Entropy (J/K)

- Entropy, **the measure of a system's thermal energy per unit temperature that is unavailable for doing useful work**.
- Because work is obtained from ordered molecular motion, the amount of entropy is also a measure of the molecular disorder, or randomness, of a system.

Steam Table

- Steam tables are defined as the thermodynamic data that contain the properties of water or steam. These data are commonly used by engineers.
- It is normally used to obtain the following properties using steam pressure for saturated steam temperature and saturated temperature for saturated steam pressure.
- It is also widely used for a particular enthalpy and volume. Property tables list the properties from saturated water to steam.
- This is because water is the medium that can be liquid or gas at saturation point.

- The saturated water in the steam property table is referred by subscript “f” and the saturated steam in the steam property table is referred by subscript “g.”

- There are many properties which we can get from steam Tables like steam Temperature, Heat of Saturated Liquid, Latent heat of steam, Total heat of steam & Specific Volume etc.

Nomenclatures - Steam Tables:

- P – Pressure of the steam/Water
- T – Saturation point of steam/water
- vg – Specific volume of saturated steam
- vf - Specific volume of saturated water
- hf – Specific enthalpy of Saturated water
- hfg – Latent of evaporation
- hg – Specific enthalpy of Saturated steam

		Specific volume m^3/kg		Internal energy kJ/kg			Enthalpy kJ/kg			Entropy kJ/kg-K		
Temp. T °C	Sat. Press. P_{sat} kPa	Sat. Liquid v_f	Sat. Vapor v_g	Sat. Liquid u_f	Evap. u_{fg}	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
70	31.202	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6	1.0158	6.6655	7.6812
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0	1.0756	6.5355	7.6111
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4	1.1346	6.4089	7.5435
90	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6	1.1929	6.2853	7.4782
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647	7.4151
100	101.42	0.001043	1.6720	419.06	2087.0	2506.0	419.17	2256.4	2675.6	1.3072	6.0470	7.3542
105	120.90	0.001047	1.4186	440.15	2071.8	2511.9	440.28	2243.1	2683.4	1.3634	5.9319	7.2952
110	143.38	0.001052	1.2094	461.27	2056.4	2517.7	461.42	2229.7	2691.1	1.4188	5.8193	7.2382
115	169.18	0.001056	1.0360	482.42	2040.9	2523.3	482.59	2216.0	2698.6	1.4737	5.7092	7.1829
120	198.67	0.001060	0.89133	503.60	2025.3	2528.9	503.81	2202.1	2706.0	1.5279	5.6013	7.1292

Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m³/kg: Sat. liquid, v_f	Specific volume, m³/kg: Sat. vapor, v_g	Internal energy, kJ/kg: Sat. liquid, u_f	Internal energy, kJ/kg: Evap., u_{fg}	Internal energy, kJ/kg: Sat. vapor, u_g	Enthalpy, kJ/kg: Sat. liquid, h_f	Enthalpy, kJ/kg: Evap., h_{fg}	Enthalpy, kJ/kg: Sat. vapor, h_g	Entropy, kJ/kg·K: Sat. liquid, s_f	Entropy, kJ/kg·K: Evap., s_{fg}	Entropy, kJ/kg·K: Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
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60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
70	31.202	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1	0.9551	6.7989	7.7540
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6	1.0158	6.6655	7.6812
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0	1.0756	6.5355	7.6111
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4	1.1346	6.4089	7.5435
90	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6	1.1929	6.2853	7.4782
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647	7.4151
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105	120.90	0.001047	1.4186	440.15	2071.8	2511.9	440.28	2243.1	2683.4	1.3634	5.9319	7.2952
110	143.38	0.001052	1.2094	461.27	2056.4	2517.7	461.42	2229.7	2691.1	1.4188	5.8193	7.2382
115	169.18	0.001056	1.0360	482.42	2040.9	2523.3	482.59	2216.0	2698.6	1.4737	5.7092	7.1829
120	198.67	0.001060	0.89133	503.60	2025.3	2528.9	503.81	2202.1	2706.0	1.5279	5.6013	7.1292
125	232.23	0.001065	0.77012	524.83	2009.5	2534.3	525.07	2188.1	2713.1	1.5816	5.4956	7.0771
130	270.28	0.001070	0.66808	546.10	1993.4	2539.5	546.38	2173.7	2720.1	1.6346	5.3919	7.0266
135	313.22	0.001075	0.58179	567.41	1977.3	2544.7	567.75	2159.1	2726.9	1.6872	5.2901	7.0773
140	361.53	0.001080	0.50850	588.77	1960.9	2549.6	589.16	2144.3	2733.5	1.7392	5.1901	6.9293

■ Pressure-Based Saturated Steam Table

(Excerpt From Japan Society of Mechanical Engineers, 1999)

