CHAPTER 4
EXPERIMENTAL WORK

The essential components for the experimental setup is chosen properly and assembled keeping in mind the objectives of the research work. The instrumentation systems were selected judiciously with a clear understanding of working, range and limitations.

4.1 Engine Modifications & Experimental Setup for CASE I

A single cylinder kirlosker direct injection diesel engine is chosen to carry out the experiments. This engine is modified to SI engine by incorporating spark plug, ignition system and timing. The experimental study has been accomplished in two stages. In the first stage pure gasoline is used separately in the single cylinder compression ignition engine modified to spark ignition engine. In the second stage, ethanol blends with gasoline is used to determine the performance.

The following modifications are made to the engine for an ultra-lean burn combustion of commercially available gasoline and ethanol with carburetion and spark ignition.

- Thermocouple arrangement is made to measure the temperature of the exhaust gases.
- The squish heights are varied by changing the thickness of the gasket and varying the number of gaskets.
- The fuel injection system is replaced by a carburetor and a spark plug. The spark plug is located in place of the injector with an inclination of 25° to the vertical.
- Provision for a pressure transducer and intake manifold vacuum tapping are made in the cylinder head.
- Exhaust gas sampling points are provided in the exhaust pipe for emission measurement.
- A selected carburetor jet among the available jets of different sizes is used to operate this engine on ethanol blends with gasoline.
Ignition system is of conventional low energy 12 volts magnet and coil contactless system is fitted to the engine, by mounting the coil and magnet on the crank shaft.

4.2 Approaches for Controlling NO\textsubscript{x} for Ultra-Lean Combustion

In an ultra-lean burn engine, adjusting the air/fuel ratio towards the ultra-lean operation side increases the volume of air available for the combustion process. This increases the heat capacity of the mixture and lowers the combustion temperature, resulting in lower NO\textsubscript{x} formation. EGR (whether internal or external) decreases oxygen attention in the combustion chamber by diluting the entering ambient air with exhaust. During combustion, the lower oxygen content has the effect of dropping flame temperatures, which in turn decreases NO\textsubscript{x} production since the NO\textsubscript{x} production rate is exponentially proportionate to flame temperature.

4.3 Important Components of the Experimental Setup

The various components of the experimental setup are detailed below. Fig. 4.1, gives the photograph of the experimental setup and Preparation of ignition coil and magnet on the diesel engine as shown in Fig. 4.2 and Fig. 4.3. Table 4.1 gives the specifications of the kirlosker engine.

The important components of the system are:

- The engine
- Spark plug
- Dynamometer
- Data acquisition
- Computer
Fig. 4.1 Photographic view of experimental setup for single cylinder Kirlosker diesel engine

Fig. 4.2 Photographic view of experimental setup with instrumentation attachments
Fig. 4.3 Photographic view of preparation of ignition coil and magnet on the diesel engine

Table 4.1 Specifications of Kirlosker Engine

<table>
<thead>
<tr>
<th>No. of cylinders</th>
<th>One</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connecting rod length</td>
<td>230 mm</td>
</tr>
<tr>
<td>$V_{disp}$</td>
<td>552.94 cc</td>
</tr>
<tr>
<td>Stroke</td>
<td>110 mm</td>
</tr>
<tr>
<td>Bore</td>
<td>80 mm</td>
</tr>
<tr>
<td>Rated output</td>
<td>3.68 kW (5 hp)</td>
</tr>
<tr>
<td>Inlet valve opens at</td>
<td>527°</td>
</tr>
<tr>
<td>Inlet valve closes at</td>
<td>750°</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>12</td>
</tr>
<tr>
<td>Exhaust valve opens at</td>
<td>340°</td>
</tr>
<tr>
<td>Exhaust valve closes at</td>
<td>554°</td>
</tr>
<tr>
<td>Speed</td>
<td>1500 rpm</td>
</tr>
<tr>
<td>Spark advance</td>
<td>27° BTDC</td>
</tr>
</tbody>
</table>
The exhaust gas analyzer is switched on quite early so that all its systems will get stabilized before the commencement of the experiment. The data length, frequency range to trigger the data acquisition for computer are carefully selected, based on the approximate cycle time of the engine operation, such that there appeared three TDC signals on the display, with the combustion period occupying the centre stage. Ambient condition of pressure and temperature are noted. After the starting of the engine and stabilizing it, air flow, fuel flow, temperature of ambient air, temperature of exhaust gases is noted. The dynamometer readings such as load and speed are also noted. For all the tests the dynamometer is set on constant speed mode. The pressure and TDC signals are recorded in computer and averaged for 100 consecutive cycles.

