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Exhaust Gas Recirculation (EGR) – Effective way to reduce NOx emissions

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Review Article

Abstract

This paper gives insight into usage of water cooled Exhaust Gas Recirculation (EGR) for a twin cylinder direct injection compression ignition engine to reduce oxides of nitrogen (NOx) emission from engine exhaust. Different rates of EGR from 5% to 20% in step of 5% are used for varying loads from 25% to 100% in step 25% each. From the experimental investigation it is concluded that usage of EGR will decrease NOx formation inside the combustion chamber and it decreases with increase of EGR rates and Loads. The maximum reduction is around 80% for full Load condition at 20%EGR rate when compared against without EGR condition.

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1. Introduction

Concern over health and global warming has made the policy makers to implement most stringent emission norms and set regulations for automobile industry to introduce cleaner vehicles. Mean time the share of diesel vehicles in the market is continuously rising due to their higher fuel efficiency and also available of subsidized biodiesel in some countries. Emission of NOx and Particulate matter (PM) is high in case of diesel engines. Hence there is growing need to explore all possibility to control these emissions. The usage of after treatment devices for reduction of NOx emissions is a costly affair, so study of some in cylinder strategy like EGR to control emissions is one of the option [1-2, 7].

1.1 Nitrogen Oxides (NOx) Formation

Nitric oxide (NO) and nitrogen oxide (NO2) combined together is called oxides of nitrogen and due to high temperature prevailing inside combustion chamber assists in combining the species nitrogen and oxygen together. Henceforth high mean gas temperatures and oxygen availability are the two important causes for the creation of NOx. Kinetics of NOx generation is governed by Zeldovich mechanism, and its materialization is vastly dependent on temperature and availability of oxygen [3-7].

Three probable sources of NOx formation are I.ThermalNOx II. Fuel NOx, III. Prompt NOx

The first type of source i.e Thermal NOx is generated at very high combustion temperatures, commonly above 2000°C and this is due to oxidation process of the diatomic nitrogen originated from combustion air. Thermal NOx is the principal source associated to other type in I C engines and is largely reliant on temperature of combustion and the residence time at that temperature. The second type of source Fuel NOx is generated when the nitrogen arising from fuel structure combine together with the oxygen in the air. Prompt NOx is formed during earlier phase of combustion due to chemical reaction of atmospheric nitrogen with radicals in the air [5].

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1.2 Diesel After treatment Systems

After-treatment devices minimize emission pollutants from the engine exhaust and foremost methods have concentrated on reducing emissions of nitrogen oxides (NOx), namely

Lean NOx trap (LNT)

This technique stores NOx during lean conditions and removes them in rich conditions with the help of expensive materils such as Barium and Platinum plated on the surface of the substrate. CO and THC are also used as reductants to convert the NOx into N2, CO2 and water during fuel-rich operation.

Selective catalytic reduction (SCR)

Selective catalytic reduction (SCR) systems usually ammonia or aqueous urea solution as a NOx reduction agent, here NOx is converted into to nitrogen and oxygen in the exhaust stream for mobile source applications. A brief view technologies used for NOx reduction in C I engines are as shown in Fig.1 [7].