Press.[abs]	Temp.	Specific Volume		Specific Enthalpy		
kPa	[°C]	m³ / kg		kJ / kg		
p	t	v_f	v_g	h_f	h_g	h_{fg}
1.0	6.970	0.00100014	129.183	29.30	2513.68	2484.38
2.0	17.495	0.00100136	66.9896	73.43	2532.91	2459.48
4.0	28.962	0.00100410	34.7925	121.40	2553.71	2432.31
6.0	36.160	0.00100645	23.7342	151.49	2566.67	2415.17
				173.85	2576.24	2402.39
200	120.21	0.00106052	0.885735	504.68	2706.24	2201.56
300	133.53	0.00107318	0.605785	561.46	2724.89	2163.44
400	143.61	0.00108356	0.462392	604.72	2738.06	2133.33
500	151.84	0.00109256	0.374804	640.19	2748.11	2107.92
600	158.83	0.00110061	0.315575	670.50	2756.14	2085.64
700	164.95	0.00110797	0.272764	697.14	2762.75	2065.61
800	170.41	0.00111479	0.240328	721.02	2768.30	2047.28
900	175.36	0.00112118	0.214874	742.72	2773.04	2030.31
1000	179.89	0.00112723	0.194349	762.68	2777.12	2014.44
1100	184.07	0.00113299	0.177436	781.20	2780.67	1999.47

Temperature (°C) at 200 kPa

Table On the Basis of Pressure

Absolute pressure (P) bar	Saturation temperature (t) °C	Sp. volume in m3/kg		Specific enthalpy in kJ/kg			Specific entropy in kJ/kg K	
		Water (vf)	Steam (vg)	Water (hf)	Latent heat (hfg)	Steam (hg)	Water (Sf)	Steam (Sg)
1.00	99.63	0.001	1.69	417.5	2258	2675.5	1.303	6.056
1.10	102.3	0.00104	1.59	428.8	2251	2679.8	1.333	5.994
1.20	104.8	0.00104	1.428	439.4	2244	2683.4	1.361	5.937
1.50	111.4	0.00105	1.159	467.1	2226	2693.1	1.434	5.790

Table On the Basis of Saturation Temperature

Saturation temperature (t) in °C	Absolute pressure (P) in bar	Sp. volume in m3/kg		Specific enthalpy in kJ/kg			Specific entropy in kJ/kg K	
		Water (vf)	Steam (vg)	Water (hf)	Latent heat (hfg)	Steam (hg)	Water (Sf)	Steam (Sg)
10	0.0123	0.001	106.4	42.0	2477	2519	0.151	8.749
20	0.0234	0.001	57.8	83.9	2454	2537.9	0.296	8.370
40	0.0738	0.001	19.6	167.5	2407	2574.5	0.572	7.684

Properties of steam: Numerical

- **Problem 1:** Find the enthalpy of 1 kg of steam at 12 bar when,
  - (a) steam is dry saturated,
  - (b) steam is 22% wet and
  - (c) superheated to 250°C.
- Assume the specific heat of the superheated steam as 2.25 kJ/kgK

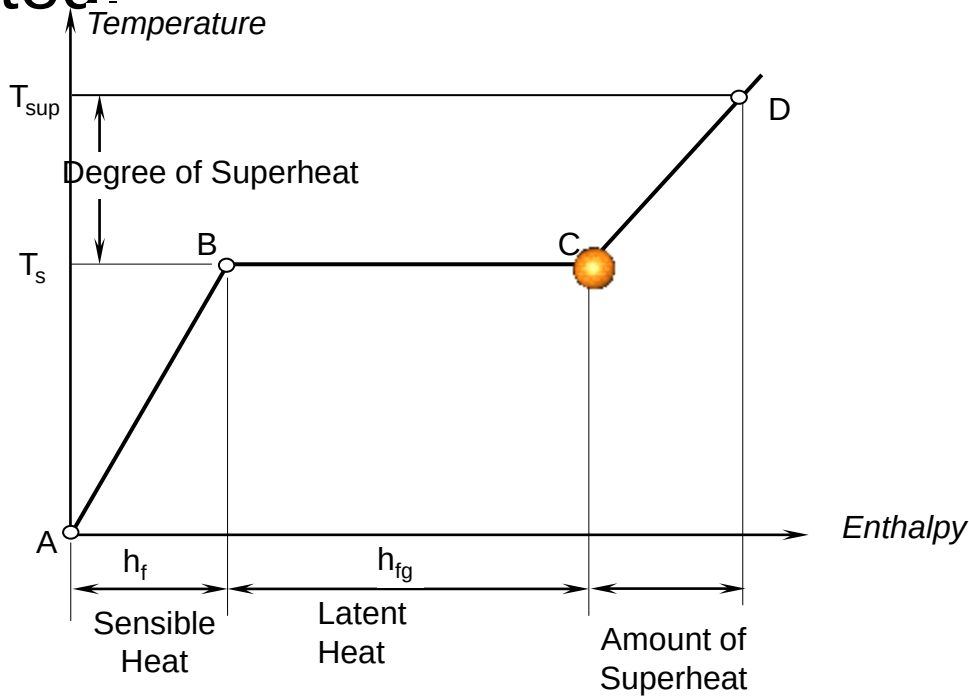
- Solution: From the steam tables at 12 bar, the following values are noted

