PERFORMANCE AND EMISSION OF A SINGLE CYLINDER STATIONARY DIESEL ENGINE WITH EXHAUST GAS RECIRCULATION

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ABSTRACT

In today's modern world the internal combustion engine has a predominant role in stationary low power generation and a virtual monopoly in mobile applications. Concentrations emitted from the internal combustion engines thus build up to levels sufficient to have adverse effects on plants and animals. From the literature we find that any technique employed to mitigate emissions has adverse effect on the performance. EGR is considered as a most efficient method to reduce the NOx exhausted. This method is employed to a single cylinder naturally aspirated DI diesel engine. The test is carried for different injection pressures and percentage of exhaust gas recirculation. Its effect on engine performance except for the smoke measurement is presented in this paper. There is a remarkable reduction in the NOx concentration but a marginal reduction in brake power and thermal efficiency are also observed.

***Keyword**: EGR, NOx, Thermal Efficiency, injection pressure*

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I. INTRODUCTION

1.1 Stationary Diesel Engines Indian Scenario

Diesel engines used either for stationary applications like captive power generation especially in remote locations or during electrical power failures or as prime movers like for pumps, harvesters, threshers, expellers, flour mills etc (**Table.1**). Diesel engines with power less than 20 hp used primarily for agricultural machinery, irrigation purposes and more than 20 hp mainly used for power generation. Not all Indian products meet international standards, International emission norms. Future outlook are based on electricity demand supply gap, currently at 8%, likely to continue. Hence a growth rate of 8-10% expected in the industry. Emphasis shifting to environment friendly that is less polluting that meets stringent emission requirements.

1.3 Diesel Emissions

During the combustion process of a diesel engine, chemical energy is converted into mechanical energy at high temperatures and under high pressure. A variety of combustion products are formed when diesel fuel is burnt. These are typically carbon monoxide, hydrocarbons, nitrogen oxides and fine particles. For diesel combustion the most important stack emissions are NO_X, particulates and SO_2.

Table.1 Diesel Engine Applications

Segment	Capacity	Application Areas
Small range	2-20 HP	Pump sets, agricultural machinery, water pump sets, threshers, harvesters, and oil expellers
Medium range	20-25 HP	Tractors, power gensets, industrial applications
	25-140HP	Power generation, industrial applications and others.
Large range	140-400HP	Power generation(captive standby sets), industrial application
	400-750HP	Power generation and marine applications
Very large range	750-1200HP	Power generation
	1200-7200HP	Power generation (base load) and marine applications.

Control measures are necessary to reduce emissions of diesel particulate matter (PM) and oxides of nitrogen (NOx) that cause adverse health effects. Exposure to diesel PM may result in both cancer and non-cancer health effects. Non-cancer health effects may include eye and lung irritation, allergic reactions in the lungs, asthma exacerbation, blood toxicity, immune system dysfunction, and developmental disorders. NOx has been shown to have adverse health effects like respiratory irritant, immunosuppressant, and asthma exacerbation in humans.

1.4 Emission Regulations

Standards for permissible levels of emissions are always based on realistic assessment of costs and benefits, keeping in view the technical and administrative feasibilities. There are three major regulatory programs around the world, the United States, the European Union and Japan. Each has unique test procedures for different vehicle categories, as well as different emission standards. Other countries have mainly adopted these norms with some combinations and a schedule for implementation to suit their conditions. Today, emission legislation for stationary reciprocating internal combustion engines is regulated primarily on a national level, e.g. national legislation or guidelines on specific emission limits can be found in Japan, South Korea, Taiwan, UK, France, Germany, Italy, Portugal, Ecuador, Finland and in India as well. The most effective emission legislation is based on an environmental quality need approach taking into account both environmental and cost aspects.

2. EMISSION CONTROL METHODS

The commonly used term NOx includes the compounds nitrogen oxide (NO) and Nitrogen dioxide (NO_2). Although NO is primarily generated during combustion, subsequent oxidation results in the formation of (NO_2). The reduction of particulate emissions is typically addressed through either internal measures, such as improved mixture preparation and formation or the application of external particulate traps. Potential measures for NOx reduction include retarded fuel injection timing; exhaust gas recirculation (EGR), active or passive lean NOx catalysts, SCR and NOx adsorber catalysts, as well as non thermal plasma.

