EFFECTS OF EXHAUST GAS RECIRCULATION ON EMISSION AND PERFORMANCE OF DIESEL ENGINES

R. P. Pandey, P. Rai, N. Gautam

Abstract

The Exhaust Gas Recirculation (EGR) system is designed to reduce the amount of oxides of nitrogen (NOx) created by the engine during operating periods that usually result in high combustion temperatures. NOx is formed in high concentrations whenever combustion temperatures exceed about 2000K. Exhaust gas recirculation is a very effective technique to reduce NOx emission in diesel engine because it increases the CO2 concentration in combustion chamber which increases the heat capacity of the intake charge, thus there is a reduction in the cylinder peak temperature. Because of the Lower cylinder peak temperature NOx formation reduces. However, particulate emission is comparatively in using EGR technique. With the increase in the recirculated amount of exhaust gas, particulate emission increases and engine loses power. With increasing EGR, soot content and PAN increases in the engine oil of combustion chamber. This increased amount of soot and PAN increases the wear and corrosion of the engine components. The aim of this paper is to study the effect of using EGR on emission and performance in diesel engine. High EGR flow is necessary during cruising and mid-range acceleration, when combustion temperatures are typically very high. Low EGR flow is needed during low speed and light load conditions.

Keywords- Exhaust Gas Recirculation (EGR), oxides, particulate emission.

I. Introduction

In diesel engines, NOx formation is the major issue. NOx formation is a temperature dependentphenomena and it generates when the combustion chamber temperature increasesbeyond 2000K . One very simple way to reduce this NOx emission is late injection of fuel in1the combustion chamber, but it increases the fuel consumption. Exhaust Gas Recirculation(EGR) is more effective technique to reduce NOx emission. In fact, partial recirculation ofexhaust gas, which is not a new technique, has recently become essential, in combination withother techniques, for attaining lower emission levels. There are many reasons for this interest.First reason is the proposals of the future European directive establishes, and even morestringent limits for NOx emissions. Second reason is the further reductions in NOx emissionshave probably become the most difficult target to attain, which can create reverse effect onother recently used techniques, such as high supercharging, an improved mixing process bymore efficient injection systems etc. Third reason is the development of a new generation ofEGR valves and improvements in electronic controls allow a better EGR accuracy and shorterresponse time. Fourth reason is the most common operating conditions, mainly in passengercars, has moved to lower engine loads, owing to the increase in urban traffic density, and itmust be considered that it is mainly at partial loads where EGR is indicated because of itshigher oxygen content. Modern engines implement EGR to reduce NOx. NOx is producedduring the combustion event at high temperatures. Oxygen combines with nitrogen to formNO and NO2. NOx combines with hydrocarbons or volatile organic compounds in sunlight toform SMOG. Since the 1970s, automobiles have used EGR to control NOx production. EGRcontrols NOx by lowering the combustion temperature and reducing the oxygen content in thecombustion chamber. Most EGR is used at cruising speeds with moderate acceleration. Othertimes EGR is turnedoff due to undesirable effects. EGR is effective up to about 15% before itstarts causing misfires or other engine problems. Most EGR systems use a vacuum solenoid toopen and close a valve at the desired times to introduce exhaust gas into the intake system.EGR systems have helped to clean up the air quality of many cities around the world.

II. NOx Formation

In the early 1970s exhaust gas recirculation was introduced, in vehicles, as a means to controlNOx. NOx stands for Oxides of Nitrogen or Nitrogen Oxide. The primary compounds foundin NOx are NO and NO2. Nitric oxide (NO) is the predominant oxide of nitrogen producedinside the engine cylinder. The principal source of NO is the oxidation of atmosphericnitrogen. NOx is formed during the combustion due high temperature. It is generally acceptedthat in combustion of near stoichiometric fuel-air mixtures the principal reactions governingthe formation of NO from molecular nitrogen are, [6]

$O + N_2 \rightarrow NO + N$
$N + O_2 \rightarrow NO + O$
$N + OH \rightarrow NO + H$

NO forms in both fl ame front and post flame gases. Although the amount of NO2 intotal NOx emission is less but still it is around 30% for the diesel engines. The mechanism ofNO2 formation is below, [6]

$NO + HO_2 \rightarrow NO_2 + OH$

Subsequently, conversion of NO_2 to NO occurs,

$NO_2 + O \rightarrow NO + O_2$

NOx in itself is not a huge problem, but what it does in certain areas of the world is.When NOx accumulates in a sunny area in the presence of either Hydrocarbons (HCs) orVolatile Organic Compounds (VOCs), it produces what has been termed SMOG. Theseaccumulations happen in valleys and areas where weather conditions do not easily dispersethe NOx.

