# Experimental Study on Blending of Ethanol & Diesel with EGR System in IC Engine

**Sagar R Tailor[1] Jignesh Patel[2] Anil J. Patel[3]**
[1,2,3]Student
[1,2,3]Department of Mechanical Engineering
[1,2]Mahatma Gandhi Institute of Technical Education & Research Centre Navsari, Gujarat [3]SNPIT, Umarakh

*Abstract*— Internal combustion engines are established as the main power source for the automobile vehicles. At present emission norms becomes strict for any I.C. Engine. The main pollutant are CO, HC, NOx,PM, soot, etc from which NOx are one of the most harmful component. It is possible to limit the negative effect of NOx on the environment by various methods like exhaust gas recirculation (EGR), catalyst and water injection. The aim of this work is to review the effect of exhaust gas recirculation (EGR) to reduce the NOx emission from tailpipe of homogeneous charged C.I.engines. Cooled exhaust gas recirculation (EGR) is a common way to control the NOx generation in engine cylinder .It was found that the thermal resistance and thickness of the fouling layer as well as the fouling rate decrease with increasing gas velocity in EGR coolers It was found that adding EGR to the fresh air charge to homogeneous charged engines will beneficial to reduce the NOx emission substantially. Substantial reductions in NOx emission are achieved by previous investigators with 10% to 30% EGR. ethanol is suitable In diesel engine as a substitute fuel. up to 15% (v/v) ethanol/85% (v/v) diesel fuel blends can be recommended as fuel for diesel engines once flash point and blend stability are improved by the use of additives.

***Key words:*** C.I.engines, Cooled exhaust gas recirculation, Production of ethanol

## I. INTRODUCTION

### A. Energy Scenario:

The sudden increase in energy usage, the depletion of fossil fuels and the air pollution from ground transportation have been attracting a lot of attention to the development of alternative fuels and engines with high thermal efficiency and clearness. The diesel engine has greater thermal efficiency than does the gasoline engine, but it exhausts many emissions such as nitrogen oxides (NOx) and particulate matter (PM). Hence, this engine type requires more investigation in order to satisfy the strengthened regulation of exhaust emissions. Many researchers worldwide put forth a multilateral effort to solve emissions problems in many ways: the development of the clean diesel engine by the optimization of injection and combustion strategies, and the applications of alternative fuels such as dimethyl ether (DME), biodiesel, and compressed natural gas (CNG).

Aside from these methods, recent technologies that reduce exhaust emissions while maintaining combustion performance are suggested through the blending of various fuels with conventional diesel fuel. Among them, the investigation into the application of diesel–ethanol fuel blends to the conventional diesel engine is progressing broadly in the USA and Europe as a project named E-diesel. The recycling of some of the exhaust back into the engine intake system, commonly known as exhaust gas recirculation (EGR) has become almost essential for achieving significant NOx reductions to meet the current and future diesel emission regulations.

### B. Ethanol Scenario:

#### 1) What Is Ethanol ?

Ethanol is a quasi-renewable energy source because while the energy is partially generated by using a resource, sunlight, which cannot be depleted, the harvesting process requires vast amounts of energy that typically comes from non-renewable sources. Creation of ethanol starts with photosynthesis causing a feedstock, such as sugar cane or a grain such as maize (corn), to grow. These feedstocks are processed into ethanol.

#### 2) Production Of Ethanol:

Molasses is the main raw material used for production of Ethanol. It contains about 50% of the total sugar; of which 30 to 33% is cane sugar and rest is reducing sugar. During the fermentation, yeast strains to the species Saccharomyces Cerevisiae, a living microorganism belonging to class fungi converts sugar present in the molasses such as sucrose and glucose to alcohol. This conversion is done in large tank type Fermenters. There will be machinery for separation of this ethanol from aqueous solution which is low temperature distillation using low pressure steam for heating. This ethanol is further purified using multiple distillation process and forming azeo-tropic mixture with Benzene to get total anhydrous alcohol, which is used for blending with petrol or diesel. In modern Fuel Ethanol plants, molecular sieve technology is used for removing water molecules from alcohol and manufacture alcohol, which gives substantial savings in terms of energy consumption.

The Ethanol manufacturing process from Molasses is schematically shown in the following Material Flow chart.

