ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Emission Characteristics for Single Cylinder DI Diesel Engine with EGR (Exhaust Gas Recirculation) System

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Abstracts

This paper includes experimental investigations of various exhaust gas recirculation rates on engine emission characteristics like NOx, HC, CO, CO2, exhaust gas temperature by AVL gas meter. By passing exhaust gas from venturi meter and regulating it with EGR valve so as to find out its effect on critical NOx emission and other harmful HC,CO & NOx emission parameter. So to reduce such harmful gases exhaust gas recirculation is economical and effective method to control emission. We cant reduced it 100% but up to little bit extent we can reduce it from CI as well as in SI type of CI engine. Some external coupling technology like EGR of cold type installed with turbo intercooler, hydrogen, oxygen enriched air to displace fresh intake air volume and so reduced amount of oxygen in combustion chamber to control peak temperature of cylinder. in this paper we have also look toward some coal trapping method installed with dampener cause to break bond between NO at high temperature.

Keywords:EGR, Diesel Engine, NOx, Cold EGR, emission, AVL.

Introduction

As day by day emission causes air pollution and cause to result in global warming, emission regulation is to become strict. it is very necessary to reduce NOx from CI as well as gasoline engine and PM;CI engine. Exhaust gas emission from internal engines have significant effect on human health, animal, Plant and environmental health and welfare. This lead us to use different advance technological method to control exhaust emission from internal combustion engine. If we are going to adopts this method to control emission it would allow to reduce engine performance it have some adverse effect on engine performance.EGR technique is well proven technique to decrease NOx. Pratik Sapre et al have conducted an experiment to find out the effect of EGR on combustion phenomenon of CI engine. He observed that reducing EGR temperature by 120˚C resulted in decrease of exhaust gas temperature by 21˚C.Using cold EGR at 1500 rpm[11].The main aim of the present study is to analysis and pollutant emission is studied using different percentage of EGR. It was found by analysis that adding EGR to air flow rate is more beneficial way of utilizing EGR rather than displacing some of inlet air.

"In diesel engine NOx formation is temperature dependant phenomenon and it is possible to reduce NOx when cylinder is at its peak level. if it would crosses 2000k then % of NOx is increase. so to control this it is mandatory to have temperature control on cylinder head and this could be possible with EGR technique"

Literature Review

In IC Engine exhaust gas recirculation (EGR) is a technique which reduces the harmful emission such as NOx in gasoline well as in CI/Diesel engine. EGR is simple technique to supply already exhausted gas again back to combustion chamber by some cooling and filtered media so as to increase or to maintain temperature of cylinder head.
" Avinash wankhade et al,Pratik Sapre et al carry out this experiment on laboratory engine say single cylinder four stroke CI water cooled DI diesel direct injection engine to check out effect of exhaust gas recirculation on emission as well as performance parameter with cold and hot EGR mode and got 65% and 61% reduction on NOx respectively"[11].

N.k. Miller jothi et al., [1] studied the effect of Exhaust Gas Recirculation (EGR) on homogeneous charge ignition engine. A stationary four stroke, single cylinder, direct injection (DI) diesel engine capable of developing 3.7 kW at 1500 rpm was modified to operate in Homogeneous Charge Compression Ignition (HCCI) mode. In the present work the diesel engine was operated on 100% Liquefied Petroleum Gas (LPG). The LPG has a low cetane number (< 3), therefore Diethyl ether (DEE) was added to the LPG

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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for ignition purpose. DEE is an excellent ignition enhancer (cetane number >125) and has a low auto ignition temperature (160 ◦C). Experimental results 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 maximum load.

