<u>UNIT – 1</u> <u>FORMATION OF STEAM</u>

<u>Introduction :</u> **S**team is a vapour of water. When water is heated beyond its boiling point , liquid phase of water is converted in to gaseous phase to form vapour of water known as steam.The steam is invisible when pure and dry. It is used as a working substance in the operation of steam engines and steam turbines.

Formation of steam under constant pressure : Consider 1 kg of water at 0^0c in a cylinder with piston and weights as shown in fig (a).

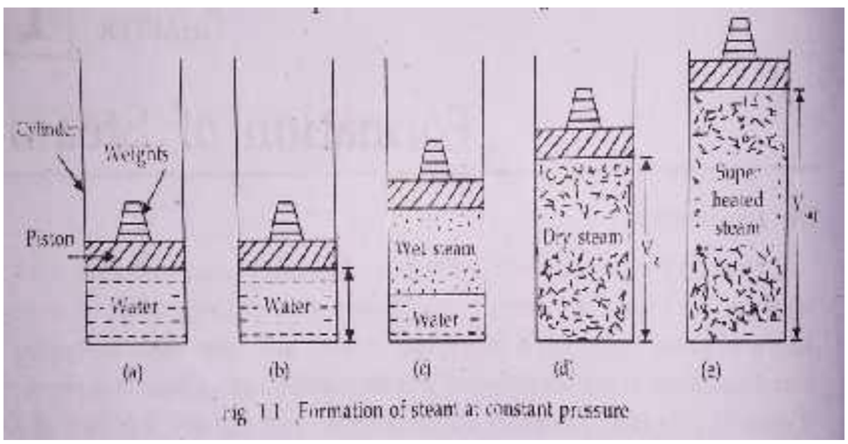


Fig 1.1 Formation of steam at constant pressure

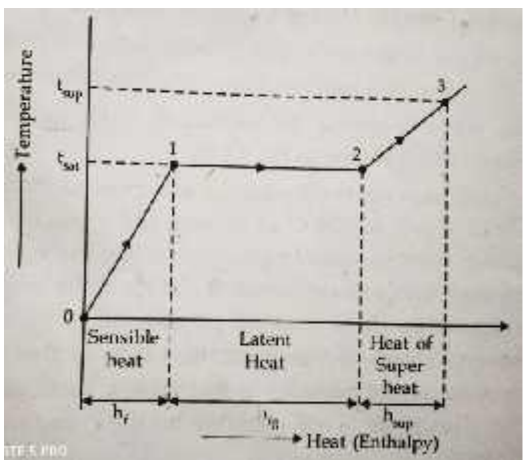
The piston and weights maintain a constant pressure in the cylinder.

- When water is heated , the volume of water increases with increase in temperature as shown in fig (b).
- On further heating , temperature of water reaches boiling point . The boiling point of water is 100^0c at normal atm pressure of 1.013 bar , but it increases with increase in pressure. When the boiling point is reached the temperature

remains constant and the water evaporates , thus pushing the piston upward at constant pressure , there by increasing the specific volume of steam as shown in fig (c). At this stage , the steam will have some water particles in suspension , such steam is known as wet steam. This process will continue till the entire water is converted in to wet steam.

- On further heating , all the water particles are converted in to steam . This steam is known as dry steam or saturated steam as shown in fig (d). The dry steam behaves like a perfect gas.
- On further heating , the dry steam is converted in to super heated steam with increase in temperature as shown in fig (e).

T-H Diagram during steam formation. (Temperature – Enthalpy diagram).



Generally the steam exists in three forms :

i) Wet steam ii) Dry steam iii) Superheated steam .

The temperature – Enthalpy (T-H) diagram is as shown in fig.The line 0-1 shows the heating of water at 0^0c to the boiling temperature or saturation temperature.

The line 1-2 shows the evaporation of water till the dry steam is obtained.The line 2-3 shows the formation of superheated steam. When water is heated up to boiling temperature shown by a line 1-2, the heat absorbed by the water is known as **Sensible heat or Total heat of water.**

Wet steam : When the steam contains particles of water in suspension is known as wet steam , i.e., evaporation of water is not complete. The steam at any point on the 1-2 in fig is the wet steam .

Dry Saturated Steam : When the wet steam is further heated , and it does not contain any water particles then , it is known as dry saturated steam. This steam absorb all the latent heat of evaporation .The steam at point " 2"is the dry saturated steam.

Superheated Steam : When the dry steam is further heated at a constant pressure , which increases the temperature of the steam , it is known as superheated steam.The steam at any point on the curve 2-3 is the superheated steam .

Advantages of Superheated Steam :

- The capacity to do work is more since superheated steam contains more heat.
- Super heating is done by waste furnace gases.
- The high temperature of superheated steam increases the thermal efficiency of the boiler.
- Because of superheat , heat losses due to condensation of steam on engine cylinder walls can be avoided to the greater extent.

Saturated steam or Dry saturated steam : The saturated steam results when water is heated to the boiling point(sensible heating)and then vaporized with additional heat (latent heating).

Saturation temperature : The temperature at which water starts boiling , when the water is heated is known as saturation temperature.

Saturation pressure : The pressure at which a liquid boils in to its vapour phase is known as saturation pressure.

Critical pressure and Critical temperature : When the pressure and saturation temperature increases , the latent heat of vaporization decreases and it becomes zero at some point say N where liquid and dry steam line meet. This point is known as critical point.At this point the liquid and vapour phases merge and become identical in every respect.

The temperature corresponding to critical point (N) is known as critical temperature and the pressure corresponding to this critical point (N) is known as critical pressure, for the steam the critical pressure is 221.2 bar and critical temperature is 374.15^0c.

Properties of Steam :

The following are the important properties of steam :

1. **Sensible heat or Heat of liquid or Total heat of water (h_f):** It is the amount of heat absorbed by the 1 kg of water , when heated at a constant pressure , from 0^0c

(freezing point) to the temperature of formation of steam i.e., saturation temperature (t_{sat}).

The specific heat of water = 4.2 kj/kg K.

Therefore , the sensible heat absorbed by 1 kg of water :

= Mass x sp ecific heat x Rise in temperature

$=1 \times 4.2 \ (t_{sat}+273) – (0 + 273)$

$= 4.2 \ t_{sat}$ kj/kg K.

2**. Latent heat of Vapourisation (h_{fg}):** It is the amount of heat absorbed to evaporate 1 kg of water at its saturation temperature without change in temperature.

