Emission Analysis of Compression Ignition Engine using Various Blends – 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 and use of various alternative fuels for reduction of oxides of nitrogen (NO_x) emissions from diesel. 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.

Keywords
EGR, Biodiesel, BSFC, BTE, EGT, VCR.

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 causing various problems related to the health especially for the people living in urban areas. Emissions from automobiles usually consist of carbon monoxides, oxides from nitrogen and sulphur, unburnt hydrocarbons, and particulate matter. Reserves of the fossil fuels are decreasing in a great pace, engineers and scientists are finding different methods to optimize the fuel efficiency and to decrease the pollution which is in the form of carbon emission.

Future regulations like BS 5 will compel manufacturers of diesel engine can decrease the amount of NO_x and particulate matter (PM) emissions. Major improvements in the future can be performed with the help of after-treatment devices to seek major reduction in both NOx and PM emissions. Car exhaust is one the important place for utilizing the energy and maximizing the fuel efficiency in which maximum energy is being wasted Technologies have been made to optimize the efficiency of a vehicle's exhaust which is known as exhaust heat recovery and recirculation. EGR valve is an important device to deal with this recirculation, which opens when there is back pressure from the car's exhaust.

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
Diesel engines are mainly used in heavy-duty applications because they provide fuel economy and other advantages for buses, trucks, and some other non-road equipments used in construction and agriculture. Recent technologies have greatly improved the performance of diesel vehicles. Due to its higher fuel economy as compared to petrol vehicles, makes it more popular in passenger vehicles also. Emissions from the diesel exhaust consist of complex mixture of gases, liquid aerosols, and particles. Following are the various types of emissions that occurs from the exhaust of diesel engines-

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 Carbon monoxide
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 Oxides of Nitrogen
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. GWP measurement can explain the reason behind, that why the major concern is over control of NO_x emissions. 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 researchers try to curb and control these types of 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 part of 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

The reduction in NOx emissions with the increment of EGR rate is due to various effects:

3.1 The thermal effect

With the recirculation of CO_2 and H_2O which are of high heat capacity as compared to O_2 and N_2 (at constant pressure) there will be increase of inlet heat capacity, results in lowering of gas temperature during combustion, and particularly in a lowering of flame temperature.

3.2 The dilution effect

Mixing between fuel and O_2 is decelerated 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 decreasein partial pressure of oxygen which is cause of NO formation

3.3 The chemical effect

During recirculation CO_2 and water vapour are dissociated during combustion, which leads to modification in the combustion process and formation of NO_x. There is a decrease of the flame temperature due to endothermic dissociation of H_2O.

3.4 Soot formation

There is an increase of the flame radiation due to increase of soot formation with EGR, and hence there is decrease in the flame temperature.

3.5 Increase of ignition delay

The rate of heat release (ROHR) is lower with EGR, so it reduces NO_x emissions with the increase of the ignition delay (ID).

4. ALTERNATIVE FUEL MIXTURES

There are various types of alternative motor fuels like bio ethanol, biodiesel, hydrogen, LPG, natural gas, solar fuels and boron. These fuels are competitive to petroleum, so they are considered to be very important fuels. The important reason for interest in alternative fuels is the concern for greenhouse effect. They give many benefits to the environment, consumers and economy. An important turning point occurred, when use of renewable energy was promoted by the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 to cut the greenhouse gas emissions. Greenhouse gas emissions should be estimated annually, so the levels from year to year vary significantly. The present energy scenario has stimulated active research interest in non-petroleum, renewable, and non-polluting fuels. The world reserves of primary energy and raw materials are, obviously, limited. According to an estimate, the reserves will last for 218 years for coal, 41 years for oil, and 63 years for natural gas, under a business-as-usual scenario.

Oxygenates blended into diesel fuel can serve at least two purposes. Such components could be bio-ethanol, biodiesel or synthetic components made from biomass via gasification and synthesis gas. Oxygenates blended into diesel fuel might help to reduce emissions. Especially for heavy-duty vehicles, the most critical emission components are particles and oxides of nitrogen. In the case of oxides of nitrogen, oxygenates can work in two directions. Conventional biodiesel tends to increase NOx emissions, but on the other hand alcohol based fuels and emulsions (diesel + alcohol, diesel + water) tend to lower NOx emissions. The critical factors of the potential commercial use of these blends include blend properties such as stability, viscosity and lubricity, safety and materials compatibility.

