"Diminution of Emissions by using EGR Valve in IC Engine and study the Temperature of the Exhaust Gas on various Load Conditions"

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Abstract : This work is to review the looming of exhaust gas recirculation (EGR) to reduce the exhaust emissions, particularly NO_X emissions under various load conditions. The major task of the proposed work includes calculation of CO, CO_2, NO_X, HC content in engine exhaust with and without the execution of EGR Valve under the submission of various loads. In this process we use the exhaust gas imminent from exhaust manifold and rerouting it to inlet manifold in order to reduce the maximum emission content. Engine without EGR are more pollutant and uses excess atmospheric air for combustion process. By implementation of EGR valve in the engine, the Partial exhaust gas is re-circulated again into the engine. The exhaust gas is first passed in EGR and mixed with the atmospheric air before entering into the Combustion Chamber. Hence the amount of fresh atmospheric air is reduced which in turns reduces the emissions (CO, CO_2, HC, NO_X etc.) is abridged and is analyzed by the gas analyzer. The process is very much Eco-friendly. Using exhaust gas recirculation (EGR) technique in engines, the emissions are very much reduced and also the temperature of the exhaust gases is measured by using an infrared thermometer.

Keywords

Exhaust Gas Recirculation, Combustion chamber, NO_X emissions, Gas analyzer, Infrared thermometer.

I. INTRODUCTION

The diesel engine provides a high efficiency and CO_2 emissions, which are believed to be the main cause of global warming. Diesel exhaust also contains toxic gases, mainly nitrogen oxides (NO_X) and other soot particles. These emissions are therefore limited by the authorities in most countries. A way to reduce these emissions of a diesel engine is the use of exhaust gas recirculation (EGR) process. Here, a part of the exhaust gases is rerouted into the combustion Chamber. This leads to a lower peak combustion temperature which in turn reduces the formation of NO_X and other contents. In modern turbocharged engines it can be difficult to provide the amount of EGR that is needed to reach the emission limits. Other concerns can be the transitory response of both the EGR-valve and the engine.

The Exhaust Gas Recirculation (EGR) valve is designed to reduce the amount of oxides created by the engine during operating periods that usually result in high combustion temperature. The NO_X is formed in high concentrations.

The EGR valve helps in reducing NO_X production by recirculation a portion of exhaust gas into the intake manifold where it mixes with the incoming air. By diluting the air-fuel mixture, the peak temperature, pressures are reduced resulting in reduction of NO output. Generally speaking EGR flow should match following operating conditions:

- High EGR flow is necessary during cruising mid-range acceleration, when combustion temperature is typically very high.
- Low EGR flow is needed during low speed and light load conditions.
- No EGR flow should occur when EGR operation could adversely affect engine operating efficiency such as engine warm up, idle, wide open throttle, etc.

EGR is an effective method for NO_X control. The exhaust gases mainly consist of inert carbon dioxide, nitrogen and possess high specific heat. The exhaust gas when circulated into the engine inlet, it can reduce the oxygen concentration and act as heat sink. This process reduces oxygen concentration and peak combustion temperatures, which results in reduction of NO_X. EGR is the most effective technique which is currently available for reducing NO_X emissions in the IC engines.

II. SCOPE OF WORK

A. Review of Work

There are four areas in the automobile, which can emit pollutants into the atmosphere. Those are the fuel tank, the carburetor, the crankcase and the exhaust valve. The fuel tank and the carburetor emits fuel vapors, the crankcase gives out the party burnt a/f mixture blown off through the piston rings, while the emissions from the exhaust valve include unburnt hydro carbons, carbon monoxide, nitrogen oxides and sulphur oxides. Therefore, the atmospheric pollution can be decreased by controlling these areas of the automobile, for these different approaches have been suggested… [4] to [8]:

- To reduce the formation of pollutants in the emissions by redesigning the engine ventilation valve, carburetor and fuel tank. The combustion chamber along with fuel valve, cooling valve, ignition valve and the exhaust valve are also to be redesigned, thus improving upon the combustion efficiency which reduces the emissions.
- To destroy the pollutants after these have been formed.

B. Emission Reduction Process

The reduction of emissions can be achieved by the following [9]:

i. Closed crankcase ventilation
ii. Fuel tank and carburetor ventilation
iii. Redesigning the engine components such as

(a) Combustion chamber
(b) Cooling valve
(c) Fuel supply valve
(d) Ignition valve.

Remedy

However, the designing of the engine components were being complicated and can't be known what the amount of pollutants may take place or give rise in the engine while going with combustion process in the combustion chamber. So, it is recovered that beyond going with the unknown composition it is better to destroy them when the composition is known i.e. when they have formed. So, it is therefore concluded that emissions can be controlled easily when their composition is known.

Execution

The air cleaner is controlled thermostatically so that the temperature of the air entering the carburetor is about 30-40^{0}C. Hence the heating is done by utilizing the heat of the exhaust gases only. The supply of the air to the engine at higher temperature results in decrease of exhaust emissions due to increase in combustion efficiency. For this process a EGR valve is used enroot for recirculation of the Exhaust gases into the inlet manifold in which the gases mix up with the fuel by decreasing the oxygen content in the intake air and then passed into the combustion chamber for the further process as normal combustion as a result there is a reduction in the NO_X emissions from the exhaust and further process continues till the engine reaches the idle position.

In the internal combustion (IC) engines, exhaust gas recirculation (EGR) is a nitrogen oxygen (NO_X) reduction technique used in petrol or diesel engines. EGR works by re-circulating a portion of an exhaust gas back to the engine cylinders. This process continues for the time when the valve is in running condition such the engine will be free from pollutants and much Eco-friendly in nature.

N.K.MillerJothi et al., [1] studied the effect of Exhaust Gas Recirculation of homogeneous charge ignition engine. A stationary 4-stroke single cylinder engine, direct ignition (DI) diesel engine capable of developing 3.7kW @1500rpm was modified to operate in a homogeneous charge compression ignition (HCCI) mode. In the present work the diesel engine was operated on 100% liquid petroleum gas (LPG).

