Performance and Emission Analysis of Compression Ignition Engine Using Various Emission Reducing Techniques – A Review

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ABSTRACT- *In day today's relevance, it is mandatory to device the usage of diesel in an economic way. In present scenario, the very low combustion efficiency of CI engine leads to poor performance of engine and produces emission due to incomplete combustion. Study of research papers is focused on the improvement in efficiency of the engine and reduction in emissions by comparing different techniques and using various blends. Engine manufacturers are compelled to incorporate different type of techniques to reduce emissions especially $NO_x$and particulate matters from the engine. This paper mainly deals with the application of Exhaust Gas Recirculation (EGR) technique for reduction of oxides of nitrogen (NO_x) emissions from diesel and petrol engine. High combustion temperature leads to formation of NO_x and this paper indicates that EGR is an attractive method to reduce combustion temperature. EGR temperature plays an important role while admitting higher percentage of EGR in the engine. When the higher ratios of EGR are applied then cooled EGR can be advantageous. Some other emissions like CO & HC are also found to be reduced using different types of blends such as biodiesel and additives which are also known as cetane improvers.*

Key Words: Biodiesel , VCR, EGR, NOx, PM

1 INTRODUCTION

Vehicles and automobiles from last few years causing pollution in a great amount causing alarming effects on environment and health.Due to large number of motor vehicles on roads major types of problems are arising in day to day life. Strict legislations and norms have been developed to curb this problem and different technologies are invented to put limit on the emissions.Emissions from automobile and truck exhausts causingvarious problems related to the health especially for the people living in urban areas. Emissions from automobiles usually consist of carbonmonoxides, oxides from nitrogen and sulfur, unburnthydrocarbons, and particulate matter. With gradual decrease in worldwide reserves of fossil fuels and increase in air pollution, automotive engineers are making ways to make cars more fuel efficient and to reduce their carbon emissions.

Future regulations like BS 5 will compel manufacturers of diesel engine can decrease the amount of NO_x and particulate matter (PM) emissions. We can see major improvements in the future due to after-treatment devices to seek major reductionin both NOx and PM emissions. One of the most surprising places they've found in relation to wasted energy is in the car's exhaust. Technologies have been made to optimize the efficiency of a vehicle's exhaust which is known as exhaust heat recovery and recirculation. The key to exhaust heat recirculation is a device called an exhaust gas recirculation **(**EGR**)** valve. The EGR valve opens when it encounters back pressure from the cars.

The performance of a Diesel engine is influenced by various parameters like CR, F/A ratio, speed etc. The performance of a diesel engine increases with increase in CR. Variable compression (VCR) technologies in IC engines are used to increase fuel efficiency under variable loads.

2 EMISSIONS

2.1 Hydrocarbons

HC emissions result from the presence of unburnt fuel in the engine exhaust which decreases the thermal efficiency. It include a number of toxic substances such as benzene, polycyclic aromatic hydrocarbons (PAHs), 1,3-butadiene and three aldehydes (formaldehyde, acetaldehyde, acrolein) in SI engines. HC emissions in diesel engine are caused due to over mixing and under mixing of fuel and air.

2.2 Carbonmonoxide

Locally there may not be enough O_2 available for complete oxidation and some of the carbon in the fuel ends up as CO. Highest CO emissions occurs during warm up (start up), as rich fuel mixture is provided during start up. As the fuel is leaner in case of CI engine as compared to SI engine, less CO concentration will be produced in CI engine.

2.3 NO_x

NO_x includes nitric oxide (NO) and nitrogen dioxide (NO_2), in SI engines the dominant component of NO_x is NO. NO is only formed at high temperatures (>2000K) and the reaction rate is relatively slow. In SI Engines,Increased spark advance and intake manifold pressure both result in higher cylinder temperatures and thus higher NO concentrations in the exhaust gas. In CI Engines the cylinder gas temperature is governed by the Load and Injection Timing.Why our major concern is over control of NO_x emissions? For that we have to understand about GWP. Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere equivalent to carbon dioxide over a specific time interval, commonly 20, 100 or 500 years. The GWP for nitrous oxide is 298 for 100 yrs. This means that emissions of 1 million metric tonnes of nitrous oxide (N_2O) are equivalent to emissions of 298 million metric tonnes of carbon dioxide. As NO_x emissions are cause of making (N_2O), that's why we have to control these emissions.