Solubility of ethanol into diesel fuel is very low. Diesel and ethanol do not form stable blends like gasoline and ethanol. Therefore, if diesel/ethanol blends are to be used, the only practical solution is emulsions. However, new improved additives have been developed capable of forming microemulsions of ethanol and diesel. Fatty acid methyl esters (FAME) are reported to act as an emulsifier for ethanol. This is an interesting option as FAME could improve lubricity of ethanol, whereas ethanol could reduce NOx emissions and improve cold properties, both of which are shortcomings of FAME. Both components reduce particulate matter emission.

5. LITERATURE

Sapre et al [1] 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. Compression ratio was set at 17.5:1 and speed at 1500 rpm on a single cylinder, four-stroke engine. They evaluate the emission characteristics of Engine with and without EGR mode, and found that NO_x got reduced up to 64.75%. Emission of Carbon Monoxide was also reduced from 0.43 % volume to 0.29 % volume.

Emission of HC is increased in EGR mode but it was less in amount in without EGR mode. By performing experiment it was found that 20% of EGR was optimum for reduction in NOx without any penalty on BSFC and HC emission.

Simeon Iliev et al [2] performed the 1D CFD modelling of 4-stroke DI diesel engine which was developed by AVL Boost software. Effects of EGR on performance, combustion and emissions of a VCR Diesel Engine were studied. The test was done at different 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 increase in CR the specific fuel consumption (SFC) decreases. NOx emissions were gradually reduced at different CR's with increase in % EGR due to reduction in flame temperatures and less oxygen amount in the combustion 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.

Ghazikhani et al [3] 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. The experiment was performed on different EGR % (5, 10, and 15) and different speeds (1300, 1400, 1500, and 1600) rpm. With increasing EGR, mixing between fuel and O_2 is decelerated 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 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.

Chaichan [4] studied the effects of EGR and Injection Timing Variation on Engine Run in HCCI Mode. The engine speed fixed at 1500 rpm using neat diesel fuel with engine standard injection timing 21°BTDC at 17:1 compression ratio. Two cases were examined- first case, the injection of diesel fuel at advanced injection timing 35 degrees before top dead center (°BTDC). In 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 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 BSFC is obtained, higher BTE is achieved, lower emitted EGT 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.

Choi [5] studied the effect of animal fat biodiesel and cooled-exhaust gas recirculation system for reduction of toxic emission from direct injection engine. Commercial diesel fuel was blended with 5, 10, 15, 20, and 30 vol. % mixed ratio of lard BD. They concluded that 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. But, 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.

Xuea et al [6] studied the effect of biodiesel on engine performances and emissions. They had gone through various high rated journals to study the effect of biodiesel on economy, engine power, durability and emissions including regulated and unregulated emissions. They concluded that the use of biodiesel leads to the substantial reduction in PM, HC and CO emissions accompanying with the imperceptible power loss, the increase in fuel consumption and the increase in NOx emission on conventional diesel engines with no or fewer modification. And it favors to reduce carbon deposit and wear of the key engine parts.

D.C. Rakopoulos et al [7] conducted experiments to evaluate the effects of using blends of n-butanol (normal butanol) with conventional diesel fuel, with 8%, 16% and 24% (by volume) n-butanol, on the performance and exhaust emissions of a four stroke diesel engine. The tests are conducted using each of the above fuel blends or neat diesel fuel, with the engine working at a speed of 2000 rpm and at three different loads. The smoke density, NOx and CO emissions were significantly reduced with the use of the butanol–diesel fuel blends with respect to those of the neat diesel fuel, with this reduction being higher the higher the percentage of butanol in the blend. On the contrary, the unburned hydrocarbons (HC) emissions were increased with the use of the butanol–diesel fuel blends with respect to those of the neat diesel fuel, with this increase being higher the higher the percentage of butanol in the blend. With increasing percentage of butanol in the blends, a little higher specific fuel consumption was observed with corresponding slight increase of brake thermal efficiency and little lower exhaust gas temperatures.