The value of latent heat depends on the pressure.The latent heat of steam is 2257 kj/kg at atmospheric pressure. The value of latent heat decreases with increase in pressure and becomes zero at critical pressure.

3. Dryness fraction or Quality of steam (x) : Dryness fraction is the ratio of mass of the actual dry steam to the mass of same quantity of wet steam and it is denoted by ‘x’.

$$x = \frac{m_g}{m_g + m_f} = \frac{m_g}{m}$$

Where , m_g= mass of actual dry steam.

m_f = mass of water in suspension.

m = mass of wet steam in suspension = $m_f + m_g$.

For dry steam value of dryness fraction is one i.e., mass of water suspension (m_f) is zero.

If the steam is wet with dryness fraction x , then the heat absorbed by it during evaporation is **x. h_{fg} .**

4. Degree of superheat : It is the difference between the temperature of superheated steam and saturation temperature at a given pressure . Therefore ,

Degree of superheat = $t_{sup} - t_{sat}$

5. Enthalpy of water : Enthalpy (total heat) of water in KJ may be defined as the quantity of heat required to rise the temperature of one kg of water from 0^0c to its boiling point or saturation temperature corresponding to the pressure applied.

The total heat of water is also known as liquid heat is represented by h_f .It can be calculated by multiplying the specific heat of water by the rise in temperature in ^{0}c.

6.Enthalpy of steam or Total heat of steam (h_g): It is the amount of heat absorbed by water from freezing point to the saturation temperature plus the heat absorbed during evaporation , therefore ,

Enthalpy (h_g) =sensible heat + latent heat

$$h_g = h_f + h_{fg} \text{ kj/kg}$$

The value of h_g can be read from the steam tables.

i) **Enthalpy of wet steam :** It is the amount of heat supplied at constant pressure to convert 1 kg of water at 0 ^{0}c to 1 kg of wet steam at the specified dryness fraction.

Enthalpy , $h = h_f + x .h_{fg}$ kj/kg , where x= dryness fraction.

ii) **Enthalpy of dry steam :** It is the amount of heat supplied at constant pressure to convert 1 kg of water in to 1 kg of dry saturated steam at its saturation temperature.

Enthalpy, $h = h_f + h_{fg}$

iii) **Enthalpy of superheated steam (h_{sup}):**

$h_{sup} = h_f + h_{fg} + c_p (t_{sup} - t_{sat})$

$= h_g + c_p (t_{sup} - t_{sat})$

Where c_p = Mean specific heat at constant pressure for super heated steam i.e c_p= 1.6 to 2.5 kj/kg K

t_{sup}= Temperature of the superheated steam.

t_{sat}=Saturation temperature at given constant pressure.

7. **Specific volume of steam (v):** It is the volume occupied by the steam per unit mass at a given temperature and pressure . It is represented by v and expressed in m^3/ kg.It is the reciprocal of density of the steam in kg/ m^3 .

i) **Wet steam :** Consider 1 kg of wet steam of dryness fraction x, then ,

specific volume of wet steam = x. v_g m^3/ kg .

ii) **Dry steam :** In this case , x=1

Specific volume of dry steam , v= v_g m^3/ kg .

iii) Superheated steam : When dry steam is heated at constant pressure volume and temperature of steam increases . The superheated steam behaves like a perfect gas, therefore

$$\frac{v_{sup}}{t_{sup}} = \frac{v_g}{t_{sat}} \quad (\because \text{P is constant})$$

$$v_{sup} = \frac{v_g T_{sup}}{T_{sat}} \ m^3/kg$$

8. External work done during Evaporation (w):

For wet steam , W= 100 . P. x. v_g ---- kj.

For dry steam , W= 100 . P. v_g ----kj

For superheated steam, W= 100. P. v_{sup} ---- kj

9. Internal energy of steam (U): It can be defined as the actual heat energy stored in the steam, above the freezing point of water. Or it is the difference between enthalpy and the external work done during evaporation .

Internal energy (U) = Enthalpy – External work done during evaporation.

i) For wet steam, U= h - 100.P.x. v_g --- kj/kg

ii) For dry steam, U= h_g-100.P. v_g --- kj/kg

iii) For superheated steam , U = h_{sup}-100.P. v_{sup} --- kj/kg

= (h_g + c_p (t_{sup}-t_{sat}) - 100.P. v_{sup} --- kj/kg

ENTROPY OF STEAM (S) :

It is an important property of steam and entropy of a steam increases with the addition of heat and decreases with the removal of heat . Entropy consists of

- Increase in entropy of water while heating from 0 ^{0}c to boiling point at a given pressure.
- Increase in entropy during evaporation.
- Increase in entropy while superheating.

Entropy of wet steam : $S = S_f + x.\ S_{fg}$ ---- kj/kg K.

Entropy of dry saturated steam : $S = S_f + S_{fg}$ ----- kj/kg K.

Entropy of superheated steam :

$$S_{sup} = S_g + 2.3\ C_p \log\left(\frac{T_{sup}}{T}\right)$$

In kj / kg K.

Steam tables and their uses: The properties of dry saturated steam like its temperature of formation, sensible heat , latent heat of vapourisation , enthalpy or total heat , specific volume , entropy, etc.are found experiementally and their values are determined and are made available in a tabular form known as steam tables.

There are two important steam tables , one is in terms of absolute pressure and other in terms of temperature as shown in table .The calculations for wet steam can also be easily made by making use of these tables.

Steam table interms of absolute pressure .

