Experimental Study on Performance and NOx Emission Control in Diesel Engine Using Air and Argon Gas Mixture

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Abstract---The concept of present study is to investigate effect of argon gas on performance and emission. Argon gas was supplied to engine with intake air by different rate, and performance and emission was experimentally investigated. The experiment was conducted at constant 1500 rpm with different load, with and without argon gas. The results revealed that great reduction in NOx emission was achieved at 11% of argon rate. Also CO emission was decreased with increase in argon rate and achieved optimum at 11% of argon rate. Performance was slightly improved at 9% of argon rate and sfc was decreased with increase in argon rate. It can be observed 9% of argon rate was found to be effective for NOx and CO emission reduction and improve performance at expense of FA. It was only suffered by HC emission, which was increases the increase in argon rate.

I. INTRODUCTION

Diesel engine runs transport vehicles, passenger vehicles, cars, earth moving vehicles and agriculture vehicles. Diesel engine runs economy of country. Diesel engine is used in transport vehicles due to its superior merits. It has low maintenance, better fuel economy, large power range and compact size. It is very much suitable for large power generation. Due to such advantages of diesel engine its demand is growing day by day. Rails and ships are powered by diesel engine.

Diesel engines are very popular power plants for decentralized power production in rural areas all over the world as well as for powering the farm equipment due to their fuel economy, ease of maintenance and robustness. Due to limited primary energy resources and economical problems has increased diesel fuel rate. So diesel engine manufacturer are working towards increase fuel economy and minimizing emission from engine.

Diesel engines are assumed as a good alternative to gasoline engines because they produce lower amount of emissions on the other hand, higher emissions of oxides of nitrogen (NOx) and particulate matter (PM) have been noticed as major problems. Although, major constituents of diesel exhaust include carbon dioxide (CO2), water vapor (H2O), nitrogen (N2), and oxygen (O2); carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx), and particulate matter (PM) are present in smaller but environmentally significant quantities. In modern diesel engines, first four species normally consist of more than 99% exhaust, while last four (the harmful pollutants) account for less than 1% exhaust. NOx comprise of nitric oxide (NO) and nitrogen dioxide (NO2) and both are considered to be deleterious to humans as well as environmental health. NO2 is considered to be more toxic than NO. It affects human health directly and is precursor to ozone formation, which is mainly responsible for smog formation. Exhaust emission is most responsible for air pollution and environment problems like global warming, green house effect, acid rain, etc. The ratio of NO2 and NO in diesel engine exhaust is quite small, but NO gets quickly oxidized in the environment, forming NO2. Since diesel engine mainly emits NO hence attention has been given to reduce the NO formation.

A. NOx Emission Formation

NO is formed inside the combustion chamber in post-flame combustion process in the high temperature region. The NO formation and decomposition inside the combustion chamber can be described by extended Zeldovich Mechanism. The principal reactions at near stoichiometric fuel–air mixture governing the formation of NO from molecular nitrogen are:

\[
N_2 + O = NO + N
\]
\[
N + O_2 = NO + O
\]
\[
N + OH = NO + H
\]

The initial rate controlled NO formation (i.e. when \([NO]/[NO2]e\) can be described by the Eq. (1). In the expression, \([NO]\) denotes the molar concentration of the species and \([O2]e\) and \([N2]e\) denotes the equilibrium concentration [7].

\[
d[NO]/dt = \frac{6 \times 10^9}{T^{0.5}} \exp \left( \frac{-69,096}{T} \right) [O2]e^2 [N2]e \text{ Mol s}^{-1} \text{cm}^{-2}
\]

The sensitivity of NO formation rate to temperature and oxygen concentration is evident from this equation. Hence in order to reduce the NOx formation inside the combustion chamber, the temperature and oxygen concentration in the combustion chamber need to be reduced. Even though, certain cetane improving additives are capable of reducing NOx, the amount of reduction is reported to be inadequate. Moreover, most of these additives are expensive. retarded injection is an effective method employed in diesel engines for NOx control. However, this method leads to increased fuel consumption, reduced power, increased HC emissions and smoke. Water injection is another method for NOx control however this method enhances corrosion of vital engine components. In addition, it adds to the weight of the engine system because of requirement of a water storage tank. It is also difficult to retain water at a desired temperature during cold climate.

II. SELECTION OF ARGON GAS

From literature of survey it is concluded that specific heat of intake charge affect the performance and NOx emission. Performance is increase with increase the specific heat of working fluid, where the NOx is controlled by controlling peak combustion temperature. There are many methods for reducing NOx emission but in this research dilution of intake...
charge concept is used to reduce NO\textsubscript{x} emission using higher specific heat gas. So NO\textsubscript{x} emission can be reduce by increasing the specific heat of intake air. Therefore Argon is best suitable to achieve both functions because it has higher specific heat. It also has mono atomic property. So argon is selected for dilute the intake air. The properties of argon gas are given in following table 1.

