Investigation on NO\textsubscript{x} control in SI Engine Assisted with Hot and Cold EGR

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Abstract. In this paper, we have conducted a study in a 2.2 kW variable speed SI engine coupled with electrical loading, whose main objective is to reduce the NO\textsubscript{x} emissions coming out of the engine. To achieve this outcome, we have opted for the EGR technique. We have opted for this technique because firstly it is a proven technique that has been successfully implemented in CI engine and secondly as it reduces the peak engine temperature leading to increased engine life. EGR is implemented by using EGR manifold which replaces the regular intake manifold. Also, a flow control valve is used to control the percentage flow of exhaust gases. From this study, we can conclude Cold EGR is effective in reducing NO\textsubscript{x} but lowers the efficiency. Additionally, a reduction in CO\textsubscript{2} percentage is also observed at the cost of the increase in HC.

1. Introduction

In this modern era, where we have found solutions to many problems, like from developing robots to full-fledged studies which can be used to perform the tasks done by humans effectively and efficiently (Artificial Intelligence), we have progressed less in the field of reducing the emissions from factories and engines. Electric vehicles are the future they say. But, if we keep on polluting our Mother Earth at the pace which we are going right now, there won’t be a future to witness it. That is why we wanted to create a solution for the present. The major pollutants in the air are Carbon Monoxide, Lead, Nitrogen Oxides, Sulfur Dioxide, Ozone, and Particulate Matter \cite{1}\cite{2}. Among these, the major pollutants coming from automobile engines are Nitrogen Oxides and Carbon Monoxide. Some of the short-term ill effects of Oxides of Nitrogen on humans are excessive sweating, shivering, nausea, vomiting, fatigue, and dizziness. Long term ill effects include hallucination, seizures, wheezing and many more. These oxides, when vaporized, gets mixed in the water cycle and results in acid rain, which causes skin irritation in humans and animals, and degradation of buildings and statues.

NO\textsubscript{x} is produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures. The major causes of the NO\textsubscript{x} emission in the engine are the presence of nitrogen in the air and high combustion temperature in the combustion chamber. Using EGR makes the engine burn lean. Using EGR makes the engine burn lean. This can both be used for controlling emission as well as improving fuel consumption \cite{3}\cite{4}. But, we can’t keep on adding the exhaust gas such that there’s a drop in the performance. This maximum value can be around 20\% of volume says another study \cite{5}. It can be increased to 25\% by using one cylinder’s exhaust specifically for the other
three says another study [6][7][8]. Another study [9] reveals that EGR at mid-high load can even reduce throttling losses and can enhance fuel consumption. The other characteristics of using an EGR system is studied with varying parameters [10][11][12].

2. EGR

Different techniques were available for emission control. There are four main sources for NO\textsubscript{x} formation. They are the engine exhaust, the crankcase, the fuel tank, and the carburetor. In our case, we have chosen the EGR technique to reduce NO\textsubscript{x} formation. EGR consist of a valve in which the exhaust gas is recirculated to the inlet valve. EGR technique helps for the potential reduction of throttling losses on spark ignition engines at part load and improved engine life through reduced cylinder temperatures. The below figure shows the schematic diagram of EGR. We will be using Hot and Cold EGR techniques in our study. Also, a fuel blend will be used to compare the pollution as well as the performance.

![Figure 1. Layout of the engine with EGR setup [13].](image)

2.1. *Working of EGR*

EGR is used to reduce NO\textsubscript{x} emissions. The formation of NO\textsubscript{x} takes place at temperatures above 2000°C. EGR prevents the formation by reducing the peak temperature inside the cylinder, preventing the formation of NO\textsubscript{x}.

2.2. *Hot EGR*

Hot EGR, also called as the regular EGR, in which the exhaust gas is directly fed into the inlet air-fuel mixture. The exhaust gas, in that particular combustion reaction, acts as an inert gas, reducing the peak temperature in the cylinder. This, in some cases leads to engine knocking, which is a dis-advantage and can also lead to rise in temperature.

2.3. *Cold EGR*

Cold EGR is a type of technique, in which the exhaust gas is cooled before it is fed into the engine. The cold air helps in absorbing the heat in the engine, which goes in line with the primary objective of the project.