Staturated Water and Steam (Pressure) Tables 7

Absolute pressure in bar	Temperature in °C	Specific volume in m^3/kg		Specific enthalpy in kJ/kg			Specific entropy in kJ/kg K			Absolute pressure in bar
(p)	(t)	water (v_f)	Steam (v_g)	Water (h_f)	Evaporation (h_{fg})	Steam (h_g)	Water (s_f)	Evaporation (s_{fg})	Steam (s_g)	(p)
0.006 1	0.000	0.001 000	205.31	0.0	2 501.6	2 501.6	0.000	9.158	9.158	**0.006 1**
0.010	6.983	0.001 000	129.21	29.3	2 485.1	2 514.4	0.106	8.871	8.977	**0.010**
0.015	13.04	0.001 001	87.982	54.7	2 470.8	2 525.5	0.196	8.634	8.830	**0.015**
0.020	17.51	0.001 001	67.006	73.5	2 460.1	2 533.6	0.261	8.464	8.725	**0.020**
0.025	21.10	0.001 002	54.256	88.4	2 451.8	2 540.2	0.312	8.333	8.645	**0.025**
0.030	24.10	0.001 003	45.667	101.0	2 444.6	2 545.6	0.354	8.224	8.578	**0.030**
0.035	26.69	0.001 003	39.479	111.8	2 438.6	2 550.4	0.391	8.132	8.522	**0.035**
0.040	28.98	0.001 004	34.802	121.4	2 433.1	2 554.5	0.423	8.053	8.476	**0.040**
0.045	31.03	0.001 005	31.141	130.0	2 428.2	2 558.2	0.451	7.983	8.434	**0.045**
0.050	32.90	0.001 005	28.194	137.8	2 423.8	2 561.6	0.476	7.920	8.396	**0.050**
0.060	36.18	0.001 006	23.741	151.5	2 416.0	2 567.5	0.521	7.810	8.331	**0.06**
0.070	39.03	0.001 007	20.531	163.4	2 409.2	2 572.6	0.559	7.718	8.277	**0.07**
0.080	41.53	0.001 008	18.105	173.9	2 403.2	2 577.1	0.593	7.637	8.230	**0.08**
0.090	43.79	0.001 009	16.204	183.3	2 397.8	2 581.1	0.622	7.566	8.188	**0.09**
0.100	45.83	0.001 010	14.675	191.8	2 392.9	2 584.7	0.649	7.502	8.151	**0.10**
0.11	47.71	0.001 011	13.416	199.7	2 388.4	2 588.1	0.674	7.444	8.118	**0.11**
0.12	49.45	0.001 012	12.362	205.9	2 384.3	2 591.2	0.696	7.391	8.087	**0.12**
0.13	51.06	0.001 013	11.466	213.7	2 380.3	2 594.0	0.717	7.342	8.059	**0.13**
0.14	52.57	0.001 013	10.694	220.0	2 376.7	2 596.7	0.737	7.296	8.033	**0.14**
0.15	54.00	0.001 014	10.023	226.0	2 373.2	2 599.2	0.755	7.254	8.009	**0.15**

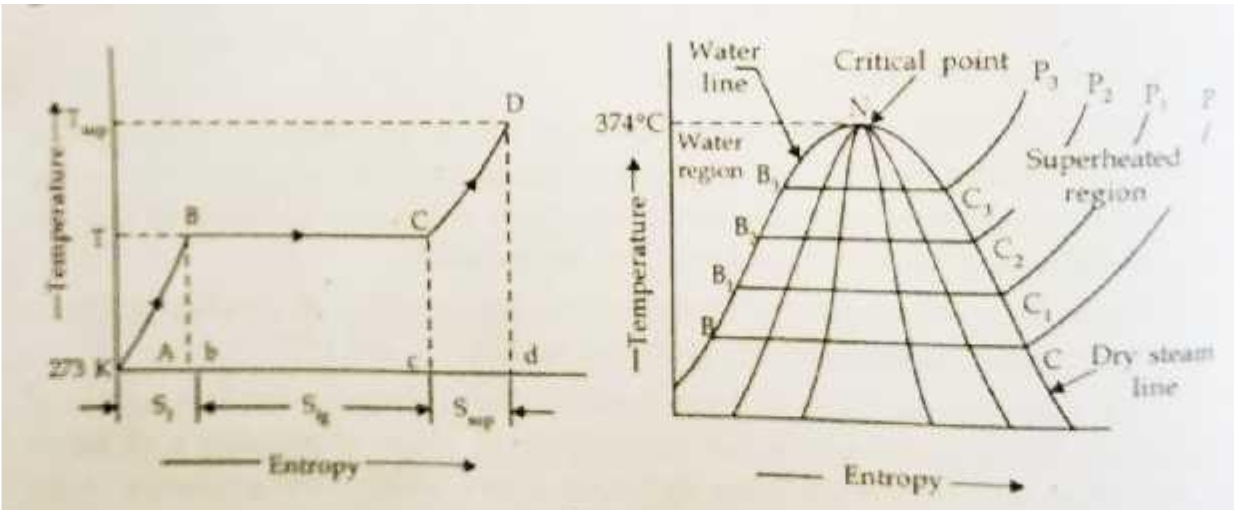
Steam table in terms of Temperature basis.

Staturated Water and Steam (Temperature) Tables

Temperature in °C	Absolute pressure in bar	Specific volume in m^3/kg		Specific enthalpy in kJ/kg			Specific entropy in kJ/kg K			Temperature in °C
(t)	(p)	Water (v_f)	Steam (v_g)	Water (h_f)	Evaporation (h_{fg})	Steam (h_g)	Water (s_f)	Evaporation (s_{fg})	Steam (s_g)	(t)
0	0.006 11	0.001 000	206.31	0.0	2 501.6	2 501.6	0.000	9.158	9.158	**0**
1	0.006 57	0.001 000	192.61	4.2	2 499.2	2 503.4	0.015	9.116	9.131	**1**
2	0.007 06	0.001 000	179.92	8.4	2 496.8	2 505.2	0.031	9.074	9.105	**2**
3	0.007 58	0.001 000	168.17	12.6	2 494.5	2 507.1	0.046	9.033	9.079	**3**
4	0.008 13	0.001 000	157.27	16.8	2 492.1	2 508.9	0.061	8.992	9.053	**4**
5	0.008 72	0.001 000	147.16	21.0	2 489.7	2 510.7	0.076	8.951	9.027	**5**
6	0.009 35	0.001 000	137.78	25.2	2 487.4	2 512.6	0.091	8.911	9.002	**6**
7	0.010 01	0.001 000	129.06	29.4	2 485.0	2 514.4	0.106	8.870	8.976	**7**
8	0.010 72	0.001 000	120.97	33.6	2 482.6	2 516.2	0.121	8.830	8.951	**8**
9	0.011 47	0.001 000	113.44	37.8	2 480.3	2 518.1	0.136	8.791	8.927	**9**
10	0.012 27	0.001 000	106.43	42.0	2 477.9	2 519.9	0.151	8.751	8.902	**10**
11	0.013 12	0.001 000	99.909	46.2	2 475.5	2 521.7	0.166	8.712	8.878	**11**
12	0.014 01	0.001 000	93.835	50.4	2 473.2	2 523.6	0.181	8.673	8.854	**12**
13	0.014 97	0.001 001	88.176	54.6	2 470.8	2 525.4	0.195	8.635	8.830	**13**
14	0.015 97	0.001 001	82.900	58.7	2 468.5	2 527.2	0.210	8.597	8.806	**14**
15	0.017 04	0.001 001	77.978	62.9	2 466.1	2 529.1	0.224	8.559	8.783	**15**
16	0.018 17	0.001 001	73.384	67.1	2 463.8	2 530.9	0.239	8.520	8.759	**16**
17	0.019 36	0.001 001	69.095	71.3	2 461.4	2 532.7	0.253	8.483	8.736	**17**
18	0.020 62	0.001 001	65.087	75.5	2 459.0	2 534.5	0.268	8.446	8.714	**18**
19	0.021 96	0.001 002	61.341	79.7	2 456.7	2 536.4	0.282	8.409	8.691	**19**