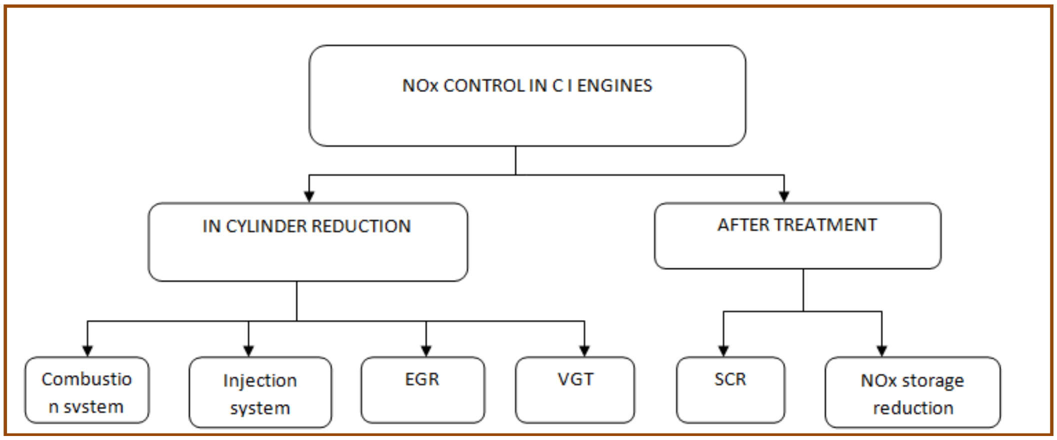

Fig. 1 *Technologies used for NOx reduction in C I engines*

2. Exhaust Gas Recirculation (EGR)

EGR technique has been used to suppress NOx formation and is one of today's most common emissions control systems. Here exhaust gases are reintroduced into the engine intake air, diluting the fuel-air mixture in the combustion chamber and increasing its heat capacity, this reduces the temperature rise during combustion. NOx formation is suppressed in combustion environments with EGR because peak temperatures are kept below 3000^0C, the temperature above which NOx is readily formed.

Diesel engines are generally lean burn systems and operate at much leaner (excess air) fuel- air ratios than spark-ignition engines. Hence diesel engines must use much higher proportions of re-circulated exhaust gases in the intake air, especially at lower loads when the fuel-air mixtures contain the largest amount of excess air. To control both NOx and PM emissions accurately, the amount of re-circulated exhaust gas and air entering the engine must be controlled precisely under all operating conditions at different load conditions [3].

For conventional naturally aspirated Diesel engines the implementation of EGR is straight forward because the exhaust tailpipe backpressure is normally higher than the intake pressure. When a flow passage is devised between the exhaust and the Intake manifolds and regulated with a throttling valve exhaust gas recirculation is established [6].The pressure differences generally 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 differential pressure. If the exhaust gas is recycled to the intake directly as in Fig. 2a, the operation is called hot EGR. If an EGR cooler is applied to condition the recycled exhaust as shown in Fig. 2b, it is called cooled EGR, but most modern diesel engines, however, are commonly turbocharged, and the implementation of EGR is, therefore, more difficult. Depending on applications a low pressure loop EGR and high pressure loop EGR are used [6].

Most current diesel engines operate with cooled EGR systems. These systems use a heat exchanger to reduce exhaust gas temperatures before introduction into the intake system, resulting in higher EGR rates and lower combustion temperatures, which results in even lower NOx formation. Despite their additional cost cooled EGR systems are becoming increasingly common owing to more stringent emissions regulations.