4.4 Experimental Approach

The experimental study has been performed in two stages. In the first stage normal gasoline is used separately in the catalytic and non-catalytic combustion chamber with a manifold vacuum of 30mm Hg. Then in the second stage, catalytic with a manifold vacuum of 60 mm Hg, to ascertain the performance. For all the tests a cyanide bath coated piston with hemi-spherical combustion chamber which has a squish height of 2.4 mm, with a compression ratio of 12:1 used. High energy electronic contact-less ignition system with extended electrode is used. The electrode is centrally located with a deep penetration of 15mm into the combustion chamber. The plug is water-cooler to avoid pre-ignition. These techniques are employed based on the test results obtained in the earlier research which are presented.

4.5 Experimental Setup for CASE II

The schematic diagram of the experimental setup is shown in figure 4.3 and 4.4. The test setup is explained below with complete details. Significant elements of the experimental setup are described in this section.

4.5.1 The Engine Test Rig

The most significant portion of the present work is the selection of a test engine. The engine used in the present study is a Kirloskar TV-1, single cylinder, water-cooled, four stroke and single acting compression ignition diesel engine.

The specifications of test engine are presented in Appendix I. This engine is coupled to an Eddy Current Dynamometer. Air temperature, coolant temperature and
throttle position are connected to open ECU which control fuel injector, fuel pump and idle air. The engine was modified and provision were provided to vary the compression ratio from 17.5:1 to 18.5:1. The intake temperature and pressure were chosen to give stable and knock free engine operation.
Fig. 4.5  Schematic view of experimental test setup with instrumentation
4.6 Engine Modifications

4.6.1 Variation of Compression Ratio

To perform the experiments at varied CR, the engine test rig is to be modified. There is a provision in the engine that the clearance volume of the combustion chamber can be varied by lifting up the cylinder head of the engine. A wide range of CR can be obtained of 14.5 to 18.5, by which there is a possibility of conducting the tests at many operating conditions. However, for the analysis of the efficiency, performance, combustion and exhaust emissions of the engine two different compression ratios are chosen i.e. 17.5 and 18.5. The details are shown in figure 4.5.

The detailed information about the VCR calculations is given in the Appendix IV.

![Photographic view of Manual Variation of CR of Engine Test Rig.](image)

4.6.2 Variation of Injection pressure

The experiment is conducted at various injection opening pressures to find an optimum injection pressure at which a good engine performance is obtained. Two different calibrated fuel injectors (200 bar and 220 bar) are used. A detailed illustration on how to adjust IOP manually is shown in figure 4.7.
4.6.3 Mixing of Hydrogen and air

The engine is modified for the direct induction of Hydrogen through the inlet manifold as shown in the figure 4.8. The pressure of Hydrogen was controlled directly by the pressure regulator provided at the Hydrogen cylinder opening. The diesel was controlled by the governor mechanism provided in the engine for the constant speed operation.

Fig. 4.8 Schematic diagram of Mixing Chamber.
4.6.4 Variation of Cooling Rate

The experimentation requires a varied cooling ratio in order to facilitate fine working conditions at various heat exhausts from engine. An open type water cooling system is used to keep the temperature of cooling water at a constant value.

The cooling water flow rate is measured by using a rotameter and the water flow rate is controlled by a gate valve.

4.7 Measurement System

Different types of modern measuring devices are used to measure respective parameters. A brief explanation of each parameter is given below.

4.7.1 Pressure Measurement

PiezoSensor is used in the experiment for the dynamic measurement of compression, combustion, explosion, pulsation, cavitations and blast pressure as shown in figure 4.9. A computer interface piezoelectric sensors of range 350 bar was used to measure in-cylinder pressures. Pressure signals were obtained at 1°C.A using a digital data acquisition system. The average pressure data from 100 consecutive cycle was used for calculating combustion parameters. The signals from Piezo sensors and the crank encoder were acquired using a national instruments logical cards shown in figure 4.10. The transducer is connected to the computer through a logical card which converts the pressure signals to the digital signals.

![Fig. 4.9](image)

**Fig. 4.9** Photographic view of Piezo Sensors.
4.7.2 Speed Measurement

Following different speed measuring devices are used for speed measurement.