T_{sat} = 188°C

h_f = 798.43 kJ/kg

h_{fg} = 1984.3 kJ/kg

Now,



(a) Enthalpy of Dry saturated Steam:

$$hg = h_f + h_{fg}$$

$$= 798.43 + 1984.3 \text{ kJ/kg}$$

$$= 2782.73 \text{ kJ/kg}$$

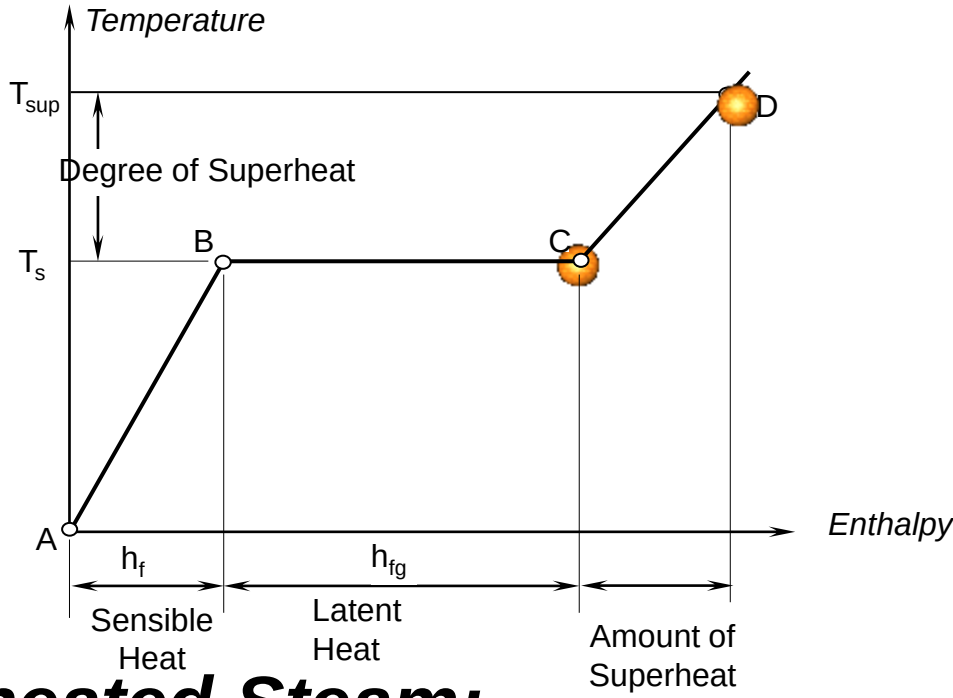
- ***(b) Enthalpy of Wet Steam:***

When the steam is 22% wet, it will be 78% dry.

Therefore the dryness fraction x = 0.78

$h_x = h_f + x\, h_{fg}$

$= 2346.18 \ kJ/kg$



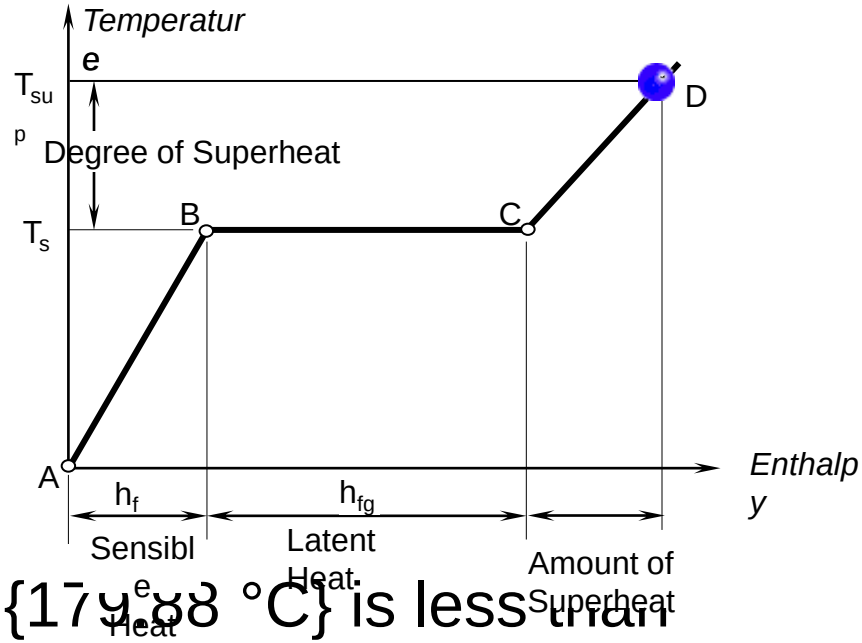
- ***(c) Enthalpy of Superheated Steam:***
- $h_{sup} = h_f + h_{fg} + C_{sup}(T_{sup} - T_{sat})$

$= 2922.23 \ kJ/kg$

Problem 2: Determine the conditions of steam from the following data:

a) Pressure is 10 bar and temperature 200°C,

b) Pressure is 12 bar and enthalpy of 2600 kJ/kg.



Solution:

a)P = 10 bar, T = 200°C

From steam tables,

at pressure of 10 bar,

T_{sat} = 179.88°C

Since the saturation temperature {179.88 °C} is less than given steam temperature of [200°C], therefore the ***steam is superheated.***

∴ Degree of superheat = T - T_{sat} = 20.12 °C

b) P = 12 bar, h = 2600 kJ/kg.