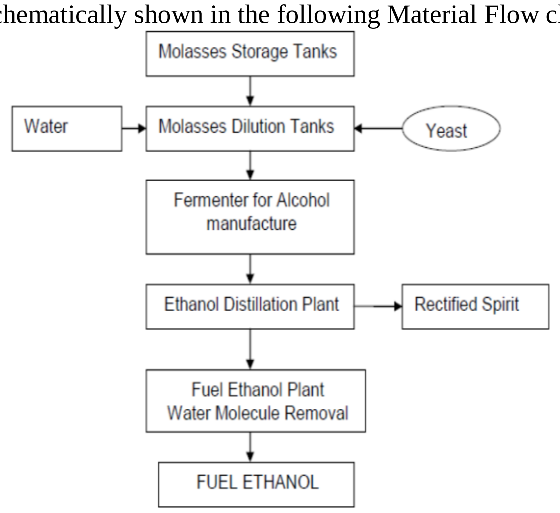



Fig. 1.1: Ethanol Manufacturing Flow Chart

*3) Application Of Ethanol:*

- Ethanol is used extensively as a solvent in the manufacture of varnishes and perfume.
- It is also used as as a preservative for biological specimens.
- It is used in the preparation of essences and flavorings.
- It is also used as a fuel or gasoline as well as diesel additive.

### *C. Exhaust Gas Recirculation:*

*1) What Is EGR ?*

EGR technique was firstly adopted in diesel engines in order to limit thermal NOx formation rate by reducing combustion chamber temperature thanks to the dilution of fresh charge with a certain amount of exhaust gas recycled at engine intake. exhaust gas is taken from the exhaust port and supplied into the inlet port.

*2) EGR Cooler:*

EGR cooler is provided for reducing the temperature of the exhaust gas which have supplied to the air intake of the IC engine.in EGR cooler is one type of heat exchanger.In EGR cooler cooling water is supplied around the egr pipe.

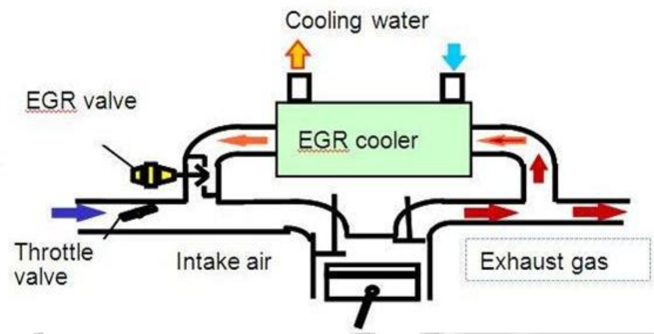



Fig. 1.2: EGR System

Here ,EGR valve is used to maintain the EGR flow rate. the formula for finding EGR rate are as follows :

$$\text{EGR Rate(\%)}= \frac{[Ma]without\ EGR - [Ma]with\ EGR}{[Ma]without\ EGR}$$

Where [Ma] =Mass flow rate of air, kg/s

*3) Advantages Of EGR System:*

- Reduced NOx
- Potential reduction of throttling losses on spark ignition engines at part load
- Improved engine life through reduced cylinder temperatures (particularly exhaust valve life)

### *D. Catalytic Converter:*

*1) What Is Catalytic Converter?*

When the vehicle exhaust flows over the catalyst particles the various reactions of oxidation and reduction are completed. In this Nox can be reduced in the presence of or reducing agents HC and Co and H2 over some suitable catalyst. Similarly HC and Co can be oxidized to completion in the presence of certain catalyst. Reduction of No can be represented by following chemical equations.

- $NO + Co \rightarrow Co_2 + ½ N_2$
- $NO + HC \rightarrow H_2O + CO_2 + ½ N_2$
- HC/CO Oxidation is represented by
- $CO + ½ O_2 \rightarrow Co_2$
- $4HC + SO_2 \rightarrow 2H_20 + 4CO_2$