Temperature – Entropy (T-S) Diagram for water and steam :

The temperature – Entropy diagram represents the heat absorbed or rejected during the adiabatic expansion and compression of steam as shown in fig.



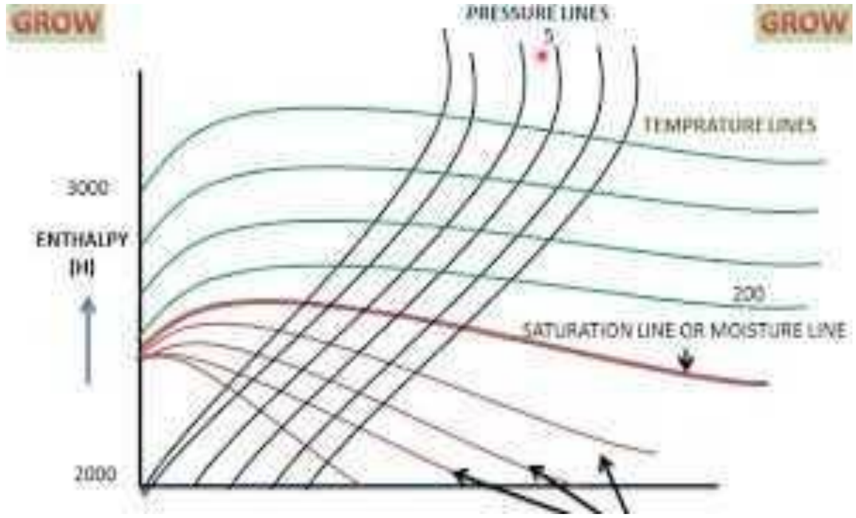
Consider 1 kg of water heated at a constant pressure P , when heat is added to water its entropy increases . If we plot the graph of temperature against entropy , we find that the entropy increases up to boiling temperature (T_{sat}). It is shown by a line AB with corresponding increase in entropy (S_f) by a line Ab. On further heating, water starts evaporation and absorb heat at constant temperature (T_{sat}).The entropy goes on increasing till all the latent heat is absorbed to evaporate 1 kg of water. The increase in entropy (S_{fg}) is represented by a line bc.

In fig the line A-B-B_1-B_2--- B_3 etc is called water line, and the line C-C_1-C_2-C_2 etc is called the dry steam line .The point "N" where the water line and dry steam line meets is called critical point, and it represents 374.15^0c. The line BC represents the increase in entropy at constant temperature with increase in dryness fraction of the steam from x=0 to x= 1 at C as shown in fig.

Mollier – chart or Entropy (h-s) diagram : Mollier chart is a graphical representation of the steam table in which the enthalpy (h) is plotted along the ordinate and the entropy (s) along abscissa. In this case enthalpy and entropy of water and dry saturated steam , for any particular pressure are obtained from steam tables and these values are plotted in enthalpy and entropy graph and then liquid line and dry saturated line is obtained. Both these lines meet at point "C" called critical point and this corresponds to the enthalpy of liquid and dry saturated steam at 221.2 bar.

The Mollier chart consists of following lines :

- Dryness fraction lines.
- Constant volume lines.
- Constant pressure lines.
- Isothermal lines.
- Isentropic lines.
- Throttling lines.



.

Vapour power cycles :

The vapour power cycles are similar to the thermodynamic cycles except the working substance , which is steam in this case. The steam may be in any form, i.e. wet , dry saturated or superheated . The heat energy of the steam is converted in to mechanical work by using an engine, which may operate with the following cycles :

1) Carnot cycle.
2) Rankine cycle.
3) Modified Rankine cycle.

Sketch and Explain Carnot Cycle:

A simple line diagram of a carnot engine as shown in fig, with P-V ,and T-S diagrams of carnot cycle shown in fig.

The cycle consists of four processes , two isothermal process and two reversible adiabatic process.

Consider 1 kg of saturated water at pressure P_1 and temperature T_1 at point '1' as shown in fig.

Isothermal Expansion (1-2): Heat is supplied at constant pressure $P_1$and temperature T_1 and water is convertwd in to steam in a boiler.Point '2' is a dry saturated state of steam.