2.1 EGR and NOx Control

One of the simplest but very effective means to particularly reduce NOx emissions is the application of EGR. During this process, a portion of the exhaust gas is reintroduced into the intake air and induced back into the engine. This technology has been applied successfully on high-speed diesel and gasoline engines in passenger car applications for more than a decade.

The most critical parameters contributing to the formation of NOx is local combustion temperature, which is directly a function of several hardware and operating parameters such as; load, compression ratio, boost level, charge temperature, injection timing, mixture formation (nozzle configuration, etc.) cylinder peak pressure, cetane number, etc. The higher the combustion temperature inside the cylinder during combustion, the more energy is available to split the strong triple-bonding between the atoms of the molecular nitrogen of the combustion air to generate atomic nitrogen chain carriers resulting in NO formation.

The second most critical parameter is oxygen content or availability, which is a required participant of the chemical reaction which results in the formation of nitrogen oxide. Due to the air distribution inside the cylinder during combustion, it has to be taken into account that it is the local relative air/fuel ratio (λ) which influences the NOx formation and not the overall λ value.

The third most important parameter is time. Only a short period of time is available to the NO formation process, since the most critical gas temperatures are achieved between the start of combustion and shortly after the occurrence of peak cylinder pressure. However, investigations have shown that the formation process of NO takes place in the post-flame area, providing a sufficient amount of time for the NO formation reaction. Nevertheless, the chemical equilibrium in the NO formation process can never be achieved. Once the gas temperature decreases due to the expansion process, the NO chemistry is frozen between 2000 to 2200 K. The most common process describing the NO formation is the **Zeldovich mechanism**, which consists of two bimolecular exchange reactions. During the NO formation process, the concentrations of the individual chain carriers O and N are low:

$[O_2] + N \rightarrow NO + O$

$[N_2] + O \rightarrow NO + N$

During the application of EGR, the recirculated exhaust gas, which is reintroduced into the combustion chamber to participate in the combustion process for a second time, significantly changes the composition of the cylinder charge. The introduction of an inert gas results in a lower combustion peak temperature since it does not participate in the combustion, as would a fresh gas such as air. This is primarily based on the significantly increased CO_2 content and its much higher specific heat capacity when compared to N_2, resulting in lower local peak temperatures and therefore reduced NOx formation. Furthermore, the EGR fraction displaces fresh oxygen, making less available for combustion and therefore reducing the probability of interaction between nitrogen and oxygen atoms even under lean conditions.

3. EXPERIMENTAL METHOD

3.1 Experimental Set Up

Modification to existing engine is done to facilitate routing of measured exhaust gas back in to engine inlet. GI pipes and three way valves are used to pass the exhaust through two heat exchangers for hot and cooled EGR modes. Data acquisition systems (DAS) were used for recording engine measurements. At steady state conditions, the low-speed DAS was used to record various engine temperatures, pressures, and engine out emissions. Data acquisition system enables computerized measurements. Indus five gas analyzer* is used for emission measurements. The Lay-out is shown in the **Fig. 1**

Table.2 Experimental Engine

Make	Kirloskar AV-1
Type	Single Cylinder Diesel Engine, PC Based
Loading	Electrical, Resistive Heater
Rated	3.7 kW,1500rpm
Bore and Stroke	85mmX110mm
C. R.	16.5:1

Cylinder capacity	624.19cc
Dynamometer	DC machine with swinging field
Cylinder Pressure	Piezo censor, range:20000psi, Ajay Sensors Make
Starting	Auto Start
Orifice Diameter (air flow)	15mm