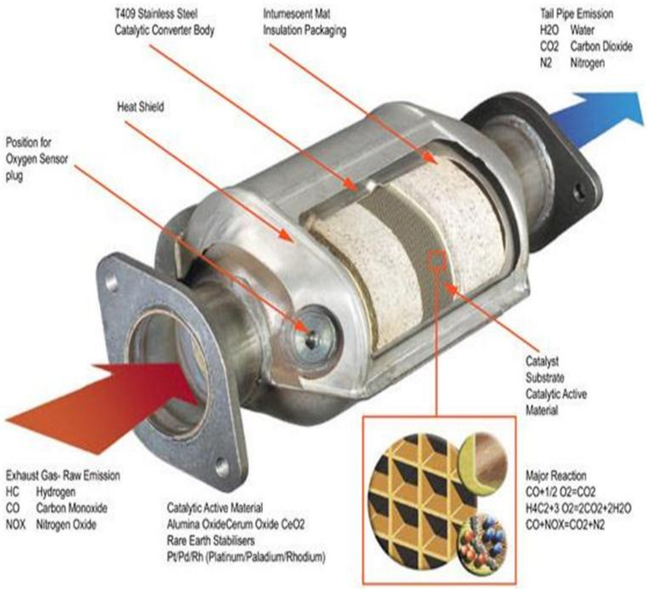



Fig. 1.3: Catalytic Converter

*2) Advantages Of Catalytic Converter:*

- The catalytic converters sole purpose is to reduce the amount of harmful pollution produced by the combustion of hydrocarbon-based fossil fuels in cars.
- Catalytic converters decrease hydrocarbon emissions by about 87 percent, carbon monoxide by 85 percent and nitrous oxide by 62 percent during the expected life of a vehicle.

*3) Application Of Catalytic Converter:*

- catalytic converters are most commonly applied to exhaust systems in automobiles
- Also used on electrical generators,
- They are also used in forklifts,
- Used in mining equipment,
- Used in vehicle like trucks, buses locomotives, motorcycles, and airplanes,
- They are also used on some wood stoves to control emissions.

## II. LITERATURE REVIEW

### *A. Literature Review On Ethanol Blended Diesel:*

**V.N Banugopan,et al.[1] (2010)** had discussed the performance, and to control the emissions of the diesel engine using blended fuel by preheating the inlet air. The present work has been carried out using single cylinder, four stroke, water cooled diesel engine. In this phase, experiment investigations are conducted using five sets of blended fuels i.e 10%, 15%, 20%, 25%, 30% Ethanol – Diesel blend have been prepared and preheating the inlet air to 40ºC, 50ºC and 60ºC. The performance and emission characteristics are studied and compared with the base fuel.

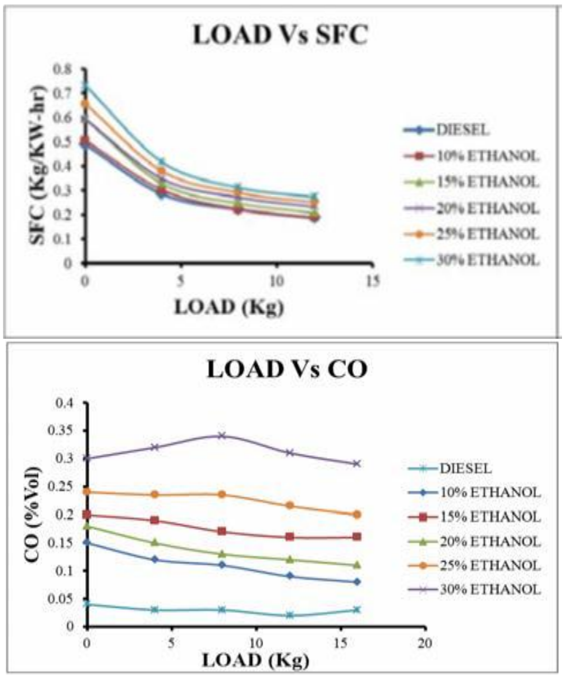



Fig. 2.1: Comparison of SFC& Co Emission with Load for Base And Various Ethanol Blend

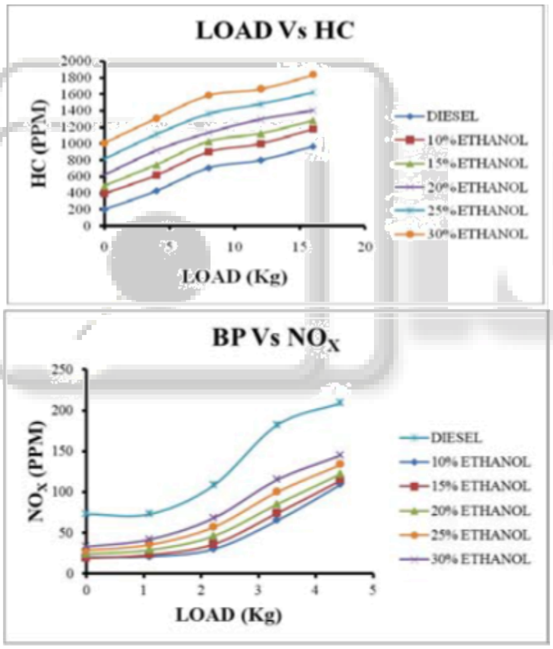



Fig. 2.2: Comparison of HC & $NO_x$ Emission with Load for Base And Various Ethanol Blend

The Total fuel consumption and SFC of ethanol diesel blended fuels increased for the reason that the low heating value of ethanol is about 2/3 of that of diesel, and it is increasing with increasing concentration of ethanol in blend. On emission characteristics CO and HC emission is increasing. Addition of ethanol will lead to complete combustion so that HC and CO emission should reduce, but here the indroduction of ethanol in diesel fuel, HC emission increased at various load condition. CO and HC emission is higher for the pre heated condition compare to without pre heating condition.