Sehmus Altun et al [8] conducted experiments to evaluate the effect of using n-butanol in conventional diesel fuel-biodiesel blends on the engine performance and exhaust emissions of a single cylinder direct injection compression ignition engine with the engine working at a constant engine speed and at different three engine loads. A blend of biodiesel and diesel fuel known as B20 (20% biodiesel and 80% diesel in volume) was prepared, and then n-butanol was added to B20 at a volume percent of 10% and 20% (denoted as B20Bu10 and B20Bu20, respectively). For all of the fuel mixtures, the brake specific fuel consumption showed an increase, whereas brake thermal efficiency showed a decrease as compared to conventional diesel fuel for the same torque output. On the other hand, the addition of n-butanol to the B20 fuel blend caused a slight increase in the brake specific fuel consumption and brake thermal efficiency in comparison to the B20 fuel blend. For exhaust emissions, carbon monoxide (CO) and hydrocarbon (HCs) emissions decreased, and NOx remained almost unchanged at low engine loads, while it decreased at high engine loads. Fuel blends also resulted in a sharp reduction of smoke opacity in the whole range of engine tests.

L Zhu et al [9] had done their experimental investigation using biodiesel and biodiesel–methanol (BM) blends to investigate the combustion and emissions in low temperature combustion. They concluded that the BM blends could prolong the ignition delay. With increasing EGR rate, the heat release rate decreases and move towards TDC. With increasing EGR rate, the BSFC increases generally at each engine load. For BM blends, the NOx emissions decrease correspondingly at each tested EGR level, compared with those from biodiesel. However, the reduction in the NOx emissions is limited. As the EGR rate increases, the NOx emissions decrease monotonically for all fuels at different engine loads. As the EGR rate increases and the oxygen concentration decreases, the CO and HC emissions increase, especially when the EGR rate exceeds 40–45 per cent. However, it is noted that the use of BM10 could reduce the HC emissions, compared with biodiesel, or even diesel fuel. Thus, it can be concluded that the use of BM blends is effective in simultaneously reducing the soot and NOx emissions in the LTC regime.

In his experimental work **Yilmaz [10]** tested on standard diesel fuel, biodiesel (45%)-methanol (10%)-diesel (45%), biodiesel (40%)-methanol (20%)-diesel (40%), biodiesel (45%)-ethanol (10%)-diesel (45%) and biodiesel (40%)-ethanol (20%)-diesel (40%) blends using compression ignited engine under the same operating conditions. Performance and emission characteristics of the engine fueled with biodiesel-methanol-diesel (BMD) and biodiesel-ethanol-diesel (BED) are compared to standard diesel fuel as the baseline. Overall, biodiesel-alcohol-diesel blends show higher brake specific fuel consumption than diesel. As alcohol concentrations in blends increase, CO and HC emissions increase, while NO emissions are reduced. Also, methanol blends are more effective than ethanol blends for reducing CO and HC emissions, while NO reduction is achieved by ethanol blends. So, Methanol blends would be the choice if CO and HC emissions are the aim. Ethanol blends would be the right choice for reducing NO emissions.

Yasin et al [11] had done their experimental investigation using biodiesel (20%)-methanol (5%)-diesel (75%), biodiesel (20%)-methanol (10%)-diesel (70%), biodiesel (20%) - diesel (80%), and standard mineral diesel as a baseline fuel. Those biodiesel-alcohol low proportion blends are investigated under the same operating conditions at 20%, 40% and 60% of engine loads to determine the engine performance and emission of the diesel engine. Overall, biodiesel-methanol-diesel blends show higher brake specific fuel consumption than mineral diesel. As methanol proportions in blends increase, NO emissions increase, while CO emissions are reduced. Also, biodiesel-diesel blend with 5% of methanol is more effective than biodiesel blend with 20% for reducing CO emissions. There were increases in exhaust gas temperatures for biodiesel-methanol-diesel blends varying at all engine loads.

Zhu et al [12] tested Euro V diesel fuel, pure biodiesel and biodiesel blended with 5%, 10% and 15% of ethanol or methanol on a 4-cylinder naturally-aspirated direct-injection diesel engine. On the whole, compared with Euro V diesel fuel, the blended fuels leads to reduction of both NOx and PM of a diesel engine, with the biodiesel–methanol blends being more effective than the biodiesel–ethanol blends. The effectiveness of NOx and particulate reductions is more effective with increase of alcohol in the blends. With high percentage of alcohol in the blends the brake thermal efficiency might be slightly reduced. For the 10% and 15% blends, the HC and CO emissions increase compared with biodiesel and Euro V diesel fuel, but for the 5% blends the HC and CO emissions decrease. Moreover, the methanol blends give higher HC and CO emissions than the ethanol blends. With the diesel oxidation catalyst (DOC), the HC, CO and particulate emissions can be further reduced. The brake specific fuel consumption of the blended fuels increases with percentage of ethanol or methanol in the fuel due to the lower heat values of the alcohols. The brake specific fuel consumption is higher for the biodiesel–methanol blends.

