When the excess air used is known and minimum quantity of air required is also known, the actual quantity of air supplied per cu. m. of fuel gas can be found.

12.13. FLUE GAS ANALYSIS

A simple and convenient apparatus used for the volumetric analysis of dry flue gases is known as Orsat apparatus.

The construction of the apparatus is shown in Fig. 12.1. It consists of three flasks *a*, *b* and *c* each containing different chemicals for absorbing CO_2, O_2 and CO. The percentage of N_2 is obtained by difference. The percentage of SO_2 in the gases cannot be measured separately by the apparatus.

The absorbents used in flask '*a*' are NaOH or KOH solution (one part of KOH + 2 parts of water by weight) and this solution absorbs CO_2. The flask '*b*' contains alkaline solution of pyrogallic acid (5 gm pyrogallic acid in 15 c.c. of water mixed with 120 gm of KOH in 80 c.c. of water) and this solution absorbs O_2. The flask '*c*' contains cuprous chloride (CuO dissolved in 20 times its weight of concentrated HCl till it becomes colourless) which absorbs CO. Keeping valves *x*, *y* and *z* closed the three-way valve is opened and the aspirator bottle is moved down, so that the flue gas enters the eudiometer tube. The flue gas is drawn in until the level in the eudiometer reads zero. The 3-way valve is closed and then the valve *x* of the flask '*a*' is opened and the aspirator bottle is moved up and down several times pushing the gas into the flask '*a*' containing KOH solution, which absorbs the CO_2 gas. Now the flue gas is taken into the eudiometer by lowering the aspirating bottle and the valve *x* is closed keeping the original level of solution. The aspirator is then brought near to eudiometer and placed at such a position that the water level in both is same and the reading of eudiometer tube is taken. The difference in reading (before absorbing and after absorbing CO_2) gives the percentage of CO_2 in the flue gas. The procedure is repeated with the flasks '*b*' and '*c*' to find the percentage of O_2 and CO. The remainder of the flue gas after the absorption of CO is taken as N_2.

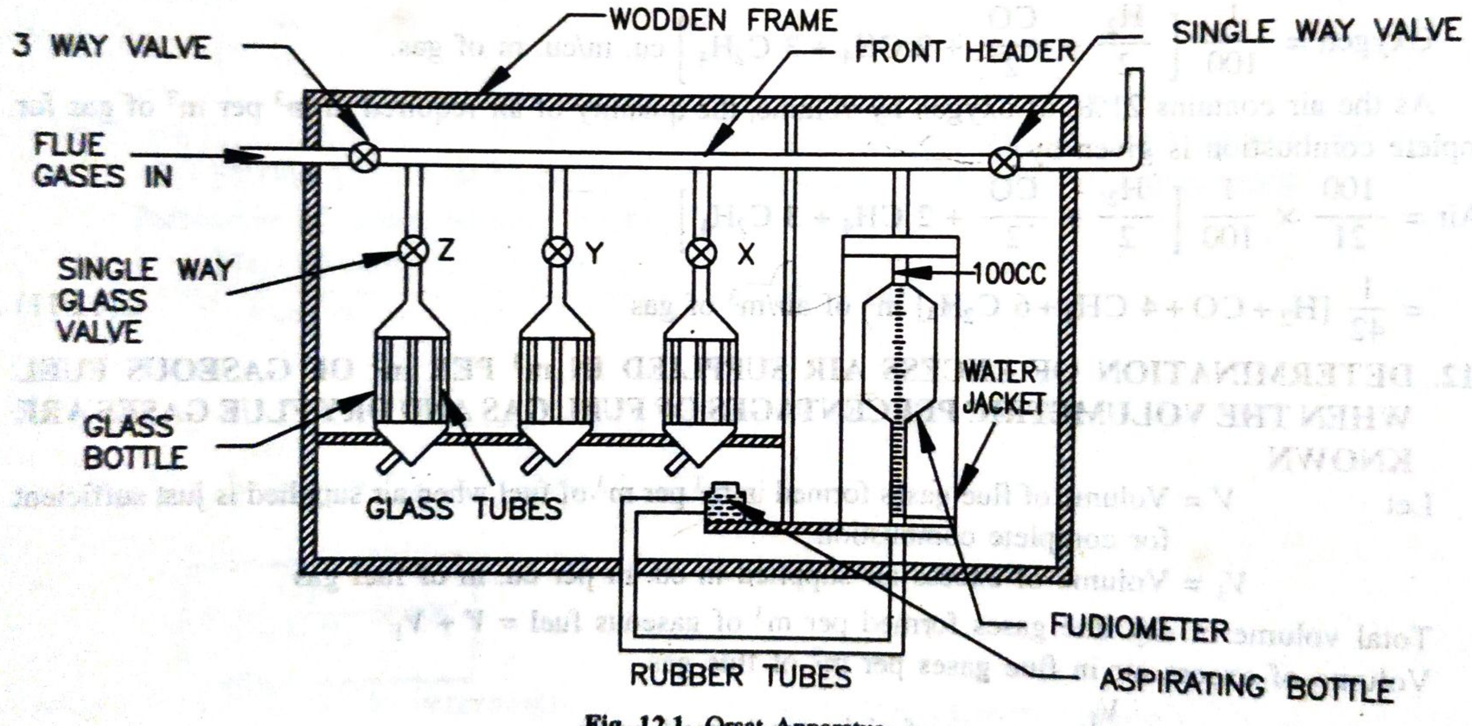

Fig. 12.1. Orsat Apparatus.