Table 1.1 Technical Specifications of the Engine

Parameter	Specification
Bore × stroke	80mm × 110mm
Displacement volume	553cm^3
Compression Ratio	16.5:1
Type of cooling	Water cooled
Rated Power	3.7kW@1500rpm

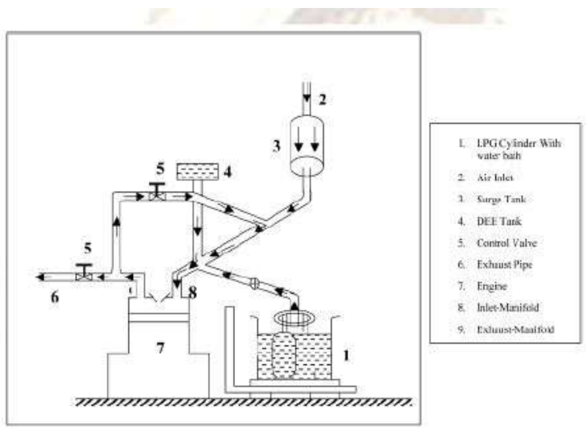

Fig.1.1 Schematic View of the EGR Setup.

Deepak Agarwal et al., [2] investigate the effect of EGR on soot deposits, and wear of vital engine parts, especially piston rings, apart from performance and emissions in a two cylinder, air cooled, constant speed direct injection diesel engine, which is typically used in agricultural farm machinery and decentralized captive power generation. 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 capacity of the exhaust gas etc. were measured. Performance parameters such as thermal efficiency, brake specific fuel consumption (BSFC) were calculated. Reductions in NOX 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 96 hr in normal running conditions and the deposits on vital engine parts were assessed. The engine was again operated for 96 h with EGR and similar observations were recorded.

Table 1.2 Technical Specifications of the Engine

Engine Type	Two cylinder, direct injection
Bore/stroke	87.3/110mm
Rated power	9 kW
Rated speed	1500 rpm
C.R.	16.5:1
Total displacement volume	13181
Fuel injection release pr.	210 bar
Inlet valve open/inlet valve close.	45˚ BTDC/35.5˚C ATDC
Exhaust valve opens/exhaust valve closes	35.5˚ BBTDC/45˚ ATDC

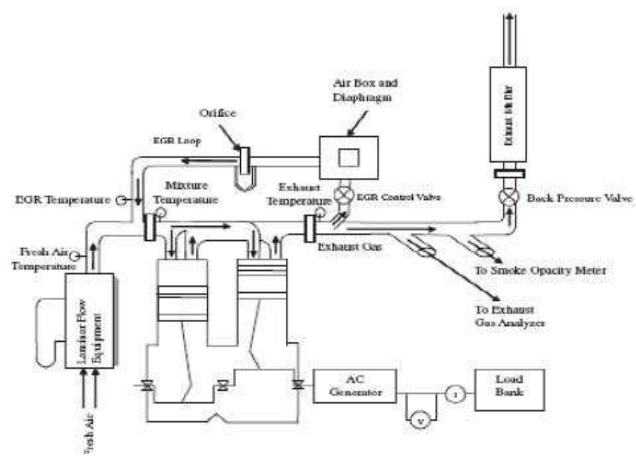

Fig.1.2 Schematic Diagram of Engine Setup using EGR.

N. Saravanan et al., [4] used hydrogen-enriched air as intake charge in a diesel engine adopting exhaust gas recirculation (EGR) technique with hydrogen flow rate at 20 l/min. Experiments are conducted in a single cylinder, four stroke, water-cooled, direct-injection diesel engine coupled to an electrical generator. Performance parameters such as specific energy consumption, brake thermal efficiency are determined and emissions such as oxides of nitrogen, hydrocarbon, carbon monoxide, particulate matter, smoke and exhaust gas temperature are measured. Usage of hydrogen in dual fuel mode with EGR

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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technique results in lowered smoke level, particulate and NOX emissions.

Table.1.3 Schematic of the Experimental Test Rig

parameters	specification
bore	80 mm
stroke	110 mm
Swept volume	553 cm^3
Clearance volume	36.87 cm_3
C.R.	16.5:1
Rated output	3.7kW @ 1500 rpm
Rated speed	1500 rpm
Injection pressure	240 bar

H.E.Saleh [3] studied Jojoba methyl ester (JME) has been used as a renewable fuel in numerous studies evaluating its potential use in diesel engines. These studies showed that this fuel is good gas oil substitute but an increase in the nitrogenous oxides emissions was observed at all operating conditions. The aim of this study mainly was to quantify the efficiency of exhaust gas recirculation (EGR) when using JME fuel in a fully instrumented, two-cylinder, naturally aspirated, four-stroke direct injection diesel engine. The tests were carried out in three sections.