1. Photoelectric/Inductive proximity pickup with speed indicator
2. Rotary encoder.

On the shaft projection, a reference indicator was provided to mark the TDC, which was detected by a proximity sensor. Proximity sensor is placed very close to the dynamometer which measures the speed in rpm (see Fig. 4.11.). The proximity RPM sensor senses the speed and displays on the digital RPM indicator. The computer interfacing of the engine helps in easy and accurate interpretation of results.
4.7.3 Temperature Measurement

In this study, temperature sensors are used for the measurement of temperature. Two temperature sensors are used for measuring different temperatures as shown in figure 4.11. Temperature sensor used is made by Radix of type RTD, PT100. It ranges from 0-250°C. It is used to measure the engine water inlet temperature, engine water outlet temperature, calorimeter water inlet temperature and calorimeter water outlet temperature. The other temperature sensor used is also made by Radix of Thermocouple type K (Chromel/Alumel). This temperature sensor ranges from 0-400°C. This is used to measure Exhaust gas temperature of the engine and calorimeter inlet and outlet temperatures. To read directly the temperatures are displayed on the panel board digital display system.

Fig. 4.12.A Photographic view of temperature sensors on calorimeter.
4.7.4 Hydrogen flow measurement

The hydrogen flow was measured by using a specially designed flow meter. To damp the pressure fluctuations in the intake line, which particularly occur with large displacement single cylinder engines, flash back arresters for is located at the inlet of the engine. When the hydrogen supply was increased the diesel injection was
automatically decreases by the governor mechanism of the engine to maintain the speed constant. For hydrogen flow meters are shown in figure 4.13.

![Fig. 4.13 Photographic view of Hydrogen Flow meter.](image)

4.7.5 Fuel Consumption Measurement

The fuel consumed by an engine is measured by determining the volume flow of the fuel in a given time interval and multiplying it by the specific gravity of fuel to get its mass. Generally a glass burette having graduations in ml is used for volume flow measurement. Time taken by the engine to consume 10 cc fuel consumption is measured by stopwatch. Differential pressure transmitter is used in the present study. It is a Yokogawa-make and EJA110A model, which is made in Japan. It measures the flow rate of fuel and also the pressure of the liquids and it ranges from 0-500 mm WC. It gives a linear output. Specifications of DP are given in Appendix I-A.
4.7.6 Dynamometer

The purpose of using a dynamometer is to test the load capability of an engine prior to putting it back into service. An engine without a load can only produce speed. Maintaining a given rate of engine speed, revolutions per minute, takes a very small amount of engine horsepower. The engine in the present study is coupled to an Eddy current dynamometer as shown in figure 4.15.

This dynamometer consists of a stator on which are fitted a number of electromagnets and a rotor disc and coupled to the output shaft of the engine. When rotor rotates eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electromagnets. These eddy currents oppose the rotor motion, thus loading the engine. These eddy currents are dissipated in producing heat so that this type of dynamometer needs cooling arrangement.

A moment arm measures the torque. Regulating the current in electromagnets controls the load. The AG series eddy current dynamometers designed for the testing of engines up to 400kW and may be used with various control systems. Specifications of Dynamometer are shown in Appendix I-B.

The dynamometer is bi-directional. The shaft mounted finger type rotor runs in a dry gap. A closed circuit type cooling system permits for a sump. The common nature
of these machines is that power is absorbed or transformed into electrical energy, either power generated or eddy currents. This gives rise to energy loss in the form of heat that is transferred to the cooling water.

![Eddy Current Dynamometer](image)

**Fig. 4.15 Photographic view of Eddy Current Dynamometer.**

### 4.7.7 Air Flow Measurement

In IC engines the satisfactory measurement of air flow is quite difficult because of pulsating flow of air due to the cyclic nature of the engine and because the air is compressible in nature. An air flow transmitter shown in figure 4.16, is used for the measurement of flow rate in the present study. The rugged case of air flow meter is made of stainless steel and provided with the electrical connection. The Electronic pressure transmitter has been designed for the measurement of ultra-low pressures with dry gaseous media. It stands for high accuracy as well as rigid and compact in design. It has very wide applications in glass and plastic industries, air-conditioning, filter technology etc.

