PROPERTIES OF STEAM

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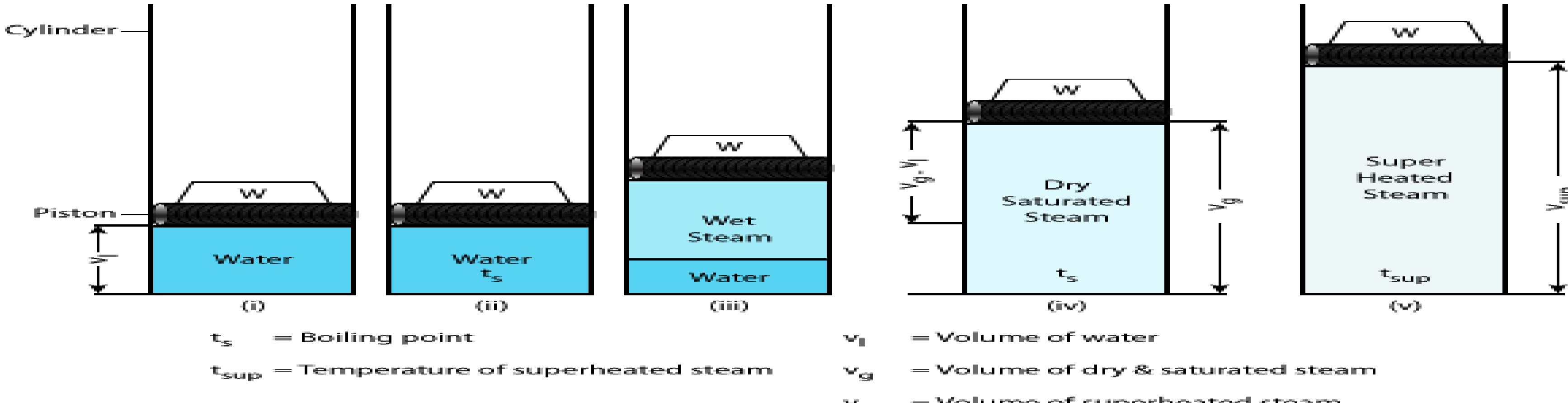
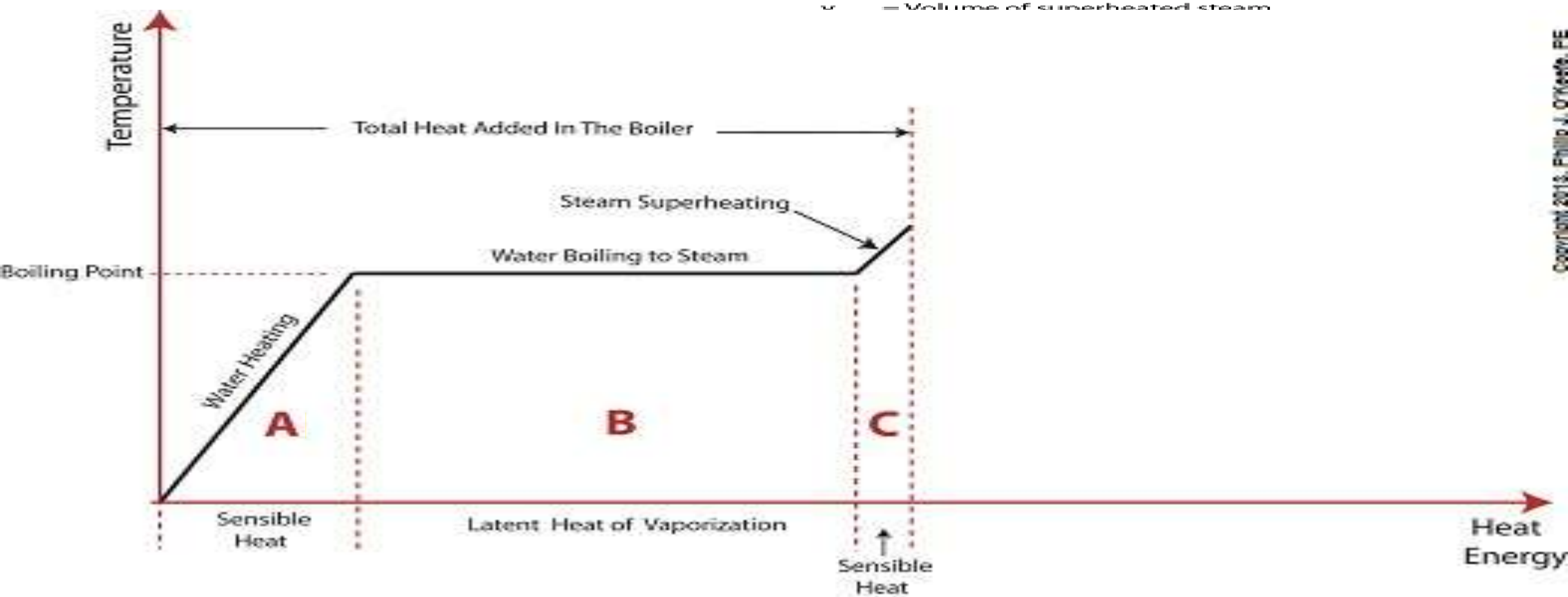
- Steam is the vapour or gaseous phase of water
- It is produced by heating of water and carries large quantities of heat within itself.
- Hence, it could be used as a working substance for heat engines and steam turbines.
- It does not obey ideal gas laws but in superheated state it behaves like an ideal gas.

