ROHIINI COLLEGE OF ENGINEERING AND TECHNOLOGY

ME 3391 ENGINERING THERMODYNAMICS

DIGITAL NOTES

UNIT –IV

Type of Steam

Wet steam:

Wet steam is defined as steam which is partly vapour and partly liquid suspended in it. It means that evaporation of water is not complete.

Dry saturated steam:

When the wet steam is further heated, and it does not contain any suspended particles of water, it is known as dry saturated steam.

Superheated steam: When the dry steam is further heated at constant pressure, thus raising its temperature, it is called superheated steam.

Measurement of Steam Quality:

The state of a pure substance gets fixed if two independent properties are given. A pure substance is thus said to have two degrees of freedom. Of all thermodynamic properties, it is easiest to measure the pressure and temperature of a substance. Therefore, whenever pressure and temperature are independent properties, it is the practice to measure them to determine that state of the substance.

Types of Calorimeters used for measurement of Steam Quality

- Barrel Calorimeter
- Separating Calorimeter
- Throttling Calorimeter
- Combined Separating and Throttling calorimeter

Barrel Calorimeter

Dryness fraction of steam can be found out very conveniently by barrel calorimeter as shown in figure. A vessel contains a measured quantity of water. Also water equivalent of the vessel is determined experimentally and stamped platform of weighing machine. Sample of steam is passed through the sampling tube into fine exit holes for discharge of steam in the cold water.

The steam gets condensed and the temperature of water rises. The weighing machine gives the steam condensed.

$$HeatLost = HeatGain$$

$$m\{x \; h_{fg} + (t_s - t_2)\} = C_p \quad M \; (t_2$$

$$x = \frac{C_p\{M \, m(t_2 - t_1) - (t_s - t_2)\}}{h_{fg}}$$

From the law of conservation of energy,

Where, x = quantity of steam in the main pipe

hfg = latent heat of vaporization at pressure p

Cp = specific heat of water at constant pressure p

m = mass of steam condensed

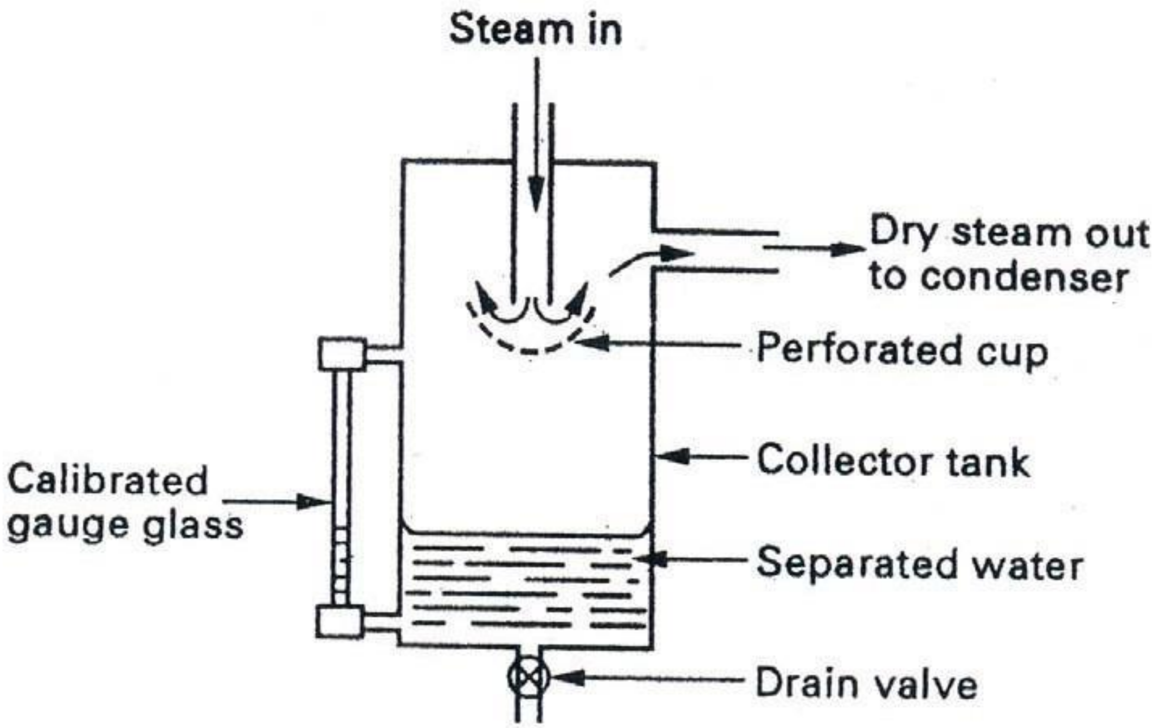
M =Equivalent mass of water at commencement