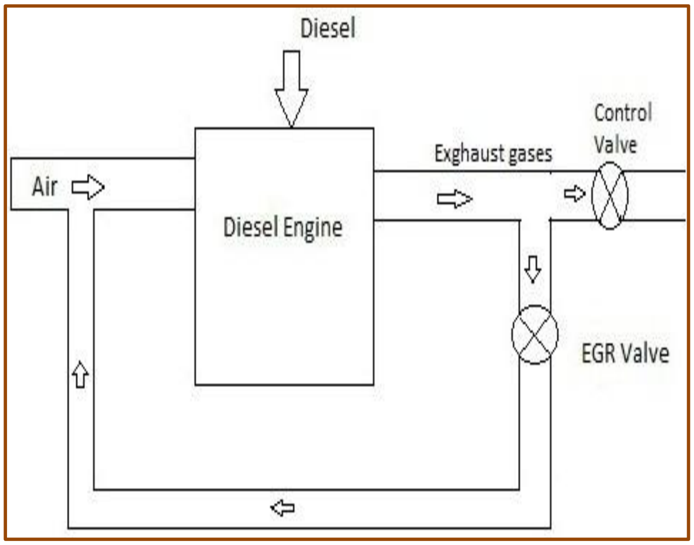

Fig. 2 (a) *Exhaust gas is recycled to the intake directly*

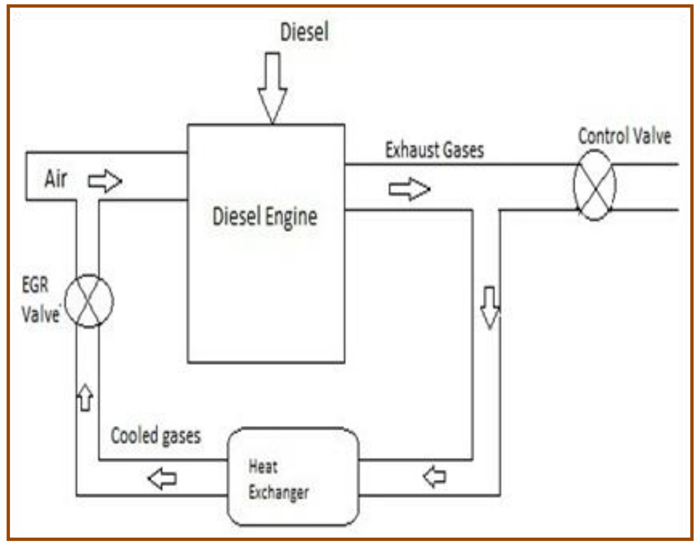

Fig. 2 (b) *EGR cooler is applied to condition the recycled exhaust*

3. Experimental Setup and Methodology

Naturally aspirated twin cylinder 4 stroke C I Engine is used for conducting the experiments. The detailed specification of the engine is given in Table 2 and experimental set up is shown in figure 3. A 44 kW capacity engine is coupled with alternator for load measurement from 0% to 100%. AVL DI Gas 444 gas analyser was used for exhaust gas analysis and its detailed specification shown in table 1. Fraction of cooled exhaust is reintroduced into intake manifold by use of the EGR valve. Engine was started at ambient temperature condition; engine speed at the end of full load condition was about 2000 rpm. EGR was varied in step of 5%, up to 20%. Engine load varied from zero to 100% in step of 25% each. All necessary readings were noted to study the effect EGR on NOx emissions of a diesel engine.

