CHAPTER 3

EXPERIMENTAL SET-UP AND TECHNIQUES

3.1 EXPERIMENTAL SET-UP

The schematic view of the experimental test set-up used in the present investigation is shown in Figure 3.1. A photographic view of the entire experimental set up is shown in Figure 3.2. The test facility includes the following arrangements:

1. Test engine coupled to an alternator with electrical resistance loading device.
2. Burette and stop watch arrangement for diesel and DEE flow measurements.
3. Orifice plate and U-tube manometer for air flow measurements.
4. Thermocouple for measuring the temperature of exhaust gas, intake charge, cylinder head and cooling water.
5. Digital platform type electronic weighing machine for LPG flow measurements.
6. Piezo-electric pick up for cylinder pressure measurements.
7. Needle valve and intra venous needle valve for the control of LPG and DEE flow respectively.
8. Electro magnetic inductive pick up for TDC position.
1. LPG Cylinder on a Digital Platform Type Weighing Machine
2. Pressure Regulator
3. LPG Flow Regulating Needle Valve
4. Positive Displacement Gas Flow Meter
5. Flame Trap
6. Alternator
7. Gas-Air Mixer
8. Air pre Heater
9. Surge Tank
10. Air Inlet
11. Engine
12. Control Valve for DEE
13. Thermocouple
14. DEE Tank
15. EGR Gate valve
16. Emission Analyser
17. Charge Amplifier
18. P.C. Based Data Acquisition System
19. Magnetic inductive pick up
20. Engine Inlet
21. Fly wheel

Figure 3.1 Schematic diagram of the experimental set-up
Figure 3.2 Photographic view of the engine set-up

1. LPG Cylinder With water bath
2. Digital Platform Type Weighing Machine
3. LPG Line
4. LPG Flow Regulating Needle Valve
5. Flame Trap
6. Loading Device
7. Variable Voltage Source
8. Burette for Diesel Measurement
9. U-tube Manometer for Airflow Measurements
10. Temperature Indicator for Engine Head
11. DEE Tank
12. Burette for DEE Measurement
13. Temperature Indicator for Inlet Air
14. Relay
15. Surge Tank
16. Air pre Heater
17. Alternator
18. Engine
19. Electro Magnetic Inductive Pickup
20. EGR Flexible Metal Piper pre Heater
9. P.C. based digital data acquisition system and required software for acquiring and analyzing the pressure crank angle data to get combustion parameters.

10. Arrangement for maintaining the LPG cylinder at constant temperature for ease of flow.

11. Exhaust-gas sampling arrangements for measuring HC, CO and NO with online analyzers.

12. Smoke meter for measuring the exhaust smoke.

### 3.1.1 Test Engine Details

The engine employed for the experimental work was a single cylinder, four stroke, water-cooled, vertical, naturally aspirated DI diesel engine developing power of 3.73 kW at 1500 rpm with compression ratio of 16.5:1. The engine was modified to operate in HCCI engine mode by mounting gas-air mixture arrangement in the intake manifold to supply LPG. The technical data of test engine is given in Appendix 2.

### 3.1.2 LPG and DEE Flow Arrangement

Copper tube of 3 mm diameter with an intra venous needle arrangement for admitting DEE into intake manifold was provided in the intake port to operate in HCCI mode. The photographic view of the LPG and DEE flow arrangement is shown in Figure 3.3 and Figure 3.4. Cylinder pressure data was acquired at one-degree crank angle intervals used with a piezoelectric pressure pickup and signals were recorded on personal computer via an analogue to digital converter with 12-bit resolution.
Figure 3.3 Photographic view of LPG line arrangement

1. LPG Cylinder With Water Bath
2. Digital Platform Type Weighing Machine
3. LPG Flow Regulating Needle Valve
4. Flame Trap
5. Flow Meter
1. EGR Inlet
2. Engine Inlet Pipe
3. Gas-Air Mixer
4. LPG Line
5. Engine Head
6. Injection Needle For DEE
7. Fine Control Valve
8. Cooling Water Pipe Line
9. Temperature Indicator

Figure 3.4 Photographic view of LPG-DEE port admission
3.1.3  Inlet Mixture Preheating System

Electric heater of capacity 2 kW was provided in the intake air pipeline to preheat the air. A thermocouple was inserted just before the intake port to monitor the intake temperature and was connected to a temperature controller. The temperature controller was used to control the set temperature. As the intake air temperature was raised above the set temperature, the temperature controller gives a signal to the relay to cut the power supply to the electric heater. The electric heater was connected through the variable voltage source, which was used to gradually increase or decrease the voltage according to the set temperature. The entire intake air pipeline was insulated by asbestos rope to avoid heat losses to the atmosphere. The photographic view of the air preheater set up is shown in Figure 3.5.