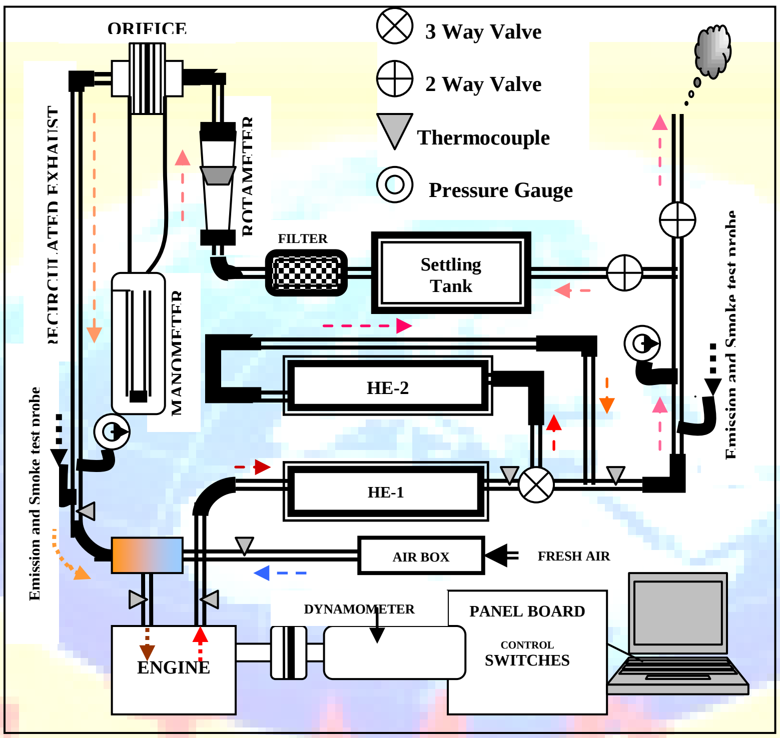

Fig.1 Schematic of experimental set up.

4. ANALYSIS AND INTERPRETATION

In this experiment, a percentage of the exhaust gases which varies between 0-50% and consists mainly of N_2, CO_2, H_2O and O_2 is recycled to the intake system to dilute the fresh mixture for control of NOx emissions. Although a number of papers have been written on various aspects of EGR, there are still unresolved questions especially in the case of practical EGR levels and Composition in engines with nearly production geometries operating at realistic speed and load and using commercial fuel injection systems. A summary of the findings concerning the effects of EGR on combustion and emissions is given below:

1. A wide experimental parametric study, focused on the operating conditions with EGR, showed that this technique provides significant reductions on NO*x* emissions (**Fig.2)**, and therefore, it may be useful for achieving future regulations in the tested type of engines, despite the associated increase in particulate emissions, which should be predicted from the observed increase on smoke emissions (not presented in this paper).

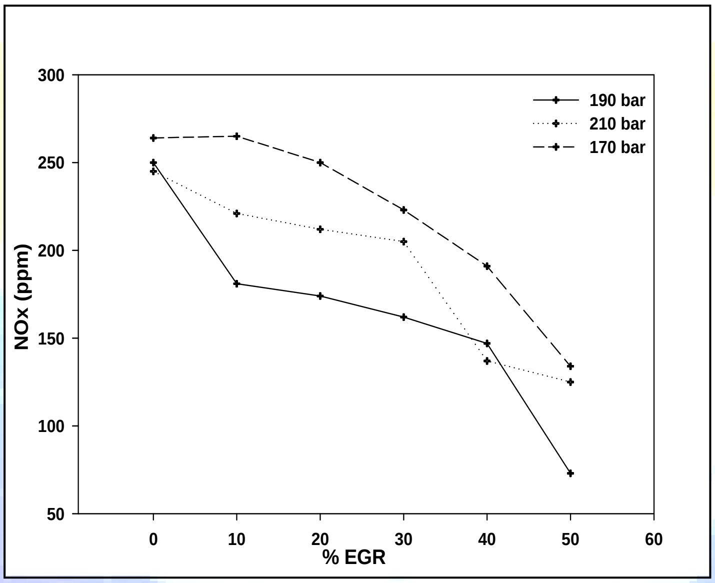

Fig. 2. Reduction in NOx concentrations with increased EGR percentage.

2. The reduction of NO*x* emissions with EGR can be mainly explained by the reduction of adiabatic flame temperature, which is a consequence of the lower oxygen concentration in the charge. Other parameters changing with the engine load have lower effects, which leads to similarity of the curves combining reduction of NO*x* with oxygen concentration in the charge.