**Cenk sayin ,et al.[2](2010)** had discussed the effects of methanol–diesel (M5, M10) and ethanol–diesel (E5, E10) fuel blends on the performance and exhaust emissions were experimentally investigated. For this work, a single cylinder, four-stroke, direct injection, naturally aspirated diesel engine was used. The tests were performed by varying the engine speed between 1000 and 1800 rpm while keeping the engine torque at 30 Nm.The use of methanol–diesel and ethanol–diesel blends caused a decrease in the emissions of smoke opacity, CO and THC. However, NOx emissions increased with the use of blends. The formation of exhaust emissions was seriously affected by the methanol or ethanol content of the blend.The BSFC with the all fuel blends increased mainly due to the lower LHV of methanol and ethanol. The increase in BSFC with the blend M10 was higher than that of E10 and M5 was higher than that of E5.

**Eloisa Torres-Jimenez,et al.[3] (2011)** had discussed the physical–chemical properties of ethanol–diesel fuel blends. Main properties have been investigated experimentally.Physical and chemical properties of diesel fuel and ethanol–diesel fuel blends were measured according to requirements and test methods for diesel fuel. The tested fuels were neat mineral diesel fuel (D100),ethanol/diesel fuel blend (E05D95), ethanol–diesel fuel blend (E10D90) and ethanol- diesel fuel blend (E15D85). It has been proved that, for ethanol–diesel fuel blends, some additives are necessary to keep stability under low temperature conditions. Also, cold weather properties test, such as cloud point and pour point tests are negatively affected by phase separation. The rest of the properties, excepting flash point, were within diesel fuel standard specifications. Based on this study, it can be concluded that using additives to avoid phase separation and to raise flash point, blends of diesel fuel with ethanol up to 15% can be used to fuel diesel engines if engine performance tests corroborate it. up to 15% (v/v) ethanol/85% (v/v) diesel fuel blends can be recommended as fuel for diesel engines once flash point and blend stability are improved by the use of additives.