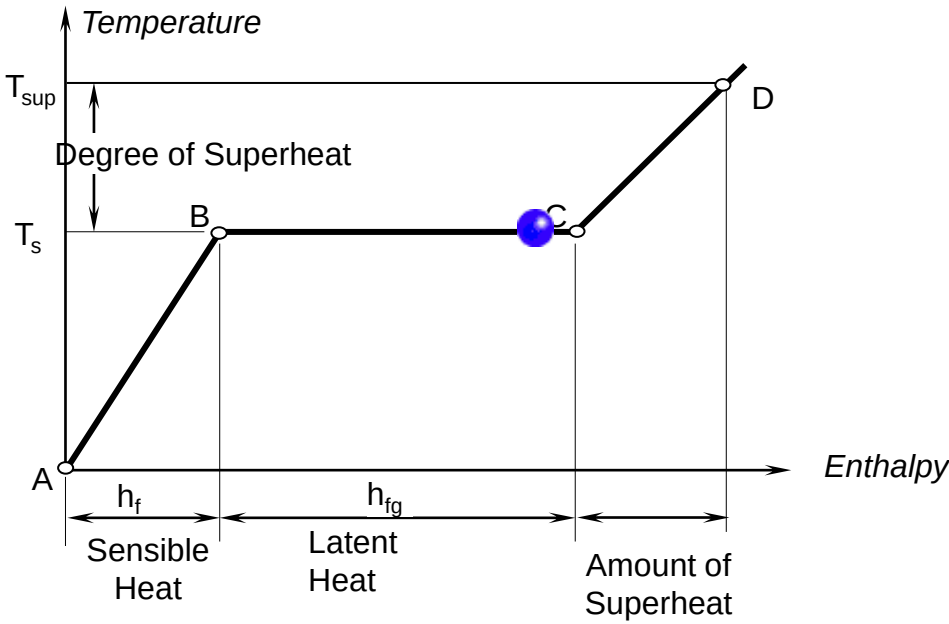
From steam tables,

at of 12 bar.

h_f=*798.43* kJ/kg.

h_{fg} = 1984.27 kJ/kg

h_g = 2782.7 kJ/kg.



Since the value of specific enthalpy of steam h_g is greater than the given enthalpy of 2600 kJ/kg., the ***steam is wet.***

Enthalpy of wet steam $h = h_f + x\, h_{fg}$

i.e., 2600 = 798.43 + x 1984.27

$\therefore$ Dryness fraction **x = 0.908**

Problem 3: **Given enthalpy of steam at 30 bar is 3681 kJ. Is the steam wet or superheated? If it is wet; find its dryness fraction. If it is superheated; find its degree of superheat.**

Solution:

From steam table, at 30 bar,

T_{sat}= 233.8°C

h_f = 1008.3 kJ/kg.

h_{fg} = 1794 kJ/kg.

h_g = 2802.3 kJ/kg.

But, given enthalpy of steam [3681KJ/kg] is greater than enthalpy of dry saturated steam h_g [2802.3 kJ/kg].

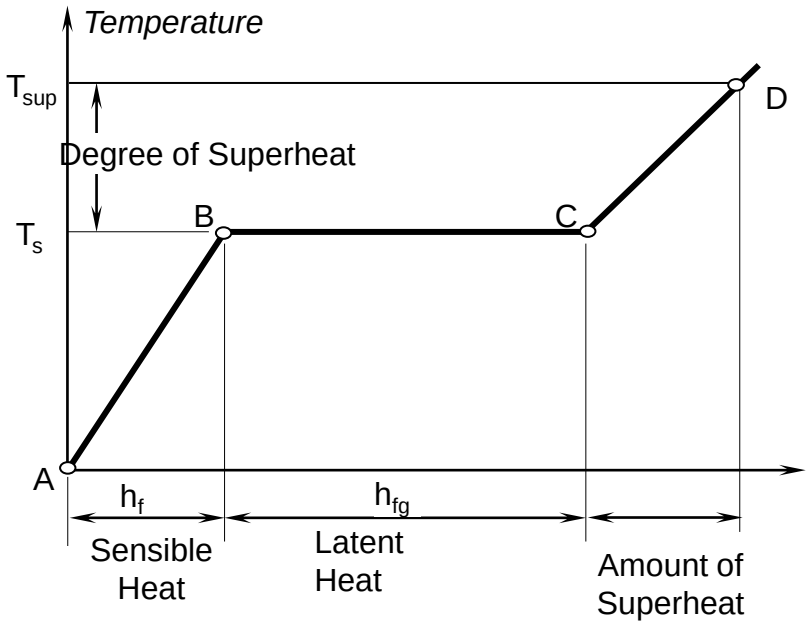
This infers that the steam is superheated, hence we to find the superheated temperature.