2.4 Particulates Matter

According to WHO, particulate matter in India is higher than WHO limits. Significant population of India breathes air with much higher PM that is lesser than 2.5 micrometre (PM2.5) in size than the limit set by the WHO according to the recent study. Particulate matter has been declared as class-1 cancer-causing agent (carcinogen) in 2013 by the International Agency for Research on Cancer (IARC), which is part of the WHO. Besides, it causes other respiratory and heart diseases.DPM contains a large portion of the polynuclear aromatic hydrocarbons (PAH) found in diesel exhaust. Diesel particulates include small nuclei mode particles of diameters below 0.04 μm and their agglomerates of diameters up to 1 μm.

3. EXHAUST GAS RECIRCULATION

It is a technique to control NO_x emission which is applicable to all types of diesel engines from light to heavy duty diesel engine, in which a partof exhaust gas is recirculated. Introduction of EGR leads to reduction in oxygen concentration and increase in specific heat of incoming charge, which ultimately reduces peak combustion temperature. EGR ratio is calculated as

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

Megr/ Mi = Mass of recirculated gas/ Mass of total intake air of cylinder

4 BIODIESEL

Biodiesel is one the categoryof alternative fuels. Biodiesel can be derived from vegetable or soybean oil, various types of plants such as jatropha and animal fats used for frying or cooking.Transesterification of vegetable oil helps to make biodiesel.

Biodiesel is an advantageous fuel because it providesengine lubricity, cleaner emissions, renewable sources and nontoxic properties. Unburnt hydrocarbons drop up to 67 percent; carbon monoxide is down to 48 percent; and sulfates declines to 100 percent with pure biodiesel. 75% reduction can be found in Carcinogenic byproducts. There is an only increase in NO_x, which is a component of smog. The oils within biodiesel can prevent wear in pumps and other moving parts. Biodiesel fuel is biodegradable, nontoxic, and has a higher flashpoint than diesel. Biodiesel fuel of 100 percent is also known as B100 or neat biodiesel, which can be used to start a vehicle. Some petroleum producers are mixing 2 percent (B2), 5 percent (B5), or 20 percent (B20) biodiesel into their diesel.

5LITERATURE

Rishant Sharma et al [1]studied the application of Exhaust Gas Recirculation (EGR) for reduced oxides of nitrogen (NO_x) emissions from gasoline engine.

The experimentation was performedon Legion brotherssingle cylinder enginein various steps by varying various parameters and its speed was set at 1500 rpm.Loads on the engine were varied from 2.0 to 8.0 kg in steps of two. Two compression ratios CR7 and CR8 were used to conduct the experiment. Data was collected with and without EGR so as to see how EGR affects the engine performance and its emissions.Emission analyzer was used to find out the NO_x, HC emissions with and without the use of EGR.

The experiments were conducted under the standard conditions. So, the EGR was found to decrease the value of NO_x and HC Emissions by an appreciable amount. EGR was found to be more effective at higher values of compression ratios. EGR was also found to be effective in reducing knock as it reduces the Heat Release Rate as well as Cylinder Pressure.

Pratik G. Sapreet al [2]evaluates the suitability of exhaust gas recirculation system for CI engine to get the results of various emissions such as NO_x,HC,CO etc.

A single cylinder, naturally aspirated 4-strokes,vertical air cooled Kirloskarengine was used. Compression ratio was set at 17.5:1. AVL five gas analyzer was used to measure various emission like NOx,CO,HC etc. Speed of engine was set at 1500 rpm. Running on same speed without applying load first of all they measured all emission parameters by using AVL analyzer likewise then by allow to run engine of 5, 10, 15, 20, 25, 30, 35, 40, and 45 N-m.Then Compares parameters with different torque condition so as to check on which mode emission is more.

So, they evaluate the emission characteristics ofEngine with and without EGR mode, and found that NO_x got reduced up to 64.75%.Emission of Carbon Monoxide was alsoreduced from 0.43 % volume to 0.29 % volume.Emission of HC is increased in EGR modebut it was less in amount in without EGRmode.By performing experiment it was found that 20% of EGR was optimum for reduction in NOxwithout any penalty on BSFC and HC emission.

Simeon Iliev et al [3]performed the 1D CFD modeling of 4-stroke DI diesel engine which was developed by AVLBoost software. The running simulation results in all data including engine performance with the constant speed (rpm) of the engine by varying the CR.

The setup was run at a speed of 2000 rpm. Effectsof EGR on performance, combustion and emissions of a VCR Diesel Engine were studied. The test was done atdifferent CR (15, 16, 17,18 and 19) with different loads (full load, half load, one-fourth load) and for different EGR rates (5% & 10%).