3.1.4  Exhaust Gas Recirculation System

A schematic diagram of the EGR arrangement is shown in Figure 3.6. A spring type flexible metal pipe was installed between the exhaust pipe and the intake pipe, to route the exhaust gases back to the engine inlet system, where the hot gases were inducted into the succeeding cycles. Two gate valves were provided, one in the exhaust pipe and other in the intake pipe to divert a fixed quantity of the exhaust gases into the intake manifold so as to mix with the incoming air before being inducted into the combustion chamber. The photographic view is shown in Figure 3.7.

The EGR ratio was obtained from the measured mass flow rate of air with and without EGR and the EGR percentage was calculated using the formula given by Nicos Ladommatos et al 1996:
1. Air Preheater
2. Electrical Relay Contactor
3. Digital Temperature Indicator
4. Engine

Figure 3.5 Photographic view of air preheater
Figure 3.6 Schematic view of the EGR set-up

1. LPG Cylinder With water bath
2. Air Inlet
3. Surge Tank
4. DEE Tank
5. Control Valve
6. Exhaust Pipe
7. Engine
8. Inlet-Manifold
9. Exhaust-Manifold
Figure 3.7 Photographic view of EGR set-up

1. Surge Tank
2. Control Valve
3. Exhaust Pipe
4. EGR Flexible Metal Pipe
5. Engine Inlet Pipe
6. Gas-Air Mixer
7. Engine
Where, $=[M_a]$ Mass flow rate of air, kg/s

With the knowledge of the intake air flow without EGR, the mass flow rates and the manometer heads for the required quantities of EGR are predetermined and the EGR control valve is opened until the required head is achieved.

### 3.1.5 Air, Diesel and DEE Flow Measurements

The airflow rate was measured with the help of a U-tube manometer. Surge tank with volume fixed at approximately 500 times the swept volume was used to reduce the fluctuations in the airflow. Diesel and DEE flow rate were measured from the time taken for a fixed volume of diesel and DEE from the respective burette.

### 3.1.6 LPG Supply and Measurement System

The LPG cylinder was kept in a bath maintained at a constant temperature of 40°C. Since the gas flows from the cylinder, the temperature of the contents in the cylinder falls, which leads to reduction in the vapour pressure of LPG and hence the flow rate gradually decreases. LPG from the cylinder was allowed to flow through a regulator in order to bring the pressure to atmospheric value. LPG from the regulator was fed into fine control needle valve and passed into flame trap before being admitted into the gas carburettor in the intake manifold. The needle valve was used to control the desired quantity of LPG flow rate. The flame trap was used to arrest the

\[
\text{EGR \%} = \frac{[M_a] \text{ without EGR} - [M_a] \text{ with EGR}}{[M_a] \text{ without EGR}}
\]
backflash if any from the engine. LPG consumption was measured by weight difference method by using digital type platform weighing machine having an accuracy of 5 mg.

3.1.7 Temperature Measurement

The temperature of exhaust gases, intake charge, and cylinder head were measured by means of a K-type (chromel-alumel) thermocouples. The thermocouples were connected to a 12-channel selector switch and digital panel indicator.

3.1.8 TDC Position Sensor

The reference point used for determining the crank position was the Top Dead Center (TDC). An electro magnetic inductive pick up was used to give a voltage pulse exactly when the piston reached 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 sensed by the dial indicator. A mild steel projection fixed on the flywheel generates a voltage spike that whenever it comes closer to magnetic pick up which gives the TDC position.