III. Implementation of EGR

The implementation of EGR is straightforward for naturally aspirated Diesel engines becausethe exhaust tailpipe backpressure is normally higher than the intake pressure. When a flowpassage is devised between the exhaust and the intake manifolds and regulated with athrottling valve, fig 1, exhaust gas recirculation is established. The pressure differencesgenerally are sufficient to drive the EGR flow of a desired amount, except during idling whilst
a partial throttling in the tailpipe itself can be activated to produce the desired differentialpressure. If the exhaust gas is recycled to the intake directly, the operation is called hot EGR.If an EGR cooler is applied to condition the recycled exhaust, it is called cooled EGR.

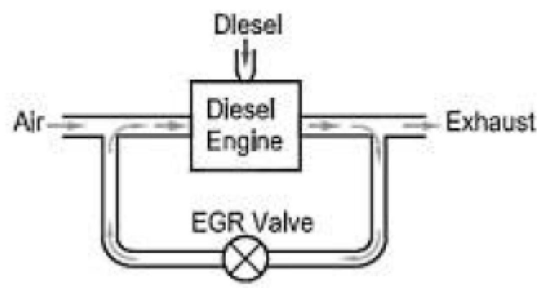

Fig. 1Exhaust gas recirculation [11]

In modern turbocharged diesel engines, implementation of EGR is more difficult. Thereare mainly two types of system used for turbocharged diesel engine: (i) Low pressure loopEGR (fig 2) (ii) High pressure loop EGR (fig 3). A low pressure loop EGR is less favorablethat of the high pressure loop EGR because of the larger volume contaminated with exhaustgas in dynamic operation.

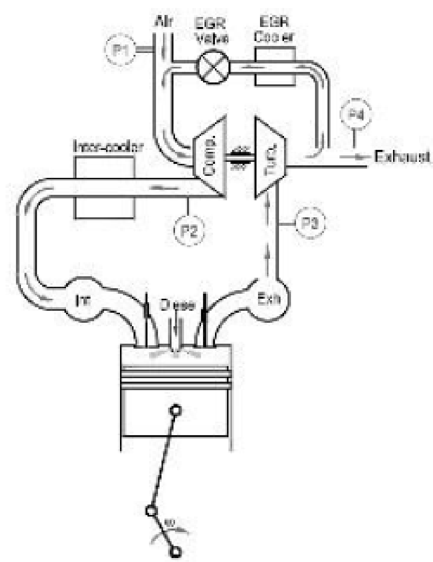

Fig.2 Low pressure loop EGR [11]

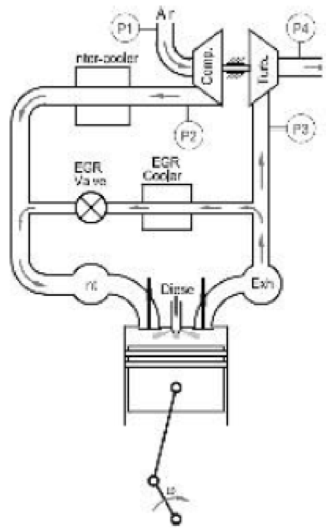

Fig.3High pressure loop EGR [11]