### Table 1: Properties of Argon

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical formula</td>
<td>Ar</td>
</tr>
<tr>
<td>Molecular Weight</td>
<td>39.94 M Kg/K mol</td>
</tr>
<tr>
<td>Specific heat ratio</td>
<td>1.667</td>
</tr>
<tr>
<td>Specific heat at constant volume</td>
<td>0.3122 KJ/Kg k</td>
</tr>
<tr>
<td>Specific heat at constant pressure</td>
<td>0.5203 KJ/Kg k</td>
</tr>
<tr>
<td>Gas constant</td>
<td>0.2081 KJ/Kg k</td>
</tr>
<tr>
<td>Density</td>
<td>1394 Kg/m\textsuperscript{3}</td>
</tr>
</tbody>
</table>

Argon gas dilute the intake air and reduce the oxygen concentration. Argon gas increase the specific heat of intake air. Argon is inert gas so it does not take part in combustion process. It is mono atomic gas therefore it does not possess association and dissociation phenomena. During combustion process argon absorb heat due to higher specific heat and reduce combustion temperature. So NO\textsubscript{x} emission is reduced.

There are many gases used to dilute intake air, such as Hydrogen, Oxygen, Carbon dioxide, Nitrogen and water. Argon is not used to dilute the intake air in diesel engine. Good research has done in petrol engine using argon to dilute intake charge. So argon is used in this research to evaluate performance and NO\textsubscript{x} emission.

### III. EXPERIMENTAL SET-UP

The setup consists of single cylinder, four stroke, multi-fuel, research engine connected to eddy type dynamometer for loading. The operation mode of the engine can be changed from Diesel to Petrol or from Petrol to Diesel with some necessary changes. In both modes the compression ratio can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement.

The set up has stand-alone panel box consisting of air box, two fuel flow measurements, process indicator and hardware interface. Rota meters are provided for cooling water and calorimeter water flow measurement. A battery, starter and battery charger is provided for engine electric start arrangement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance and combustion analysis. Lab view based Engine Performance Analysis software package “Engine soft” is provided for on line performance evaluation.

Exhaust gas emission measurements were done by five gas exhaust gas emission analyzer, which can measure CO, CO\textsubscript{2}, NO\textsubscript{x}, HC, O\textsubscript{2}. The argon gas was supplied to engine inlet manifold using hose pipe. U-tube manometer was fitted across hose pipe to measure argon flow rate. Pressure reducer and argon gas flow controller was used to supply constant flow.

![Experimental Setup](Fig_1.png)

**Fig. 1:** Experimental Setup

To achieve the objectives of the study, engine was run under normal operating condition and at different argon rate. The data for HC, NO\textsubscript{x}, CO, exhaust gas temperature, thermal efficiency and fuel consumption were recorded. Then, engine performance and emission patterns were compared. Optimum argon rate was found on the basis of performance and emissions of the engine.

### Table 2: Technical Specification of Engine

<table>
<thead>
<tr>
<th>Model</th>
<th>TV1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>Kirloskar Oil Engines</td>
</tr>
<tr>
<td>Type</td>
<td>Four stroke Single cylinder, Water cooled, Diesel</td>
</tr>
<tr>
<td>No. of cylinder</td>
<td>One</td>
</tr>
<tr>
<td>Bore</td>
<td>87.5 mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>110 mm</td>
</tr>
<tr>
<td>Combustion principle</td>
<td>Compression Ignition</td>
</tr>
<tr>
<td>Cubic Capacity (cc)</td>
<td>0.661 liters</td>
</tr>
<tr>
<td>Max. Speed</td>
<td>2000 rpm</td>
</tr>
<tr>
<td>Min. operating speed</td>
<td>1200 rpm</td>
</tr>
<tr>
<td>Connecting rod length</td>
<td>234 mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>17.5</td>
</tr>
<tr>
<td>Valve timing</td>
<td>-</td>
</tr>
<tr>
<td>Inlet opens BTDC</td>
<td>4.5\degree</td>
</tr>
<tr>
<td>Inlet closes ABDC</td>
<td>35.5\degree</td>
</tr>
<tr>
<td>Exhaust opens BBDC</td>
<td>35.5\degree</td>
</tr>
<tr>
<td>Exhaust closes ATDC</td>
<td>4.5\degree</td>
</tr>
</tbody>
</table>

![4-stroke Single cylinder diesel engine test rig](Fig_2.png)

**Fig. 2:** 4-stroke Single cylinder diesel engine test rig
IV. RESULTS AND DISCUSSION

A. Emission Analysis

1) No\textsubscript{x} Emission

Great amount of No\textsubscript{x} emission is reduced with increase in argon rate. As the argon rate increase the No\textsubscript{x} emission is decreased. It also reduces No\textsubscript{x} emission with increase in load. Grate amount of reduction in No\textsubscript{x} emission is found at 11% of argon rate. This is because of higher specific heat of argon gas. Due to higher specific heat of argon gas, it absorbs more heat during combustion process, so temperature is controlled and NO\textsubscript{x} emission is reduced. It is also mono atomic gas, thus it is free from association and disassociation phenomena. Argon gas does not take part in combustion process because it is an inert gas.