Firstly, the measured performance and exhaust emissions of the diesel engine operating with diesel fuel and JME at various speeds under full load are determined and compared.

Secondly, tests were performed at constant speed with two loads to investigate the EGR effect on engine performance and exhaust emissions including nitrogenous oxides (NOX), carbon monoxide (CO), unburned hydrocarbons (HC) and exhaust gas temperatures. Thirdly, the effect of cooled EGR with high ratio at full load on engine performance and emissions was examined. With the application of the EGR method, the CO and HC concentration in the engine out emissions increased. For all operating conditions, a better trade-off between HC, CO and NOX emissions can be attained within a limited EGR rate of 5–15% with very little economy penalty.

Table 1.4 Engine Specifications

Engine Type	Single cylinder, Naturally aspirated air cooled
Displacement	436.00 CC
Maximum power	5.53 kW
Maximum speed	3600 rpm
Fuel type	Diesel

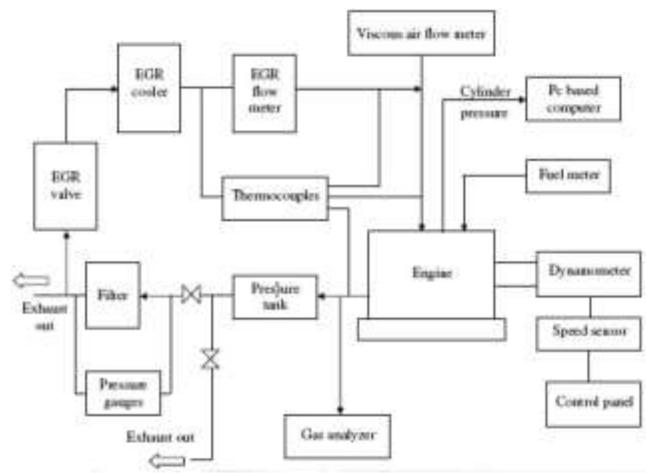

Fig.1.3 Schematic of the Experimental Test Rig

Experimental setup & methodology

A single cylinder,naturally aspirated four strokes,vertical air cooled engineis taken.Various parameters are measure by electric alternator type dynamometer used to measure brake power,techometer to find rpm of engine,thermocouple to measure temperature,AVL five gas analyser to measure varoius emissions like NOx,CO,HC etc.

Specification of the diesel engine

Diesel engine used for this test is naturally aspirated water cooled single cylinder four stroke CI engine.

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Engine Specification:-

4 Stroke single Cylinder air cooled self start CI engine.	Make:-Kirloskar
Rated Power:-7.5kw (10 HP)	Bore Dia.:-80mm
Stoke Length:-110mm	Connecting Rod Length:-234mm
Swept Volume:-562cc	Compression Ratio:-17.5:1
Rated Speed:-rpm	Rated Torque:-4.6kg-m
Arm Length:-150mm	

EGR Technique

It is a well known to reduce NOx emission in which a part of exhaust gas is recirculation. It acts as diluents to the combustion mixture. Introduction of EGR is to reduce oxygen concentration. Increase specific heat of incoming charge which ultimately reduce peak combustion temperature. Resupply of unburnt hydrocarbon (opportunity to reburn).