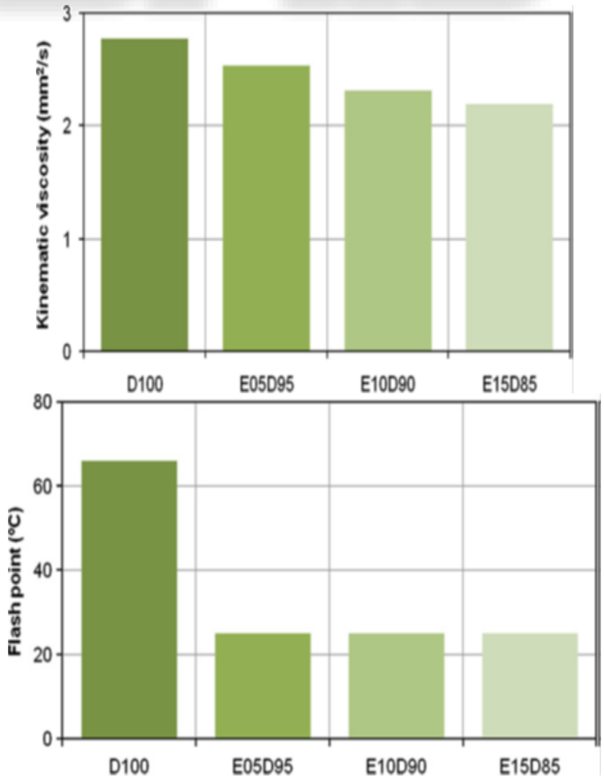



Fig. 2.3: Kinematic Viscosity & Flash Point Vs Types Of Fuel

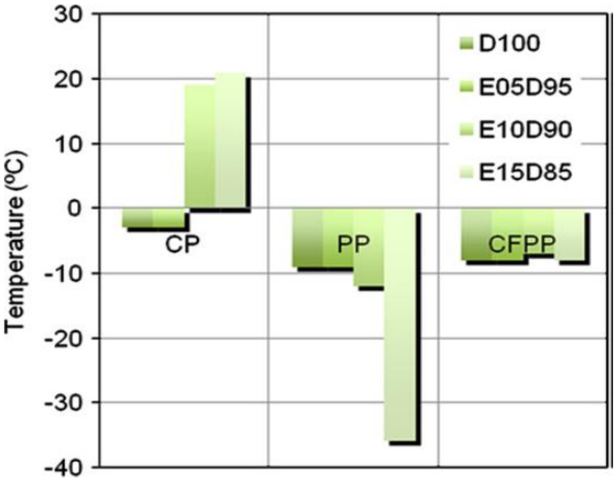



Fig. 2.4: CP, PP and CFPP Vs Type Of Fuel

**Srinivas padala,et al.[4](2013)** had discussed that investigates the potential of ethanol fuelling in a diesel engine to achieve higher efficiency. Experiments are performed using a single-cylinder version of a common-rail diesel engine that is widely used in passenger cars. A dual-fuelling technology is implemented such that ethanol is introduced into the intake manifold using a port-fuel injector while diesel is injected directly into the cylinder. The main focus is the effect of ethanol energy fraction and diesel injection timing on engine efficiency and tailpipe emissions. While these two parameters are varied, in-cylinder pressure measurement and sub sequent analysis of indicated mean effective pressure, apparent heat release rate ,ignition delay, combustion phasing,and burn duration are performed. From the ethanol energy variation tests at fixed diesel injection timing, it is found that increased ethanol energy fraction increases the engine efficiency until the operation is limited by misfiring associated with over-retarded combustion phasing.

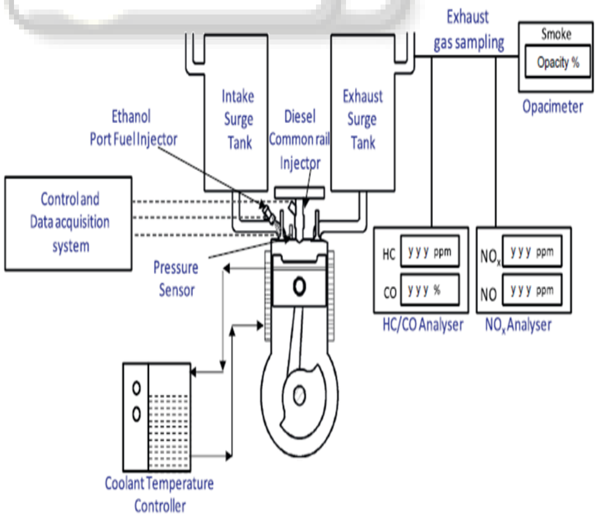



Fig. 2.5: Schematic Diagram of Experimental Facility

By energy fraction,upto60%ofdiesel is replaced by ethanol, which achieves 10%efficiencygain compared with diesel-only operation. Detailed analysis of the results reveals that the decreased burn duration is the primary cause for the efficiency gain, i.e. the fast burning of ethanol improves the combustion .However, the burn duration app ears to increase with advancing the diesel injection timing at a fixed ethanol energy ratio despite the fact that the highest indicated mean effective pressure of1020 kPa is measured when the diesel injection timing is set at eight crank angle degrees before top dead centre, the most advanced diesel injection timing of this study. This is due to optimised combustion phasing such that the main heat release occurs near top dead centre, which outperforms the increased burn duration. Therefore, both burn duration and combustion phasing should be considered to explain trends in the indicated mean effective pressure or efficiency of dual-fuel combustion engines. The tailpipe emissions suggest that unburnt hydrocarbon, carbon monoxide and NOx emissions increase with increasing ethanol fraction, which raises a question on the advantages of utilising ethanol in a diesel engine. However, negligible smoke emissions are measured at ethanol energy ratio of20%orhigher suggesting that optimisation of these emissions would be much easier compared with conventional diesel combustion.

### *B. Literature Review On EGR System In Diesel Engine:*

**H.E.Saleh,et al.[5](2009)**had studied the effect of exhaust gas recirculation on exhaust emissions and performance in diesel engine operating with JME. Tests were made at two speeds and loads. Engine performance, exhaust emissions, exhaust gas temperatures and combustion quality were investigated. From the study carried out the following conclusions may be drawn:

JME is a good gas oil substitute as the brake power output with JME was higher than that with gas oil and $NO_x$ was higher with JME than those with gas oil.The $NO_x$ emissions decreased with increasing the EGR rate. Also, at all engine speeds and loads, the JME produced a higher CO and HC emissions when the EGR rate is increased.$NO_x$ emissions with minimum loss in fuel economy are obtained by increasing EGR rate to 15% at low load. Using high levels of EGR (in excess of 40%) at low load has the beneficial effect of lowering the flame temperature, which leads to low NOx emissions of 50% with increase in bsfc of 5%. The optimum EGR level is 5–15% for all engine speeds and loads and that may be favorable in a trade-off between HC, CO and NOx emissions with little economy penalty. When the exhaust gas temperature has decreased by using cooled EGR at full load, the engine economy significantly increased with decreased in the exhaust emissions.