$$\text{Heat supplied} = (S_2-S_1)\,T_2$$

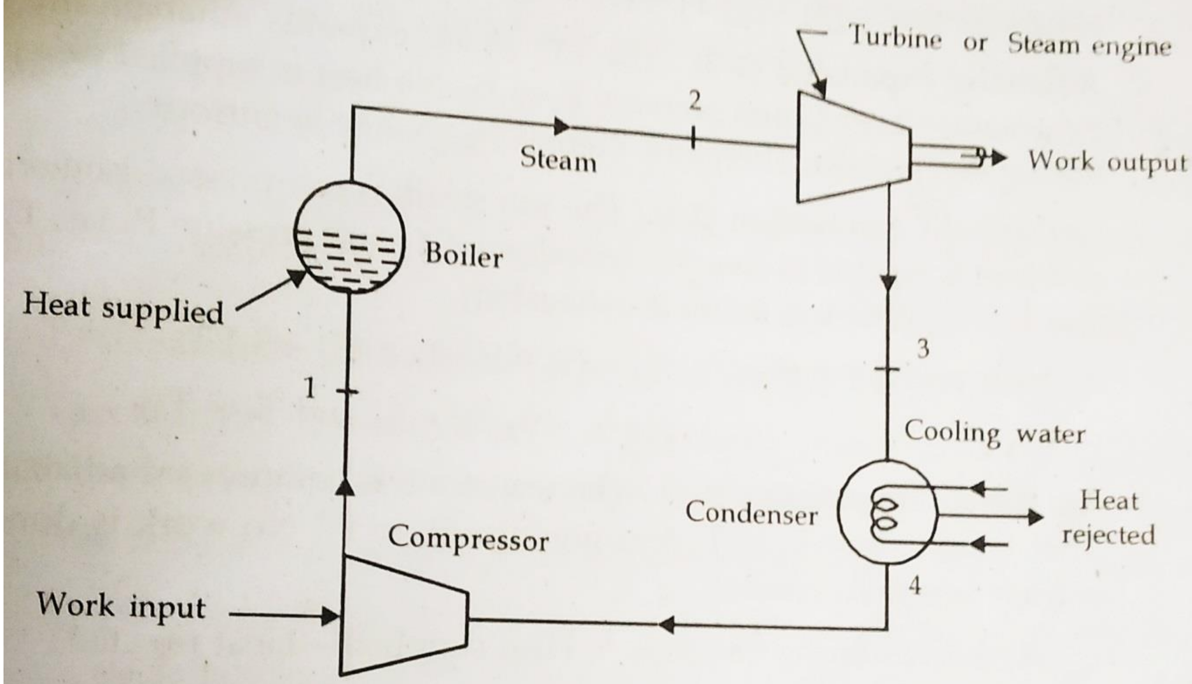
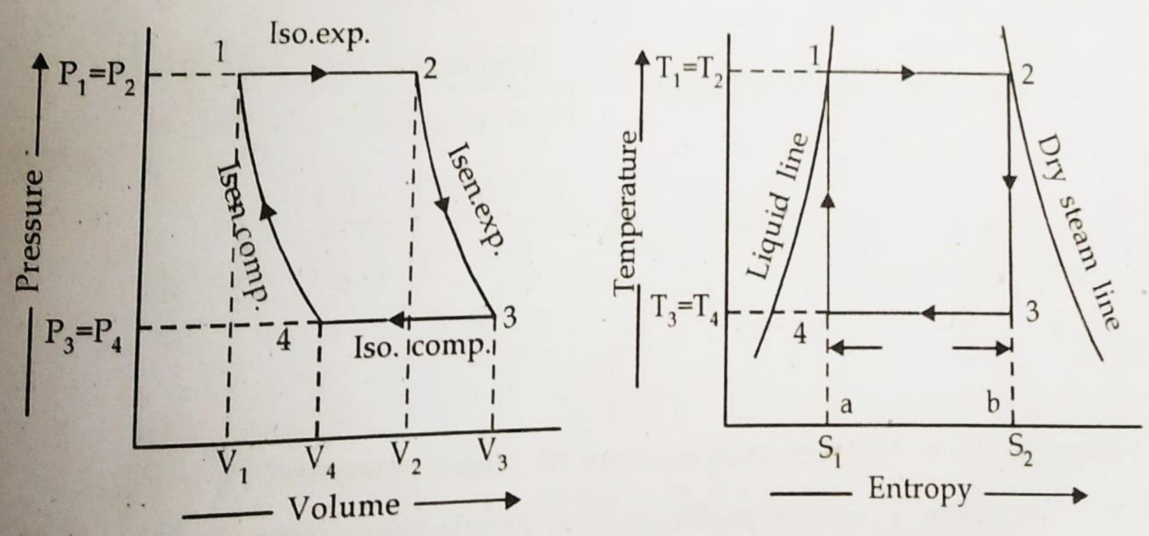


Fig. 1.7 : Line diagram of a carnot engine



(a) P-V diagram (b) T-S diagram

Carnot Cycle.

Isothermal Expansion (2-3) : The dry steam expands adiabatically from temperature T_2 to T_3 and pressure P_2 to P_3 . No heat is supplied or rejected during this process. Therefore , there is no change in entropy.

Isothermal Compression (3-4) : The wet steam is compressed isothermally and heat is rejected at constant temperature T_3 and pressure P_4 i.e. $T_3=T_4$ and $P_3=P_4$
Therefore ,

$$\text{Heat rejected} = (S_2-S_1)\,T_4$$

Adiabatic Compression (4-1): The wet steam is compressed adiabatically from temperature T_4 to T_1 and pressure P_4 to P_1. No work is done and entropy remains constant.

$$\text{Work done during the cycle} = (\text{Heat supplied} - \text{Heat rejected})$$

$$= (S_2-S_1)\,T_1 - (S_2-S_1)\,T_3$$

$$= (S_2 - S_1)\,(T_1 - T_3)$$

$$\text{Efficiency of Carnot Cycle} = \frac{work\ done}{Heat\ supplied}$$

$$= \frac{(S2 - S1)\,(T1 - T3)}{(S2 - S1)\,T1}$$

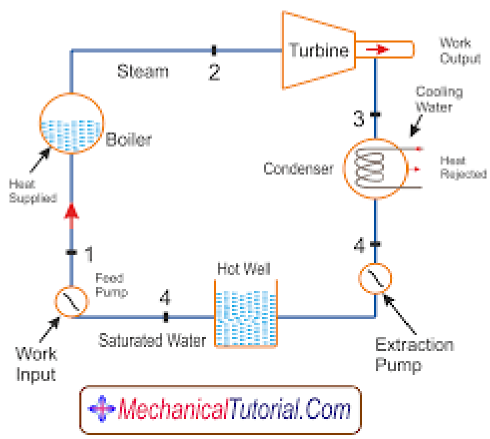
$$= \frac{T1 - T3}{T1}$$

Where T_1= Higher temperature at boiler pressure, $P_1 = P_2$

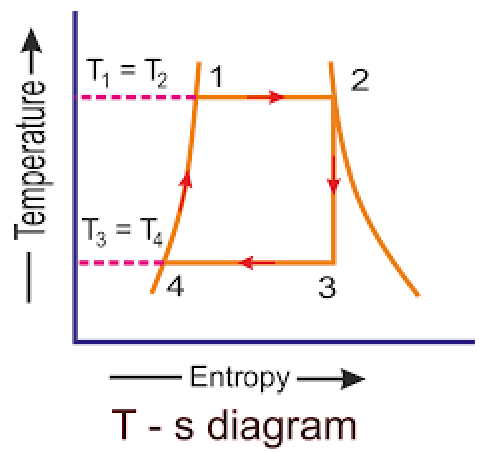
T_2 = Lower temperature at condenser pressure , $P_3 = P_4$.