- Steam exists in following states or types or conditions.
- (i) Wet steam (mixture of dry steam and some water particles) – evaporation of water into steam is not complete.
- (ii) Dry steam (dry saturated steam) – all water is completely converted into dry saturated steam.
- (iii) Superheated steam – obtained by further heating of dry saturated steam with increase in dry steam temperature.

FORMATION OF STEAM



7



- ENTHALPY OF STEAM
- Enthalpy of liquid or Sensible heat (hf)

It is the amount of heat required to raise the temperature of one kg of water from 0°C to its saturation temperature (boiling point) at constant pressure. (Line R-S)

hf = cpw (tsat – 0) kJ/kg

cpw = 4.187 kJ/kgK = specific heat of water

- Enthalpy of Evaporation or Latent heat (hfg)
- It is the amount of heat required to change the phase of one kg of water from saturated liquid state to saturated vapour state at constant saturation temperature and pressure. (Line S-T)
- Enthalpy of dry saturated steam (hg)
- It is the total amount of heat required to generate one kg of dry saturated steam from water at
- 0°C. (Line R-S-T)
- hg = hf + hfg

▣ Enthalpy of wet steam (h)

It is the total amount of heat required to generate one kg of wet steam having dryness fraction x from water at 0°C. It is the sum of sensible heat and latent heat taken by the dry part (x) of the wet steam.

$h = hf + x(hfg)$

▣ Enthalpy of superheated steam (hsup)

It is the total amount of heat required to generate one kg of superheated steam at required superheat temperature from water at 0°C. Superheated steam behaves like an ideal gas and obeys gas laws. (Line R-S-T-U)

$hsup = hf + hfg + cps\ (Tsup – Tsat)$

$hsup = hg + cps\ (Tsup – Tsat)$

cps = 2.1 kJ/KgK = specific heat of superheated steam

▣ Heat of superheat

Amount of heat required to get superheated steam from dry saturated steam is called heat of superheat. (Line T-U)

Heat of superheat = cps (Tsup – Tsat) kJ/Kg

Degree of superheat

It is the temperature difference between superheated steam and dry saturated steam.

Degree of superheat = ($T_{sup} - T_{sat}$)

Dryness Fraction of Saturated Steam (x)

It is a measure of quality of wet steam. It is the ratio of the mass of dry steam (m_s) to the mass of total wet steam (m_s+m_w), where m_w is the mass of water particles in suspension.

$x = m_s/(m_s+m_w)$

Quality of Steam

It is the representation of dryness fraction in percentage: Quality of Steam = 100(x)

Wetness Fraction

It is the ratio of the mass of water vapor (m_w) to the mass of total wet steam (m_s+m_w)

Wetness fraction = $m_w/(m_s+m_w) = (1-x)$

Priming

It is the wetness fraction expressed in percentage.