We have, $h_{sup} = h_g + C_{sup}(T_{sup} - T_{sat})$

$3681 = 2802.4 + 2.25(T_{sup} - 233.8)$

$\therefore$ **$T_{sup} = 600^0C$**

$\therefore$ **Degree of super heat = 366.2^0C**



Problem 4: **By actual measurement, the enthalpy of steam at 6 bar is found to be 2500 kJ/kg.**

a) What is the quality of steam?

b) If 500kJ/kg of heat is added to this steam, what is the

- **Superheated temperature**
- **Degree of superheat**
- **Enthalpy of superheat**

Solution: **For 6 bar pressure,**

$T_{sat} = 158.8^{o}C$, $h_f = 670.4$ kJ/kg,

$h_{fg} = 2085$ kJ/kg, $h_g = 2755.5$ kJ/kg.

Case a) Given enthalpy [2500 kJ/kg] is less than h_g [2755.5 kJ/kg.]

$\therefore$ This indicates that the steam is wet.

$\therefore$ Enthalpy of wet steam, $h = h_f + x\ h_{fg}$

$\therefore x = 87.77\%$

Case b) If 500kJ/kg of heat is added to "h", then the resulting enthalpy,

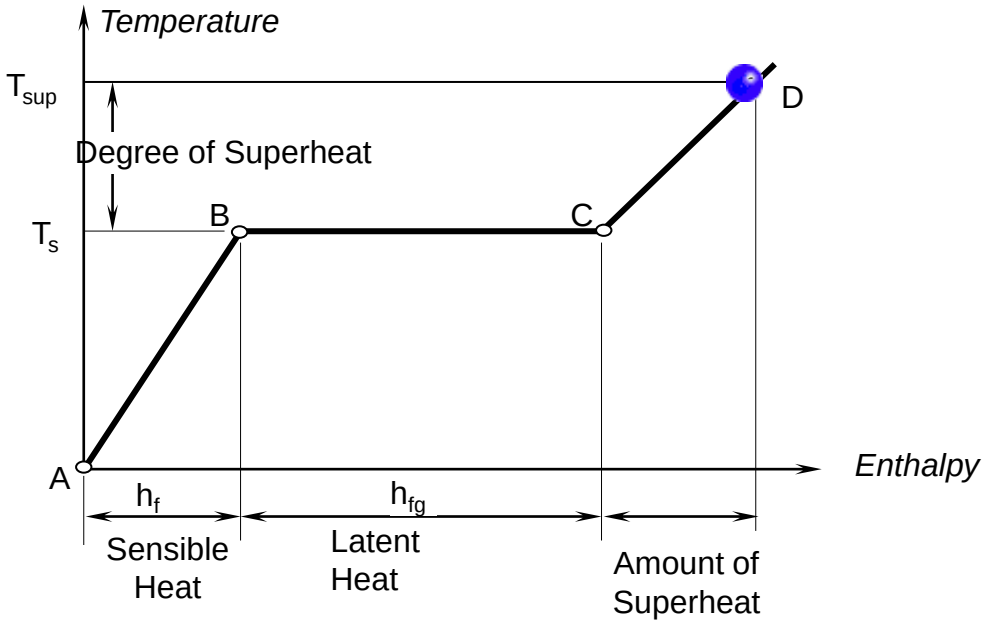
$h = 2500 + 500 = 3000$ kJ/kg which is $> h_g = 2755.5$ kJ/kg.

$\therefore$ The resulting steam is superheated.

Then find the superheated temperature

$$h_{sup} = h_g + C_{sup} (T_{sup} - T_{sat})$$

$$\therefore T_{sup} = 267.47\ ^oC$$



$$\therefore \text{Degree of superheat} = T_{sup} - T_{sat}$$

$$= 108.67\ ^oC$$

$$\text{Enthalpy of superheat} = C_{sup} (T_{sup} - T_{sat})$$

$$= 244.5\ kJ/kg$$

Problem 5: 2 kg of water at 30°C is heated continuously at constant pressure of 5 bar. The total amount of heat added is 500 kJ. Determine the dryness fraction or degree of superheat of the resulting steam as the case may be.

Solution:

At 5 bar pressure, T_{sat} = 151.9°C, h_f = 640.1 kJ/kg, h_{fg} = 2107.4 kJ/kg & h_g = 2747.5 kJ/kg.

$\therefore$ Initial enthalpy at 30°C,

$h_i = m. C_{pw}. \Delta T$

$= 2 \times 4.1868 \times 30$

= 250.8 kJ for 2 kg of steam.

But heat added is 500 kJ/kg.