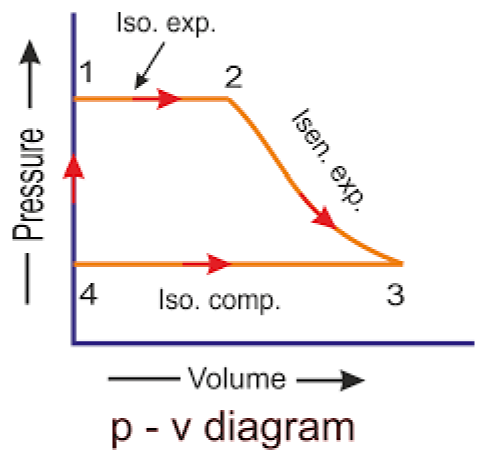
Rankine Cycle :

Explain with sketch Rankine Cycle .



Line diagram of a steam engine





Rakine cycle is a modified form of Carnot cycle , in which the condensation process (3-4) is carried until the steam is condensed in to water as shown in fig. The Rankine cycle is represented on P-V and T–S diagram . Consider 1 kg of saturated water at temperature T_1 and pressure P_1 . The Cycle consists of four processes :

Isothermal Process (1-2) : The saturated water at point '1' is converted in to dry saturated

Steam isothermally in a boiler at a constant temperature T_1 and pressure P_1 i.e. $T_1 = T_2$ and $P_1=P_2$.

Heat absorbed , $Q_{1-2}= h_{fg1} = h_{fg2}$

Isentropic Expansion (2-3): The dry saturated steam at point '2' is now expands isentropically from temperature T_2 to T_3 and pressure P_2 to P_3 with a dryness fraction x_3. No heat is supplied or rejected and entropy remains constant.

Isothermal Compression Process (3-4) : The wet steam at point '3' is now compressed isothermally and the steam is condensed in to water completely in a condenser and heat is rejected at a constant temperature T_3 and pressure P_3 i.e. $T_3=T_4$ and $P_3=P_4$.

Heat rejected, $Q_{3-4}= x_3 h_{fg3}$

Process 4-1: The water at point '4' is now warmed in a boiler at constant volume from temperature T_4 to T_1 and pressure increases from P_4 to P_1.The heat absorbed by water is equal to the sensible heat at P_1at point '1' minus sensible heat at point '4'.

Rankine efficiency , η_R= $\frac{work\ done}{Heat\ supplied}$

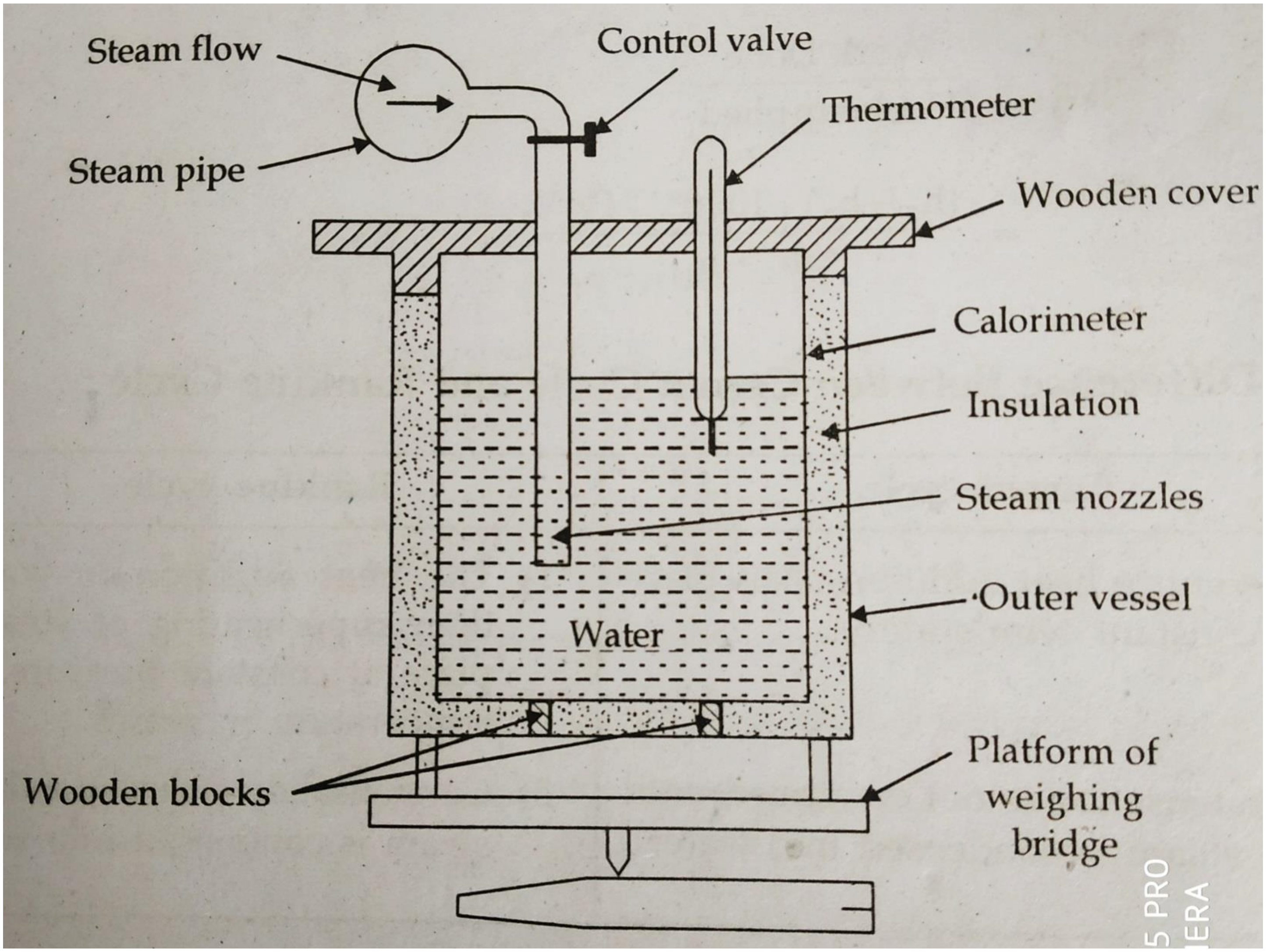
$$= \frac{h2-h3}{h2-hf3}$$

Steam calorimeters : The steam calorimeter is an experiemental apparatus used for experiemental determination of Dryness fraction of wet steam.There are four calorimeters are available .