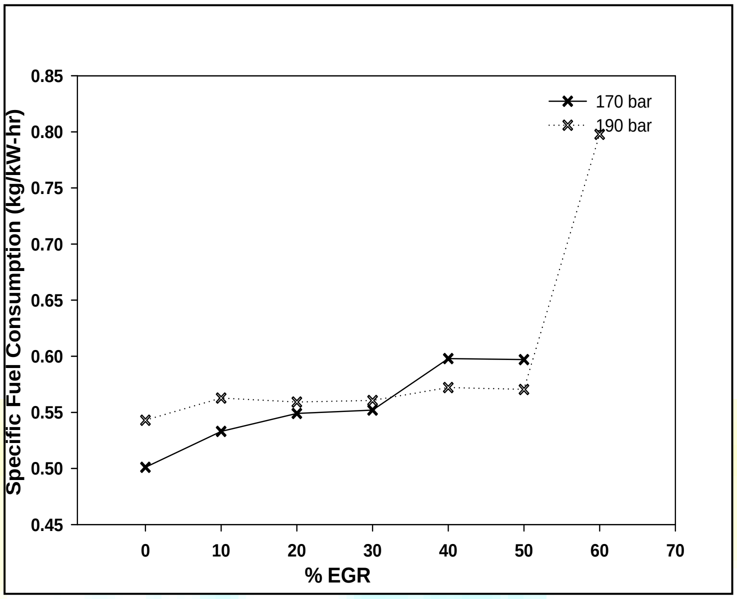

Fig. 3. Specific fuel consumption showing minor variation for increased percentage of EGR.

3. EGR is constrained at high loads by the increase in SFC resulting from reductions in air-fuel ratio as EGR is applied and by the high intake pressures relative to mean exhaust pressures which oppose EGR flow.

4. EGR at low levels and loads has only a minor effect on specific fuel consumption (**Fig.3**).

5. The gas quantity in the cylinder does not change with EGR. Hence the heat capacity changes only slightly and air fuel ratio is reduced due to the replacement of EGR gas. **Fig.4** shows this effect with reduced oxygen concentration with EGR.

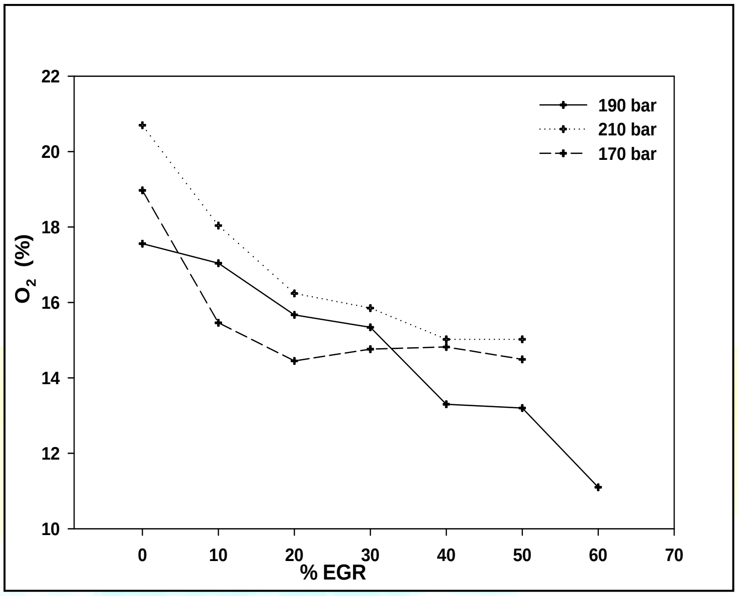

Fig. 4. Dilution effect: Reduced Oxygen fraction with increased percentage EGR.

6. EGR affects ignition delay through increased average intake temperature whiles the reduced O_2 concentration (**Fig.5**) due to dilution with CO_2 and N_2 (lower air/fuel ratio).

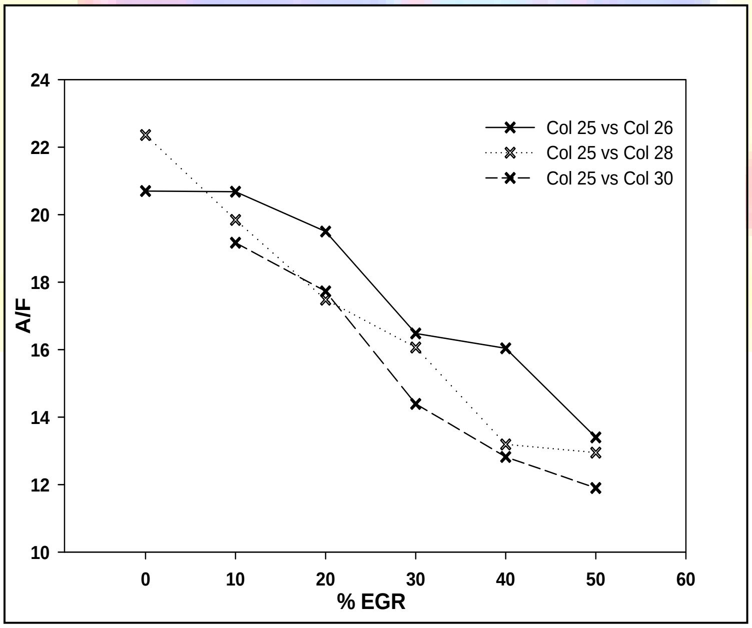

Fig. 5. Lower Air Fuel Ratio with increased EGR percentage.

