CHAPTER 5

ANALYSIS AND PROCEDURE

5.1 GENERAL

In this section the details of combustion and heat release analysis of experiments conducted in various modes of operation are presented. All the tests were conducted at the rated speed of 1500 rpm. All readings were taken only after the engine attained stable operation. The gas analyzers were switched on before starting the experiments to stabilize them before starting the measurements. All the instruments were periodically calibrated. The injector opening pressure and injection timing were kept constant at the rated value throughout the experiments. The following paragraphs describe the procedure adopted for the analysis of the experimental data obtained during this investigation.

The injection timing is kept constant in all the experiments. The dynamic injection timing was used to calculate the ignition delay. The engine output was varied from no load to full load in steps of 25%, 50%, 75% and 100% in the normal operation of the engine. At each load the fuel flow rate, air flow rate, exhaust gas temperature, emissions of carbon monoxide, hydrocarbon and oxides of nitrogen and smoke readings were recorded. The pressures crank angle history of 50 cycles was also recorded by using the data acquisition system and the personal computer. The following sections explain the analysis and procedure for the performance and combustion parameters of the diesel engine.
5.2 PERFORMANCE PARAMETERS

The performance characteristics are estimated from the measured values

i) Brake thermal efficiency: (BTE)

\[ BTE = \frac{\text{Output power}}{[\text{FC} \times \text{CV}]} \]

ii) Brake specific fuel consumption: (BSFC)

\[ \text{BSFC} = \frac{\text{FC}}{\text{BP}} \]

Brake specific energy consumption: (BSEC)

\[ \text{BSEC} = \text{BSFC} \times \text{C.V} \text{ [where C.V is the calorific value of the fuel]} \]

iii) Fuel consumption : FC

\[ \text{FC} = \left[ \text{known quantity of fuel consumed/time taken for the known quantity of the fuel consumed} \right] \times \text{density of the fuel} \]

Brake specific energy consumption: (BSEC)

\[ \text{BSEC} = \text{BSFC} \times \text{CV} \]

iv) Brake power : (BP)

\[ \text{BP} = \frac{\text{W} \times \text{N} \times \text{C}}{} \]

where W is the load on the dynamometer, N is the speed of the engine and C is the dynamometer constant.

5.3 COMBUSTION ANALYSIS

The instantaneous experimental data are acquired over several cycles. For averaging, pressure data of approximately 50 thermodynamic cycles are chosen. The first in the voltage signal due to TDC indicator is taken
as a TDC position. At affixed clock frequency of the data acquisition card of 100 kHz, approximately 370-380 pressure-voltage readings are acquired by the PC for each rotation of the crank shaft. By interpolation, the pressure-voltage readings are arranged at a spacing of 1° CA degree. The interpolation is more accurate, if done through spline fitting. Since the engine is four stroke type, 720 such interpolated data correspond to one complete thermodynamic cycle (intake, compression, combustion and exhaust) of the engine. The interpolated data are corrected for the transducer drift by subtracting from them, a linearly increasing voltage (≈2mV/s). Subsequently these data are multiplied by the constant ‘B’ to obtain it into relative pressure values at each instant. These pressure data are required to be referenced using a particular known pressure, hence pressure at inlet BDC is taken equal to the inlet manifold pressure. This is because at this instant, the inlet valve is completely open and the cylinder pressure is considered in equilibrium with the inlet manifold pressure, which is atmospheric pressure in the naturally aspirated engine case. The value of calibration constant of B for the pressure transducer is found to be 9.9831 bar/volt and the linear curve fit equation between pressure and voltage yields:

\[
\text{Pressure (bar)} = 9.9831 \times (\text{charge amplifier voltage in volts}) - 0.0263.
\]

5.4 HEAT RELEASE RATE ANALYSIS

A piezo-electric pressure transducer was flush mounted on the cylinder head and the signals are recorded on a data acquisition system. Along with the pressure signal the TDC position signal was also acquired by the A/D converter installed in the personal computer. These voltage signals were stored in two columns in a file at uniform time intervals. Since a piezo-electric pressure transducer provides only relative pressures, it is necessary to know the absolute pressure at some point in the cycle so that the pressure at all other points can be had. For this the cylinder pressure at suction
BDC was assumed to be equal to mean manifold pressure (Lancaster et al., 1975). Software was used to compute the average pressure crank angle values for 50 consecutive cycles. From this peak pressure, occurrence of peak pressure, maximum rate of pressure rise and heat release were calculated.

The rate at which combustion occurs i.e., the rate of heat release affects the efficiency, power output and emissions of an engine. The heat release rate curve provides a good insight into the combustion process that takes place in the engine. A program was used to compute the heat release rate based on the first law of thermodynamics.

\[
Q_{app} = \frac{\gamma}{\gamma - 1} PdV + \frac{1}{\gamma - 1} VdP + Q_w
\]

where \( Q_{app} \) - Apparent heat release rate (J)

Ratio of specific heats \( \gamma = \frac{C_p}{C_p - R} \)

\( R \) - Gas constant in (J / kmol-K)

\( C_p \) - Specific heat at constant pressure (J / kmol-K)

\( P \) - Cylinder pressure (bar)

\( Q_w \) - Heat transfer to the wall (J)

For this calculation the contents of the cylinder were assumed to behave as an ideal gas (air) with specific heats dependant on temperature. The specific heat was calculated using the equation given below (Heyas 1986)
\[
C_p = \left( 3.6359 - \frac{1.33736T}{1000} + \frac{3.2942T^2}{1*10^6} - \frac{1.91142T^3}{1*10^9} + \frac{0.275462T^4}{1*10^{12}} \right)R
\]

For \( T > 1000 \text{ K} \)

\[
C_p = \left( 3.04473 + \frac{1.338056T}{1000} - \frac{0.488256T^2}{1*10^6} + \frac{0.0855475T^3}{1*10^9} - \frac{0.00570127T^4}{1*10^{12}} \right)R
\]

For \( T > 1000 \text{ K} \)

The heat transfer was calculated based on the Hohenberg equation (Hohenberg, 1986) given below and the wall temperature was assumed to be 723 K (Heyes, 1986)

\[
h = C_1V^{-0.06}P^{0.8}T^{-0.4}(V_p + C_2)^{0.8}
\]

where
- \( h \) - Heat transfer coefficient in W/m\(^2\)K
- \( C_1 \) & \( C_2 \) - Constants, 130 & 1.4
- \( V \) - Cylinder volume in m\(^3\)
- \( P \) - Cylinder pressure in bar
- \( T \) - Cylinder gas temperature in K
- \( V_p \) - Piston mean speed in m/s

Start of combustion was determined from the heat release rate curve. The crank angle at which there is a sudden rise in heat release rate was taken as the start of combustion. End of combustion was determined from the cumulative heat release curve. It was taken as the point where 90\% of heat release had occurred. Ignition delay is the time lag between the start of injection to the start of combustion. The dynamic injection timing was used to calculate the ignition delay.
5.5 ERROR ANALYSIS OF THE EXPERIMENTAL DATA

Any measurement, irrespective of the type of instrument used, possesses a certain amount of uncertainty or error. Some of these errors are of random nature and needs a device to specify consistently the uncertainty in analytical form. Hence, a brief attempt is made to estimate the magnitude of uncertainty in various measurements by theoretical methods. The procedure used for the uncertainty analysis is given in the Appendix 4.