tS =Sat. temperature;

t1 = temperature of Water at commencement

t2 = final temperature after steam has condensed

Separating Calorimeter



The wet steam enters at the top from the main steam pipe through holes in the sampling pipe facing up stream which should be as far as possible downstream from elbows and valves to ensure representative sample of steam when in operation the wet steam entering passes down the central passage and undergoes a sudden reversal of direction of motion when strikes perforated cup.

Advantages:

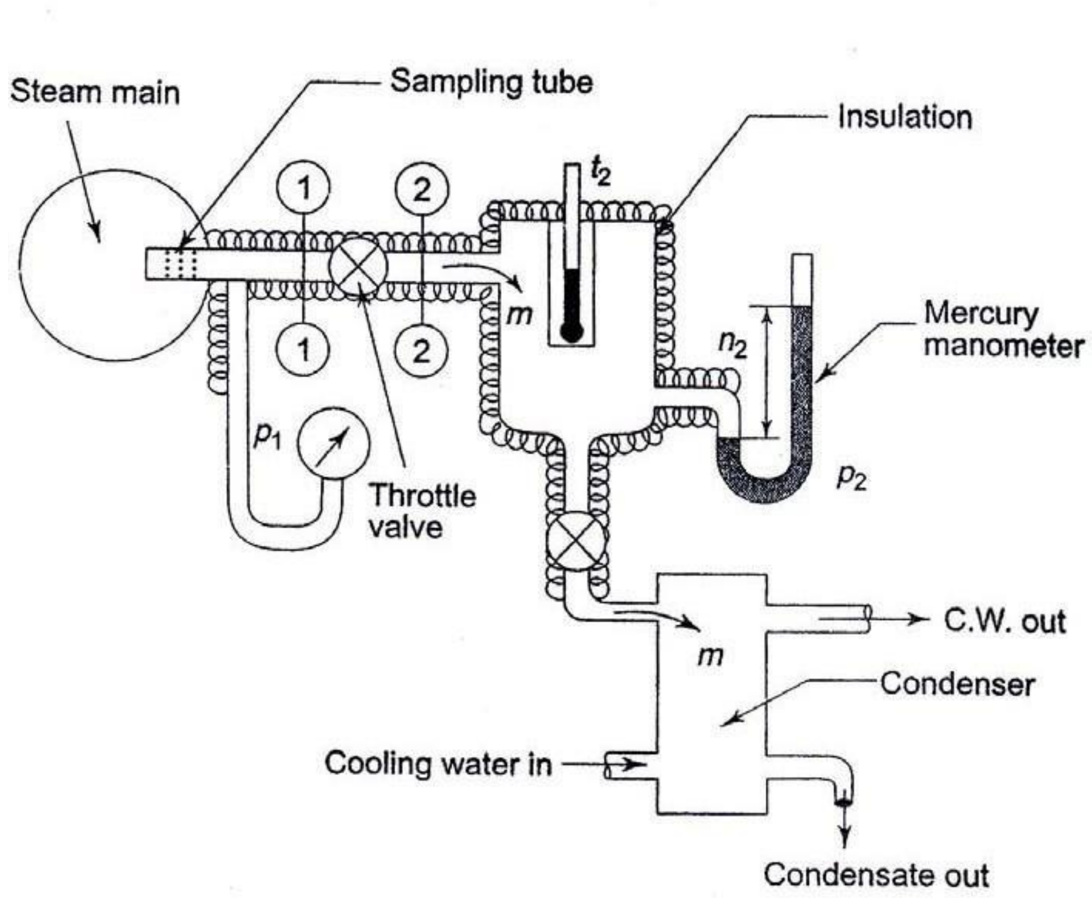
Quick determination of dryness fraction of very wet steam

Disadvantages:

It leads to inaccuracy due to incomplete separation of water

Dryness fraction calculated is always greater than actual dryness fraction.