The LPG has a low cetane value (<3), therefore Diethyl ether (DEE) was added to the LPG for the ignition purpose. DEE is an excellent ignition enhancer (cetane value >125) and has a low auto ignition temperature (of 160^{0}C). Experimental status showed that by EGR technique, at part loads the brake thermal efficiency increases by about 2.5% and at full load, NO concentration could be considerably reduced to about 68% as compared to LPG operation without EGR. However, higher EGR percentage affects the combustion rate and significant reduction in peak pressure at max. Load.

Table 1: Experimental Specifications

Parameter	Specification
Bore*Stroke	80mm*110mm
Displacement volume	553cm^3
Compression ratio	16.5:1
Type of cooling	Water cooled
Rated power	3.7kW @1520rpm

Deepak Agarwal et al., [2] investigate the effect of EGR on soot particles deposit an wear of vital engine parts, especially piston rings, apart from performance and emissions in a 2 cylinder, air cooled, constant speed direct ignition diesel engines, which typically used as farm machinery and decentralized captive power generation such engines are not generally operated with EGR. The experiments are carried out to evaluate the performance and emissions for different EGR toll of the engine. Emissions of HC, NO_X, CO, exhaust gas temperature and smoke capacity of the exhaust gas etc. are 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, CO were found to have increased with use of EGR. The engine has operated for 96Hr in normal running conditions and the deposits on vital engine parts were assessed. The engine was again operated for 96Hr with EGR and similar observations were recorded. Higher carbon deposits were observed on the engine parts operating with EGR. Higher wear of piston rings was also observed for engine operated with EGR.

Table 2: Experimental Specifications

Engine type	2 cylinder direct injection
Bore/stroke	87.3/110mm
Rated power	9kW @1500rpm
Compression ratio	16.5:1
Total displacement volume	13181cm^3
Fuel injection release pressure	210bar
Inlet valve open/close	45^0 BTDC / 35.5^0 ATDC
Exhaust valve open/close	35.5^0 BBDC / 45^0 ATDC

N.Sarvanan et al., [3] used hydrogen-enriched air as intake charge in a diesel engine adopting EGR technique with hydrogen flow rate @20lit/min. experiments are conducted in single cylinder 4-stroke water cooled direct ignition diesel engine coupled to an electrical generator. Performance parameters such as specific fuel consumption, brake thermal efficiency are determined and emissions of NO_X, HC, CO, PM, smoke and exhaust gas temperature are measured. Usage of hydrogen in dual fuel mode with EGR technique results in lowered smoke level, particulate and NO_X emissions.

Table 3: Experimental Specifications

Parameter	Specification
Bore	80mm
Stroke	110mm
Swept volume	553cm^3
Clearance volume	36.87cm^3
Compression ratio	16.5:1
Rated output	3.7kW @1500rpm
Ignition pressure	240bar

Experimental setup

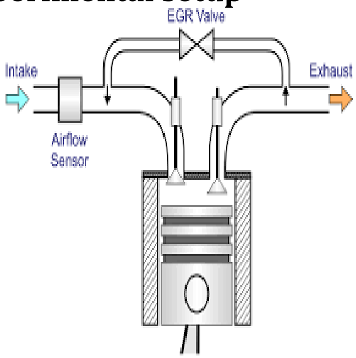

Figure 3.1: Experimental Setup

Development of EGR valve

Increased in the demands are being placed on the engine manufactures to design and build engines that provide better engine performance, improved reliability and greater durability while meeting greater stringent emission and noise requirements. One important object for internal combustion engine designers is to reduce NO_X emissions, while minimizing negative impact on the engine fuel economy and durability. An IC engine having an exhaust gas recirculation (EGR) valve which helps in reducing NO_X emissions while substantially maintaining fuel economy and durability. In many valves, for example, EGR is cooled to reduce NO_X emission levels at high engine loads. Valves in which EGR is not cooled may experience relatively high NO_X emissions during heavy engine throttle or loads. On the other hand at low engine loads, valves in which EGR is cooled experience fuel droplets vaporization which is not enhanced. Large fuel droplets affect emission by producing soot particles.

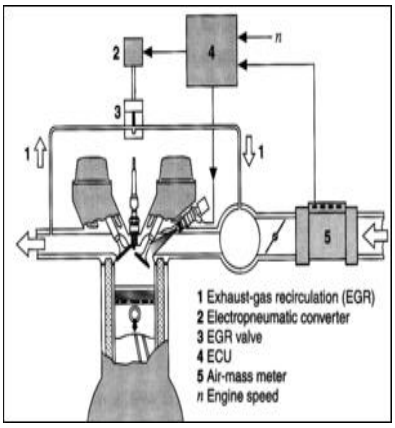

Figure 3.2: Experimental setup on the Engine

Figure 3.3: EGR Valve Used On the Experimental Setup

Structure and Functioning of EGR Valve

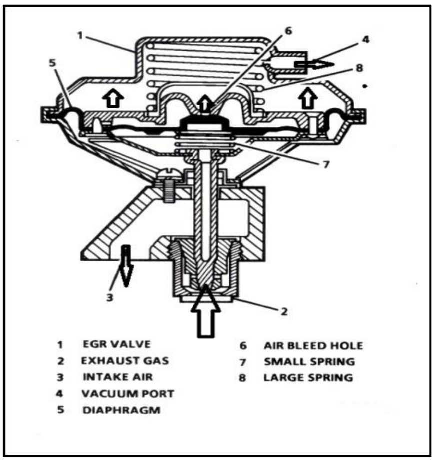

Figure 3.4: Structure of EGR Valve

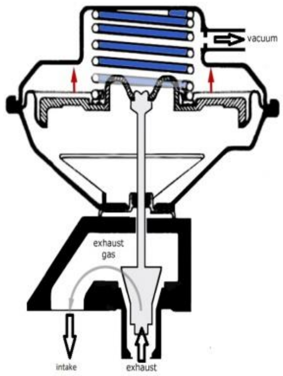

Figure 3.4: Functioning of EGR Valve

C. Specifications of the experimental engine:

Table 4: Specifications of the experimental engine

Engine type	Single cylinder C.I engine
Bore*Stroke	80mm*110mm
Compression ratio	16:8:1
Type of cooling	Water cooling
Type of fuel	Diesel
Fuel injection pressure	220lbs
Rated power @speed	5HP@1500rpm
Max. Torque produced	14.8N-m