They concluded that, with increasein CR the specific fuel consumption (SFC) decreases. NOxemissions were gradually reduced at different CR'swith increase in % EGR due to reduction in flame temperatures and less oxygen amount in thecombustion chamber. At CR 19 and 10% EGR the reduction of NO_x was 36%, so it meant that high degree of recirculation is suitable for high CR.

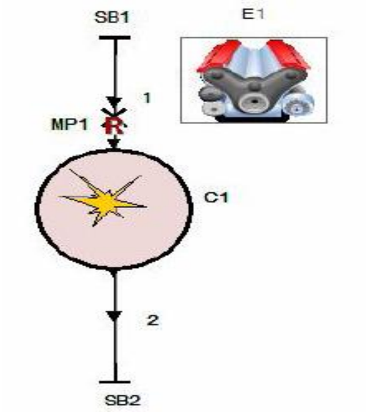

FIGURE 4

Figure 4 shows the working of AVL boost software. AVL Boost Software consists of aprogram, which is used for initial data entry and technical characteristics of the engine for model designing.Engine assembly is formed with help of Annexes systems. After that,various mathematical equations and algorithms of the model with the graphical user interface (GUI)analyzed the processes required during simulation. Cylinder (C1) of model in AVL Boost is connected with element Engine (E1), and it defines the type of engine used, different speeds on it, moments of inertia and BMEP.

M. Ghazikhani, M. R. Kalatehet al [4] studied the effects of EGR on CO and HC emissions of a dual fuel HCCI-DI engine.
Tests were conducted on a single-cylinder VCR diesel engine with CR of 17.5. Carburetor provides the premixed gasoline which was connected to intake manifold and diesel fuel was injected into the cylinder with help of an injector at pressure of 250 bars. The experiment was performed on different EGR % (5, 10, 15) and different speeds (1300,1400,1500,1600)rpm. Accordingly, emissions were analyzed by them.

The effects of engine speed variation and EGR rate on CO and HC emissions of gasoline-diesel dual fuel HCCI engine were studied.With increasing EGR, mixing between fuel and O_2 isdecelerated due to decrease of inlet concentration of O_2 which results in the flame region extension. So, due to increase in gas quantity that is absorbing the heat release, results in lowering of flame temperature. Therefore, dilution effect leads to decrease in local temperatures. Also it leads to decrease in partial pressure of oxygen which is cause of NO formation. But dilution also decreases combustiontemperature and leads to incomplete HCCI combustion andtherefore increase in CO emission occurred.High engine speeds in HCCI mode causes more HCemission due toincomplete HCCI combustion.

KavatiVenkateswarluet al [5] studied effects of EGR and cetane improver to reduce the Oxides of nitrogen (NOx) emissions by lowering combustion temperatures.

In this work, authors worked out experiments on a single cylinder 4-stroke DI and air cooled diesel engine with EGR. Di-Tertiary Butyl Peroxide (DTBP) used as a cetane improver which work as an additive to diesel-biodiesel blends.Biodiesel was derived from fish oil and it wasadded to diesel fuel in proportions as B20, B30 and B40 (B20 implies biodiesel 20% by volume) and cetane improver DTBP (chemical formula $C_8H_{18}0_2$) was added as 0.5% to diesel-biodiesel blends. The effects of EGR and DTBP on BTE, BSFC, cylinder pressure and exhaust emissions were studied.EGR rates were varied as 0%, 10% and 20% at each load. The experiment was carried out with the diesel (pure) at different loads from no-load to full load taking different EGR rates at constant speed of 1500 rpm.

Maximum BTE and minimum BSFC was found at EGR percent of around 15%. The combined effect of EGR and additive reduces the NOx emissions by 25%, but there was an increase in Carbonmonoxide (CO), Hydrocarbon (HC) and smoke opacity.

Miqdam T Chaichan, Khalil I Abaas[6] studied the effects of EGR and Injection Timing Variation on Engine Run in HCCI Mode. Performance of the engine and various emissions were analyzed.

Direct injection multi-cylinder water cooled diesel FIAT engine used in the study. The tests procedure consisted of the addition of EGR starting from 0% till burning misfire occurred. EGR system type Prodit used in this study. The engine speed fixed at 1500 rpm using neat diesel fuel with engine standard injection timing 21°BTDC. Two cases were examined- first case, the injection of diesel fuel at advanced injection timing 35 degrees before top dead center (°BTDC). At the second case- the diesel fuel injected at retarded injecting timing of 12° BTDC. All these cases compared with operating the diesel engine with neat diesel and no EGR addition. So, two selected injection timings 35°BTDC and 12 °BTDC used; and two EGR rates 20 and 50% used for each IT. The fundamental results were extracted from engine operation at 17:1 compression ratio.