$\therefore$ Enthalpy after heat addition = 250.8 + 500

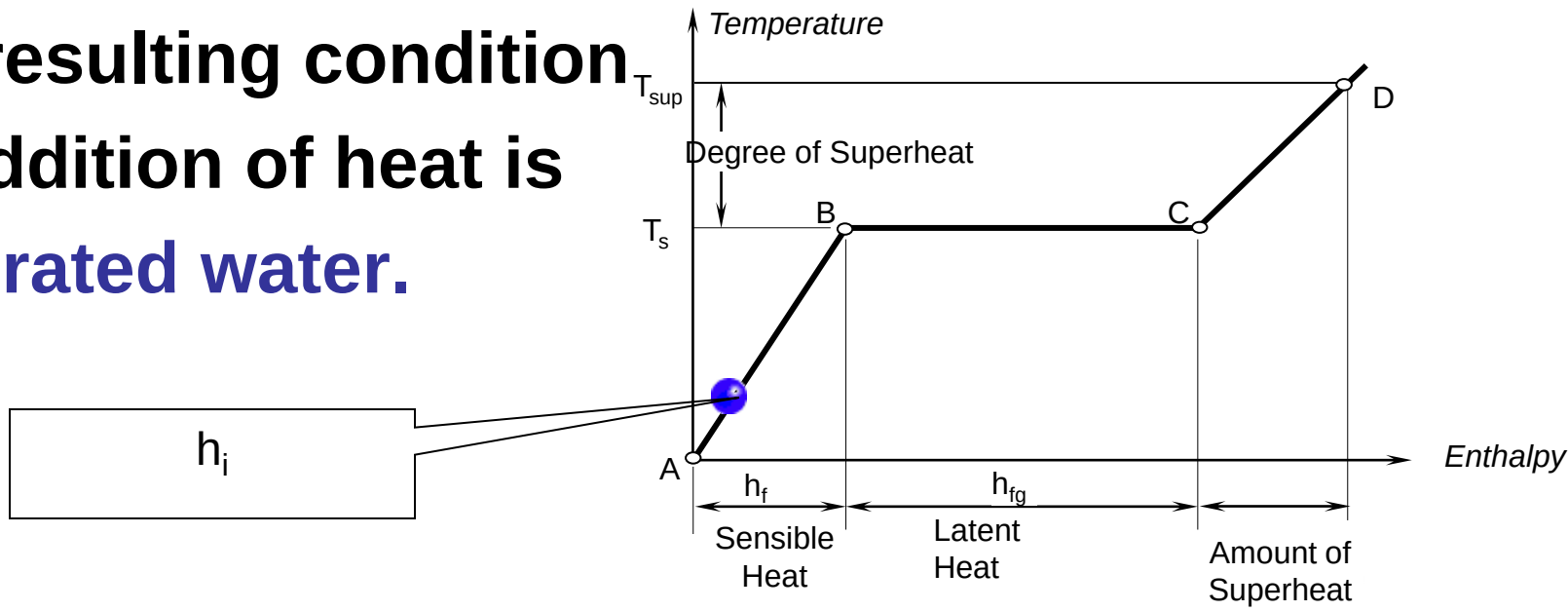
= 750.8 kJ { for 2 kg }

$\therefore$ Sensible heat for 2 kg = h_f x 2

= 640.1 x 2 = 1280.2 kJ {for 2 kg}

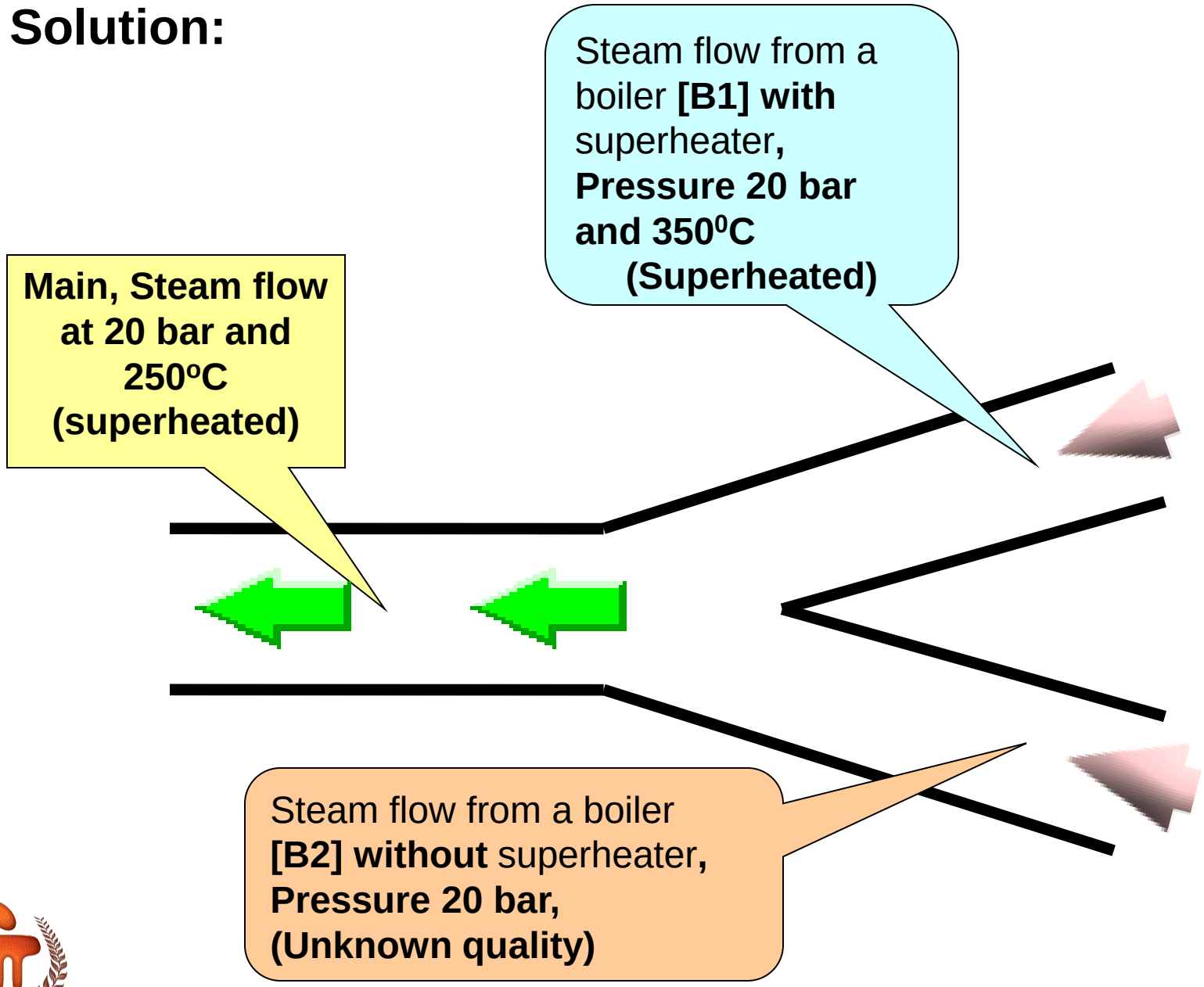
Since enthalpy after heat addition [750.8] is less than that of enthalpy of saturated water