7. Components of EGR such as NOx increase the rate of pressure rise while CO_2 reduces maximum pressure (**Fig.6**). For a static injection pressure the cylinder pressure for all loads remains lesser for higher percentage of EGR. This is presented in the **Fig. 6**

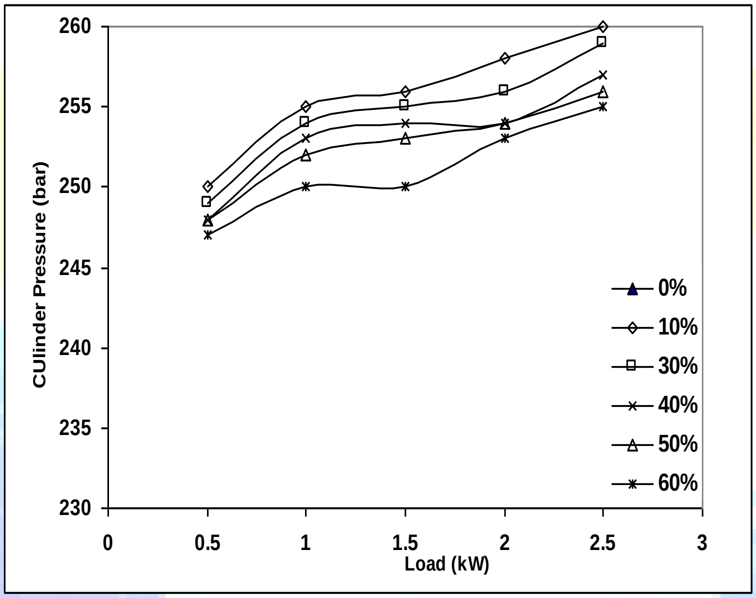

Fig.6. Cylinder peak pressure for different percentage of EGR and injection pressure of 190 bar.

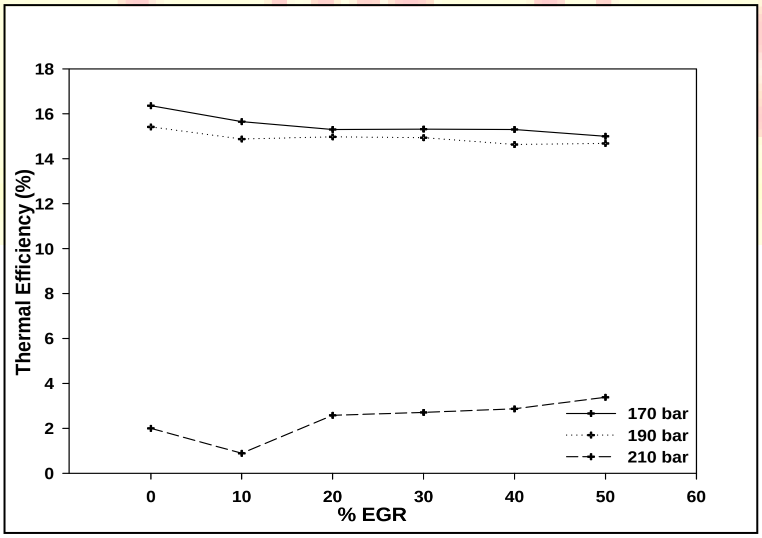

Fig. 7. Thermal efficiency decrease for increase in EGR percentage.

8. The decrease in thermal efficiency (**Fig.7**) could be the result of combustion deterioration when the EGR is increased and the gaseous fuel–air mixture gets more diluted with exhaust gases. When more EGR is introduced, the dilution effect was the most significant one influencing the combustion process and formation of emissions. The dilution effect occurs when the oxygen fraction in the inlet charge is reduced due to replacement with exhaust gases.

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