CHAPTER 3

EXPERIMENTAL SET-UP AND PROCEDURE

3.1  EXPERIMENTAL SET-UP

The details of the engine, measuring instruments and experimental procedure are discussed in this section. The schematic layout of the experimental test set-up used in the present investigation is shown in Figure 3.1 and the photographic view of experimental set-up is shown in Figure 3.2. The test facility consists of the following systems and measuring instruments:

1. Test engine coupled to an alternator with electrical resistance loading device.

2. Two separate tanks, burette and stop watch arrangement for diesel, bio-diesel supply and flow measurements.

3. Pressure regulator, flame trap, needle valve, non return valve and mixing unit to supply and control LPG to the engine.


5. Orifice plate and U-tube manometer for air flow measurements.

6. Thermocouple for measuring the temperature of exhaust gas.
7. Exhaust-gas sampling arrangements for measuring HC, CO and NO\textsubscript{x} with analyzers.

8. Smoke meter for measuring the exhaust smoke.

9. Piezo-electric pick-up with charge amplifier for cylinder pressure measurements.

10. Optical position encoder to locate TDC position.

11. PC based digital data acquisition system and required software for acquiring and analyzing the pressure crank angle data to get the combustion parameters.

### 3.1.1 Test Engine Details

The engine employed for the experimental work was a single cylinder, four stroke, air-cooled, vertical, naturally aspirated DI diesel engine developing power of 3.7 kW at 1500 rpm with a compression ratio of 16.5:1. The technical specifications of the engine are given in Appendix 1. The injector opening pressure recommended by the manufacturer was 200 bar. The governor of the engine was used to maintain a constant speed of 1500 rpm. The combustion chamber is hemispherical in shape. A provision was made to mount a piezoelectric pressure transducer with the cylinder head surface in order to measure cylinder pressure. The injection system of the engine was periodically cleaned and calibrated as recommended by the manufacturer. The engine was modified to operate in dual fuel mode by mounting a gas-air mixture in the intake manifold to supply LPG and also a glow plug was fixed on the engine cylinder head in such a way that one of the pilot jets is sprayed over the glow plug.
Figure 3.1 Schematic of the Experimental setup

1. Engine  
2. Flywheel  
3. Dynamometer  
4. Control panel  
5. Air box  
6. U – Tube Manometer  
7. Weighing machine  
8. LPG Cylinder  
9. Pressure regulator  
10. Flow control valve  
11. Flame trap  
12. Mixing Unit  
13. Diesel tank  
14. Bio diesel tank  
15. Three way valve  
16. Fuel measurement  
17. Injector  
18. Temperature measurement  
19. Exhaust gas analyser  
20. Smoke meter  
21. TDC Marker  
22. TDC position encoder  
23. TDC Amplifier circuit  
24. Pressure Pickup  
25. Charge amplifier  
26. A/D Card  
27. Personal computer  
28. Glow plug
Figure 3.2 Experimental Setup

1. Engine  2. Air box
3. Fuel tank  4. LPG Cylinder
5. Control panel  6. Glow plug heating arrangement
7. Exhaust gas analyser  8. Personal computer

3.1.2 LPG and Liquid Fuel Flow Arrangement

The engine was modified to work in the dual fuel mode by connecting LPG line to the intake manifold with a pressure regulator, flame trap, needle valve, non-return valve and mixing unit. The flame trap is a safety device which prevents the flame in case of back fire. The back flow of the LPG is prevented by the non return valve. The needle valve controls the gas flow rate. The mixing unit facilitates proper mixing of air with LPG. A digital type platform weighing machine having a capacity of 40 kg with an accuracy of 2 mg was used to measure the LPG fuel flow by difference in weight method. Diesel and bio-diesel were stored in separate tanks and
appropriate fuel was supplied to the engine through control valve, measuring burette, filter, injection pump and injector. Diesel and bio-diesel flow rates were measured from the time taken for a fixed volume of respective fuel from the measuring burette.