$\therefore$ The resulting condition after addition of heat is unsaturated water.



Problem 6: 2 boilers one with superheater and another without superheater are delivering equal quantities of steam into a common main. The pressure in the boiler and main is 20 bar. The temperature of steam from the boiler with a superheater is 350^{o}C and the temperature of steam in the main is 250^{o}C. Determine the quality of steam supplied by the other boiler.

Solution:


Steam flow from a boiler **[B1] with** superheater**, Pressure 20 bar and 350^{0}C (Superheated)**
Main, Steam flow at 20 bar and 250^{o}C (superheated)
Steam flow from a boiler **[B2] without** superheater**, Pressure 20 bar, (Unknown quality)**

Find the enthalpy of steam flowing from boiler B1 ie. P = 20 bar, T = 350°C,

From steam table at 20 bar,

T_{sat} = 212.4 °C,

h_f = 908.6 kJ/kg,

h_{fg} = 1888.7 kJ/kg

h_g = 2797.2 kJ/kg.

$\therefore T > T_{sat}$, $\therefore$ The steam is superheated.

$\therefore\ h_{sup}\ (B1) = h_g + C_{sup}\ (T_{sup} - T_{sat})$

= 3106.8 kJ/kg ------ (1)

Enthalpy of steam flowing in the main pipe: i.e., at P = 20 bar, T = 250°C

$T = 250^{o}C > T_{sat} = 212.4\ ^{o}C.$

$\therefore$ The steam is superheated

$\therefore\ h_{sup}\ (Main) = h_g + C_{sup}\ (T_{sup} - T_{sat})$

$= 2881.8$ kJ/kg ------ (2)

$\therefore$ For 2 kg = 2881.8 x 2 = 5763.6 kJ

To find Enthalpy of steam flowing from B2:

We know that, at main, T = 250°C

at B1, T = 350°C,

So the steam flowing from Boiler with out superheater (B2) is wet

$$h = h_f + x.h_{fg}$$

$$= 908.6 + x\ (1888.7) \quad \text{------ (3)}$$

$\therefore$ Energy balance, (2) = (1) + (3)

$$5763.6kJ = [3106.8]kJ + [908.6 + x\ (1888.7)]kJ$$

$$\therefore x = 92.56\%$$

Problem 7: 1000 Kg of steam at a pressure of 16 bar and 0.9 dry is generated by a boiler per hour. Steam passes through a superheater where its temperature is raised such that the degree of superheat is 180 ^{o}C. If the temperature of feed water is 30 ^{o}C, determine

a) Total heat added to feed water per hour to produce wet steam in the boiler.

b) Total heat absorbed per hour in the superheater.

Solution:

Solving per kg basis: i.e., m =1,

P: Entry of water into boiler

Q: It is the point where wet steam leaves the boiler with x = 0.9 and is the point where steam enters the superheater.

