Enhancing the Power Output of an IC Engine using Exhaust Gas Recirculation System with A Turbocharger

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Abstract- Nitrogen oxide (NOx) emissions can be reduced using internal engine technology by cooling some of the exhaust gas, which is then redirected back into the charge air. This results in the reduction of the combustion temperature and less nitrogen oxide is produced. This process is known as exhaust gas recirculation (EGR) and is one of the principal methods used to reduce nitrogen oxide emissions from diesel engine. Diesel engines function on lean mix, which is one that contains a high quantity of air to a low proportion of diesel fuel. This associated with the high temperatures that predominate in the engine combustion chamber, leads to the appearance of nitrogen oxides (NOx). By re-injecting some of the exhaust gases into the fresh air that the air intake circuit supplies to the engine, EGR reduces their formation. This works because recirculation of exhaust fumes slows down the combustion of the mixture and absorbs some of the calories. The aim of the paper is to represent the idea about the improvement of the exhaust gas recirculation system. A quantity of exhaust gas is redirected as it exits the engine, just upstream of the turbocharger turbine. A by-pass valve first makes it possible to maintain the gas during the priming phase of the catalyzer and then cool it as soon as the catalyzer is operational. An electric motor controls the EGR valve allowing it to assume any intermediate position between fully closed and fully open. As a result, the computer can command a greater or lesser degree of opening of the EGR valve in order to very precisely proportion the quantity of exhaust gas re-injected into the engine air circuit supply. This injection is carried out at the entry to the engine, downstream from the turbocharger.

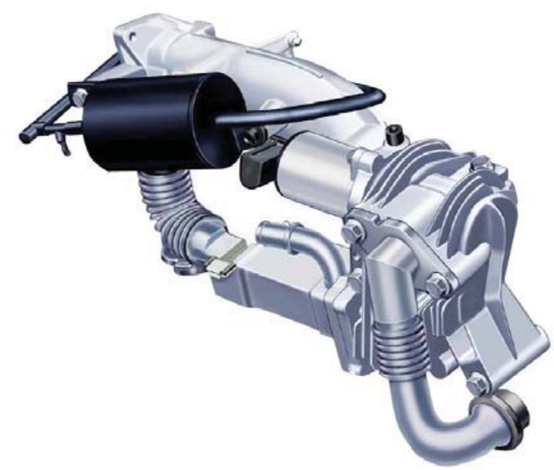
Keywords – Nitrogen oxide (NO_x), diesel engine, exhaust gas, turbocharger

I. INTRODUCTION

The worldwide focus on environmental issues, such as NOx emissions, smoke and particulate emissions emitted from automotive diesel engines and their influence on human health and acid rain, as well as legal legislations, has encouraged in the invention of new technology and the entire engine industry, to study NOx-reduction technologies more closely. The type of emissions from diesel combustion are namely carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), particulate matter and oxides of Nitrogen (NO_X). The NOx emissions from diesel engines still remain high. To achieve the requirements of environmental legislations, it is necessary to reduce the amount of NOx in the exhaust gas. NOx formation takes place in the combustion chamber when the temperature reaches 2000 K. During the recent years several alternative methods for controlling gas emissions from large, two stroke diesel engines have been developed, tested and evaluated. NOx emission can be reduced by Fuel Water Emulsion (FWE), High-pressure Water Injection, Exhaust Gas Recirculation (EGR), Scavenge Air Moistening (SAM) and Low NOx Fuel Injectors. Among all exhaust gas recirculation systems (EGR) **[fig-1]** have become very effective in reducing NOx.

Therefore in order to reduce NOx emissions, it is necessary to keep peak combustion temperatures under control. One simple way of reducing the NOx emission of a diesel engine is by late injection of fuel into the combustion chamber. This technique is effective but increases fuel consumption by 10–15%. Exhaust gases have already burnt, so they do not burn again when they are recirculated. These gases displace some of the normal intake charge. This process is used to slow down chemically process and for cooling the combustion process by several hundred degrees, thus reducing NOx formation. So EGR is the most efficient technique among others.