EGR ratio is calculated as;

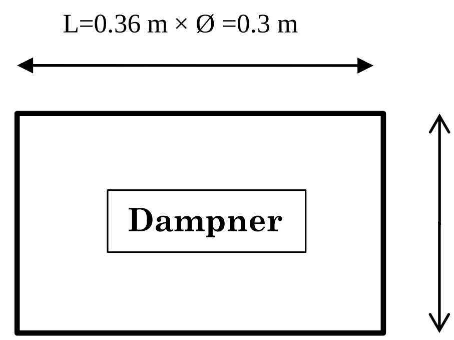
$$EGR\ \% = Megr/Mi*100$$

The objective of developing this experiment test set up is to investigate and demonstrate the effect of various EGR rates on engine performance and emission. one of most important object for internal combustion engine designers is to reduce NOx emissions ,while substantially maintaining fuel economy and durability. In many systems, for example, EGR is cooled may experienced relatively high NOx emission during heavy engine throttles or load. On low the other hand at low engine loads, systems in which EGR is cooled experienced fuel droplets vaporization which is not enhanced. Large fuel droplets affect emission by producing soot.[7]

Results and discussion

Without EGR System

The experiment was carried out on a single cylinder, air cooled, four stroke diesel engine. Engine was first started in idle condition for 10 minutes. After that we set the speed of engine as 1500 rpm.(DA system used).On running on same speed without applying load first of all measure all emission parameters by using AVL analyzer likewise then by allow to run engine of 5 N-m,10 N-m,15 N-m,20 N-m,25 N-m,30 N-m,35 N-m,40 N-m,45 N-m. Comparing parameters with different torque condition so as to check on which mode emission is more.[11] .



2D layout of the dampener with Coal trap technique system.

Fig: 1.4 Layout of Exhaust Gas Recirculation is given at last of same paper.

Fig.1.5 Schematic of the dampener with Coal trap technique system

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Fig.1.6 AVL 5 Gas Analyzer

Table .1.7 Emissions (without EGR system)

Sr. No.	Torque (N-m)	CO Corr(% vol)	HC Corr (ppm)	NOx (ppm)	CO_2 (ppm)	λ Lambda	AFR
1	0	0.43	198	300	272	5.383	77.9
2	5	0.46	201	311	288	4.837	71.2
3	10	0.44	209	350	305	4.492	67.5
4	15	0.45	225	402	326	4.25	62
5	20	0.42	195	455	350	3.97	58.1
6	25	0.36	177	520	371	3.71	54.7
7	30	0.37	175	575	393	3.51	51.9
8	35	0.31	155	640	422	3.28	48.3
9	40	0.30	175	735	443	3.134	46.3
10	45	0.31	206	801	464	3.072	45.12

The variation of NOx as shown in fig 1.8. as engine torque increases from 5 N-m to 40 N-m, NOx curve vary from 275 ppm to 800 ppm. As engine torque increase emission of NOx also increases. The main reason behind it, as the Torque increases the temperature in the combustion chamber will also increases, which is directly proportional to the emission of NOx.

Fig 1.10 gives relationship between CO corr.% by volume (ppm) and Torque (N-m), it shows at the beginning at initial value of torque it is having more percentage of CO emissions and as torque increases amount of CO percentage is decreasing significantly. In fig 1.10 CO is reduced due to significant reduction in Air Fuel rate as engine torque increases reference taken from [9] i:e (influence of Torque on AFR).CO concentration is more in combustion chamber equilibrium to adiabatic reaction of Air fuel mixtures.

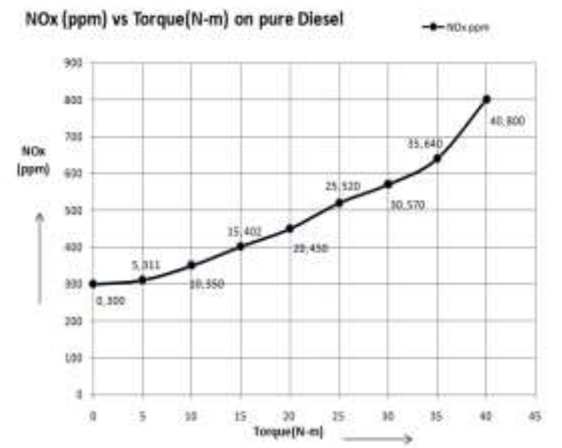

Fig 1.8 NOx (ppm) Vs. Torque (N-m)