The tests results illustrated that retarding injection timing led to a high increase in bsfc by about 17%. Also, it reduced brake thermal efficiency by about 20.88%. Engine operation with advanced IT 35°BTD with 50% EGR resulted in good performance characteristics compared with diesel engine operated with standard IT, where Lower brake specific fuel consumption is obtained, Higher brake thermal efficiency is achieved, Lower emitted exhaust gas temperatures are obtained, Lower CO and HC concentrations are obtained, Lower NO_x concentrations are achieved, PM concentrations are low and less than that emitted by standard diesel engine, The engine noise level is little. Also, tested emissions HC, NO_x, PM and engine noise were reduced remarkably compared with operating the engine with neat diesel and no EGR.

Seung Hun Choi and Young TaigOh[7] studied the effect of animal fat biodiesel and cooled-exhaust gas recirculation system for reduction of toxic emission from direct injection engine.

Water-cooled, 4 strokes, DI diesel engine was used.In the experiments, first the engine was started with diesel fuel and when the engine reached the operating temperature, lard BD blends were used. Commercial diesel fuel was blended with 5, 10, 15, 20, and 30 vol.% mixed ratio of lard BD. Effective engine power, torque, and brake specific fuel consumption (BSFC) were calculated.The engine was tested with loads ranging from 0% and 100% at intervals of 25%.A specific case of 90% load was also investigated. Also, the engine was operated at variousengine speeds (800–2000 rpm at 400 rpm intervals). Brake mean effective pressure (BMEP) was applied from 0.2 to 0.6 MPa insteps of 0.1 MPa.In the tests, CO_2(%), O_2(%), CO (ppm), and NO_x (ppm) were measured by the instruments. Data were collectedon a computer using a Lab VIEW program. The Hesbon-HBN1500/Korea model smokemeter was used to measure smoke emission concentrations. EGR rate was increased gradually bycontrolling the EGR valve from 5% to the 30% to optimize the simultaneous reduction ofsmoke and NOx concentrations.

The performance of the engine running on lard BD blends with EGR decreased slightly. The maximum BSEC increase rate was 8.5% and engine power decreased by about 4.1% with lard BD at optimum EGR rates. Reduction in performance was mainly caused by the lower calorific value of lard BD. The BTE of the DI engine working on commercial diesel decreased from 30.5% to 29.5%, whereas it was ranged from 28.3% to 26.2% for lard BD30 with EGR 30%. So, BTE was not affected significantly.Oxygen concentration in the exhaust gas reduced by about 57% for the engine with lard BD and high EGR rates due to rich air/fuel mixtures and the exhaust gas recirculation. CO_2 emission increased up to 40% for the DI engine with lard BD30.

Subject Matter	Experiment Procedure	Conclusions
Rishant Sharma et al [1] • GASOLINE • EGR • VCR	Single cylinder engine Speed - 1500 rpm Loads varied from 2.0 to 8.0 kg in steps of two Two compression ratios CR7 and CR8 were used Data collected with and without EGR.	• The EGR found to decrease the value of NO_x and HC Emissions • EGR found to be more effective at higher values of compression ratios. • EGR found to be effective in reducing knock as it reduces the Heat Release Rate as well as Cylinder Pressure.
Pratik G.Sapre et al [2] • DIESEL • EGR	A single cylinder, Kirloskar engine Compression ratio- 17.5:1 Speed of engine- 1500 rpm EGR rates- (0% & 20%) Running on same speed without applying torque first of all measure all emission parameters, then by allow running engine at 5 N-m, 10 N-m, 15 N-m, 20 Nm, 25 N-m, 30 N-m, 35 N-m, 40 N-m, and 45 N-m torque. Then Compare parameters with different torque condition so as to check on which mode, emission is more.	• NO_x got reduced up to 64.75% due to EGR. • Emission of Carbon Monoxide reduced from 0.43 % volume to 0.29 % volume. • Emission of HC increased in EGR mode but it was less in amount in without EGR mode. • 20% of EGR is optimum for NOx reduction without significant penalty on brake specific fuel consumption and HC emission.
Simeon Iliev et al [3] • One dimensional (1D) CFD modeling • DIESEL Engine in AVLBoost software. • EGR • VCR	Speed- 2000 rpm Different compression ratios (15, 16, 17, 18 and 19) Different loads (full load, half load, one-fourth load) EGR rates (5% & 10%).	• Increase in compression ratio decreases the SFC. • Increase in % EGR causes decrease in NO_x emissions gradually at different CR. • At compression ratio 19 and 10% EGR the reduction of NO_x was 36% , So they conclude that high degree of recirculation is suitable for high CR.
M. Ghazikhani, M. R. Kalateh et al [4] • DUAL FUEL HCCI-DI engine. • EGR • VARIABLE ENGINE SPEED	Single-cylinder Compression ratio- 17.5. EGR % (5, 10, and 15) Different speeds (1300, 1400, 1500, and 1600) rpm	• Dilution effect leads to decrease in local temperatures. Also it leads to decrease in partial pressure of oxygen which is cause of NO formation. • Dilution also decreases combustion temperature and leads to incomplete HCCI combustion and therefore increase in CO emission occurred. • High engine speeds in HCCI mode causes more HC emission due to incomplete HCCI combustion.
KavatiVenkateswarlu et al [5] • DIESEL • EGR • BIODIESEL BLEND • CETANE IMPROVER	Single cylinder Speed- 1500 rpm Different EGR rates 0%, 10% and 20% Biodiesel- Fish oil (B20, B30 and B40) Cetane improver- Di Tertiary Butyl Peroxide (DTBP) as an additive to (0.5%) Different loads- no-load to full load	• Maximum BTE and minimum BSFC was found at EGR percent of around 15%. • The effect of EGR and additive reduces the NOx emissions by 25% but there was an increase in Carbonmonoxide (CO), Hydrocarbon (HC) and smoke opacity.