Uludamar et al [13] performed an experiment in order to examine the effect of ethanol additive in diesel-soybean biodiesel fuel blend. In experiments, 20% (by volume) soybean biodiesel was blended with low sulphur diesel fuel, and then 5%, 10%, and 15% ethanol was added in the blend. Experiments were conducted in a water cooled, four cylinder four stroke diesel engine. The results showed that, compared to diesel and biodiesel, ethanol addition improved carbon monoxide (CO), nitrogen oxide (NOx) and smoke opacity emissions, whereas engine power and torque values reduced while brake specific fuel consumption increased. Same trend observed with increasing ethanol content in the mixture. Average reduction of CO emissions were 10.4% for soybean biodiesel, 13.7% for D75SB20E5, 16.1% for D70SB20E10, 18.2% for D65SB20E15 fuel, and smoke opacity emission reduced 1.4%, 3.7%, 5.9%, and 7.0% for soybean biodiesel, D75SB20E5, D70SB20E10 and D65SB20E15, respectively.

Shi et al [14] describes the emission characteristics of a three compounds oxygenated diesel fuel blend (BEdiesel), on a Cummins-4B diesel engine. BE-diesel is a new form of oxygenated diesel fuel blends consisted of ethanol, methyl soyate and petroleum diesel fuel. The blend ratio used in this study was 5:20:75 (ethanol: methyl soyate: diesel fuel) by volume. The results from the operation of diesel engine with BE-diesel showed a significant reduction in 30% PM emissions and 2%–14% increase of NOx emissions. The change of CO emission was not conclusive and depended on operating conditions. Total hydrocarbon (THC) from BE-diesel was lower than that from diesel fuel under most tested conditions. Formaldehyde, acetaldehyde, propionaldehyde and acetone in the exhaust were measured, and the results indicated that use of BE-diesel led to a slight increase of acetaldehyde, propionaldehyde and acetone emissions.

Gokhan Tuccar et al [15] performed experiments using the commercially available diesel fuel (D), diesel (80%)–microalgae biodiesel (20%) (by volume) (D80B20), diesel (70%)–microalgae biodiesel (20%)–butanol (10%) (D70B20But10) and diesel (60%)–microalgae biodiesel (20%)–butanol (20%) (D60B20But20) fuels to evaluate the effects of the fuel blends on the performance and exhaust emissions of a diesel engine. The results showed that; although butanol addition caused a slight reduction in torque and brake power values, the emission values of the engine were improved. The measured physical properties of MB–butanol–diesel mixtures like cetane number, density, viscosity and pour point were found comparable with those of diesel fuel according to the fuel properties test. The exhaust emission tests revealed that CO and NOx emission and smoke opacity values improved with butanol addition.

6. CONCLUSION AND FUTURE SCOPE

Various alternative fuels like biodiesels, alcohols and cetane improver additives produced from renewable and often domestic sources, represents a more sustainable source of energy and will therefore play an increasingly significant role in providing the energy requirements. Therefore, more and more researches are focused on using alternative fuels for the engine performances and emissions in the past 10 years. From the above literatures, it can be found that using alternative fuels, though performance is affected due to lower heating values as compared to diesel, but there is a reduction in NOx, CO, HC, PM emissions at different operating conditions of a diesel engine. On the other hand EGR can be the best alternative techniques for reducing NOx and can give equal performances as that of diesel. So, by going through above literatures, we can conclude that future scope of different alternative fuels due to environmental and economic reasons will be more. However, more researches and development in biodiesel resources and engine design are needed. The further improvement in production of biofuels should be performed in the future to promote biodiesel properties and quality. And the further development in additives which improve consumption of biodiesel should be needed to favor power recovery, economy and emissions especially for NOx emissions. It should be done to redesign engine and its control systems for biodiesel, especially for optimizing ignition and injection, and EGR control to achieve a more efficient combustion and thus meet the needs of biofuel engine.

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