These are :

1. Barrel Calorimeter
2. Seperating Calorimeter
3. Throttling Calorimeter
4. Combined Seperating and Throttling Calorimeter.

Explain Barrel type steam Calorimeter with a neat sketch.



Barrel Calorimeter

A simple Barrel Calorimeter as is shown fig. It consists of a copper calorimeter placed on a wooden blocks and provided with a wooden cover. It contains a known quantity of cold water and is surrounded by an outer vessel with an insulation. A thermometer is inserted through one of the holes in the wooden cover and a steam supply pipe is also inserted in to the calorimeter with control valve and steam nozzles as shown in fig. The whole assembly is placed over a platform of a weighing bridge.

In this calorimeter , the known mass of a steam sample and of known pressure is condensed by mixing it with a known mass of cold water.

The steam from the main steam pipe enters in to the calorimeter and flows in to the cold water through the steam nozzles in the condenser in to the water , thereby increasing the mass and temperature of the water in the calorimeter.The heat supplied by the condensing steam is determined with the help of the initial and final temperatures of the water and calorimeter.

Heat lost by the steam = Heat generated by water and calorimeter.

$$m_s (x\, h_{fg}) + m_s\, C_w (t_2 - t_1) = (m_w C_w + m_c C_c)\ (t_2 - t_1)$$

From this equation we get yhe dryness fraction of the wet steam.

Limitations :

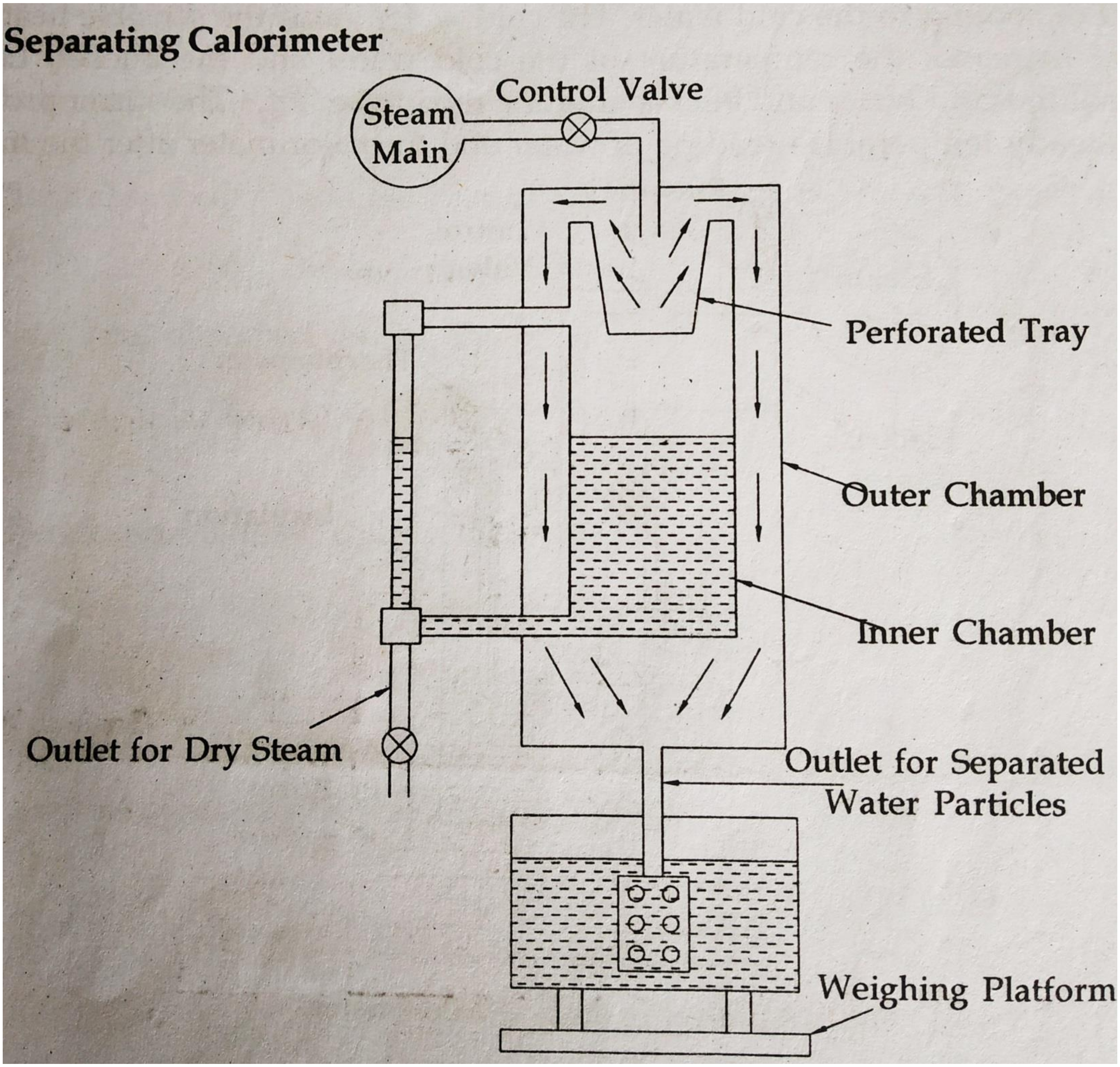
1.This method is not accurate.

2 Losses are more at higher temperature difference.

Separating Calorimeter :

Explain Separating type steam Calorimeter with a neat sketch.

A simple separating calorimeter as shown in fig . This calorimeter is used to determine the dryness fraction of the steam by mechanically separating the water particles from the wet steam.



Separating Calorimeter.