3.1.9 Cylinder Pressure Measurement

The engine cylinder pressure was measured with KISTLER make water-cooled piezoelectric pressure transducer that has a sensitivity of 14.2 pC / bar. The transducer was mounted on the cylinder head in such a way
that there was no leak of gas and was tightened to the recommended torque 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 pressure transducer had the advantage of excellent linearity and high sensitivity over the entire range of operation. The cylinder pressure signals were recorded on a personal computer using an analogue to digital converter and average pressure were obtained from 100 consecutive cycles. The amplified signal was recorded on the data acquisition system along with signals from the pressure transducer.

3.1.10 Data Acquisition System

A PC based high-speed digital data acquisition system was used to acquire pressure and TDC signals and store them in the digital form on the personal computer. A 12-bit analog to digital (A / D converter) card was used to convert the signals to digital form. The A/D card has external and internal triggering facility with eight single ended or eight differential channels. Pressure and TDC signals were recorded for 100 cycles on the PC at a resolution of 12 bit with accuracy of ± 2 bit. This amounts to a resolution of one sample per degree of crank rotation. Recorded signals were processed with a software programme (MATLAB) to obtain the heat release rate from pressure crank angle data. The heat release rate is derived from the first law of thermodynamics, which is given in Appendix 3. A photographic view of the data acquisition system is shown in Figure 3.8.
Figure 3.8 Photographic view of the data acquisition system

1. Piezo-electric Pick-up
2. Electro Magnetic Inductive Pickup
3. 12-bit Analog to Digital Converter
4. Charge Amplifier
5. Cathode Ray Oscilloscope
6. Personal Computer
3.2 EMISSION MEASUREMENTS

3.2.1 HC and CO Emissions Measurements

Carbon monoxide and unburned hydrocarbons were measured with a Horiba 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 vapor and particulates from entering the analyzer. The analyzer was periodically calibrated with standard gas containers n-hexane and CO mixture.

3.2.2 Particulate Emission Measurement

Particulate emission measurement was made by gravimetric method. The filter papers measuring 60 mm in diameter were initially heated in the oven, which was maintained at a temperature of 100°C for a period of 2 hours to remove the moisture from the filter paper. These filter papers were then weighed in micro physical balance having an accuracy of ± 0.001 gram and kept in an airtight box. The weight of a typical filter paper lies in the range of 0.35 - 0.4 grams. While conducting the experiments the filter papers were placed inside the smoke meter (one at a time) and the particulates were allowed to be trapped on the filter papers for five seconds. The filter paper was again heated to remove moisture and weighed. The difference in weight of the filter papers gave the particulate emission in g / h.
3.2.3 **Smoke Measurements**

Smoke emissions were measured by means of a Bosch 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.

3.2.4 **Nitric Oxides Measurement**

NO constitutes about 90% of the total oxides of nitrogen emitted in the engine exhaust. NO emissions from the engine were measured using a MRU make analyzer. The sample was passed through a condensing bottle to separate moisture from the exhaust. The photographic view of all analyzers used are shown in Figure 3.9.

3.3 **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 (John B. Heywood 1998).
Figure 3.9 Photographic view of the emission analysers

1. NDIR Exhaust Gas Analyser [Horiba Make]
2. MRU Gas Analyser
3. Tacho Meter
4. Bosch Type Smoke Meter
5. Exhaust Gas Trap Meter
6. Engine
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 software written in MATLAB was used to calculate the heat release rate from the averaged pressure-crank angle data of 100 consecutive engine cycles.

3.4 EXPERIMENTAL TECHNIQUES AND PROCEDURE

Experiments were conducted adopting the following techniques to study the performance, combustion and emission characteristics of the HCCI engine:

1. Tests with neat LPG using DEE as an ignition enhancer
2. Tests with technique of Inlet Air Preheating on neat LPG using DEE as an ignition enhancer.
3. Tests with technique of Exhaust Gas Recirculation on neat LPG using DEE as an ignition enhancer

The following steps were followed to operate the engine test on neat LPG using DEE as an ignition improver:

- The engine was started and brought to operating temperature using LPG-diesel in dual fuel mode.
- After the engine has reached the operating temperature, the diesel fuel supply was gradually reduced to zero.
- DEE was added through an intra-venous needle arrangement in drops and just before the intake manifold it mixes in the form of vapour with LPG-air mixture.

- The LPG and DEE flow rate varied manually according to the load with DEE optimised to give better combustion without misfiring and knocking.