D. EXPERINTAL ALLIGNMENT (INLINE DIAGRAM)

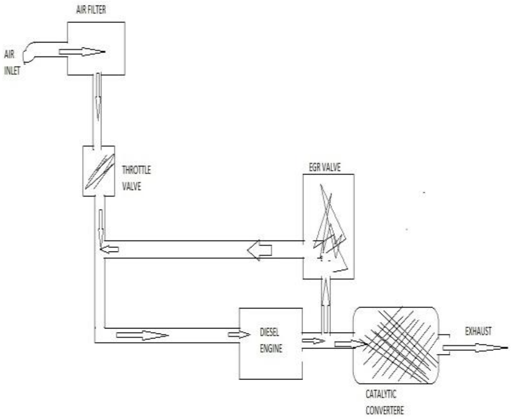

Figure 3.5: Inline Diagram of the Experimental Setup

E. Experimental Methodology

Images

Figure 4.1: Experimental Images

IV. Experimental procedure

A. Without EGR valve

The experiment was carried out on a single cylinder, water cooled, 4-stroke diesel engine with specifications shown in the above table 4. The engine was started and kept in running condition up to 10 minutes ensure that the engine is running at no load conditions. After that the speed of the engine is measured (Tachometer is used). Once speed is measured, the engine is observed for consuming 20ml of fuel (Diesel) and then the temperature of the Exhaust gas is measured at exhaust manifold and also the emissions are analyzed by using Exhaust gas analyzer and also the temperature of the exhaust gas is measured using an infrared thermometer.

The experiments are further carried out by applying the load on the engine from no load condition as that of the maximum load that can be applied on the engine i.e., 0kW, 1 kW, 2kW 3kW, after that the speed of the engine is measured and time required by the engine to consume 20ml of fuel and then the temperature and emissions are measured from the exhaust gas using Exhaust gas analyzer and infrared thermometer. The relevant difference of measurement of time and the temperature and exhaust gas emissions are measured between various loads was approximately 10 minutes i.e. after each experiment, engine kept in running condition up to approximately 10 minutes and then for time, speed, the temperature and emissions are calculated and further calculations of various parameters are done. The results of the process are tabulated as

Table 5: Calculation (without EGR Valve)

S. No	Load In Kw	Speed In RPM	Time Of Fuel consumption	Temperature ^{0}C	BP kW	FC kJ/Hr.	SFC Kg/kW Hr.	BSFC Kj/kWhr	HF Kj/Kg	BTE %
1	0	1472	61	82	2.28	0.48	0.21	9117.63	20809.2	39.48
2	1	1492	53	88	2.31	0.56	0.24	10353.21	23950.2	34.77
3	2	1638	45	90	2.54	0.66	0.26	11106.91	28208	32.41
4	3	1648	38	96	2.56	0.78	0.30	13073.11	33404.2	27.54

Where, B.P. = Brake Power
F.C. = Fuel Consumption
S.F.C. = Specific Fuel Consumption
B.S.F.C. = Brake Specific Fuel Consumption
H.F. = Heat Supplied by Fuel
B.T.E. = Brake Thermal Efficiency

Characteristic performance curves:

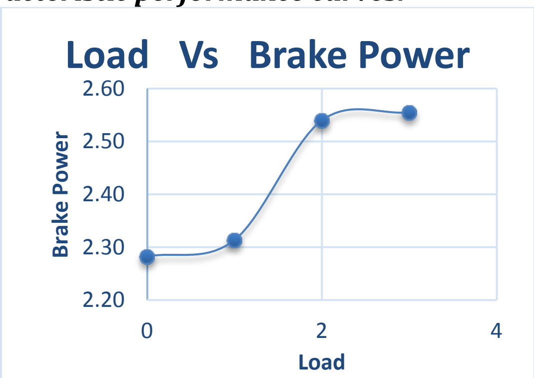

Figure 4.2.1: Load Vs Brake Power

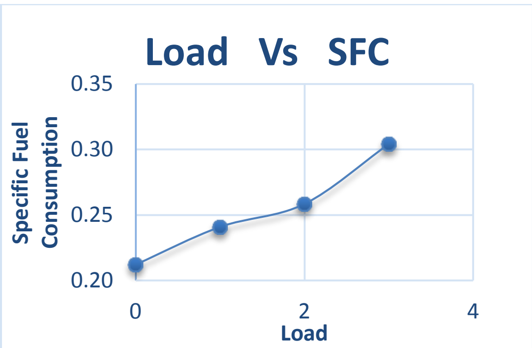

Figure 4.2.2: Load Vs Specific Fuel Consumption

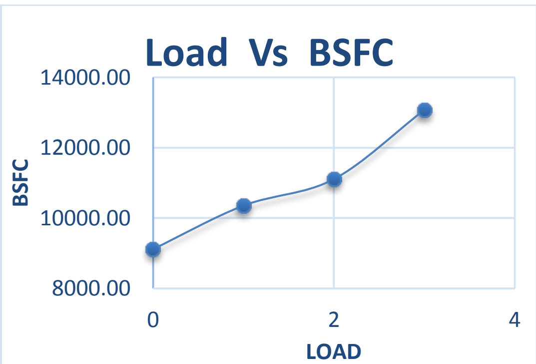

Figure 4.2.3: Load Vs Brake Specific Fuel Consumption

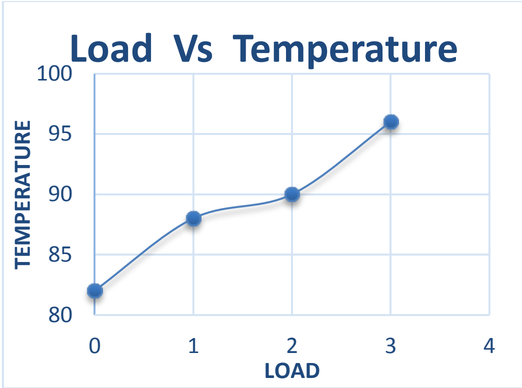

Figure 4.2.4: Load Vs Temperature

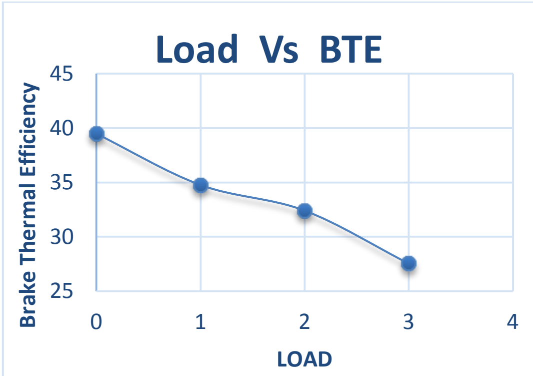

Figure 4.2.5: Load Vs Brake Thermal Efficiency

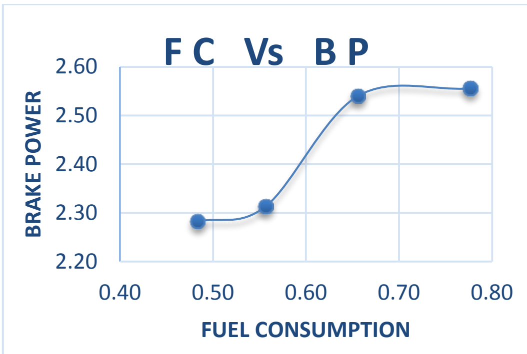

Figure 4.2.6: Fuel Consumption Vs Brake Power

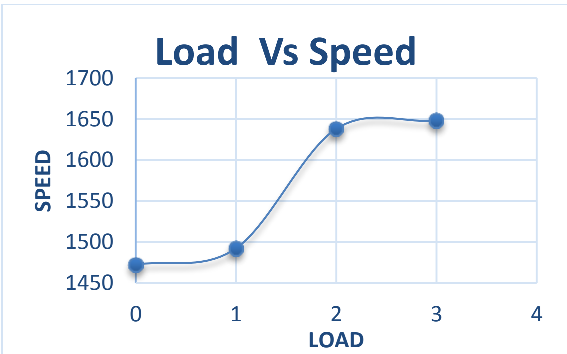

Figure 4.2.7: Load Vs Speed

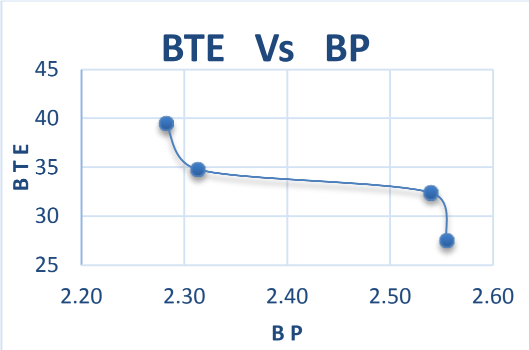

Figure 4.2.8: Brake Thermal Efficiency Vs Brake Power

B. With EGR valve

The experiment was carried out in the same cylinder, water cooled, 4-stroke diesel engine, same specifications mentioned above. It is necessary to make some modifications in the engine since the original engine has no EGR. It is necessary to connect the exhaust manifold with the air intake manifold as shown in the experimental inline Figurers below with an EGR valve.

Again the loads are applied on the engine as from no load condition as that of the maximum load that can be applied on the engine i.e., 0 kW, 1 kW, 2kW 3kW and with the help of tachometer, the speed of the engine is measured and the same process continues as before but with the help of EGR valve. The engine load is varied with changes same as before and the speed, emissions and temperature are analyzed in the vital time as done before. This EGR valve is a device which diverts the partial amount of the exhaust gas into the engine and lowers the temperature in the combustion chamber as high temperatures is the main cause for the formation of the toxic emissions in the engine exhaust. By this arrangement it decreases the combustion temperature as well as the fuel combustion timing and this helps in the reduction of the toxic NO_X emissions in the exhaust gas from the exhaust manifold which is measured from the exhaust gas analyzer as same as carried out for without EGR valve. The results of the process are tabulated as:

Table 6: Calculation (with EGR Valve)

S. No	Load In Kw	Speed In RPM	Time Of Fuel consumption	Temperature ^0C	BP kW	FC kJ/Hr.	SFC Kg/kW Hr.	BSFC Kj/kWhr	HF Kj/Kg	BTE %
0	0	1350	68	89.3	2.09	0.43	0.21	8918.20	18667.1	40.37
1	1	1468	55	90.1	2.28	0.54	0.24	10139.84	23079.3	35.5
2	2	1531	44	93.9	2.37	0.67	0.28	12153.23	28849.1	29.62
3	3	1564	38	101.7	2.42	0.78	0.32	13775.25	33404.2	26.13

Where, B.P. = Brake Power
F.C. = Fuel Consumption
S.F.C. = Specific Fuel Consumption
B.S.F.C. = Brake Specific Fuel Consumption
H.F. = Heat Supplied by Fuel
B.T.E. = Brake Thermal Efficiency

Characteristic performance curves:

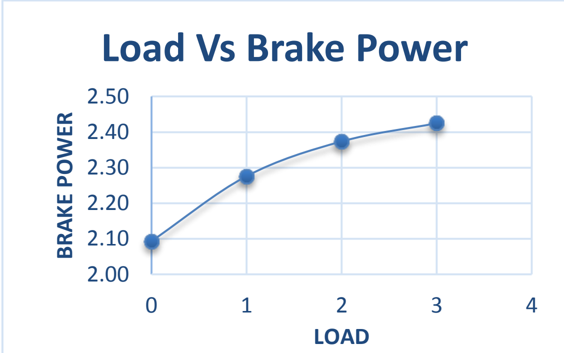

Figure 4.3.1: Load Vs Brake Power

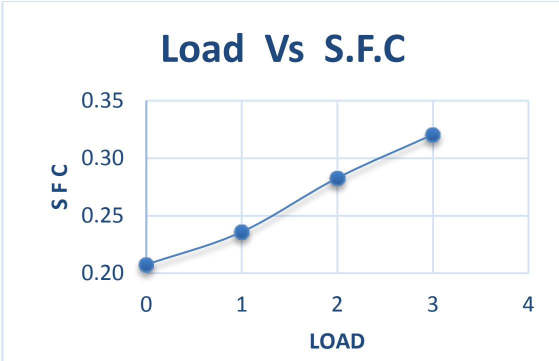

Figure 4.3.2: Load Vs Specific Fuel Consumption

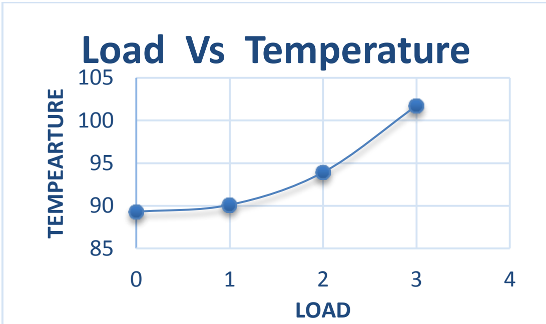

Figure 4.3.3: Load Vs Temperature

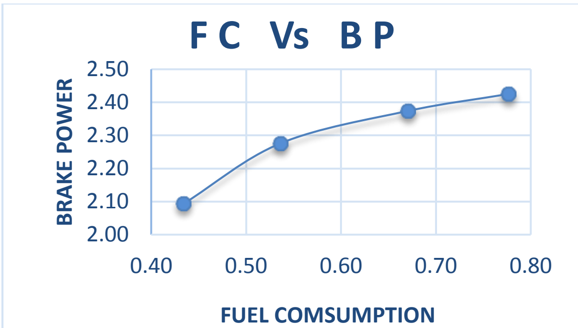

Figure 4.3.4: Fuel Consumption Vs Brake Power

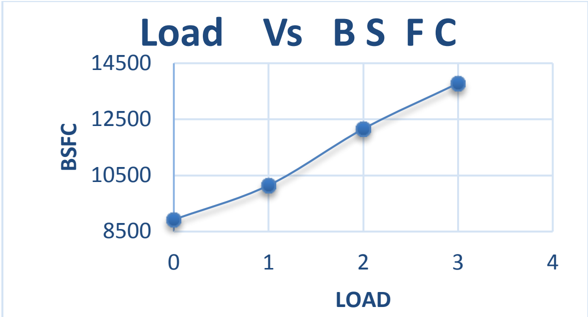

Figure 4.3.5: Load Vs Brake Specific Fuel Consumption

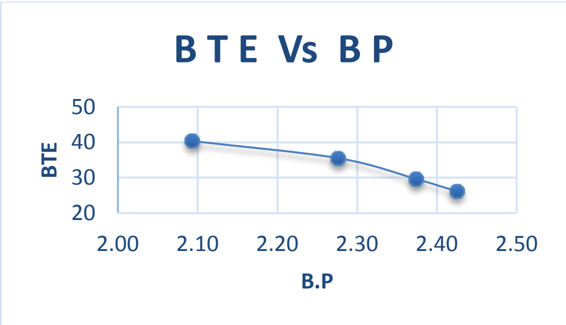

Figure 4.3.6: Brake Thermal Efficiency Vs Brake Power

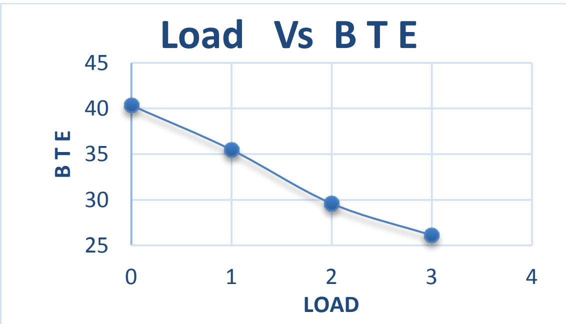

Figure 4.3.7: Load Vs Brake Thermal Efficiency

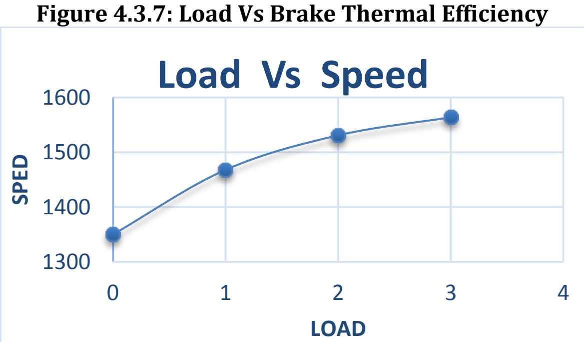

Figure 4.3.8: Load Vs Speed

C. Result and Discussion:

Calculation & Data:

Speed of the Engine – N

Weight – W = 3kg = 3*9.81 =29.43 N (1)

Time - T_f (time taken by the engine to consume 20ml of fuel/diesek0

Calorific value – CV = 43000kJ/kg (2)

Radius of the flywheel of the engine – r = 0.56m (meter)

Specific gravity = 0.82

Torque – T = W*r = 29.43*0.56 = 14.8 N-m (3)

1. BRAKE POWER (B.P):

$$\text{B.P.} = \frac{2\pi NT}{60} \quad (4)$$

2. FUEL CONSUMPTION (F.C):

$$\text{F.C.} = \frac{20}{t_f}\ x\ \frac{3600}{1000}\ x\ specific\ gravity \quad (5)$$

3. SPECIFIC FUEL CONSUMPTION (S.F.C):

$$\text{S.F.C.} = \frac{F.C}{B.P} \quad (6)$$

4. BRAKE SPECIFIC FUEL CONSUMPTION (B.S.F.C):

$$\text{B.S.F.C.} = S.F.C.\ x\ Calorific\ Value\ (C.V) \quad (7)$$

5. HEAT SUPPLIED BY THE FUEL (H.F):

$$H.F. = F.C.\ x\ Calorific\ Value\ (C.V) \quad (8)$$

6. BRAKE TERMAL EFFIECIENCY (B.T.E):

$$B.T.E. = \frac{B.P.in\ kW}{H,F}\ x\ 100 \quad (9)$$

D. Emission performance

1. Without EGR Valve

The variation of Carbon Monoxide (CO), Carbon Dioxide (CO_2), Oxides of Nitrogen (NO_X), Hydro Carbon (HC) of the engine without EGR valve at various brake power is as shown in the table and also drawn in the graph. When the brake power increases of the engine increases, exhaust gas of the engine also increases. The brake power of the engine varies with the Exhaust gas temperature is as shown in the table.