3.1.3 Air Flow Measurement

The airflow rate was measured with the help of a U-tube manometer. Surge tank with volume fixed of approximately 500 times the swept volume was used to reduce the fluctuations in the airflow.

3.1.4 Temperature Measurement

The temperature of exhaust gases was measured by means of a K-type thermocouple with a range of -200 to 1350 °C and an accuracy of ± 0.75%. The thermocouples were connected to a 6-channel selector switch and a digital panel indicator.

3.2 PRESSURE CRANK ANGLE (P-θ) MEASUREMENT AND HEAT RELEASE RATE ANALYSIS

3.2.1 Cylinder Pressure Measurement

The engine cylinder pressure was measured with KISTLER make air-cooled piezoelectric pressure transducer that has a sensitivity of ± 0.5 %. Detailed specifications of the pressure transducer and charge amplifier are given in Appendix 2. The transducer was mounted on the cylinder head in such a way that there was no leak of gas and was tightened to the torque of 15 Nm to ensure that there was no residual stresses. When the engine was in running condition, the piezoelectric transducer produces a charge output, which is proportional to the in-cylinder pressure. The charge output of the transducer was amplified and converted into voltage signals with the help of a
charge amplifier. The photographic view of the pressure transducer and charge amplifier are shown in Figure 3.3. The cylinder pressure signals were recorded on a computer.

![Figure 3.3 Pressure Transducer and Charge Amplifier](Image)

1. Pressure Transducer 2. Charge Amplifier 3. Cylinder head

### 3.2.2 TDC Position Sensor

Top Dead Centre (TDC) was used as a reference for determining the crank position. An Optical position encoder was used to give a voltage pulse exactly when the piston reaches the TDC position. In order to find the TDC position, the cylinder head was removed and a dial gauge was used to determine the highest position of the piston. To locate the exact position of TDC, the flywheel was rotated until the dial indicator indicates highest point of piston travel. The maximum top position was marked on the flywheel by means of a pointer where the piston displacement was sensed by the dial indicator. A mild steel projection fixed on the flywheel generates a voltage spike whenever it cuts the infrared signal. The photographic view of the TDC position sensor is shown in Figure 3.4.
3.2.3 Heat Release Rate Analysis

The heat release rate is a quantitative description of the burning pattern in the engine. An understanding of the effects of heat release rate on cycle efficiency can help to study the engine combustion behaviour. The pressure-crank angle variation is the net result of many effects like combustion, change in cylinder volume and heat transfer from the gases in the engine cylinder (Bertrand D. Hsu et al 1984). In order to get the effect of only the combustion process, it is necessary to relate each of the above processes to the cylinder pressure and thereby separate the effects of the combustion process alone. The method by which this is done is known as the heat release analysis (Heywood J.B 1998).

The heat release data provides a good insight into the combustion process that takes place in the engine. Literature indicates many standard
techniques for calculating heat release rates from pressure crank angle data of four-stroke engines. Hayes et al (1986) suggested a simple heat release model based on the First Law of Thermodynamics. A program written in MATLAB was used to calculate the heat release rate from the averaged pressure-crank angle data of hundred consecutive engine cycles. The heat release analysis is given in Appendix 3.

3.3 EMISSION MEASUREMENTS

3.3.1 HC and CO Emissions Measurements

Carbon monoxide and unburned hydrocarbons were measured with a Crypton make, non-dispersive infrared gas (NDIR) analyzer. The detection technique is based on the principle of selective absorption of the infrared energy at a particular wavelength peculiar to a certain gas, which will be absorbed by that gas (Yadav et al 2002). The exhaust gas sample was passed through a moisture separator and filter element to prevent water vapour and particulates from entering the analyzer. The analyzer was periodically calibrated with standard gas containers n-hexane and CO mixture. The details of the exhaust gas analyzer are given in Appendix 4.

