to 2.464 kW and Brake thermal efficiency varies from 14.15% to 17.47%.

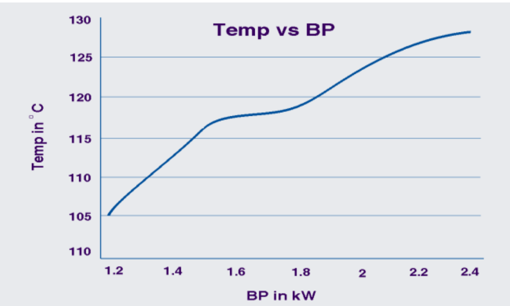

Fig. 4.1.1: Temp. vs BP

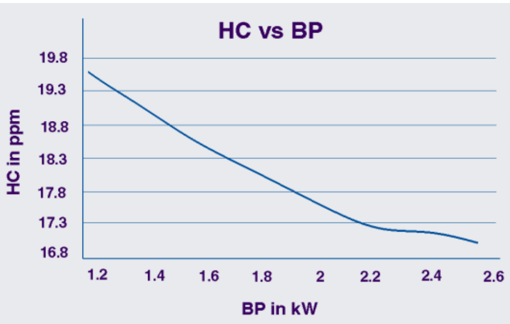

Fig. 4.1.2 : HC vs BP

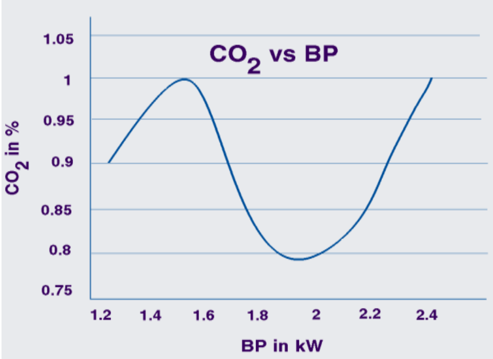

Fig. 4.1.3 : CO2 vs BP

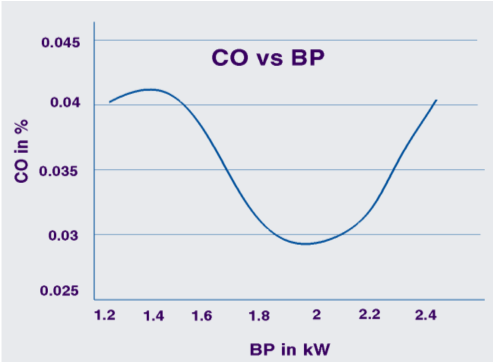

Fig. 4.1.4: CO vs BP

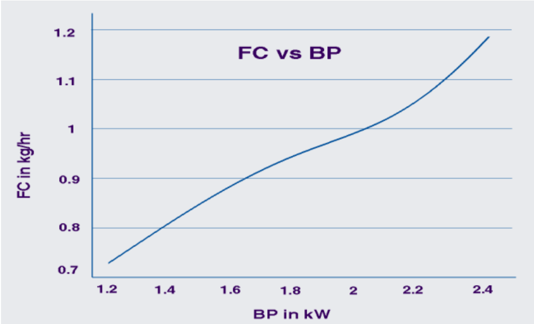

Fig. 4.1.5: FC vs BP

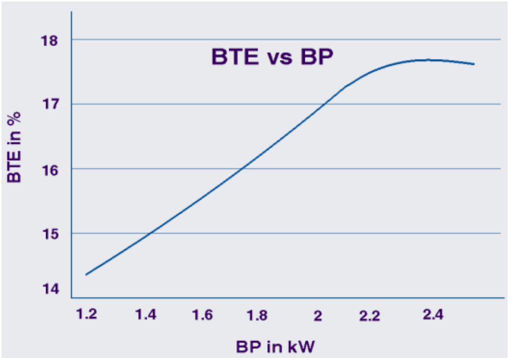

Fig. 4.1.6: BTE vs BP

V. COMPARISON GRAPH (WITH & WITHOUT EGR SYSTEM)

Figure shows Comparison graph of with and without EGR system of variation in Temperature with respect to Brake Power. From the Figure 5.7 it is clear that the value of Exhaust Gas Temperature of the diesel engine with EGR is less than that of without EGR system at same brake power. Figure 5.3 shows Comparison graph of with and without EGR system of variation in Fuel Consumption with respect to Brake Power. It is clear that the value of Fuel Consumption of the diesel engine with EGR is more than that of without EGR system at same brake power.