Generally all flue gases contain water vapour due to the presence of hydrogen in the fuel, but Orsat apparatus gives the percentages of dry flue gases only as water vapour is condensed at room temperature when the gas is drawn over water.

The flue gases may be passed through a U-tube containing calcium chloride (drying agent) before taken into the Orsat apparatus in order to ensure that only dry gas is being analysed.

The order of absorbing the gases should be CO_2 first, O_2 second and finally CO. This is necessary because the absorbent used for O_2 may absorb some CO_2 and the percentage of CO_2 given by the apparatus would be less if O_2 is absorbed first and CO_2 afterwards. Correct sequence of absorption eliminates this difficulty. The flasks *a*, *b* and *c* are made in duplicate joined together with a glass tube (not shown in figure) for proper mixing of gases with the absorbents.

The eudiometer of 100 c.c. capacity, is surrounded by water to keep the temperature constant. A 3-way valve at one end can connect the header to flue gas supply or atmosphere or isolate it. Each flask is provided with a valve at the neck, adjoining the front header as shown in figure. It is also filled with number of tubes to provide increased surface area so that the absorption is accelerated.

Eudiometer is connected to the aspirating bottle from the bottom by flexible rubber pipe. The aspirating bottle position can be changed by lifting or lowering it. The lifting of aspirating bottle pushes up the level of water in the eudiometer.

Working

The chemical solutions in the flask *a*, *b* and *c* are brought up to the points 1, 2 and 3 respectively one by one by operating the aspirator bottle and the valves in each flask. The valves of the flask *a*, *b* and *c* are then closed.

All the air or any other gas from the eudiometer is expelled to atmosphere by lifting the aspirator bottle and opening the 3-way valve. The 3-way valve is then connected to the flue gas supply and the aspirated bottle is brought down until the level in the eudiometer reads zero, taking the gas into the eudiometer. The gas in the eudiometer is again expelled to the atmosphere to remove the air left in the apparatus (mostly in the heeder). This procedure is repeated a few times to ensure a fair sample of the gas.

The pressure and temperature should be maintained constant during the analysis because the volume is very sensitive to both the factors.

(1) The apparatus is very handy and fairly accurate.

(2) The percentage of CO, in the flue gas is small and therefore the measurement should be made very carefully.

12.14. BOMB-CALORIMETER

The calorific values of solid and liquid fuels are generally determined using a Bomb-calorimeter. The arrangement of the calorimeter is shown in Fig. 12.2 (*a*). It consists of a strong steel shell known as Bomb and is designed to withstand a pressure of about 100 atmospheres. To prevent the corrosion due to high temperature combustion products, the inside surface is lined with enamel and exterior of the bomb is plated. The bottom of the bomb is provided with platinum nickel supports and connections to an electric supply. Two pillars are provided inside the bomb to support the crucible made of silica or quartz. It is also provided with a non-return valve and release valve as shown in Fig. 12.2 (*a*).

The bomb is placed in water bath and water bath itself is placed in another container as shown in figure which acts as heat insulator. The outer vessel is provided with arrangement for inserting a thermometer and stirrer.

A known quantity of fuel is taken (in case of solid fuel in the form of a pellet) in the crucible. The crucible is fixed in the bomb in such a way that the fuse touches the fuel. The bomb is then charged with oxygen to a pressure of 30 bar. The oxygen charging valve (non-return valve) and release valve are closed tightly and the bomb is placed in water bath and then it is closed with the cover. The water in the calorimeter is stirred and when the temperature remains steady, the fuel is ignited by passing a current through the fuse wire. The temperature of the bath starts increasing after the ignition very quickly and the readings on the thermometer are taken at regular intervals for ten minutes to an accuracy of 0.01°C by a Beckmann thermometer till the maximum temperature is reached. After that, the temperature starts falling slowly. When the temperature fall shows a steady rate, the temperature readings are taken at regular intervals for an additional five minutes. The cooling correction can be found by plotting time V_s temperature as shown in Fig. 12.2 (*b*).

The cooling correction should be added to the measured temperature rise.