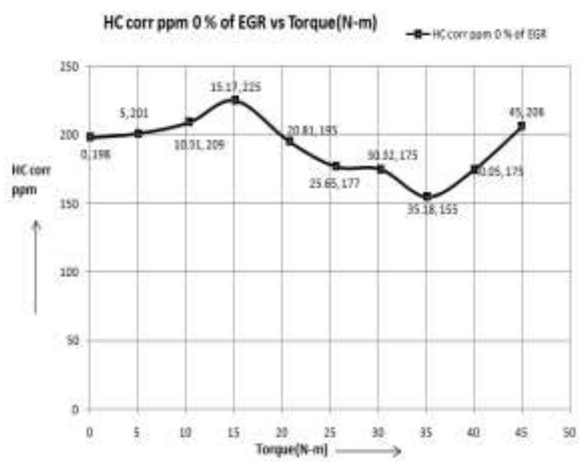

Fig 1.9. HC corr (ppm) Vs Torque (N-m)

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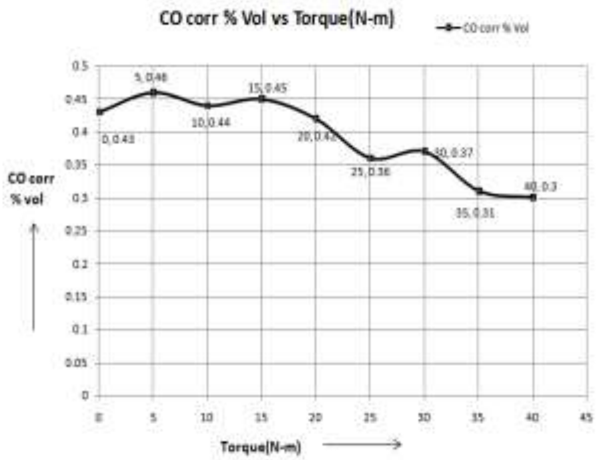

Fig 1.10. CO corr (% vol) Vs Torque (N-m)

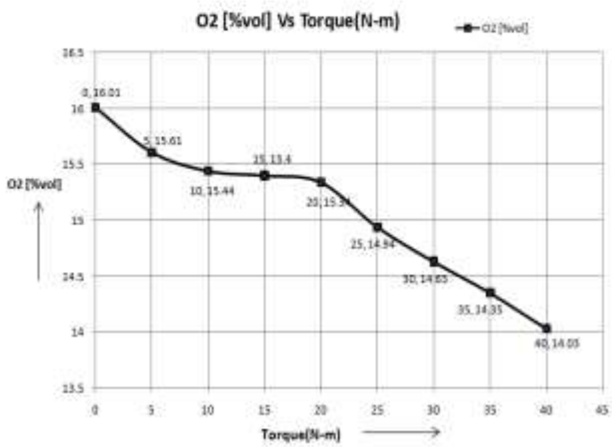

Fig 1.11. O_2 (% vol) Vs Torque (N-m)

Fig 1.9 graph gives variation of HC corr. (ppm) Vs. Torque (N-m). It is cleared that initial value of HC is directly proportional to engine torque and achieving maximum HC concentration i.e. 206 (ppm) and then changing its nature at high load and remains constant after 15 N-m. As at the initial condition amount of HC in exhaust gas is typically increasing due to somewhat incomplete combustion but once engine get loading above 15 N-m complete combustion takes place as a result of which HC concentration get stabilized.