There are two types of forced induction systems, like supercharging and turbocharging. The performance of an internal combustion engine can be increased by adding turbocharging. The turbocharger **[Fig-2]** is driven by exhaust gas. A turbocharger compresses the air so that more oxygen flows into the combustion chamber. In this way, more fuel is burned and the power output of the engine increases accordingly. By using this technology fuel settings are increased with better combustion and quieter exhaust**.** Improved combustion means not only better fuel economy, but also cleaner exhaust emissions.



(Fig-1) EGR System, EGR

(Fig-2) Turbocharger
Source: Renault Communication

By using both the equipment's EGR and turbocharger, the engine efficiency can be increased to a greater extent. The paper is fully based on this concept.

II. EXHAUST GAS RECIRCULATION SYSTEM

In order to meet with the increasingly tough emission standards worldwide, engine manufacturers are forced not only to substantially reduce emissions of soot particulates (PM), but also emissions of nitrogen oxides. Nitrogen oxide (NO_x) emissions can be reduced using internal engine technology by cooling some of the exhaust gas, which is then redirected back into the charge air. This results in the reduction of the combustion temperature and less nitrogen oxide is produced. This process is known as exhaust gas recirculation (EGR) **[Fig-3]** and is one of the principal methods used to reduce nitrogen oxide emissions from diesel engines.

There are 3 basic parts of EGR

a) EGR Valve
b) EGR Cooler
c) EGR Transfer Pipe

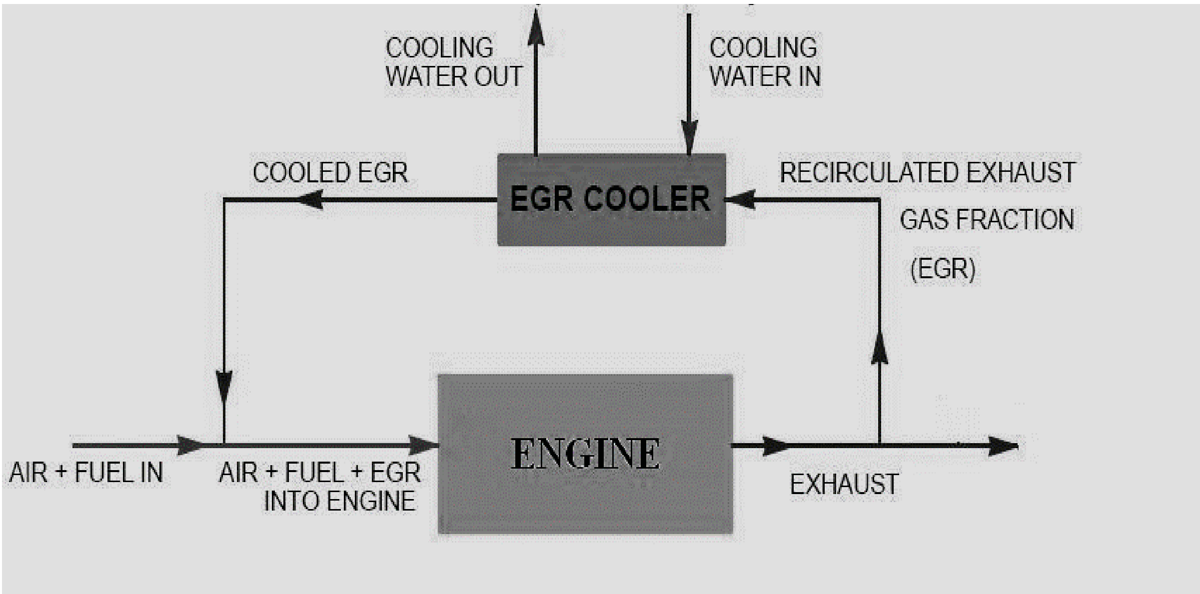


Fig 3. Schematic diagram of an engine with egr cooler

A. Formation of NO_x

NO and NO_2 are combinely called as NOx, there are some differences between these two pollutants. NO is a colourless and odourless gas, while NO_2 is a reddish brown gas with pungent odour. Both gases are considered toxic, but NO_2 has a level of toxicity 5 times greater than that of NO. Although NO_2 is largely formed from oxidation of NO.