Mass flow rate of air can be calculated as

\[ M = \rho \cdot V \cdot A \]

- \( M \) is mass flow rate of air \( \text{Kg/sec} \)
- \( \rho \) is density of air \( = 1.169 \text{ Kg/m}^3 \)
- \( V \) is a velocity through orifice \( \text{m/sec} \)
- \( A \) is area of orifice \( \text{m}^2 \)
4.7.8 Water Flow Measurement

Rota meter is used for water flow measurement (Fig. 4.17.). The rota meter used is a PG-1 to 21 model and manufactured by Eureka. Its flow rate ranges from 40 to 400 LPH. Rota meter works on the principle of variable area. Float is free to move up and down in a tapered measuring glass tube. Upward flow causes the float to take up a position in which the buoyancy forces and the weight are balanced. The vertical
position of the float as indicated by scale is a measurement of the instantaneous flow rate. Specifications of rotameter are given in Appendix I-C.

The rotameter valves must be opened slowly and carefully adjusted to the desired flow rate. A sudden jumping of the flow, which may cause damage to the measuring tube, must be avoided. For alignment a line marked RP is provided on the scale which should coincide with the line provided on measuring tube at the bottom. When the measuring tube and flow becomes dirty it is necessary to remove the tube and clean it with a soft brush, trichloroethylene or compressed air.

4.7.9 Exhaust Gas Analyzer

The exhaust gas analyzer used is MN-05 multi gas analyzer (5 gas version) is based on infrared spectroscopy technology with signal inputs from an electrochemical cell shown in figure 4.18. Non-dispersive infrared measurement technique used for the measurement of CO, CO₂, and HC gases. Each individual gas absorbs infrared radiation that can be used to calculate the concentration of sample gas. Analyzer uses an electrochemical cell to measure oxygen concentration. It consists of two electrodes separated by an electrically conducted liquid or cell. The cell is mounted behind a poly-tetra-floroethane membrane through which oxygen can diffuse. The device therefore measures oxygen partial pressure. If a polarizing voltage is applied between the electrodes the resultant current is proportional to the oxygen partial pressure.
4.7.10 Hydrogen storage systems

Hydrogen is stored in a compressed gaseous form at a pressure of 150 and 200 bar in commercially available cylinders with pressure indicators to read the inside pressure and with pressure reduction valves, its pressure is reduced to atmosphere before injecting in the inlet manifold. The outlet pressure is indicated in separate pressure gauges. For Hydrogen cylinders are shown in figure 4.19.

4.7.11 Flash arrester & Flame trap

Since hydrogen is a colourless, odourless gas and burns without flame. The flame sometimes travels along the hose and enters into the storage cylinder and proves to be hazardous. In order to have safe operations, a safety device called flash arrester is used in figure 4.20. This is used to prevent the flame entering into the cylinder. This is placed near the gas cylinder. Along with the flash back arrester, a flame trap is also used in the hydrogen supply line. It consists of two inter-connected stainless steel cylinders half filled with water. The hydrogen has to pass through these traps before reaching the engine manifold. In case of any accidental flame generation in the supply hose, once it reaches the flame trap the flame is put off by the trap water and in case if the flame survives in the trap and tries to reach the cylinder, the flashback arrester in
the supply line near the cylinder disconnects the hydrogen supply. The flash back arrester senses the high-pressure pulse that gets generated upon the fire and immediately disconnects the hydrogen supply by closing its inner passage which is pressure sensitive.

![Photographic view of Hydrogen Flame Arresters.](image)

**Fig. 4.20 Photographic view of Hydrogen Flame Arresters.**

### 4.7.12 Water cooling system

The test engine is a water cooled engine. A continuous flow of water with a flow rate of 100LPH for calorimeter and 200 LPH to engine and dynamometer is supplied two rotameters of Eureka model PG-1 to 21 are used to measure the flow rates of cooling water. A mono block pump is used to pressure rise the water to flow through the entire coolant water jacket and calorimeter pipe fittings.

### 4.8 Test Matrix

The test matrix A and B shown in the Table 4.2. and 4.3., was designed to minimize the variables and study the effect of performance, combustion and emissions analysis on a dual fuel enriched with Hydrogen with varying the blend percentage by 0%, 10% and 20% by mass of fuel, an ultra-lean fuel injection opening pressures at 200 and 220 bar and compression ratios of 17.5 and 18.5. The engine operating load was 25%, 50%, 75% and 100%(full load) at constant speed of 1500 rpm. First the engine was operated at standard compression ratio (17.5) and an ultra-lean fuel injection
opening pressure (200 bar) then the compression ratio and an ultra-lean fuel injection opening pressure was modified to 18.5 CR and 220 bar respectively.