3.3.2 Smoke Measurements

Smoke emissions were measured by means of a Diesel tune type smoke meter. Gas samples were trapped on filter papers and the spot made on the filter paper was evaluated by means of a photocell reflectometer unit that gives a precise assessment of the intensity of spot. The details of the smoke meter are given in Appendix 5.
3.3.3 **NO\textsubscript{x} Emission Measurement**

NO\textsubscript{x} emissions from the engine were measured using a Crypton make five gas analyzer. The sample was passed through a condensing bottle to separate moisture from the exhaust.

3.4 **GLOW PLUG ARRANGEMENT**

The experimental engine was modified to accommodate the glow plug and was located at the down stream side and close to the fuel injector. The glow plug used was standard Mico Bosch make 5mm dia pencil type. It was supplied with current by means of a 12 volt battery, and has been located into the combustion chamber in such a way that more area was exposed to the injected liquid fuel. A current supply of 3.5 to 4 amperes gives glow plug temperature of about 850 °C after 30 seconds and the glow plug was allowed to be in operation continuously throughout the engine operation. The current supply to the glow plug was varied by means of a rheostat. The amount of current and voltage applied to the plug were measured by means of an ammeter and a voltmeter respectively.

Glow plug position is important, hence, care was taken in locating a suitable position for the glow plug, the angle of the glow plug position was determined by considering the angle of the fuel injector, and the angle of fuel spray. The glow plug was positioned in between the exhaust valve and the fuel injector in such a way that one of the fuel sprays impinge on the surface of the glow plug. The presence of the glow plug also heats the surrounding air thereby raising its temperature. The location of the glow plug was mainly decided based on the cylinder head configuration. The photographic view of the cylinder head with glow plug is shown in Figure 3.5.
Figure 3.5 Engine Cylinder Head with Glow plug

1. Glow plug    2. Injector location    3. Exhaust valve
4. Inlet valve  5. Cylinder head

3.5   UNCERTAINTY ANALYSIS

Any experimental measurement, irrespective of the type of instrument used, possesses a certain amount of uncertainty. The uncertainty in any measurement may be caused by either fixed or random errors. As the fixed errors are repeatable in nature they can be easily accounted for to get the true value of measurement. However random errors have to be estimated only analytically. Any independently measured parameter has its own uncertainty, which in turn causes uncertainty in the computed parameter in which it is used. The uncertainty in measured and calculated parameters and the method of estimation that was followed in the present work is given in Appendix 6.
3.6 TRANSESTERIFICATION OF NEEM OIL

The production of neem oil ethyl esters (NOEE) by transesterification of neem oil requires raw oil, ethanol 6:1 molar ratio and 5% of sodium hydroxide (NaOH) on mass basis. However, transesterification is an equilibrium reaction in which excess alcohol is required to drive the reaction very close to completion. The vegetable oil reacts with an alcohol in the presence of a catalyst to produce ethyl esters. Glycerol was produced as a by-product of transesterification reaction.

\[
\begin{align*}
\text{CH}_2\text{-COOR}_1 & \quad \text{Catalyst} & \quad \text{CH}_2\text{-OH} & \quad \text{R}_1\text{COO CH}_3 \\
\text{CH}_2\text{-COOR}_2 + 3 \text{CH}_3\text{OH} & \quad \Delta & \quad \text{CH}_2\text{-OH} & \quad \text{CH} - \text{OH} + \quad \text{R}_2\text{COO CH}_3 \\
\text{CH}_2\text{-COOR}_3 & \quad & \quad \text{CH}_2\text{-OH} & \quad \text{R}_3\text{COO CH}_3 \\
\text{Triglyceride} & \quad \text{Ethanol} & \quad \text{Glycerol} & \quad \text{Biodiesel}
\end{align*}
\]

The mixture was stirred continuously and the temperature was maintained 55 °C to 60 °C for one hour duration and then it was allowed to settle under gravity in a separating funnel. Two distinct layers were formed after gravity settling. The upper layer was ester and the lower layer was glycerol. The lower layer was separated out. The separated ester was mixed with warm distilled water (around 10% volume of ester) to remove the catalyst present in ester. The NOEE prepared was used as a pilot fuel in the dual fuel operation.