Miqdam T Chaichan, Khalil I Abaas [6] • DIESEL–HCCI mode • EGR • INJECTION TIMING VARIATION	Multi-cylinder- FIAT engine Speed- 1500 rpm compression ratio- 17:1 Using neat diesel fuel with engine standard injection timing 21°BTDC. Two cases were examined- first case, the injection of diesel fuel at advanced injection timing 35 degrees before top dead center (°BTDC). At the second case- the diesel fuel injected at retarded injecting timing of 12° BTDC. All these cases were compared with operating the diesel engine with neat diesel and no EGR addition. Different EGR rates- 20 and 50% used for each IT.	• Retarding injection timing led to a high increase in BSFC by about 17%. Also, it reduced brake thermal efficiency by about 20.88%. • Engine operation with advanced IT 35°BTD with 50% EGR resulted in good performance characteristics compared with diesel engine operated with standard IT, where Higher BTE is achieved, Lower emitted exhaust gas temperatures are obtained, Lower CO and HC concentrations are obtained, Lower NO_x concentrations are achieved, PM concentrations are low and less than that emitted by standard diesel engine, noise level is little. • Tested emissions HC, NO_x, PM and engine noise reduced remarkably compared with operating the engine with neat diesel and no EGR.
Seung Hun Choi and Young TaigOh[7] • DIESEL • EGR • BIODIESEL BLEND • VARIABLE ENGINE SPEED	Commercial diesel fuel was blended with 5, 10, 15, 20, and 30 vol.% mixed ratio of lard BD. Different loads ranging from 0% and 100% at intervals of 25%. A specific case of 90% load was also investigated. Different engine speeds- (800–2000 rpm at 400 rpm intervals). Brake mean effective pressure (BMEP) - 0.2 to 0.6 MPa in steps of 0.1 MPa. EGR rate- (5% to the 30%)	• The performance of the engine running on lard BD blends with EGR decreased slightly. The maximum BSEC increase rate was 8.5% and engine power decreased by about 4.1% with lard BD at optimum EGR rates. Reduction in performance was mainly caused by the lower calorific value of lard BD. • The BTE of the DI engine working on commercial diesel decreased from 30.5% to 29.5%, whereas it was ranged from 28.3% to 26.2% for lard BD30 with EGR 30%. So, BTE was not affected significantly. • Oxygen concentration in the exhaust gas reduced by about 57% for the engine with lard BD and high EGR rates due to rich air/fuel mixtures and the exhaust gas recirculation. • CO_2 emission increased up to 40% for the DI engine with lard BD30. • The lard BD engine with cooled EGR decreased the NOx concentration significantly. • When the EGR rate increased, the engine generates more BSEC and smoke opacity. The smoke emission of the engine increased at a slower rate (about 16%) and NOx decreased at a higher rate (about 39%) with lard BD blend and EGR.

5 SUMMARY

Summary of all the respective journals are given in the form of a tabular form. First column represents the subject matter; second column represents the experiment procedure and the last column represents the conclusion from the experiments. Study of various papers can be compared by analyzing the summary. Different results have been shown in the table, with and without EGR, with and without additives (cetane improver) as well as blends such as biodiesel etc.

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