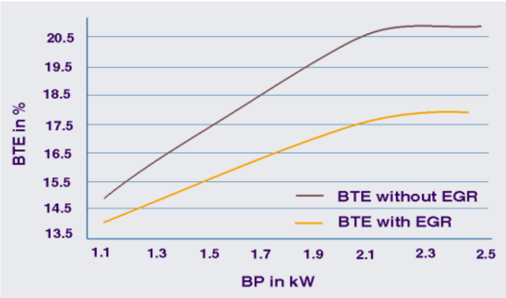

Fig.5.1: BTE vs BP

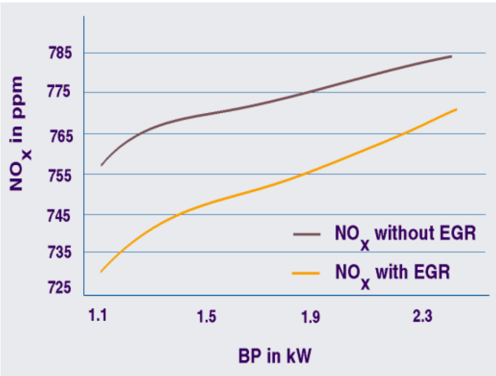

Fig. **5.2:** NOx vs BP

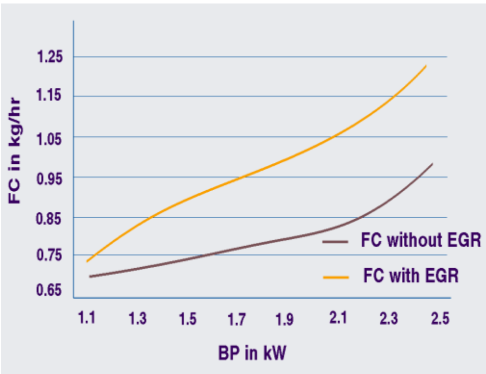

Fig. 5.3: FC vs BP

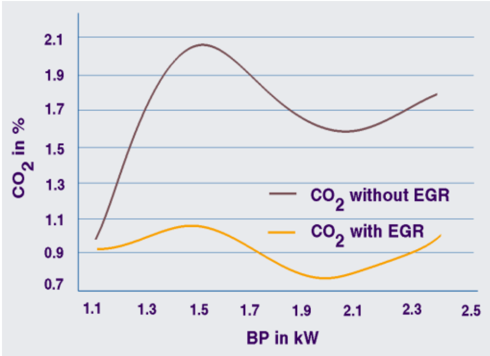

Fig. 5.4: CO2 vs BP

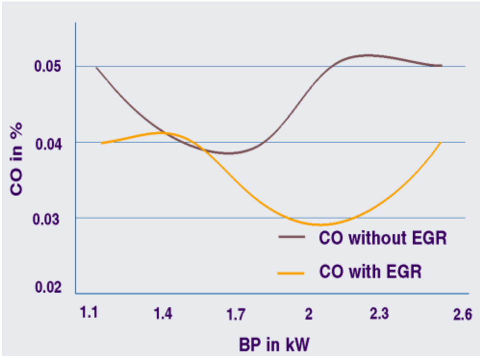

Fig. 5.5: CO vs BP

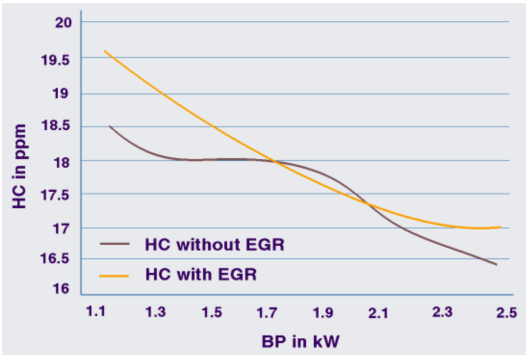

Fig. 5.6: HC vs BP

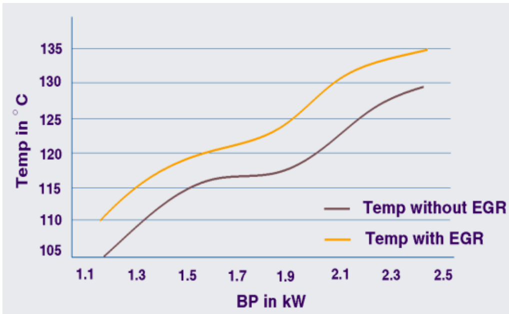

Fig. 5.7: Temp. vs BP

VI. CONCLUSION

A. The main objective of the present investigation was to evaluate suitability of Exhaust Gas Recirculation system for use in a C.I. engine and to evaluate the performance and emission characteristics of the engine.

B. The engine performance on EGR system, Exhaust Gas Temperature reduces as compared to that of without EGR system, so it is beneficial for surrounding.

C. Figure shows Comparison graph of with and without EGR system of variation in Fuel consumption with respect to Brake Power. From the above figure it is clear that the value of Fuel Consumption of the diesel engine with EGR increases than that of without EGR system at same brake power.

D. The Brake Thermal Efficiency (BTE) of the engine was partially lower and the Brake Specific Fuel Consumption (BSFC) of the engine was partially higher when EGR system was implemented with engine.

E. Emission of Oxide of Nitrogen (NOx) was very much reduced by implementation of EGR system. Emission of Carbon Dioxide (CO_2) and Carbon Mono-oxide (CO) was also reduced.

F. Emission of Hydro Carbon (HC) increases by implementing EGR system with engine than that of operating engine without EGR system.

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