Priming = $(1 - x)\,100$

SPECIFIC VOLUME OF STEAM

It is the volume occupied by steam per kg of its mass.

Specific volume of dry steam (v_g) : Its value can be obtained directly from the steam tables

Specific volume of wet steam (v) : $v = x (v_g)$

Specific volume of superheated steam (v_{sup}): $v_{sup} = v_g (T_{sup}/T_{sat})$

INTERNAL ENERGY OF STEAM:

$h = u + Pv$

$u = h – Pv$

P = Pressure of steam

v = Specific volume of steam

$u_g = h_g – P(v_g)$ for dry saturated steam

$u = h – P (v)$ for wet steam

$u_{sup} = h_{sup} – P(v_{sup})$ for superheated steam

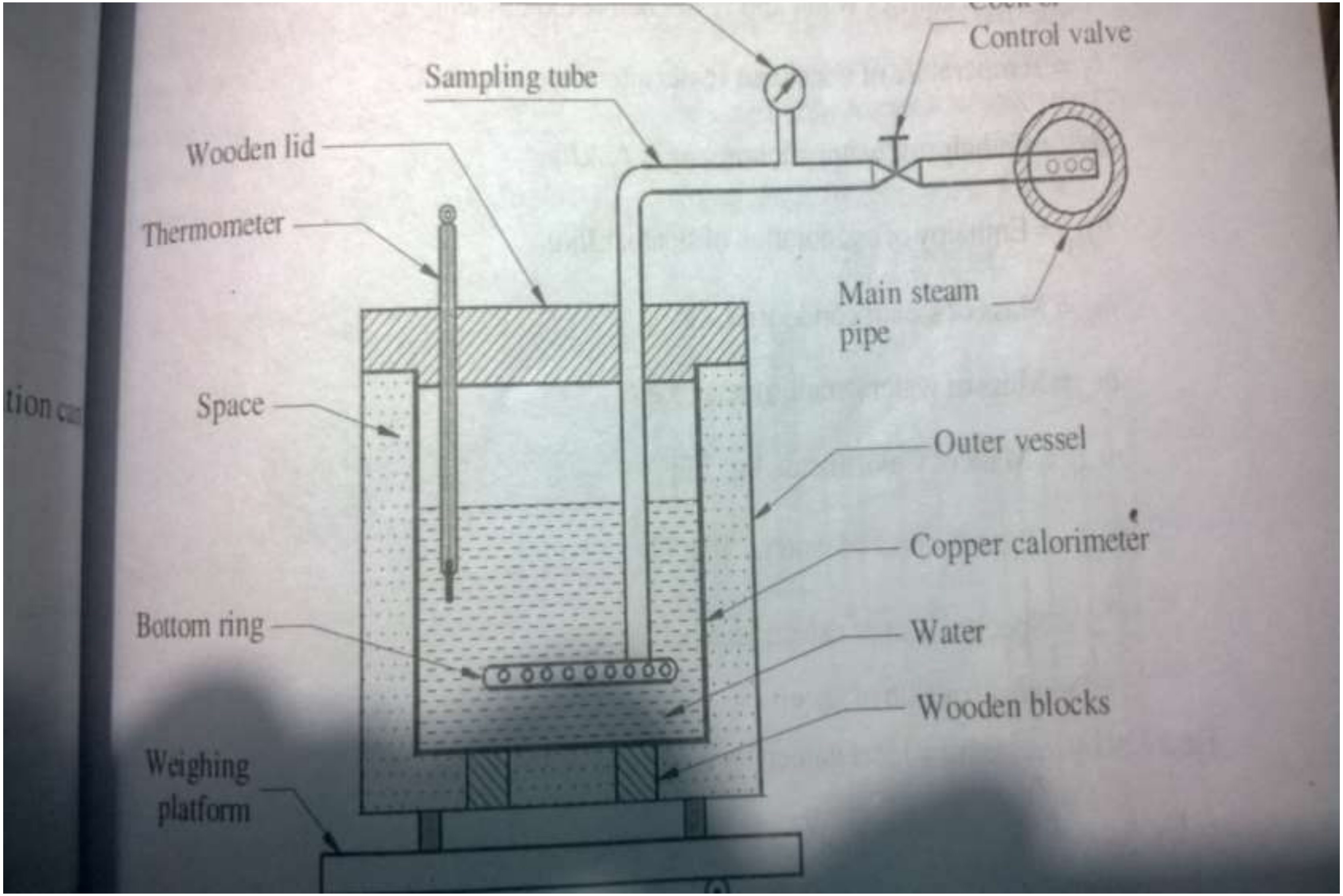
Calorimeters

Calorimeters are used for measurement of dryness fraction of steam.