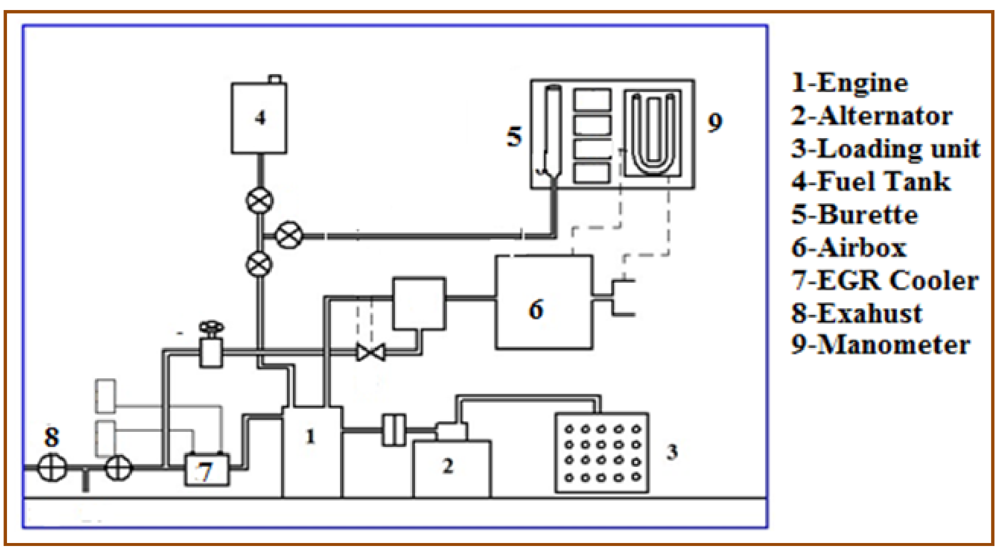

Fig. 3 *Experimental set up*

4. Results and Discussion

From the Fig. 4(a-d) it is clear that there is a drastic reduction in NOX emissions from engine with increase of Load and EGR rate. The highest reduction is at 20% EGR rate for all load conditions and the maximum reduction occurs at 100% Load. The possible reason for less NOx Emissions compared against without EGR condition may be due toreduced oxygen concentration with re-introduction of exhaust gases into the engine intake air which dilutes the fuel-air mixture in the combustion chamber and increases its heat capacity, thereby reducing the temperature rise during combustion. Also NOx formation is suppressed in combustion environments with EGR because peak temperatures are kept below 3000^{0}C, the temperature above which NOx is readily formed.

Table 1 Engine details

Parameter	Specification
Method of cooling	Air cooled with axial fan
Bore x Stroke (mm)	87.5 x 110
Compression ratio	17.5:1
Injection timing	15^0 before TDC
Injection pressure	200 bar

Table 2 Analyser details

CO	0-10 %Vol.	HC	0- 20000 PPM
CO2	0-20 %Vol.	O2	0- 22 %Vol.
NO	0-5000		
Table 2 Analyser details		Measured Item	Measurement range
CO	0-10 %Vol.	HC	0- 20000 PPM
CO2	0-20 %Vol.	O2	0- 22 %Vol.