With 20% of EGR System

Table .1.12 Emissions (with 20% of EGR system)

Sr. No.	Torque (N-m)	CO_{corr} (% vol)	HC_{corr} (ppm)	NOx (ppm)	CO_2 (ppm)	λ (Lambda)	AFR
1	0	0.43	210	125	323	4.11	60.1
2	5	0.46	275	145	335	3.9	59.5
3	10.31	0.44	317	156	364	3.804	56.2
4	15.17	0.41	313	165	372	3.6	53.1
5	20.81	0.35	313	226	413	3.364	59.5
6	25.65	0.31	310	250	433	3.2	47.1
7	30.32	0.35	308	262	470	2.99	44.1
8	35.18	0.33	295	278	360	3.695	43.9
9	40.05	0.31	294	282	384	3.31	41
10	45	0.29	289	290	394	3.699	45.4

Above table containing values of emission parameter taken from AVL five gas analyzer when engine running at various engine torque at 1500 rpm speed. After study Pratik Sapre et al found that after caring bunch of investigation for different EGR rates emission characteristics varies according to amount of exhaust gas supply via venturi meter and got minimum emission at 20 % of EGR supplement [11], so we will discussing for 0% EGR and 20 % EGR only so that we can find actual relationship between NOx emission at different engine loading condition.

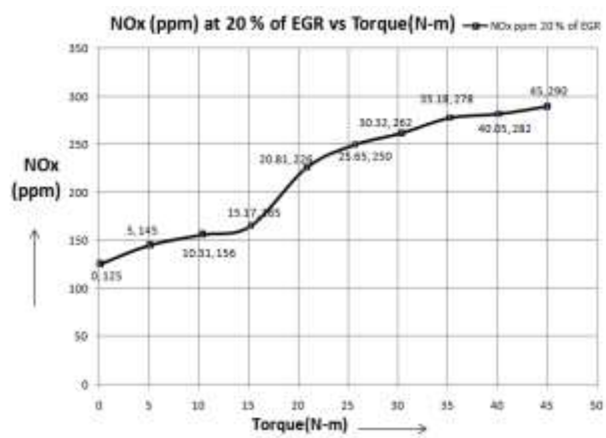

Fig 1.13. NOx (ppm) Vs.Torque (N-m) 20 % of EGR

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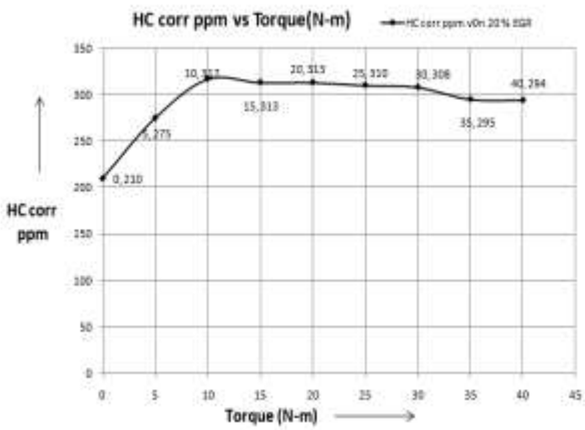