NO is formed during the after flame combustion process in a high temperature region. The most widely accepted mechanism was suggested by Zeldovich (Heywood 1988). The principal source of NO formation is the oxidation of the nitrogen present in atmospheric air. The nitric oxide formation chain reactions are initiated by atomic oxygen, which forms from the dissociation of oxygen molecules at the high temperatures reached during the combustion process. The principal reactions governing the formation of NO from molecular nitrogen are,

$$\mathbf{N_2 + O \rightarrow NO + N;}$$
$$\mathbf{N + O_2 \rightarrow NO + O;}$$
$$\mathbf{N + OH \rightarrow NO + H;}$$

NO formed in the flame zone can be rapidly converted to NO_2 via reactions such as,

$$\mathbf{NO + HO_2 \rightarrow NO_2 + OH}$$

Subsequently, conversion of this NO_2 to NO occurs via,

$$\mathbf{NO_2 + O \rightarrow NO + O_2}$$

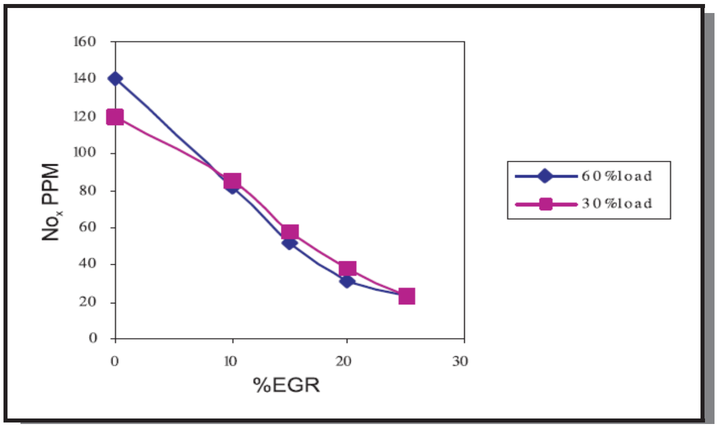
Unless the NO2 formed in the flame is quenched by mixing with cooler fluid.

Basic principle that governs the process of combustion, if the fuel burns at a higher temperature inside the cylinder, little soot is produced, but a large amount of nitrogen oxide. At lower combustion temperatures, nitrogen oxide emissions are low, but the production of soot particulates is high. The use of exhaust gas recirculation results in a combustion process that produces significantly lower levels of nitrogen oxide.

B. EGR TECHNIQUE FOR NOX REDUCTION

EGR is a useful technique for reducing NOx formation in the combustion chamber. Exhaust consists of CO_2, N_2 and water vapours mainly. When a part of this exhaust gas is re-circulated to the cylinder, it acts as diluent to the combusting mixture. This also reduces the O_2 concentration in the combustion chamber. The specific heat of the EGR is much higher than fresh air, hence EGR increases the heat capacity (specific heat) of the intake charge, thus decreasing the temperature rise for the same heat release in the combustion chamber.

At fixed power conditions, as the percentage EGR increases (0–21%), the temperature of the exhaust gas continuously decreases. This is shown in **figure 4**.



(Fig-4) Effect of EGR on NOx (Source: Mehta *et al* 1994)

C. TURBOCHARGER WITH EGR SYSTEM

The EGR process used is based on the recirculation of exhaust gas on the engine side of the turbocharger **[Fig- 5]**. Part of the exhaust gas is recirculated from the exhaust-gas receiver to the air cooler system. An electrical, high-pressure blower forces the exhaust gas (3.3 bar) to the higher-pressure air cooler (3.7 bar). The exhaust gas is cleaned by removing SOx and particulates and also cools it through humidification before reintroduction to the EGR cooler. The resultant NOx-reducing effect is due to part replacement of the oxygen by CO_2, which reduces the maximum peak temperatures due to deceleration of the combustion.