The variation of the fuel consumption of the engine without EGR valve at various Brake power, when the brake power of the engine increases, the fuel consumption of the engine also increases. The brake power of the engine varies with the fuel consumption as shown in the table and the graph shows the variation as shown.

Table 7: Emissions (without EGR valve)

S. No.	Speed	Time of fuel consumption	*Temperature* ^oC	Brake Power in kW	Percentage (%) of Emissions			
					CO	CO_2	NO_X	HC
1	1472	61	82	2.28	0.05	1.0	759	18.5
2	1492	53	88	2.31	0.03	2.0	765	18.3
3	1638	45	90	2.54	0.05	1.4	782	17.3
4	1648	38	96	2.56	0.06	1.8	793	16.4

CO – Carbon Monoxide

CO_2 – Carbon Dioxide

NO_X – Oxides of Nitrogen

HC – Hydro Carbon

Characteristic performance curves of emissions

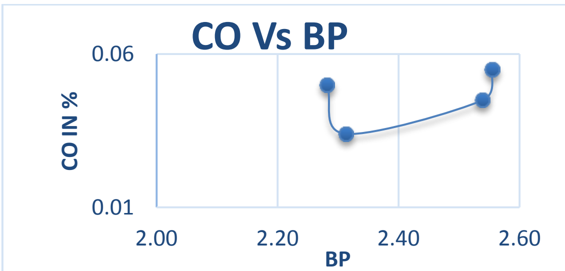

Figure 4.3.9: CO Vs Brake Power

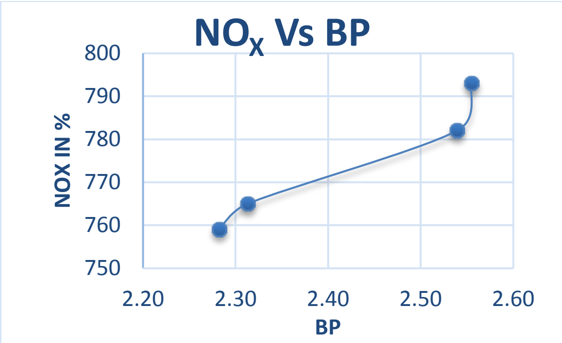

Figure 4.3.10; NO_X Vs Brake Power

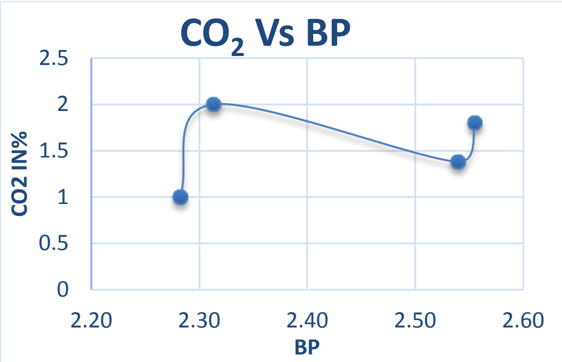

Figure 4.3.11: CO_2 Vs Brake Power

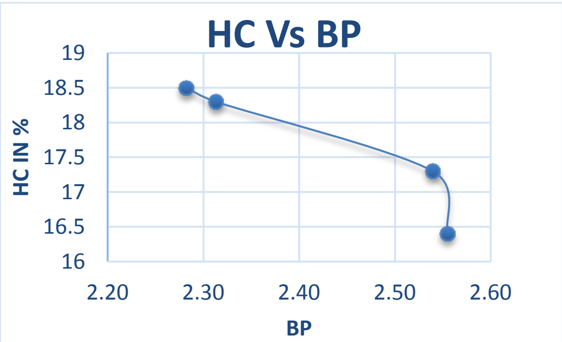

Figure 4.3.12: HC Vs Brake Power

2. With EGR Valve

The variation of Carbon Monoxide (CO), Carbon Dioxide (CO_2), Oxides of Nitrogen (NO_X), Hydro Carbon (HC) of the engine without EGR valve at various brake power is as shown in the table and also drawn in the graph. When the brake power increases of the engine increases, exhaust gas of the engine also increases. The Brake power of the engine varies with the Exhaust gas temperature is as shown in the table.

The variation of the fuel consumption of the engine without EGR valve at various Brake power, when the brake power of the engine increases, the fuel consumption of the engine also increases. The brake power of the engine varies with the fuel consumption as shown in the table and the graph shows the variation as shown.

Table 8: Emissions (with EGR valve)

S. No	Speed	Time Of Fuel Consumption	*Temperature* ^0C	Brake Power in kW	Percentage (%) of Emissions			
					CO	CO_2	NO_X	HC
1	1350	68	89.3	2.09	0.028	0.86	728	19.6
2	1468	55	90.1	2.28	0.032	1.86	751	17.8
3	1531	44	93.9	2.37	0.028	0.69	768	17.2
4	1564	38	101.7	2.42	0.04	1.8	785	16.1

Characteristic performance curves of emissions:

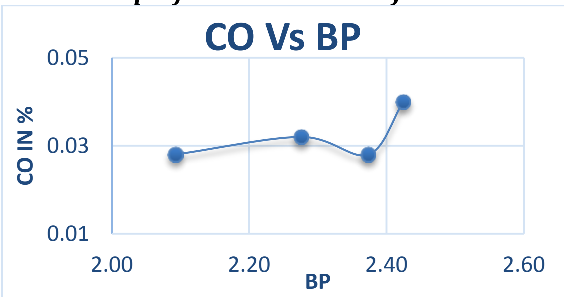

Figure 4.3.13: CO Vs Brake Power

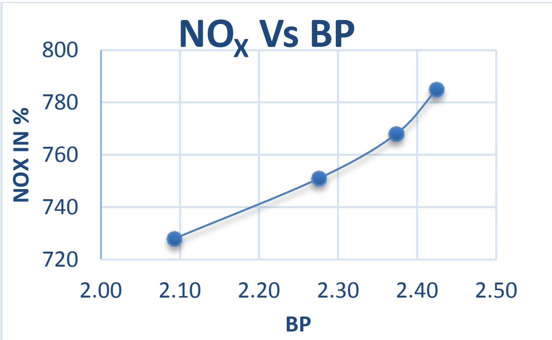

Figure 4.3.14: NO_X Vs Brake Power

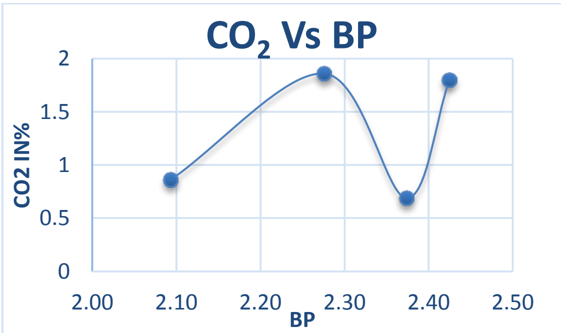

Figure 4.3.15: CO_2 Vs Brake Power

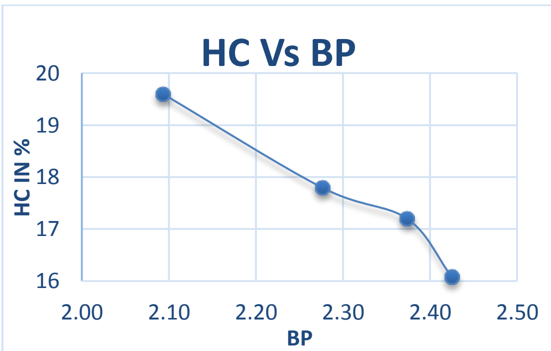

Figure 4.3.16: HC Vs Brake Power

V. Comparison graph (with and without EGR valve)

Figure below shows the comparison graph of with and without EGR valve of variation in Various parameters such as load, speed, brake power, specific fuel consumption, brake specific fuel consumption, heat supplied by the fuel, brake thermal efficiency and emissions discussed such as CO, CO_2, NO_X and HC.

Characteristic performance curves of comparison:

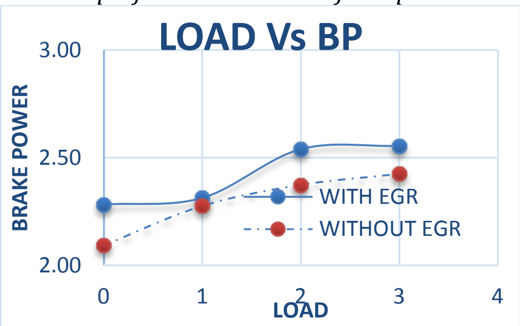

Figure 5.1.1: Load Vs Brake Power

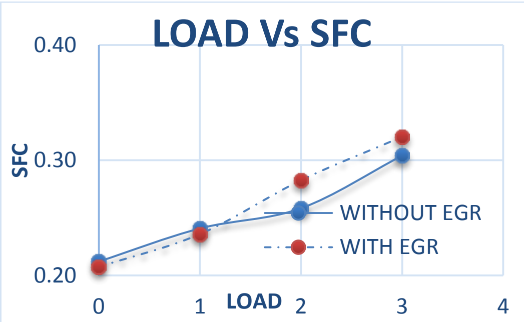

Figure 5.1.2: Load Vs Specific Fuel Consumption

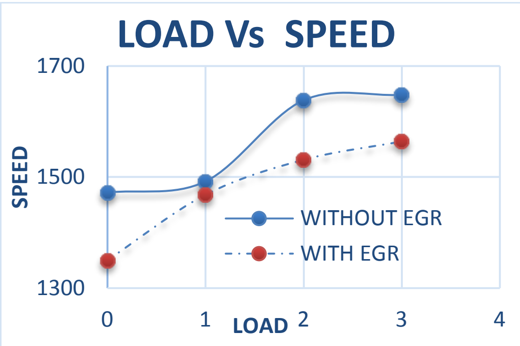

Figure 5.1.3: Load Vs Speed

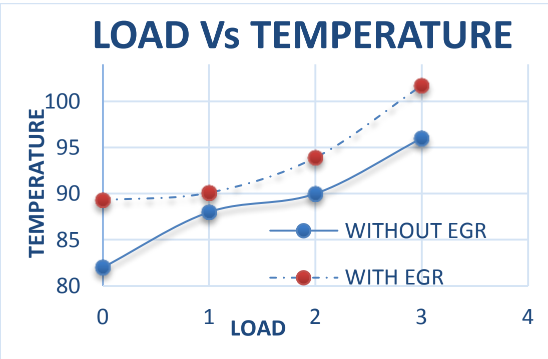

Figure 5.1.4: Load Vs Temperature

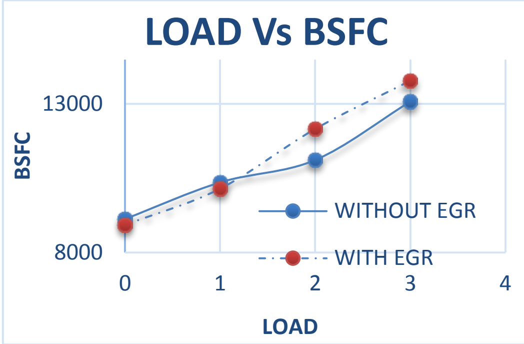

Figure.5.1.5: Load Vs Brake Specific Fuel Consumption

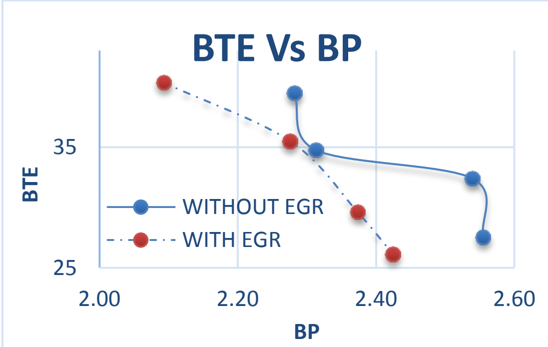

Figure.5.1.6: Brake Thermal Efficiency Vs Brake Power

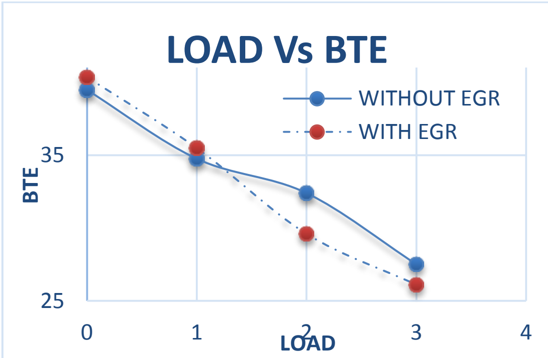

Figure 5.1.7: Load Vs Brake Thermal Efficiency

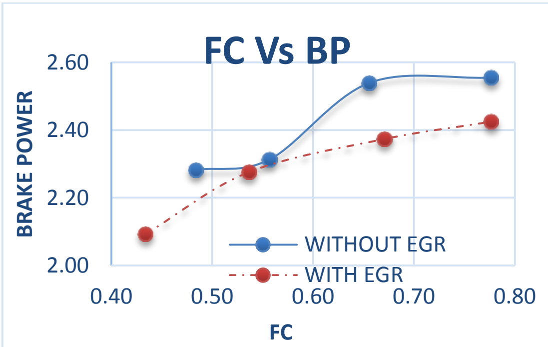

Figure 5.1.8: Fuel Consumption Vs Brake Power

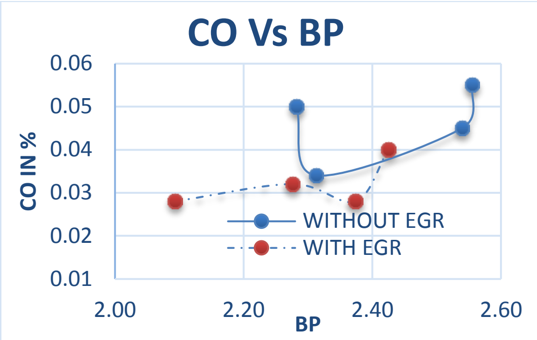

Figure 5.1.9: CO Vs Brake Power

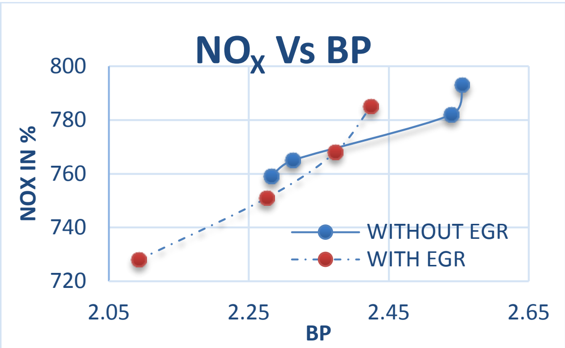

Figure 5.1.10: NO_X Vs Brake Power

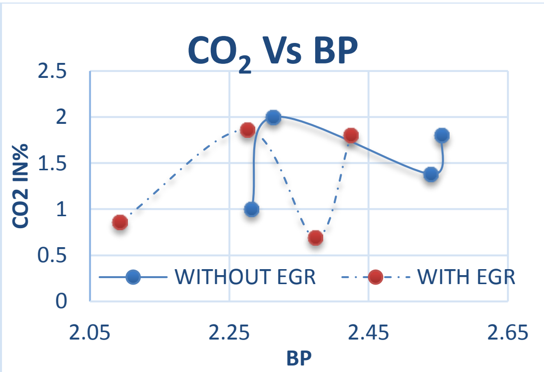

Figure 5.1.11: CO_2 Vs Brake Power

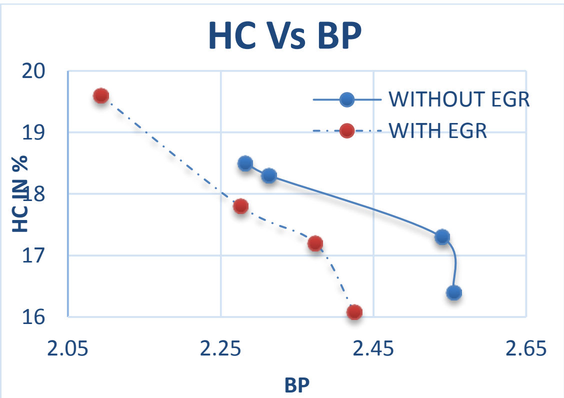

Figure 5.1.12: HC Vs Brake Power

CONCLUSION

Te main objective of the present investigation was to evaluate suitability of EGR use in diesel engines and to examine the performance and emissions of the engine. This Experimental study shows the following results:

- The engine performance with EGR valve, Exhaust gas temperature reduces as compared to that of without EGR valve, so it is a great advantage for the surrounding.
- The comparison graphs shows with and without EGR valve performance with respect to Brake power and from the figure it is very clear that the value of the fuel consumption of the diesel engine with EGR increases than that of without EGR system.
- The Brake Thermal Efficiency of the engine was partially lower and the Brake specific fuel consumption of the engine was partially higher when EGR valve implemented in the engine.
- An emission of Nitrogen Oxides (NO_X) was very much reduced by implementation of EGR valve.
- Emission of Carbon Dioxides (CO_2) and Carbon Monoxides (CO) are also reduced.
- Emissions of Hydro Carbons are also reduced by implementing EGR valve in the Engine to that of operating without EGR valve.

VII. FUTURE SCOPE

- Exhaust Gas Recirculation system advantageous for environment
- Further work in same project can be done for measurement of inlet air flow and exhaust air flow and percentage flow of EGR can be calculated and optimum value of EGR rate can be used for practical use.
- Biodiesel contain more sulphur and lead, while using biodiesel in engine it produces more emission in surrounding due to sulphur and lead. As EGR valve reduces the emission rate, Biodiesel can be used as fuel in engines.

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