3. Experimental Setup

The experiment was performed in a 4 stroke 2.2kW variable speed engine. In this setup, EGR manifold [14][15] and the flow control valve is fixed to this 2.95HP engine. An electric dynamometer is used to apply loads [16]. A specific percentage of the exhaust gas is fed into the engine and the emission values are measured by maintaining the same temperature throughout the cycles. This helps in attaining the steady values of the exhaust gas throughout the load region. In addition to the setup, a pipe has been used with the provision to take water circulation. The T-joint at the exhaust pipe connects the Exhaust gas to the inlet of the engine with the help of a braided hose. The EGR control valve acts as a flow control valve for the exhaust gas and the flow of exhaust gas into the system is...
being controlled. With the help of flow control valve 6, 12 and 18% of the total volume of the gas are being sent into the cylinder. By using protractor, the angles are measured. Keep in mind that the angles are approximate and the experimentation is performed keeping the trend in mind. Since the engine is air-cooled and the experiment is performed in a closed environment, to avoid overheating of the engine, a physical blower is kept to cool the engine manually. A reducer is placed at the end of the exhaust pipe to facilitate easier connection of the emission analyzer [17], which is placed at the end of the exhaust pipe for measuring the emissions. The complete specifications of the engine are shown in table 1.

| Table 1. Specification of the Engine |
|--------------------------------------|
| No of cylinder | 1 |
| No of stroke | 4 |
| Fuel | Petrol |
| Rated Power | 2.95 HP (2.2kW) at 3000 RPM |
| Type of dynamometer | Electrical loading |
| Cylinder Diameter | 55mm |
| Stroke length | 50mm |
| Manometer Liquid | Water |
| Internal Diameter of the EGR hose | 30mm |
| Exhaust inner diameter | 70 mm |

**Figure 2.** The engine upon which experimentation is going to be performed.

**Figure 3.** Complete over haul has been done in the engine to remove dirt and debris. Gaskets at all places were replaced and moving parts were lubricated.
4. Procedure
In this experiment, the emission from the exhaust is measured at different loads. Initially, the engine was allowed to run 10 minutes for it to reach the optimum temperature, then the emission from the exhaust was measured using the emission analyzer without EGR set up at varying loads. Then series of readings were taken by varying the control valve to 20 deg (6% of vol), 50 deg (12% of vol), 80 deg (18% of vol) and their respective readings were noted. Cold EGR setup is then connected and the experimentation is repeated. Water circulation is done by collecting water in a bucket and a 16W motor was used to circulate this collected water. NOₓ, CO, CO₂, HC values are noted. Also, the Performance and efficiency were also calculated in addition to the values taken from the emission analyzer. Many graphs are plotted to compare among various experiments along with the varying load.

Table 2. Properties of Petrol.

| Property                  | Value          |
|---------------------------|----------------|
| Density                   | 747.4 kg/m³    |
| Specific Gravity          | 0.71-0.77      |
| Octane Rating             | 87-91 RON      |
| Autoignition Temperature   | 280 °C         |
| Flash Point               | -43 °C         |
| Fire Point                | -23 °C         |

**Figure 4.** Emission Analyser in action.

**Figure 5.** Cold EGR setup has been installed. A T-Joint in the exhaust line is taken for this. Transparent tube is the inlet and orange tube are the outlet. Water circulation is carried out to cool the exhaust gas.
4.1. Calculations

- Inner Diameter of exhaust pipe: 70mm
- Inner Diameter of EGR hose: 30mm
- Circumference area of exhaust pipe: $3848.45\text{mm}^2$
- Circumference area of EGR hose: $706.85\text{mm}^2$
- Ratio of circumference area of EGR hose to the exhaust pipe = 0.1836 or 18.36% vol (approximately 18%)
- For 50-degree valve opening = 11.48% vol (approximately 12%)
- For 20-degree valve opening = 5.6% vol (approximately 6%)

5. Result and Discussion

The study conducted in this 2.2kW engine showed amazing improvements during the before and after EGR setup. While initially, the NO$_x$ has increased because, in hot EGR, the knocking effect occurs, which can be seen with the increase. But in Cold EGR, since the gas is cooled a bit, it absorbs the necessary heat in the cylinder, leading to a more decrease in the in-cylinder temperature, resulting in a decrease of NO$_x$. Also, due to the high density of cold air resulting in more gas entering the cylinder, 18 percentage of Cold EGR has the highest NO$_x$ among all.

| Load (%) | Without EGR | 6% Hot | 6% Cold | 12% Hot | 12% Cold | 18% Hot | 18% Cold |
|----------|-------------|--------|---------|---------|----------|---------|----------|
| 0        | 38          | 45     | 17      | 40      | 25       | 26      | 16       |
| 25       | 25          | 29     | 30      | 29      | 36       | 25      | 65       |
| 50       | 9           | 31     | 21      | 30      | 27       | 23      | 59       |
| 75       | 30          | 38     | 32      | 31      | 40       | 11      | 87       |
| 100      | 57          | 61     | 31      | 61      | 45       | 26      | 75       |

Table 3. The NO$_x$ values(ppm) of different types of experimentation performed across the load range.