Throttling Calorimeter



In the throttling calorimeter, a sample of wet steam of mass m and at pressure P1 is taken from the steam main through a perforated sampling tube. Then it is throttled by the partially-opened valve (or orifice) to a pressure P2 measured by mercury manometer, and temperature t2, so that after throttling the steam is in the superheated region.

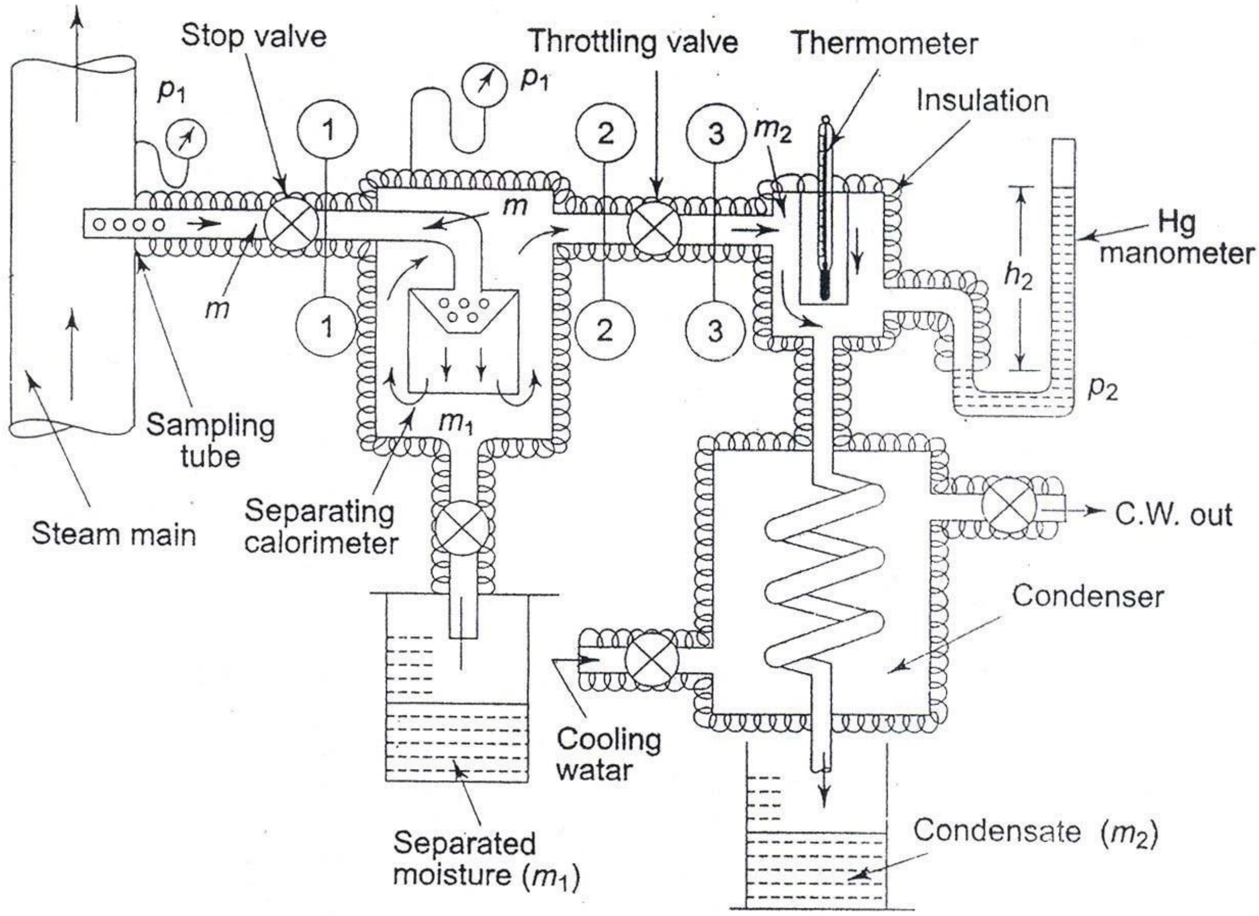
The steady flow energy equation gives the enthalpy after throttling as equal to enthalpy before throttling. The initial and final equilibrium states 1 and 2 are joined by a dotted line since throttling is irreversible (adiabatic but not isentropic) and the intermediate states are non-equilibrium states not describable by thermodynamic coordinates. The initial state(wet) is given by P1and x1 and the final state by P2 and t2.