IV. Effects of EGR on Emission and Performance

At present, EGR technique is one of the most effective techniques for reducing NOx emissionin internal combustion engines. There are mainly three explanations of effect of EGR on NOxreduction. First, EGR causes the increase in ignition delay, which has the same effect asretarding in injection timing. Secondly, exhaust gases always contains CO_2, N_2 and moisturecontents. As the heat capacity of EGR is much higher than the fresh air, it increases the heatcapacity of the combustion mixture. Because of this increased heat capacity of the combustionmixture, the peak temperature reduces in the combustion chamber. Subsequently, theformation of NOx reduces because of the lower combustion temperature. Thirdly, the dilutiontheory, it reduces the combustion temperature because of the recirculated saturated gases suchas CO_2, N_2 and moisture. EGR ratio is defined as

$$EGR_{ratio} = \frac{[CO_2]intake - [CO_2]ambient}{[CO_2]exhaust - [CO_2]ambient}$$

Increase in EGR ratio suppresses the rapid burning during premixed combustion andconsequently reduces NOx formation. NOx can be reduced almost in proportion to the EGRratio and that an approximately 50% NOx reduction at a 20% EGR ratio can be achievedwithout much emission of smoke and unburned HC emissions. Diesel engines admit into thecylinders as much air as it is practicable to trap at a given engine running condition. Thus, theapplication of EGR involves displacement of some of the inlet air by EGR. Because of this airdisplacement, there is a reduction in the air available for combustion. Since for a given torqueand power output, the amount of fuel supplied to the engine must be constant, the reduced airavailable for combustion lowers the air fuel ratio at which the engine operates. Thisreduction in air fuel ratio can affect exhaust emissions substantially. When EGR is mixedwith the inlet air supplied to a Diesel engine, the temperature of the inlet charge to the engineincreases, which can significantly affect the compressed charge temperature and thecombustion process. As diesel engines operate with the airflow unthrottled, at part load, theCO_2 and H_2O concentrations in the exhaust gas are low. Because of this, high EGR levels arerequired for significant reductions in NOx emissions. Fig 4 shows how NOx concentrationsdecrease as a DI diesel engine inlet air flow is diluted at a constant fueling rate. The dilutionis expressed in terms of oxygen concentration in the mixture after dilution.

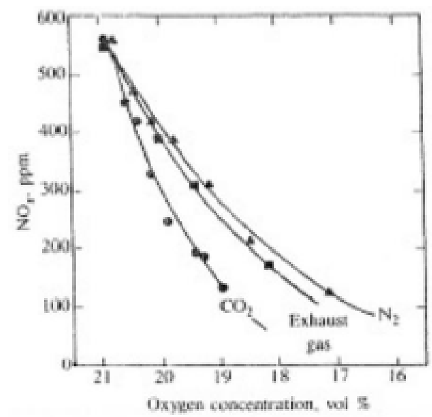

Fig.4 Effect of reduction in oxygen concentration by different diluents (EGR, CO_2, N_2) on NOx emission in DI diesel

NOx emissions are mainly affected by two factors, the presence of oxygen in the chargeand the reaction temperature, which promotes chemical activity during both the formation anddestruction stages. During the formation stage, the reaction temperature is close to theadiabatic ame temperature, which is a consequence of the oxygen concentration in thecharge, the initial temperature and pressure and the local fuel air ratio. EGR reduces theoxygen concentration in the charge and, consequently, the combustion pressure and temperature.

There are mainly two problems in using the EGR technique in diesel engines, increasedsoot emission and introduction of particulate matter into the combustion chamber. Particulatematter abrasion may occur when these high velocity particulate matter come in contact withthe cylinder components. Therefore, there is a necessity to use these EGR with particulatetrap. Because, pores of the particulate trap may clog in regular use, there should beregeneration process for the particulate trap for proper functioning. In another experiment,exhaust gas temperature have been observed with different EGR rate. The experiment wasconducted in a two-cylinder constant speed diesel engine generator set. Fig5, fig6 shows theresults of the experiment.