Types:

- Barrel Calorimeter
- Separating Calorimeter
- Throttling Calorimeter
- Combined Calorimeter

Barrel Calorimeter



8

- Let
- mb =mass of the barrel (kg)
- mw =mass of the water before the steam goes in (kg)
- ms= mass of stem condensed (kg)
- T1= temperature of the water before the steam goes in (oc)
- T2 =temperature of the water after the steam goes in (oc)
- Cb= relative heat capacity of the metal of the barrel (no units)
- hf =specific enthalpy of the saturated liquid (steam) (kJ/kg)
- hfg =specific enthalpy of the evaporar of steam(kJ/kg)
- x =dryness fraction (no units)
- hf1= specific enthalpy of the water at temperature T1 (kJ/kg)
- Hf2= specific enthalpy of the water at temperature T2 (kJ/kg)

- Here known amount of water is filled in the calorimeter. Then certain quantity of steam from the main pipe is taken into the calorimeter.
- Steam and water mixes together and so condensation of steam takes place and mass of water in the calorimeter increases.
- Latent and sensible heat of steam is given to water and its temperature will increase.

- Amount of heat lost by steam = Heat gain by water and calorimeter
- $m_s(h_{f1}+xh_{fg}-h_{f2})=m_b.c_b(t_2-t_1)+m_w.c_{pw}(t_2-t_1)$
- $=(m_b.c_b+m_wc_{pw})(t_2-t_1)$
- $=((m_b \times c_b)/c_{pw} \ +m_w)(t_2-t_1)c_{PW}$
- $(m_b \times c_b)/c_{pw}$ = water equi. Calorimeter
- Limitation
- 1)method is not accurate
- 2)losses are more at higher temp. diff.