Advantages:

Dryness fraction of very dry steam can be found out easily.

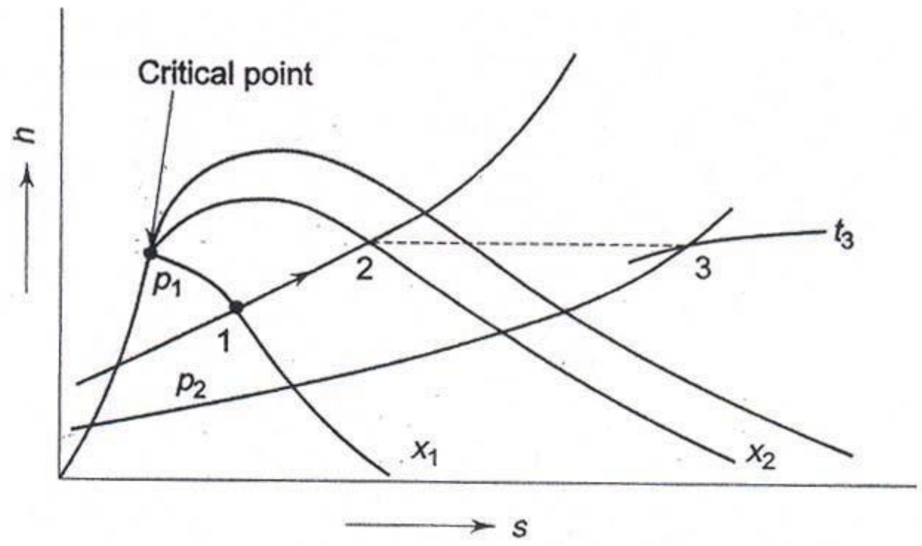
Disadvantages:
It is not possible to find dryness fraction of very wet steam.

Combined Separating and Throttling calorimeter



When the steam is very wet and the pressure after throttling is not low enough to take the steam to the superheated region, then a combined separating and throttling calorimeter is used for the measurement of quality.

Steam from the main is first passed through a separator where some part of the moisture separates out due to the sudden change in direction and falls by gravity, and the partially dry vapour is then throttled and taken to the superheated region.



Separating and throttling processes on h-s plot

In Fig. process 1-2 represents the moisture separation from the wet sample of steam at constant pressure P1 and process 2-3 represents throttling to pressure P2. With P2 and t3 being measured, h3 can be found out from the superheated steam table.

$$h_3 = h_2 = h_{f_{p1}} + x_2 h_{fg_{p1}}$$

Therefore x2, the quality of steam after partial moisture separation can be evaluated If m kg of steam, is taken through the sampling tube in t s, m1 kg of it is separated, and m2 kg is throttled and then condensed to water and collected, then m = m1 + m2 and at state 2, the mass of dry vapour will be x2 m2. Therefore, the quality of the

sample of steam at state l, x1 is given by . .

$$x_1 = \frac{mass of\ dry\ vapour\ state 1}{mass of\ liquid - vapour\ mixture at\ state 1\ x_2}$$

$$= \frac{m_2}{\mu - \xi 2}$$

Mass of water (m_f) = 1.5 kg Mass of steam

(m_g) = 50 kg

Required : Dryness fraction (x) Solution

$$\text{Dryness fraction } (x) = \frac{m_g}{m_g + m_f}$$

50

= **0.971**

Eg. Steam is generated at 8 bar from water at 32°C. Determine the heat required to produce 1 kg of steam (a) when the dryness fraction is 0.85 (b) when steam is dry saturated and (c) when the steam is superheated to 305°C. The specific heat of superheated steam may be taken as 2.093 kJ/kg-K.