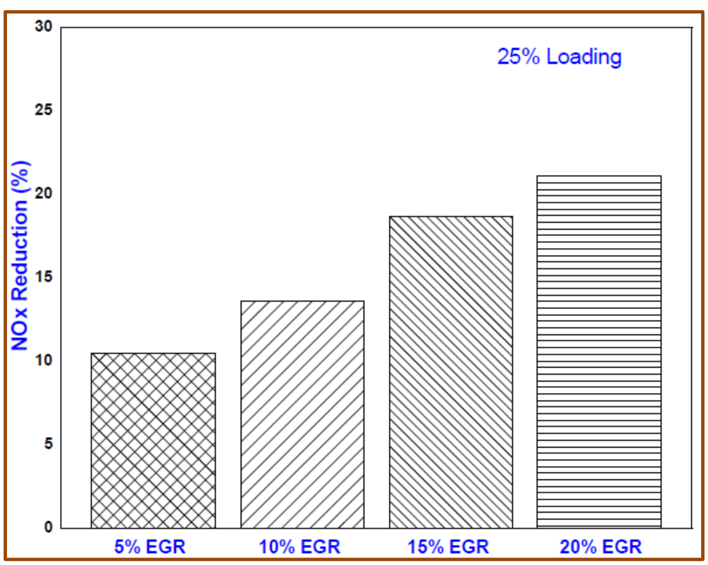

Fig. 4 *(a) NOx reduction for different EGR at 25% load*

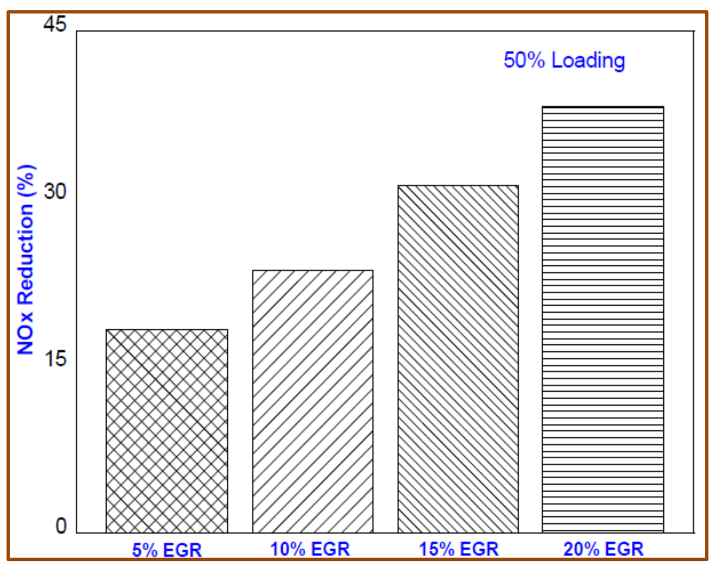

Fig. 4 *(b) NOx reduction for different EGR at 50% load*

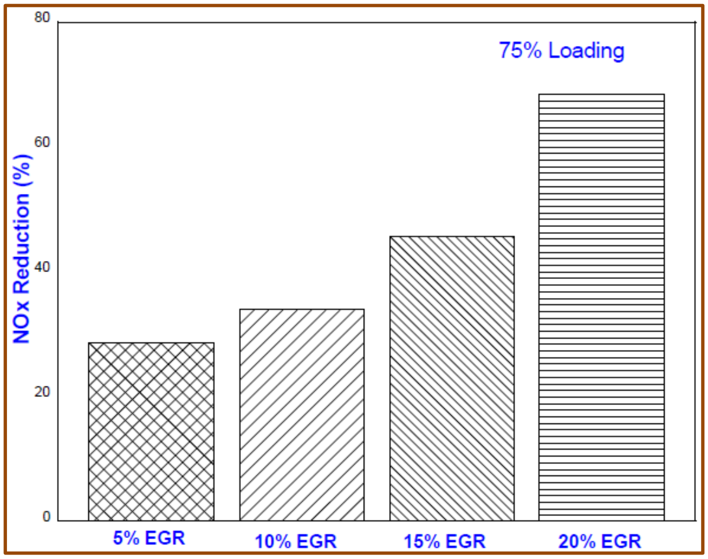

Fig. 4 *(c) NOx reduction for different EGR at 75% load*

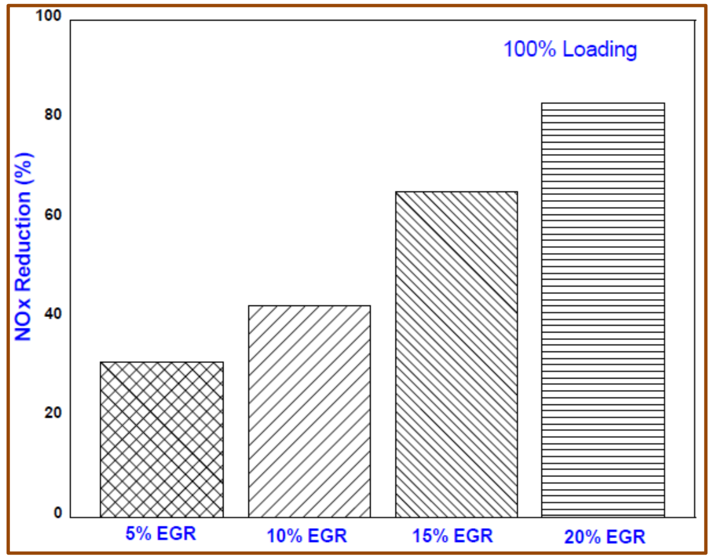

Fig. 4 *(d) NOxreduction for different EGR at 100% load*

5. Conclusion

Exhaust Gas Recirculation (EGR) is one of the simple technique that can be applied easily to suppress NOx formation. EGR dilutes the oxygen concentration in combustion chamber thereby reducing temperature below that of NOx formation zone resulting in reduced oxides of nitrogen. Usage of engine exhaust gas after treatment systems are economically burden to end users, hence instead of after treatment systems, EGR can be used.

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