**M.Mani,et al.[6](2010)** the effect of cooled exhaust gas recirculation (EGR) on four stroke, single cylinder, direct injection (DI) diesel engine using 100% waste plastic oil. Experimental results showed higher oxides of nitrogen emissions when fueled with waste plastic oil without EGR. $NO_x$ emissions were reduced when the engine was operated with cooled EGR. The brake thermal efficiency in waste plastic oil varies from 14% to 30% without EGR compared to 13–29% with 20% EGR. At full load the brake thermal efficiency decreases with increase in EGR flow rate due to high EGR percentages that result in larger replacement of air. At all loads, exhaust gas temperature decreases marginally with increase in EGR percentages. The exhaust gas temperature is higher by about 298 K in WPO operation without EGR throughout the load spectrum as compared to diesel engines.

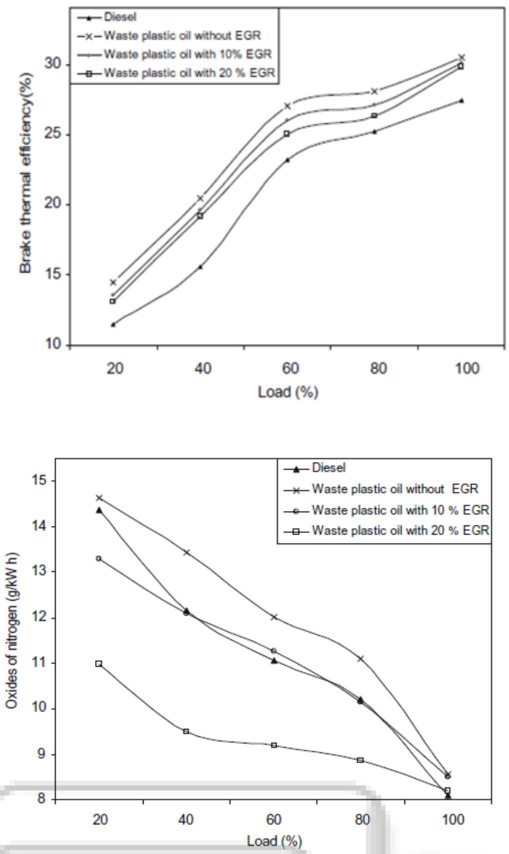



Fig. 2.6: Variation Of Oxides Of Nitrogen & Brake Thermal Efficiency With Load For Various EGR Rate

The NOx emission in waste plastic oil varies from 14.63 to 8.56 g/kWh without EGR compared to 10.97–8.2 g/kWh with 20% EGR. The NOx emission reduces with increase in EGR percentage, due to the presence of higher heat capacity gases that reduces the peak combustion temperature. Unburned hydrocarbon emission varies from 0.41 to 0.03 g/ kWh without EGR compared to 20% EGR that varies from 0.51 to 0.10 g/kWh and 0.56 to 0.13 g/kWh in diesel. Unburned hydrocarbon increased with increase in EGR rate due to the reduction of oxygen in the inlet charge by the EGR into the cylinder.

**Deepak Agarwal,et al**[7]had carried out to 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 opacity of the exhaust gas etc. were measured. Performance parameters such as thermal efficiency, brake specific fuel consumption (BSFC) were calculated. Reduction 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 h 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.

Fig. 2.7: Carbon Deposits On The Cylinder Head Of The Engine (A) Using EGR (B) Without EGR

Fig. 2.8: Carbon Deposits On The Piston Crown Of The Engine (A) Using EGR (B) Without EGR

Thermal efficiency is slightly increased and BSFC is decreased at lower loads with EGR compared to without EGR. But at higher loads, thermal efficiency and BSFC are almost similar with EGR than without EGR. Exhaust gas temperature is decreased with EGR. Hydrocarbons, carbon monoxide, and smoke opacity are increased with EGR, but NOx emission decreases significantly. It can be observed that 15% EGR rate is found to be effective to reduce NOx emission substantially without deteriorating engine performance in terms of thermal efficiency, BSFC, and emissions. At lower loads, EGR reduces NOx without deteriorating performance and emissions. At higher loads, increased rate of EGR reduces NOx to a great extent but deteriorates performance and emissions. Thus, it can be concluded that higher rate of EGR can be applied at lower loads. EGR can be applied to diesel engine without sacrificing its efficiency and fuel economy and NOx reduction can thus be achieved. The increase in CO, HC, and PM emissions can be reduced by using exhaust after-treatment techniques, such as diesel oxidation catalysts (DOCs) and soot traps.