Separating Calorimeter

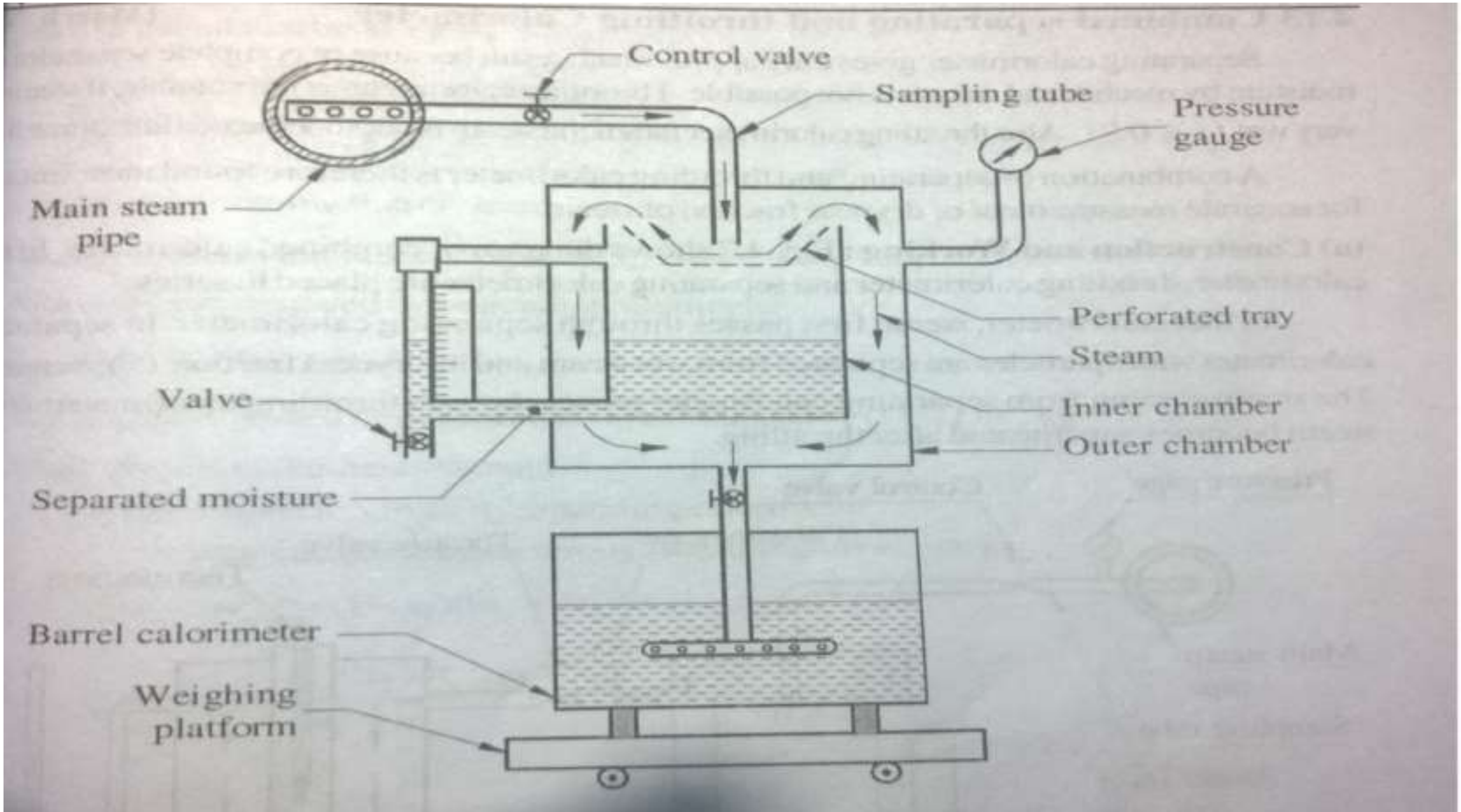


Fig. 4.6 Separating Calorimeter.

9

- In this type of calorimeter water particles from the steam are separated first in the inner chamber and its mass mw can be measured.
- The dry steam is then condensed in the barrel calorimeter and its mass ms can be calculated from the difference in mass of water of barrel
calorimeter.
- So dryness fraction x = ms/(ms + mw)

- Limitation: It gives approximate value of x as total separation of water particles from the steam is not possible by mechanical means.

Throttling Calorimeter

- **Throttling**
- A throttling process is one in which the fluid is made to flow through a restriction,
- e.g. a partially opened valve or an orifice plate, causing a considerable loss in the pressure of the fluid.

Calculations for the process are based on a formulation derived from the steady flow energy equation (SFEE),