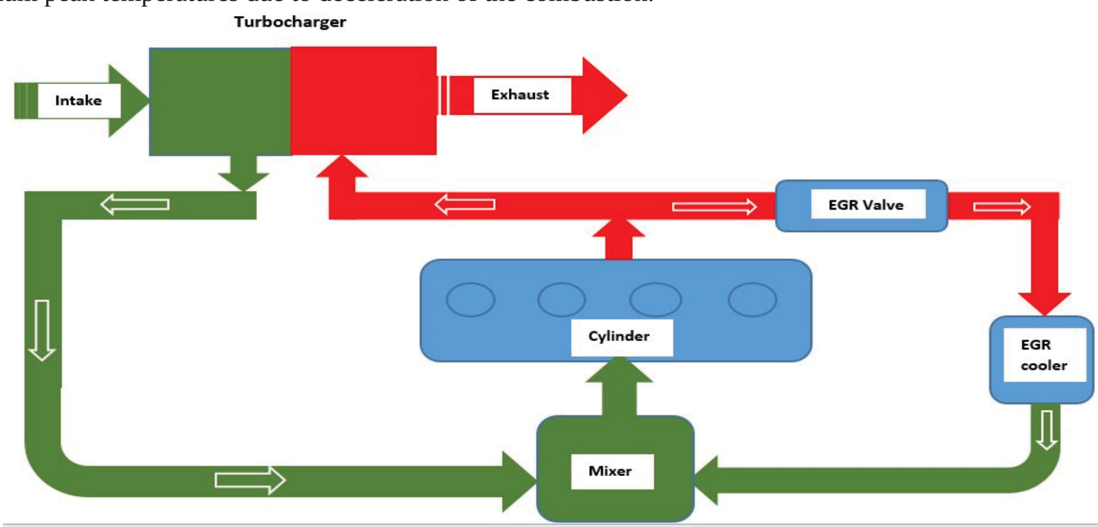
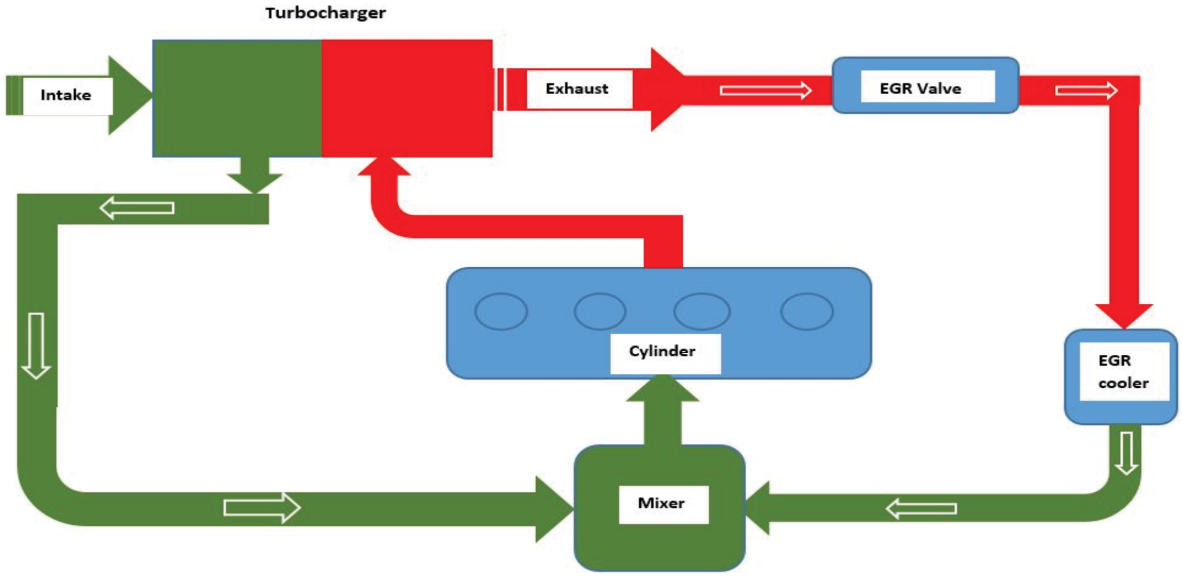


Fig-5: EGR system connected directly with the exhaust

D. MODIFIED DESIGN AND ITS ADVANTAGES

The pressure of the exhaust gas from the engine is high. In the previous design the turbocharger is connected with EGR then the pressure decreases and it may not enough to run the turbocharger efficiently. To overcome this limitation the turbocharger is directly connected with the exhaust section and it will run more efficiently and also run the compressor at high rpm. The exhaust emitted from the turbine section is connected with the EGR unit inlet, which is connected to the inlet port of the diesel engine to increase inlet pressure of the air as shown in **Fig-6**. So ultimately the engine efficiency increases.