Table 4.2 Test matrix A

| Test 1 | Combustion, Performance and Emissions analysis on a dual fuel VCR diesel fueled engine enriched with hydrogen, at variable ultra-lean fuel injection opening pressures (i.e. 200 bar and 220 bar) at standard compression ratio of 17.5. |

Table 4.3 Test matrix B

| Test 2 | Combustion, Performance and Emissions analysis on a dual fuel VCR diesel fueled engine enriched with hydrogen, at variable ultra-lean fuel injection opening pressures (i.e. 200 bar and 220 bar) at standard compression ratio of 18.5. |

4.9 Experimental Procedure

The present study is planned to develop and evaluate the performance, emission and combustion characteristics with consideration of two cases, first the ultra-lean burn Internal Combustion engine was modified to operate on ethanol blend fuels secondly, dual fuel operated diesel engine experimentally with an ultra-lean fuel injection opening pressures. The study looked at case I, constant speed operation of 0%, 10%, and 15% by volume of ethanol fuel blends with gasoline mixtures operating in ultra-lean operating systems. In experiment practice the use of homogeneous lean mixtures in engine has been handicapped by several difficulties. The most serious one is that the flame propagation through mixtures becomes gradually slower as the mixture becomes leaner. The mixture distribution in a multi-cylinder engine is a problem because even small variation in mixture ratio on the leaner side will strongly effect power output. Enhancement of lean combustion of homogeneous mixtures can be achieved by (i) using ethanol blends with gasoline (ii) using high-ignition energy (iii) providing high compression ratios (iv) creating high swirl in the combustion chamber. The study looked at case II, the experiment was conducted on a fully computer interface, single
cylinder, four stroke, variable compression ratio, multi-fuel, water cooled engine with eddy current loading as described in Appendix I, while a photographic view of the test rig setup is shown in figure 4.3. All the experiments were carried out at variable loads with a constant speed of 1500 rpm. The schematic view of instrumentation circuit is shown in figure 4.4. The engine had a provision to vary the compression ratio from 14.5 to 18.5. The engine instrumentation is given in Appendix II. The in-cylinder pressure was recorded using a Piezo-electric sensor. A digital shaft encoder was used to measure the crankshaft position. The signals from Piezo sensors and the crank encoder were acquired using a national instruments logical card. Data acquisition and combustion data analysis were measured using National Instrument Lab VIEW acquisition system. The test rig include other standard engine instrumentation, such as a thermocouple to measure oil, air, inlet manifold and exhaust temperatures and pressure gauges mounted at relevant points. The combustion analysis was based on an averaged value of 100 cycles after the engine reached steady state operation. The engine was first started on diesel stable operation, Hydrogen, was inducted through the manifold. Simultaneously the diesel supply got reduced as it’s a governor controlled flow. Various percentage substitutions of Hydrogen, with diesel are shown in Table 4.4. Load was varied ranging as 25%, 50%, 75% and 100%(full load).

Initially tests are being conducted on the standard engine i.e. standard fuel injection timing of 23° BTDC, injection opening pressure of 200 bar and CR of 17.5. The experimentation is repeated by varying the CR& IOP. The tests carried out for CR of 17.5 & 18.5. The injection opening pressure is also varied from 200 and 220 bar, for every change in IOP and CR by varying the percentage substitution of Hydrogen along with the varying load, the performance characteristics, combustion details and exhaust emissions are noted for analysis and each time all the parameters were noted down as explained above. Engine exhaust emissions were also measured using the advanced MN-05 multi gas analyzer (5 gas version).

During the operation of the engine all the parameters are noted from the digital display and from digital data acquisition system, and the data to calculate P-0, NHR diagram and Mass fraction burned are noted from the computer.
Prevention of explosive atmosphere in the test bench room was taken care by means of monitoring leakages of Hydrogen supply line, air and a powerful ventilation system. Hydrogen cylinder were placed at a safe distance from the engine to avoid heat transfer to the cylinders. The design of the experiment is given in Table 4.4.

Table 4.4 Design of experiment for case II.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Fuel Combination</th>
<th>Gaseous Fuel Substitution (%)</th>
<th>IOP (bar)</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Diesel</td>
<td>-</td>
<td>200</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>220</td>
<td>18.5</td>
</tr>
<tr>
<td>2</td>
<td>Diesel + Hydrogen</td>
<td>10</td>
<td>200</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>220</td>
<td>18.5</td>
</tr>
</tbody>
</table>
Fig. 4.21. The Experimental Flow Chart for Case II.