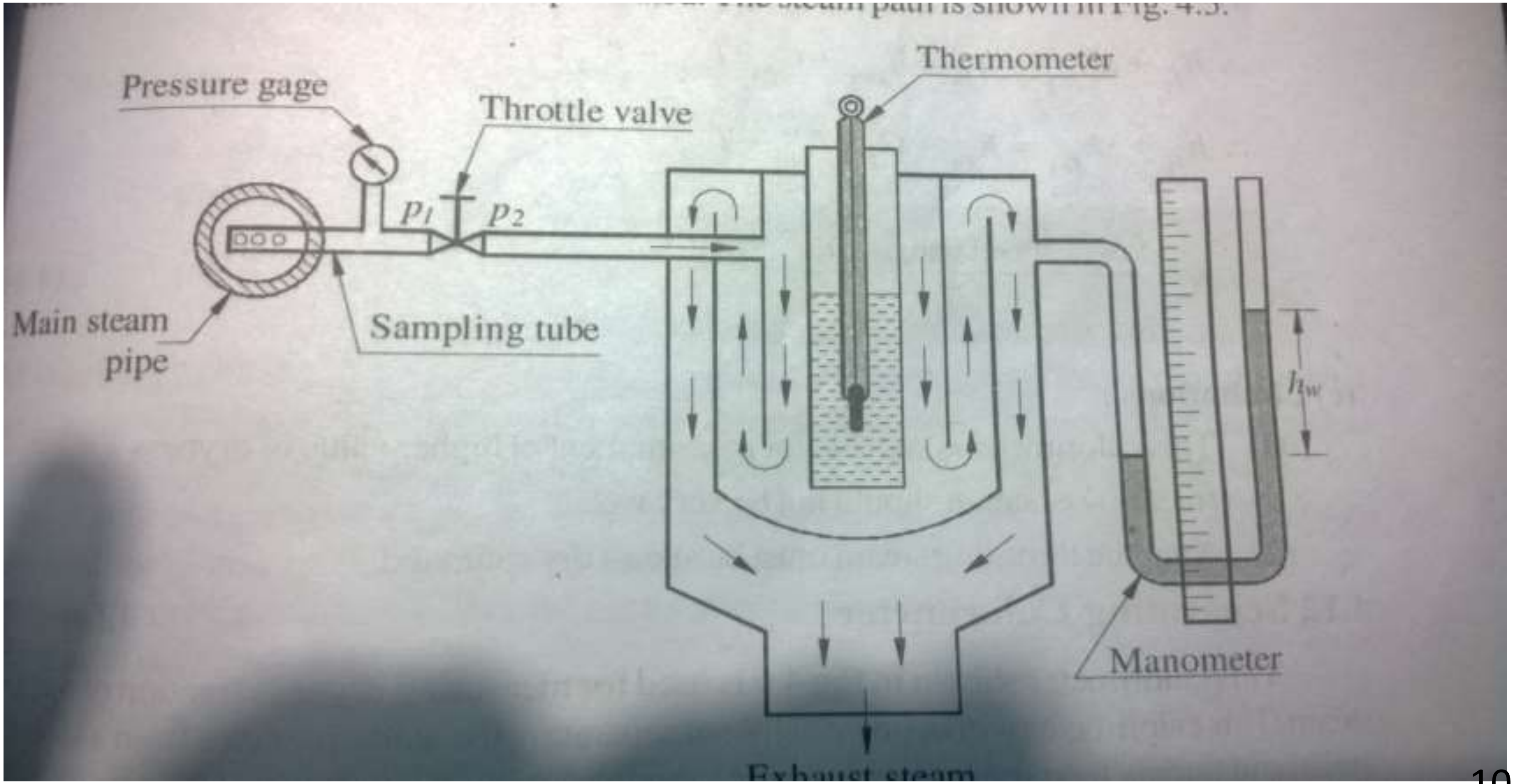
$$Q - W = m\left[(h_2 - h_1) + g(z_2 - z_1) + \frac{C_2^2 - C_1^2}{2}\right].$$

In this process there is no change in elevation so $z_2 = z_1$, so the potential energy term is zero. The velocity C_2 is similar to C_1, so the change in the kinetic energy is neglected. If the system is suitably insulated then there is no heat transfer so $Q = 0$. Finally, the system does no external work, i.e. $W = 0$. So we are left with simply

$$0 = m[h_2 - h_1] \quad \text{or} \quad h_2 = h_1.$$

In other words, during a throttling process the enthalpy remains constant.

Throttling Calorimeter



10

- In this calorimeter a throttling valve is used to throttle the steam.
- The pressure of steam reduces after throttling. Pressure and temperature of steam before and after throttling is measured.
- Enthalpy of steam before and after throttling remains constant.
- of water particles.

•To measure dryness fraction condition of steam after throttling must be superheated steam.

•Enthalpy of stem before throttling = Enthalpy of stem after throttling

$$h_1 = h_2$$
$$h_w \ at \ P_1 = h_{sup} \ at \ P_2$$
$$h_{f1} + x h_{fg1} = h_{g2} + C_P (t_{sup} - t_s),$$

$$x = \frac{h_{g2} + C_P (t_{sup} - t_s) - h_{f1}}{h_{fg1}}.$$

Limitation: Steam must become superheated after throttling. That means it is not very useful for steam containing more amount of water particles.