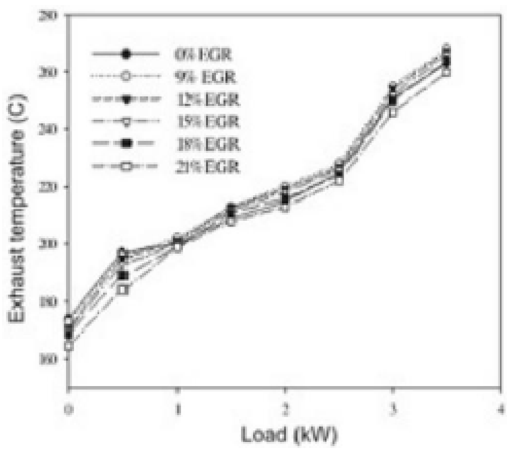

Fig.5 Exhaust gas temperature vs load at constant EGR [3]

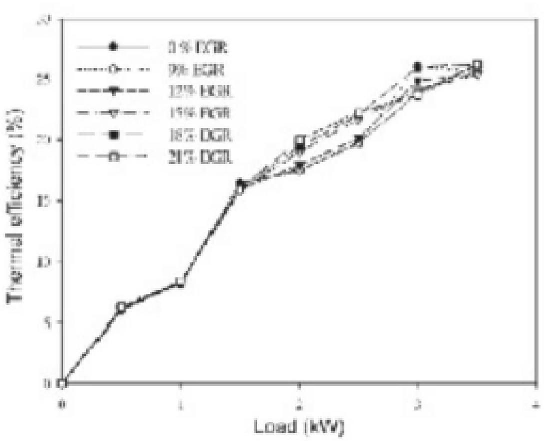

Fig.6 Thermal efficiency vs load at constant EGR [3]

Fig 5 shows the variation of exhaust temperature with load at different EGR rates. It is clearfrom fig5 that the exhaust temperature is decreasing at constant load. It is well known that themost important reason for the formation of NOx in the combustion chamber is extremely hightemperature. Experimental results indicate (Fig. 5) a decrease in the exhaust temperatureswith increasing EGR, therefore it can be safely concluded that the combustion chambertemperatures also decrease and thus the formation of NOx is decreased. Fig.6 shows that thisincrease in temperature does not affect the thermal efficiency of the engine, however, at highloads and at high EGR rates, thermal efficiency decreases slightly.

From the above discussion, it is clear that the application of EGR produces some sideeffects on the performance of diesel engines. EGR includes worsening specific fuelconsumption and particulate emissions. In particular, EGR should run optimally so that propercontrol must be there in NOx and particulate emissions, especially at high loads. Theapplication of EGR can affect adversely the lubricating oil quality and engine durability [2].Also, EGR has not been applied practically to heavy duty diesel engines because wear ofpiston rings and cylinder liner is increased by EGR. It is considered that sulfur oxide in theexhaust gas strongly relates to the wear. Studies showed that the sulfur oxide concentration inthe oil layer is related strongly to the EGR rate [2], inversely with engine speed and decreasesunder light load conditions. It was found that as the carbon dioxide levels are increased due toEGR, the combustion noise levels also increase, but the effect is more noticeable at certainfrequencies. Furthermore, whatever the carbon dioxide content of the intake mixture, it hasbeen observed that as the engine load is increased, the noise levels decrease.

V. Conclusions

Diesel exhaust contains CO2, H2O N2 and O2 in thermodynamically significantquantities and CO, HC, NOx and soot in thermodynamically insignificant butenvironmentally harmful quantities. In modern Diesel engines, the combination of theformer quantities normally comprise more than 99% of the exhaust, while the latercombination, the pollutants, accounts for less than 1% in quantity. Thus, the challenge is to minimize the pollutants by manipulating the thermodynamic properties and the oxygen concentration of the cylinder charge whilst keeping minimum degradations in power and efficiency, which is the principal reason to apply Diesel EGR. Although EGR is a very good technology for controlling the NOx emission but soot concentration and TAN (Total acid number) increases in the combustion chamber using EGR. This increased soot concentration and TAN may damage the enginecomponent by wear and corrosion rapidly.Exhaust temperature decreases with the increased EGR rate for constant loadcondition. It means the peak temperature is also lower in combustion chamber, whichreduces NOx emission.

Nomencalture

NOx -Nitrogen oxide, NO- Nitric oxide, HC-Hydrocarbon, CO-Carbon monoxide, CICompressionignition, NO2-Nitrogen dioxide, NH3 -Ammonia, Pt-Platinum, HCN-Hydrogencyanide,O2 _Oxy-gen, H2 _Hydrogen, N2-Nitrogen.

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