**M.S. Abd-Elhady et al.**[8]have shown that Two sets of fouling experiments have been performed with and without water injection, and the gas velocity in each set has varied between 30, 70 and 120 m/s. The concentration of soot particles in the gas flow is 100 mg/ m3, and the average diameter of the particles is 130 nm with a standard deviation of 55 nm. It has been found that the thermal resistance and thickness of the fouling layer and the fouling rate decrease as the gas velocity in the EGR cooler increases. If EGR coolers are operated with a gas velocity, which is just lower than the critical flow velocity for the largest particle in the flow, quick deterioration of the thermal performance of the heat exchanger will nevertheless occur.

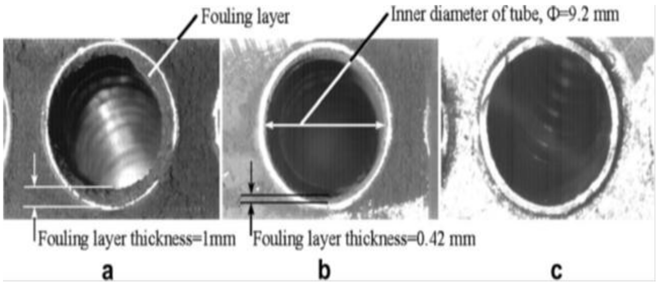
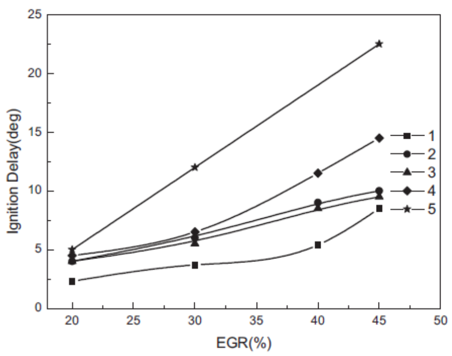



Fig. 2.9: Fouling Layer Thickness In The Tubes Of The EGR Cooler For Gas Velocities Of (A) 30 M/S, (B) 70 M/S And (C) 120 M/S

It was found that the thermal resistance and thickness of the fouling layer as well as the fouling rate decrease with increasing gas velocity in EGR coolers. Operating EGR coolers at a gas velocity, which is lower than the critical flow velocity corresponding to the largest particles in the flow will lead to rapid deterioration in the thermal performance of the heat exchanger. it has to be noted that increasing the gas velocity above 120 m/s in the tubes of EGR coolers cannot be achieved in practical diesel engines, due to the excessive pressure drop. Injecting water in the gas flow may improve the thermal performance of the cooler and decreases the fouling rate, nevertheless this beneficial influence decreases with the gas velocity.Another important factor that affects the effectiveness of EGR coolers is the concentration of water vapour. Thermal resistance and effectiveness in case of water and no water injection. The injection rate of water is 1 l/hr for all relevant experiments. Increasing the concentration of water vapour in the gas flow, increases the rate of heat transfer from the gas flow to the cooling medium passing through the tubes of the EGR cooler, and consequently improves the effectiveness of the EGR cooler.

**Hongqing Feng et al.[9]** performed using a modified six-cylinder turbocharged direct injection diesel engine with diesel of different distillation ranges to investigate the effects of (exhaust gas recirculation) EGR on engine performance and emission characteristics of low-temperature combustion engine. The results showed that for the same fuel, with the increase of the EGR rate, the cylinder pressure remained almost unchanged. Increasing the EGR rate slowed the combustion, the peak value of heat release rate increased and the indicated thermal efficiency decreased. The peak value of heat release rate increased with the decline of the initial boiling point at the same EGR rate. The ignition delay of combustion increased with the decrease of initial boiling point. When EGR rate was low, the level of HC and CO emission was low, while the HC and CO emission increased rapidly with the increase of EGR.