Fig 1.14. HC corr (ppm) Vs. Torque (N-m) at 20 % of EGR

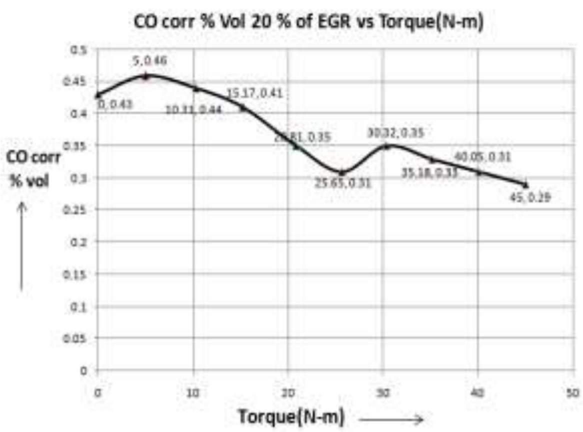

Fig 1.15. CO corr (% vol) Vs. Torque (N-m) at 20 % of EGR

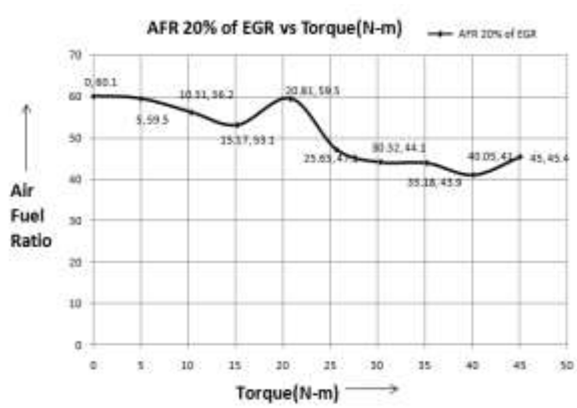

Fig 1.16. Air Fuel Ratio Vs. Torque (N-m) at 20 % of EGR

Fig 1.13 shows variation between NOx (ppm) and Torque (N-m). The nature of graph is increasing as load increases .The amount of NOx with 20% of exhaust gases is found to be 290 (ppm) at 45 (N-m). In case of without EGR it was found to be 800 (ppm).Thus resultant decrement in NOx emission is 510 (ppm) as compare to without EGR cases.Thus strignent loss in NOx emission as it having lower amount of oxygen taking part in combustion so as to reduced peak temperature but it falls adverse effect on significant decrement in volumetric & brake thermal efficiency of engine.

Fig 1.15shows variation between CO corr (% volume) and Torque (N-m). At the initial stage it increases up to 0.43% volume but after 10 (N-m) the graph goes down up to 0.29 % volume. At 45 (N-m) load amount of CO corr is 0.29 % by volume with 20% of exhaust gases, but in case of without EGR it was found to be 0.31 % by volume, thus 0.02 % volume is resultant decrement in CO corr % volume.

As air fuel mixture is taking low part in chemical reaction so CO formation in EGR mode decrement in nature as shown in fig 1.16.Graph shows variation between Air Fuel Ratio and Torque. It can be noted that conventional diesel operation exhibits lower Air Fuel ratio. This is because diesel combustion process involves utilization of large amount of excess air due to heterogeneous mixture. That is leaner mixture at high load condition. The effect becomes more visible on above graph as the EGR percentage increase at high load. As a result Air Fuel Ratio higher than that associated with diesel and effects are more apparent with high EGR percentage. If Air fuel ratio decreases Brake Specific Fuel Consumption also decreases.[6].

Comparison graph

(Without & With EGR system)

Fig 1.17 shows comparison graph of with and without EGR system of variation in Emission of NOx with respect to engine Torque(N-m).From respective figure it is clear that the value of Emission of NOx of diesel engine with EGR system is much less than that of engine running on without EGR system.

Fig 1.18 shows comparison graph of with and without EGR system of variation in emission of HC with respect to engine Torque (N-m).