By heat balance :

Heat given by the fuel due to combustion + Heat given by the combustion of fuse wire

= Heat absorbed by the water and calorimeter.

$$m_f \times \text{H.C.V.} + m_{wf}.\text{C.V.} = (m_w + m_c)\theta \; ; \text{ where } m_f = \text{mass of fuel}$$

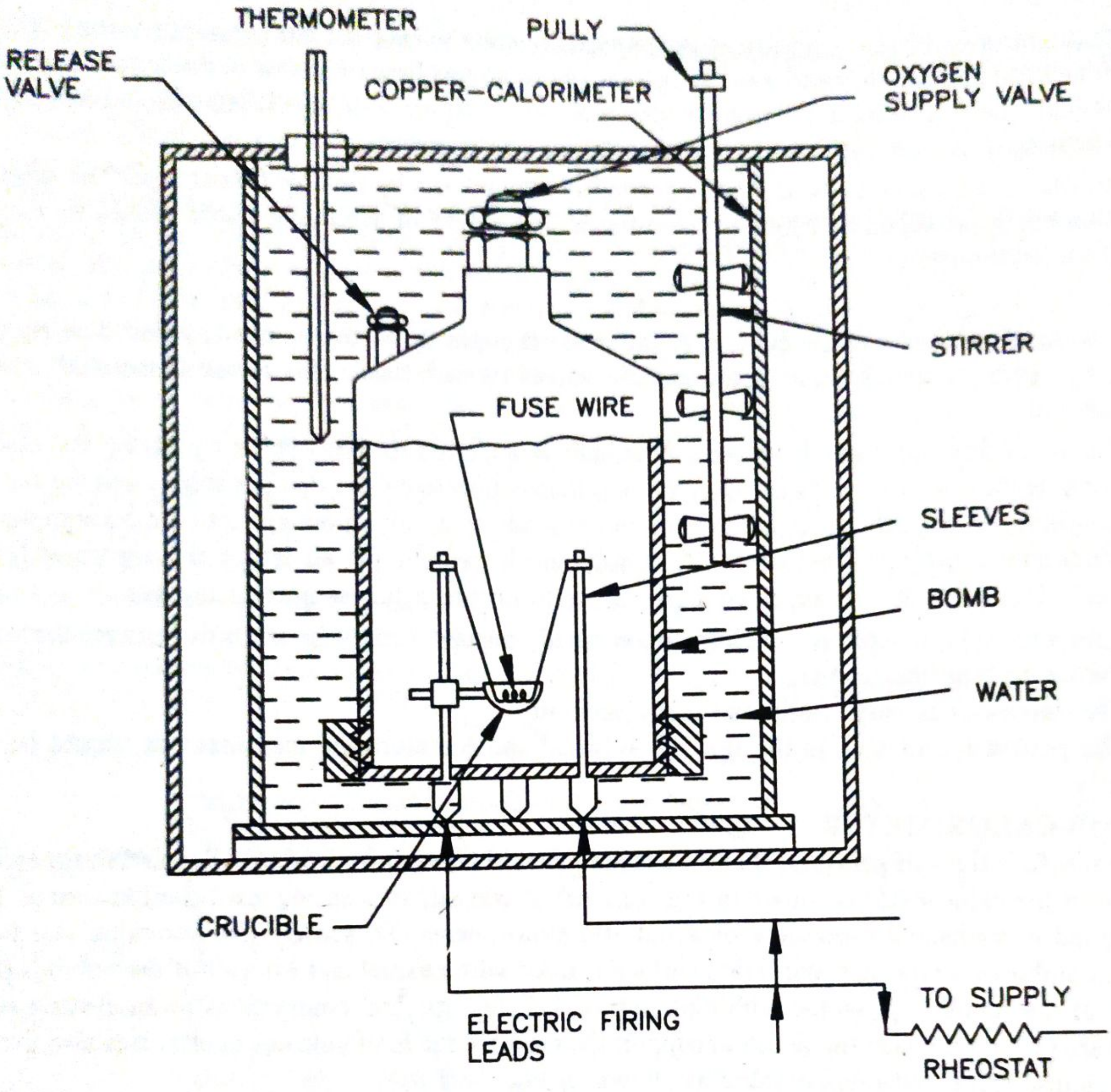

Fig. 12.2. (*a*) Bomb Calorimeter.

m_{wf} = mass of fuse wire ; m_w = mass of water in calorimeter

m_c = water equivalent of calorimeter ; θ = Correct temperature rise

H.C.V. = Higher calorific value of fuel ; C.V. = Calorific value of fuse wire

$$\therefore \quad \text{H.C.V.} = \frac{(m_w + m_e)\,\theta - m_{wf} \times \text{C.V.}}{m_f} \qquad ...(12.15)$$

The water equivalent of the calorimeter is determined by burning a fuel of known calorific value and using the above equation. The fuels used for finding the water equivalent of calorimeter are benzoic acid. (C.V. = 26565 kcal/kg) and napthaline (C.V. = 40690 kJ/kg).

The mass of the fuel used in the crucible depends upon the type of calorimeter and mass of water used. The fuel taken should be such that the temperature rise to water is limited to 3°C to minimise radiation losses.

The calorific value calculated by the equation (12.15) gives the higher calorific value of the fuel because the H_2O formed during combustion is condensed. For finding the lower calorific value of the fuel, the equation mentioned earlier should be used.