- Figure 6 shows the comparison between the NO$_x$ values across all load ranges in Hot EGR. Similarly, figure 7 shows the same comparison, but in Cold EGR. The efficiency of the hot counterpart is always higher than the cold ones because the difference in temperature will be higher in hot counterparts. Figure 8 and 9 describes the absolute value of NO$_x$ and the trend it follows. Figure 10 and 11 shows the comparison between HC across various loads. The HC value at lower load is substantially higher than the higher loads, even higher than the base reading itself. But, in the comparison between Hot and Cold, in Cold EGR, the values are lower. Figures 12 and 13 show the comparison of CO$_2$ from Hot and Cold setup respectively. We can observe very well from the graph that there is a reduction in CO$_2$. The reduction starts once EGR has been started. And, the reduction can be substantially noted at Cold EGR, which prove its effectiveness. Figure 14 shows the Brake Thermal Efficiency of the system across various load range and Exhaust gases. Higher brake thermal efficiency is obtained at Hot EGR and it follows an increasing trend with EGR percentage. This is because the temperature of the exhaust gas is not reduced and supplied into the cylinder. The NO$_x$ is highest at the full load, as expected. Also, in the below graphs, without stands for without EGR. 6%H stands for Hot EGR with 6% exhaust gas. 6%C stands for Cold EGR with 6% exhaust gas. 12%H stands for Hot EGR with 12% exhaust gas. 12%C stands for Cold EGR with 12% exhaust gas. 18%H stands for Hot EGR with 18% exhaust gas and 18%C stands for Cold EGR with 18% exhaust gas.
Figure 6. Comparison of NOx Values across EGR percentage and load for Hot EGR.

Figure 7. Comparison of NOx Values across EGR percentage and load for Cold EGR.
Figure 8. Comparison of NO\textsubscript{x} values across all load range with all experimentation.

Figure 9. The graph shows the comparison of the exhaust gases across various load range. In this graph, we can see the trend line.
Figure 10. Comparison of HC values across EGR percentage and load for Hot EGR.

Figure 11. Comparison of HC values across EGR percentage and load for Cold EGR.
Figure 12. Comparison of CO₂ values across EGR percentage and load for Hot EGR.

Figure 13. Comparison of CO₂ values across EGR percentage and load for Cold EGR.
Figure 14. Comparison of Brake Thermal Efficiency across all load range and experimentation.

6. Conclusion
We can conclude that by using the Exhaust Gas Recirculation technique, the NO\textsubscript{x} emission has been reduced significantly. For Hot EGR, the NO\textsubscript{x} decreases across the load and for Cold, NO\textsubscript{x} Increases across the load. Also, efficiency in Cold EGR is higher than hot EGR as on theory. NO\textsubscript{x} has been reduced because the maximum temperature which is attained in the cylinder has been reduced. At higher loads, Hot EGR proves to be effective and for lower load, Cold proves to be useful. The following conclusions can be drawn:

1. Cold EGR Setup has been effective in reducing NO\textsubscript{x} at 6\% of Exhaust Gas. As the percentage of Exhaust gas increases, Hot EGR proves to be useful in reducing the nitrous oxide levels.
2. CO\textsubscript{2} is reduced effectively in the EGR setup. A good difference can be seen in the Cold setup.
3. The reduction in CO\textsubscript{2} and NO\textsubscript{x} comes at the cost of slightly increase in the HC values.
4. The efficiency of Hot EGR compared with Cold EGR is higher as expected because the difference in temperature in hot counterpart is higher than cold.
5. It can be concluded that Cold EGR was very effective in reducing NO\textsubscript{x} emissions.
6. The Brake Thermal efficiency of the engine slightly increases or remains the same with the increase of exhaust gas percentage, but doesn’t decrease.
7. At 18\% Cold EGR, the NO\textsubscript{x} value tremendously increases because due to the higher density of cold air, more exhaust gas enters, resulting in incomplete combustion in the chamber.

7. References
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