3.7 EXPERIMENTAL PROCEDURE

All the experiments were conducted at the rated speed of 1500 rpm. The readings were recorded only after the engine attained stable operating conditions. All the instruments were periodically calibrated. The injector opening pressure was kept at the rated value throughout the experiments. The engine output was varied in steps from 20% of rated power to rated power in the normal operation and dual fuel operation of the engine. At each load, fuel
flow rate, mass flow rate of air, exhaust gas temperature, emissions of carbon monoxide, hydrocarbons, oxides of nitrogen and smoke readings were recorded. The pressure crank angle history of 100 consecutive cycles was also recorded by using the data acquisition system and personal computer. These data were processed to get the average pressure crank angle variation.

The experiments conducted in the present work are as follows:

- Initial tests were conducted with diesel (D) and neem oil (NO) at the rated speed and variable load conditions to compare the performance, emission and combustion characteristics of base fuels.

- Tests were conducted with neem oil ethyl ester (NOEE) to study the effects of esterified oil on the performance, emission and combustion parameters of the engine.

- Experiments were conducted with glow plug assisted hot surface ignition engine using neem oil (NO) and neem oil ethyl ester as fuel with the maximum glow plug temperature of 850 °C.

- In the next phase, the engine was operated in the dual fuel mode with LPG as the inducted fuel and neem oil and neem oil ethyl ester as the injected fuel. In each case, the flow rate of injected fuel was maintained at 7.6 mg/cycle and the LPG flow was controlled with a needle valve. Experiments were conducted at different loads from 20 % of rated power to rated power.

- Finally the effect of glow plug in the dual fuel operation of neem oil and its ethyl ester (NOEE) with LPG were studied in order to improve the part load performance of dual fuel engine. Experiments were conducted from 20 % of rated power to rated power with the optimum glow plug temperature of 450 °C.
The test matrix indicating all the experiments conducted is given in Table 3.1.

**Table 3.1 Test Matrix**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Fuel used</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal operation with neem oil and its ester</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated power at 20 %, 40 %, 60 %, 80 % and 100 % at the rated speed of 1500 rpm</td>
<td>1. Diesel (D) 2. Neem oil (NO) 3. Neem oil ethyl Ester (NOEE)</td>
<td>Evaluation of performance, emissions and combustion parameters of esterified fuel</td>
</tr>
<tr>
<td>Normal operation with glow plug</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated power at 20 %, 40 %, 60 %, 80 % and 100 % at the rated speed of 1500 rpm. Glow plug temperature was maintained at 850 °C</td>
<td>1. Diesel (D) 2. Neem oil (NO) 3. Neem oil with GP (NO - GP) 4. Neem oil ethyl Ester with GP (NOEE - GP)</td>
<td>Evaluation of performance, emissions and combustion parameters with glow plug</td>
</tr>
<tr>
<td>Dual fuel operation with LPG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated power at 20 %, 40 %, 60 %, 80 % and 100 % at the rated speed of 1500 rpm. LPG flow rate was maintained at 7.6 mg/cycle</td>
<td>1. Diesel (D) 2. Neem oil (NO) 3. Neem oil with LPG (NO - LPG) 4. Neem oil ethyl Ester with LPG (NOEE - LPG)</td>
<td>Evaluation of performance, emissions and combustion parameters in dual fuel operation</td>
</tr>
<tr>
<td>Dual fuel operation with LPG and glow plug</td>
<td></td>
<td></td>
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<tr>
<td>Rated power at 20 %, 40 %, 60 %, 80 % and 100 % at the rated speed of 1500 rpm. LPG flow rate was maintained at 7.6 mg/cycle and glow plug temperature was maintained at 450 °C</td>
<td>1. Diesel (D) 2. Neem oil with LPG (NO - LPG) 3. Neem oil (NO - LPG - GP) 4. Neem oil ethyl Ester (NOEE - LPG - GP)</td>
<td>Evaluation of performance, emissions and combustion parameters in dual fuel operation with glow plug</td>
</tr>
</tbody>
</table>