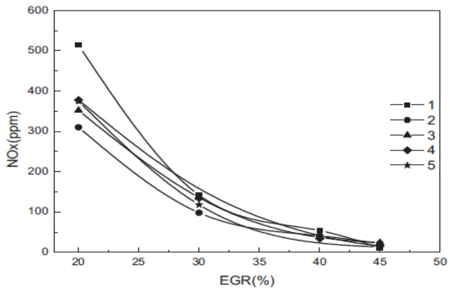




Fig 2.10: The Effect Of Egr On Ignition Delay & $No_x$

At the same EGR, with the reduction of the initial boiling point, the start of combustion delays and the heat release rate slows. The maximum heat release rate increases, and the peak time is postponed, the ignition delay extends. With the decline of the initial boiling point, the indicated thermal efficiency decreases. For the blend fuel of gasoline and diesel, the indicated thermal efficiency falls most obviously at high EGR.With the increase of EGR, HC and CO emission both increase. In the early stage of combustion, they keep at low level, but in the later stage they increase sharply. NOx emission decreases with the increase of EGR, and basically reaches zero emission when EGR is high. The soot emission decreases obviously with the reduction of initial boiling point, and it increases when the EGR becomes higher. For the blend fuel of gasoline and diesel, HC and CO emissions are always the worst while the NOx and soot emission could be improved.

## III. CONCLUSION

From the literature review ,I have concluded that blending of ethanol in Diesel engine is suitable upto 15% ethanol & 85% diesel. Blending of ethanol in diesel engine not affect on performance parameters but it reduces the level of emission parameter like CO,$NO_x$,PM. EGR is a very useful technique for reducing the $NO_x$ emission. EGR displaces oxygen in the intake air and dilute the intake charge by exhaust gas recirculated to the combustion chamber. Recirculated exhaust gas lower the oxygen concentration in combustion chamber and increase the specific heat of the intake air mixture, which results in lower flame temperatures. It was observed that 15% EGR rate is found to be effective to reduce NOx emission substantially without deteriorating engine performance in terms of thermal efficiency, bsfc and emissions. Thus, it can be concluded that higher rate of EGR can be applied at lower loads and lower rate of EGR can be applied at higher load. EGR can be applied to diesel engine fueled with diesel oil, biodiesel, LPG, hydrogen, etc without sacrificing its efficiency and fuel economy and NOx reduction can thus be achieved.

## REFERENCE

**Books:**

[1] A Course in INTERNAL COMBUSTION ENGINES ,By Dr. Prof. V.M. DOMKUNDWAR ,B.E (Osm),ME (Cal),Phd (I.I.T. Madras )

**Papers:**

[1] V.N Banugopan, S.Prabhakar, K.Annamalai, S.Jayaraj, P.Sentilkumar, “Experimental Investigation on D.I. Diesel Engine Fuelled By Ethanol Diesel Blend with Varying Inlet Air

Temperature", Madras Institute of Technology, Anna University 2010 IEEE.
[2] Cenk sayin, "Engine performance and exhaust gas emissionsof methanol and ethanol diesel blend",University of Padova, Dipartomento di Ingegneria Industrial, July 2010.
[3] Eloisa Torres-jimenez, Marta svoljsak , Andreja gregorc, "Physical and chemical properties of ethanol-diesel fuel blends", University of Jaen, C/Alfonso X el Sabio, 23700 Linares (Jaen), Spain, 2011.
[4] Srinivas Padala , Changhwan Woo, Sanghoon Kook , Evatt R.Hawkes, "Ethanol utilisation in a diesel engine using dual-fuelling technology", The University of New South Wales, Sydney NSW 2052, Australia, (2013)597-607..
[5] H.E. Saleh, "Experimental study on diesel engine nitrogen oxide reduction running with jojoba methyl ester by exhaust gas recirculation", Helwan University, P.O. Box 11718, Cairo, Egypt ,fuel 88(2009)1358-1364.
[6] M. Mani, G. Nagarajan , S. Sampath , "An experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation", Anna University, Chennai, India, Fuel 89 (2011) 1826–1832.
[7] Deepak Agarwal , Shrawan Kumar Singh , Avinash Kumar Agarwal , "Effect of Exhaust Gas Recirculation (EGR) on performance, emissions, deposits and durability of a constant speed compression ignition engine", Indian Institute of Technology Kanpur, Kanpur 208 016, India(2012), Applied Energy 88 (2011) 2900–2907
[8] M.S. Abd-Elhady , T. Zornek, M.R. Malayeri , S. Balestrino , P.G. Szymkowicz, H. Müller-Steinhagen , "Influence of gas velocity on particulate fouling of exhaust gas recirculation coolers", University of Stuttgart, Pfaffenwaldring 6, 70550 Stuttgart, Germany, International Journal of Heat and Mass Transfer 54 (2011) 838–846

**Web Site:**

[1] http://en.wikipedia.org/wiki/Ethanol
[2] http://www.ethanolindia.net/
[3] http://www.sciencedirect.com/