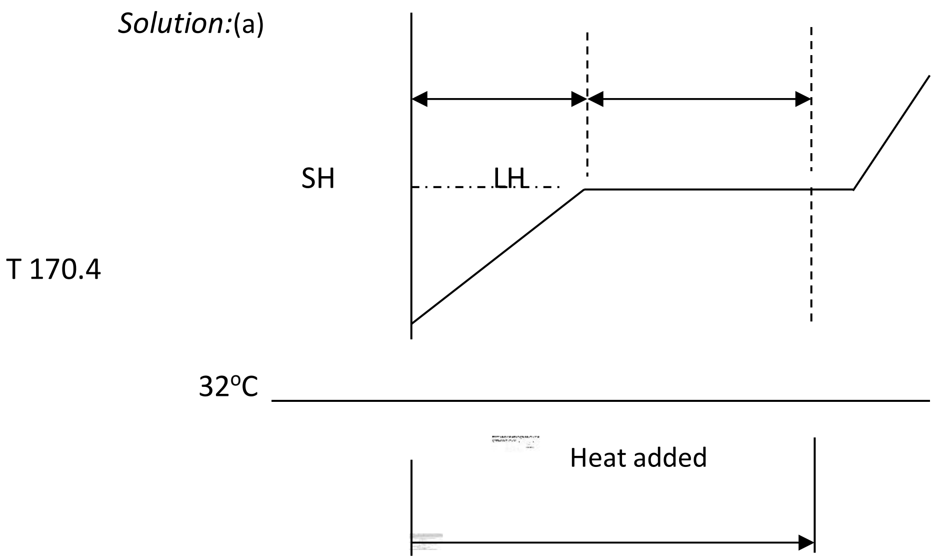
Given:

Steam pressure (p) = 8 bar

Initial temperature of water (T_1) = 32°C Mass of steam (m) = 1 kg

Required: Heat required when (a) x = 0.85 (b) x = 1 (c) T_{sup} = 305°C

Solution:(a)



Heat required = Sensible heat addition + Latent heat addition

Sensible heat addition = m C_{pw} (t_s – T_1) t_s = saturation temperature = 170.4°C at 8 bar

from steam table C_{pw} = Specific heat at constantpressure = 4.186 kJ/kg (Taken)

Sensible Heat addition = 1 x 4.186 x (170.4 – 32)

= 79.34 kJ/kg

Latent heat addition / kg = x h_{fg}

Latent heat (h_{fg}) = 2046.5 kJ/kg from steam table at 8 barLatent heat addition for 'm' kg = m x h_{fg}

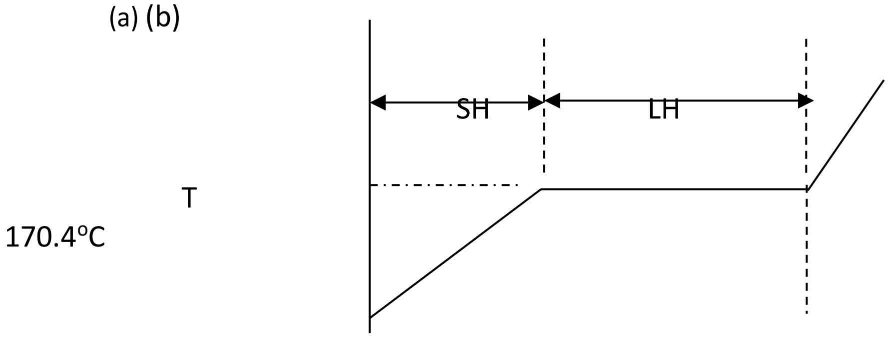
= 1 x 0.85 x (2046.5)

= 1739.525 kJ/kg

Total heat required = 579.34 + 1739.525

= 2318.865 kJ/kg --- Ans

(a) (b)



Heat required = Sensible heat addition + Latent heat addition Latent heat addition / kg = xh_{fg}

Latent heat (h_{fg}) = 2046.5 kJ/kg from steam table at 8 bar

Latent heat addition for 'm' kg = m xh_{fg}

= 1 x 1 x (2046.5)

= 2046.5 kJ/kg Total heat required = 579.34 + 2046.5

= **2625.84 kJ/kg --- Ans**

Heat required = Sensible heat addition + Latent heat addition + SensibleHeat addition Sensible heat addition to superheated steam

= m C_{pv} (T_{sup} – t_s)

= 1 x 2.093 x (305 – 170.4)

= 281.72 kJ/kg

Latent heat addition / kg = h_{fg}

Latent heat (h_{fg}) = 2046.5 kJ/kg from steam table at 8 barTotal heat required

= 579.34 + 2046.5 + 281.72

= **2907.56 kJ/kg --- Ans**