![Graph 1. O\textsubscript{2} emissions Vs load with different argon rate at 1500 RPM](image)

2) CO Emission

Graph 2 represents the effect of argon gas on CO emission. CO emission is also reduced with increase in argon rate. Good reduction in CO emission was found to be at 9% and 11% of argon rate. CO emission is decreased with increase in load. The possible reason may be mono atomic and inert gas properties of argon gas. Thus it is free from association and disassociation phenomena. Argon gas does not take part in combustion process. It does not have carbon partials present in EGR.

![Graph 2. CO Vs load with different argon rate at 1500 RPM](image)

3) Oxygen Emission

Effect of argon gas on oxygen emission is shown in graph 3. Oxygen emission is slightly decreased with increase in argon rate and it is found to be good at 9% of argon rate. The possible reason may be during combustion process the temperature is controlled. Thus it control NO\textsubscript{x} formation rate. So oxygen which does not react with nitrogen and more oxygen are available to react with hydrocarbon. Thus it reduced oxygen emission.

![Graph 3. O\textsubscript{2} emissions Vs load with different argon rate at 1500 RPM](image)

4) HC Emission

Effect of argon gas on HC emission is shown in graph 4. HC emission is increased with increase in argon rate. The possible reason may be increase in argon rate reduce oxygen concentration in intake air. So during combustion process sufficient oxygen is available for combustion and increase HC emission.

![Graph 4. HC emissions Vs load at different argon rate at 1500 RPM](image)

B. Performance Analysis

1) Brake Thermal Efficiency

Graph 5 represents the effect of argon gas on Brake thermal efficiency at different argon rate. It is found from all data set the thermal efficiency is slightly increased with increase in argon rate. The possible reason may be more oxygen is available for combustion which improves the combustion reaction. From analysis of literature survey it is concluded that thermal efficiency can be increased with increase in specific heat of inlet charge but it is does not possible in practical because higher specific heat of combustion charge absorb heat. Thus it reduces the performance but more oxygen available for combustion slightly improves performance in terms of brake thermal efficiency.

![Graph 5. Brake Thermal efficiency Vs load at different Argon rate at 1500 RPM](image)

2) BSFC

Graph 6 represents the effect of argon gas on BSFC at different argon rate. BSFC is found to have slightly
decreased at 3 kg and 9 kg load at 9% of argon rate. At 9 kg loads, amount of fuel supplied to the cylinder is increased at higher rate and oxygen available for combustion gets reduced. Thus, air fuel ratio is changed and this increases the BSFC.

![Graph 6 bsfc Vs load with different argon rate at 1500 RPM](image)

**Graph 6** bsfc Vs load with different argon rate at 1500 RPM

3) **Exhaust Gas Temperature:** The effect on Exhaust gas temperatures are shown in graph 6.

![Graph 7 Exhaust gas temperatures Vs load with different argon rate at 1500 RPM](image)

**Graph 7** Exhaust gas temperatures Vs load with different argon rate at 1500 RPM

It has been observed that with increase in load, exhaust gas temperature also increases when the engine is operated with; argon gas the temperature of exhaust gas is generally lower than temperature of exhaust gas at normal operating condition. Exhaust gas temperature decreases with increase in argon rate. The reasons for temperature reduction are relatively lower availability of oxygen for combustion and higher specific heat of intake air mixture as explained earlier.

V. CONCLUSION

Dilution of intake air with different gases uses to control NOx emission in diesel engine. H2O2, H2O, EGR, N2 were used to dilute intake air, but desire result of performance and emission have not achieved.

In present study the effect of argon gas on performance and emission was experimentally investigated. Argon gas was supplied with intake air with different rate, and performance and emission was experimentally investigated.

Grate reduction in NOx emission is achieved. Great amount of NOx emission is reduced with increase in argon rate. It also reduces CO emission. CO emission is also reduced with increase in argon rate. Good reduction in CO emission was found to be at 9% and 11% of argon rate. Performance in terms of brake thermal efficiency is slightly increased and bsfc is slightly decreased for all loads. It can be observed 9% of argon rate is found to be effective for NOx emission control and improve performance. HC emission is increased with increase in argon rate and it is found higher HC emission at 11% of argon rate. The increase in HC emission can be reduced by using recirculate part of exhaust gas into engine. It also can be reduced by using exhaust after-treatment techniques, such as diesel oxidation catalysts.