(Fig-6) Diesel engine with both EGR Systems connected to the outlet of the Turbocharger

III. RESULTS AND DISCUSSION

Previously it is mentioned that the most important reason for the formation of NOx in the combustion chamber is extremely high temperature. In the EGR system the temperature of the exhaust gas is reduced and recirculated to the inlet of the engine. Therefore it is concluded that the combustion chamber temperature also decreases and thus the formation of NOx is reduced.

EGR (Exhaust Gas Recirculation) has shown perfect results in reducing diesel-engine NOx emissions for years and is commonly used in trucks. Reductions of up to 60% have since been achieved in trucks. 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.
Turbocharger helps at high altitudes, where the air is less dense. Normal engines will experience reduced power at high altitudes because for each stroke of the piston, the engine will get a smaller mass of air. The combined use of Turbocharger with the EGR system increases the engine efficiency significantly.

The wide use of cooled EGR on heavy-duty engines attracted the attention of the technology took place in late 2002 in the North American market. NOx limit and EGR can sometimes be used as one of several alternative technologies and there is a competition between cooled EGR and urea-SCR (selective catalytic reduction) technology in heavy-duty Euro IV, Euro V and US 2010 diesel engines. However, to meet NOx emission limits, it is necessary to use EGR in combination with NOx reduction catalysts. Commercial applications of EGR on diesel engines are presented in the following [**Table -1]**.

Table no. 1: Application of EGR system on Diesel Engines (Source: Dieselnet technology Guide)

Emission Legislation	NOx Limit	Areas of EGR Application
Light-Duty Vehicles		
Euro 1/2 (1992/96)	NOx + HC = 0.97-0.7 g/km	Introduced in DI and larger IDI Euro 1 engines, EGR (non-cooled) became the main NOx reduction strategy in nearly all Euro 2 vehicles.
Euro 3/4 (2000/05)	NOx= 0.5-0.25 g/km	Cooled EGR introduced in larger size Euro 3 engines, and became the standard in Euro 4 and later diesel passenger cars and light trucks.
Heavy-Duty Engines		
US 2004 (2002-04)	NOx ≈ 2 g/bhp - hr	Cooled EGR introduced on heavy-duty truck and bus engines by most manufacturers (Cummins, Volvo/Mack, DDC, International). Miller-type intake valve timing was the alternative technology to EGR (Caterpillar).
Euro IV (2005)	NOx = 3.5 g/kWh	EGR introduced by some manufacturers of Heavy - duty truck and bus engines (Scania, MAN); used in competition to urea-SCR technology.
Japan 2005	NOx = 2.0 g/kWh	EGR introduced by some manufacturers of heavy-duty truck and bus engines (Hino, Isuzu); used in competition to urea-SCR technology.
US 2007	NOx ≈ 1 g/bhp-hr	EGR used on heavy-duty truck and bus engines by all manufacturers.
Euro V (2008)	NOx = 2 g/kWh	EGR continues to be used in some products by several OEMs (Scania and MAN), however, no OEM relies solely on EGR.
US 2010	NOx = 0.2 g/bhp-hr	EGR combined with NOx credits allows one heavy-duty diesel engine manufacturer (Navistar) to certify engines to a 0.5 g/bhp-hr NOx level. All other manufacturers rely on a combination of EGR and urea-SCR.
Non-road Engines		
US Tier 3 (2006)	NOx = 4.0 g/kWh	Cooled EGR engines introduced by John Deere. A number of other manufacturers used internal EGR.
US Tier 4i / EU Stage IIIB (2011)	NOx = 2 g/kWh	Cooled EGR introduced by a number of non-road engine manufacturers; used in competition to urea-SCR technology.

IV.CONCLUSION

Exhaust Gas Recirculation with turbocharger is an innovative one to increase engine efficiency. This method is very reliable in terms of fuel consumption. High degree of recirculation suppressed the presence of the turbocharger. Engine performance is obtained with a substantial reduction in the emissions of NO_x were accomplished only with proper selection of degree of the recirculation, proper spark timing and a specific value of air-fuel ratio.

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