Combined Separating and Throttling Calorimeter

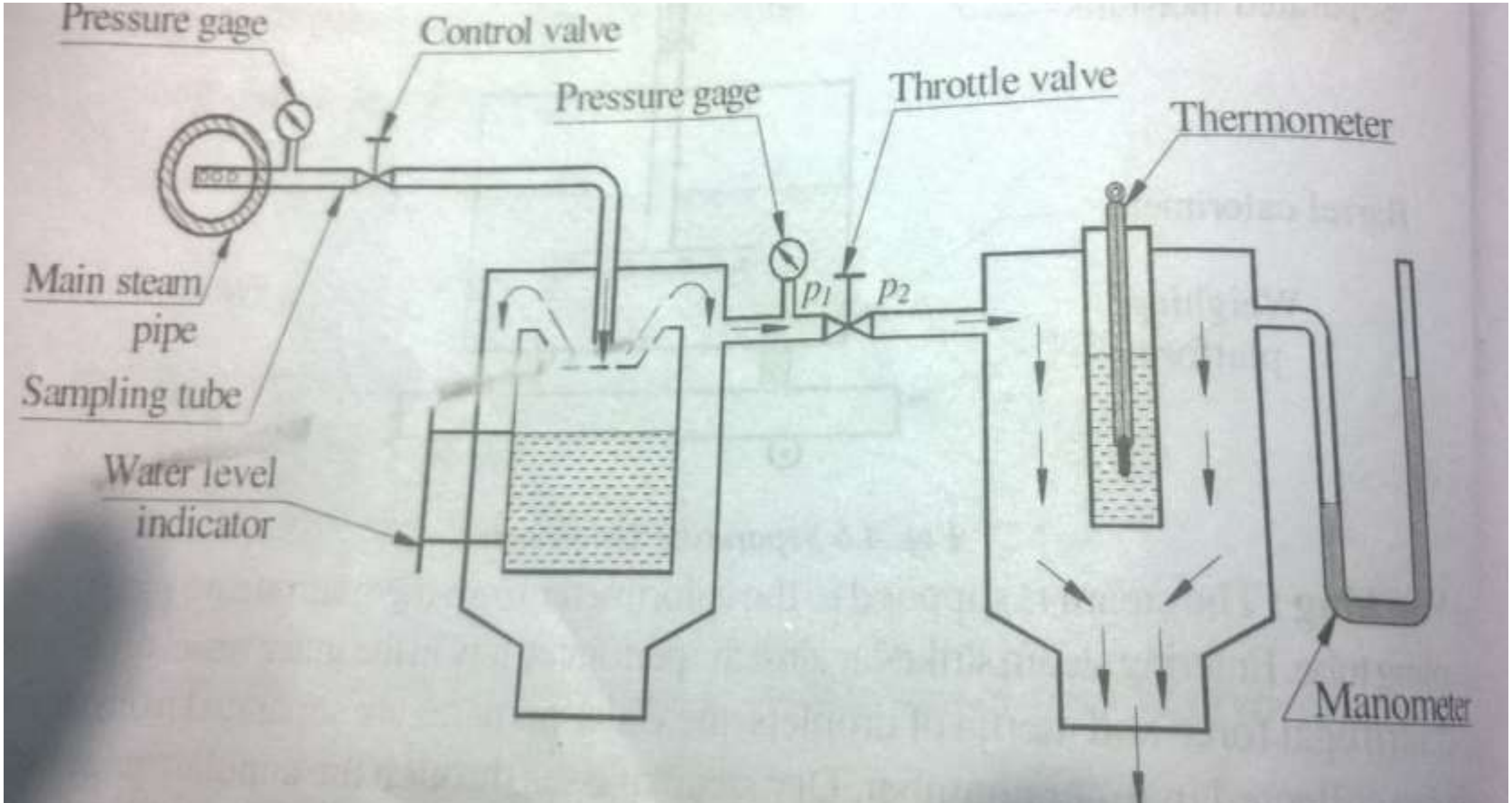


Fig. 4.7 Combined Calorimeter

11

- The limitations of separating and throttling calorimeters can be overcome if they are
used in series as in this type of calorimeter.
- It gives accurate estimation of dryness fraction.

$$x = x1.\, x2$$

x1 = dryness fraction of steam measured from separating calorimeter.

x2 = dryness fraction of steam measured from throttling calorimeter.

Reference-Sources

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Any Question ?

EXIT