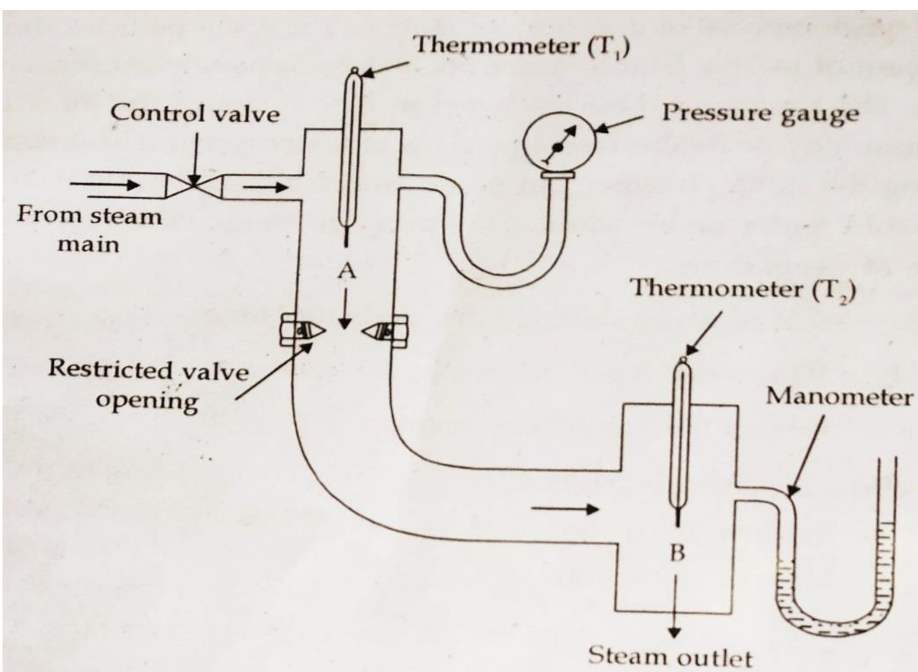
The wet steam from the steam main passes through the control valve and the steam strikes the perforated tray and thereby undergoes a quick reversal of directions of motion due to more density of water particles.The separated water moves down and mixes with the known mass of water in the barrel provided at the bottom of the calorimeter. The mass of water particles is thus noted as 'm_w'. The separated dry steam is made to flow through the outer chamber and its mass is determined by mixing it with the known mass of cold water.The mass of dry steam is noted as 'm_s'. The dryness fraction of the steam is now found by using the equation.,

$$x = \frac{ms}{ms+mw}$$

Limitations : It gives approximate values of 'x ' as total separation of water particals from the steam is not possible by mechanical means.

Throttling Calorimeter :

Explain Throttling type steam Calorimeter with a neat sketch.



Throttling Calorimeter

The enthalpy of steam remains constant during throttling process is made use in the calorimeter as shown in fig. It consists of a separator 'A' in to which the steam is admitted through a conrol valve from the steam main pipe.The pressure and temperature are measured by the pressure gauge and thermometer (T_1) provided in this section as shown in fig. The temperature recorded by T_1 is same as saturation temperature corresponds to the pressure of steam in calorimeter B. This steam is then throttled through a throttle valve and during this process enthalpy of steam remain constant. The steam is in the super heated state after throttling at a lower pressure than previous. The temperature and pressure of the steam leaving the calorimeter 'B' is noted by the thermometer T_2 and manometer respectively.

For throttling process :

Total heat before throttling = Total heat after throttling.

$$h_{f1} + x\, h_{fg1} = h_{g2} + C_p(t_{sup} - t_{sat})$$

$$\text{Dryness fraction , } x = \frac{hg2 + Cp\,(tsup - tsat) - hf1}{hfg1}$$

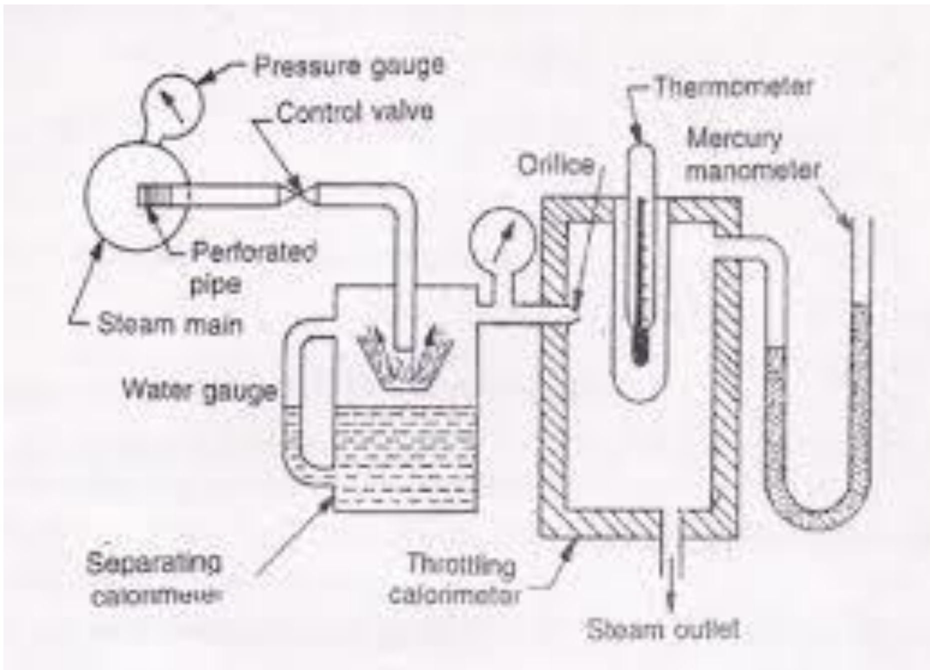
Limitations : Steam must become superheated after throttling i.e., it is not useful for the steam containing more amount of water particles.

Combined Separating and Throttling Calorimeter :

Explain Combined Separating and Throttling type steam Calorimeter with a neat sketch.

A combined separating and throttling calorimeter is as shown in fig. In this calorimeter , the wet steam to be tested is first collected in a perforated collecting pipe and then passed through a separating calorimeter. A part of the water is removed by the separating calorimeter and there is a quick change of direction of flow by a semi dry steam and flows to the throttling calorimeter, where it is throttled .

This method ensures that the steam will be superheated after throttling. This instrument is well insulated to prevent any loss of heat.



Combined Separating and Throttling Calorimeter.

Let x_1 = Dryness fraction of steam from separating calorimeter

x_2 = Dryness fraction of steam from throttling calorimeter

where $x_1 = \frac{M}{M+m}$

and $x_2 = \frac{hg2 + Cp\,(tsup - tsat) - hf1}{hfg1}$

Actual dryness fraction $x = x_1 \,.\, x_2$