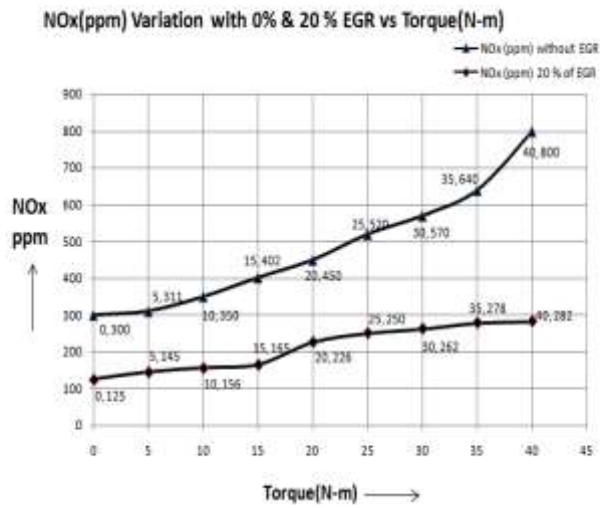

Fig 1.17. NOx Vs. Torque (N-m) variation curve

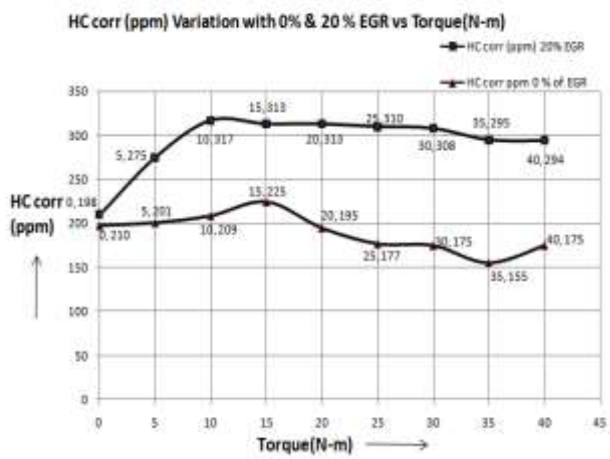

Fig 1.18. HCcorr(ppm) Vs. Torque (N-m) variation curve

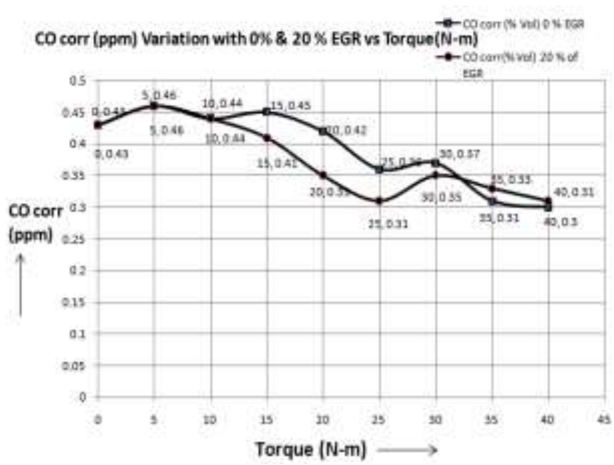

Fig 1.19. CO corr(ppm) Vs. Torque (N-m) variation curve

Fig 1.19 shows comparison graph of with and without EGR system of variation in emission of CO with respect to engine Torque (N-m). In Above graph, NOx as well as CO2 is having directly proportional relationship. Respective value taken from given table 1.12 at 45 N-m torques. Value of NOx at 20 % of EGR is found out to be 290 (ppm) .HC increases from 210 (ppm) to 289 (ppm) on 15 N-m torque also in case of Carbon monoxide it get decreases from 0.43 % vol to 0.29 % vol. The variation in NOx, CO,HC as shown above, this is because of when torque increases more amount of particulate matter, soot particles, CO, NOx, & HC are taking part in chemical reaction under high cylinder temperature(1500 F).
As EGR mode applies there is significant increment in Hydrocarbon (HC)

"Above test conducted on single cylinder four stroke water cooled CI engine, Babasaheb Naik College of Engineering Pusad 445215, SGBA University, Dist. Yavatmal, MH, India"

Conclusion

- The main aim of this experiment was to evaluate suitability of exhaust gas recirculation system for CI engine. And so to evaluate the emission characteristics of engine & NOx is get reduced up to 64.75%.
- The experimental investigation can be treated as positive test from test value taken from table& graph to have significant reduction in NOx values as well we can validate it from graph fig no.1.17 and reference taken from fig 1.16 as air fuel ratio decreases there is un availability of oxygen taking part into chemical reaction in combustion process.
- Emission of Carbon Monoxide was also reduced.
- Emission of HC is increases in EGR mode but it was less in amount in without EGR mode.
- From the experiment it can be suggested that 20% of EGR is optimum for NOx reduction without significant penalty on brake specific fuel consuption and HC emission.

Future scope

- Same test set up with duel fuel run mode i.e. EGR coupled with CNG blend ,Bioseed oil, cotton seed oil,Ambadi oil etc.
- NOx can be also be reduced with help Variable Compression Ratio (VCR).

ISSN: 2277-9655
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- NOx can be reduce by supplying O2,H2 enriched air in suction supply.
- To solve various fluid flow throw venturi, so as to use finite element method(FEM) for so doing finite element analysis such a approach using various fluid flow simulation tools such as GAMBIT, FLUENT, CFD, CFX (Ansys)etc

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