R: It is the point where it leaves the superheater

T_s= 201.4

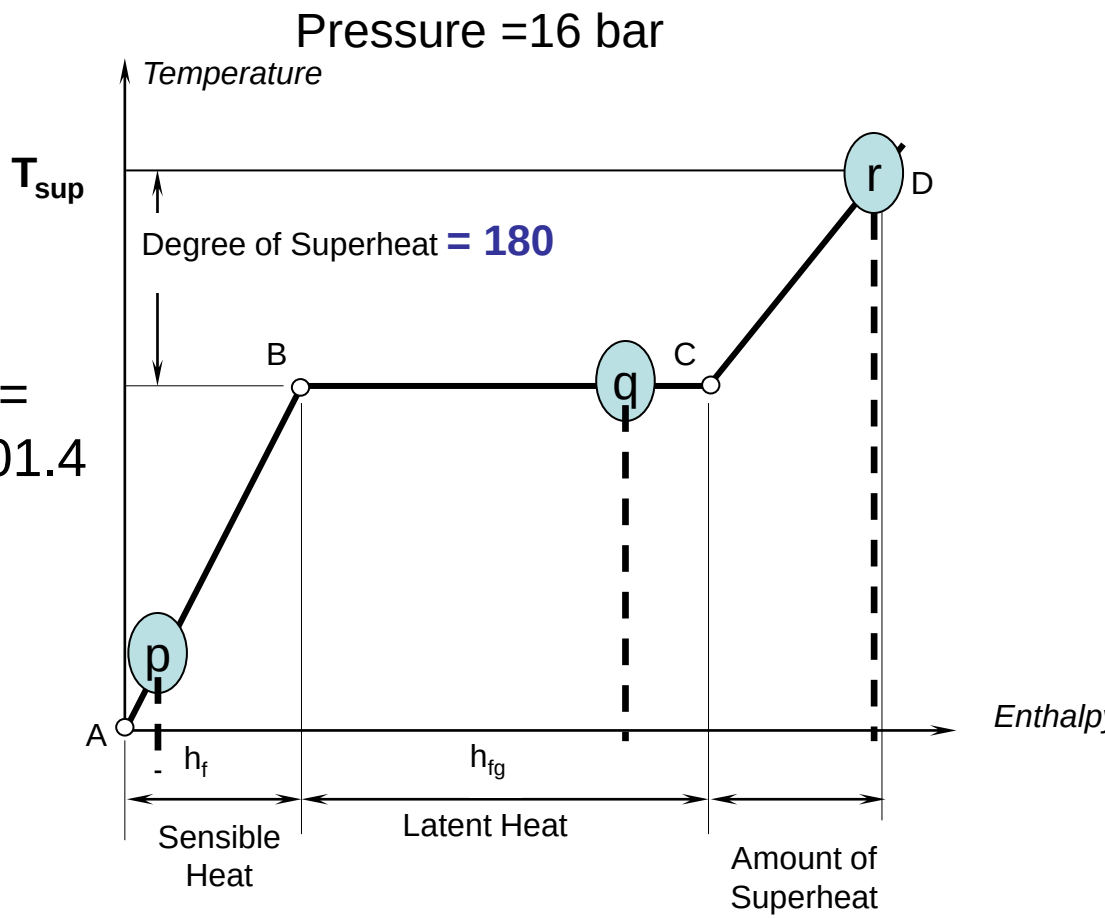
At P = 16 bar,

T_{sat}= 201.4°C,

h_f= 858.5 kJ/kg

h_{fg}=1933.2 kJ/kg

h_g=2791.7 kJ/kg.



Since, we know, Degree of superheat, $T_{sup} - T_{sat} = 180\ ^oC$

$\therefore T_{sup} = 201.4 + 180 = 381.4\ ^oC$

Answer to be calculated are:

Heat supplied to feed water = $h_Q - h_P$

Heat absorbed in the superheater = $h_R - h_Q$

$\therefore\ h_P = m.C_p.\Delta T$

$= 1 \times 4.1868 \times 30 = 125.4$ kJ/kg.

$\therefore\ h_Q = h_f + x.h_{fg}$

$= 858.5 + 0.9 \times 1933.2 = 2598.38$ kJ/kg.

$\therefore\ h_R = h_g + C_{sup}\ (T_{sup} - T_{sat}\ )$

$= 2791.7 + 2.25(180) = 3196.7$ kJ/kg.

$\therefore$ **Heat supplied to feed water = $h_Q - h_P$**

= 2472.98 kJ/kg.

$\therefore$ **For 1000 kg, heat supplied = 1000 x 2472.98**

= 24,72,980 kJ.

$\therefore$ **Heat absorbed in the superheater = $h_R - h_Q$**

= 598.32 kJ/kg.

$\therefore$ **For 1000 kg of steam,**

heat absorbed = 1000 x 598.32

= 5,98,320 kJ

Problem 8: **Feed water enters a boiler at 60°C at a pressure of 15 bar. If it leaves the boiler at 0.9 dry steam and enters the superheater at 350°C. Find the heat supplied per kg of steam**

a) in the Boiler and

b) In the superheater.

Solution:

a) Heat added in the boiler = 2344.57 kJ/kg.

b) Heat supplied in the superheater = 535.85 kJ/kg.

Problem 9:

5 kg of water is heated from 40°C to superheated steam at 150°C with constant pressure of 3 bar. Find,

a) The total amount of heat added in the heating process, and

b) Amount of superheat

Solution :

From steam table, at 3 bar pressure,

T_{sat} = 133.5 °C, h_f = 561.4 kJ/kg, h_{fg} = 2163.2 kJ/kg, h_g = 2724.7 kJ/kg.

Solving per kg basis:

Initial condition is water at 40ºC, i.e., at state-point P on t-h diagram

Enthalpy at "P"

$= m.C_p.\Delta T$

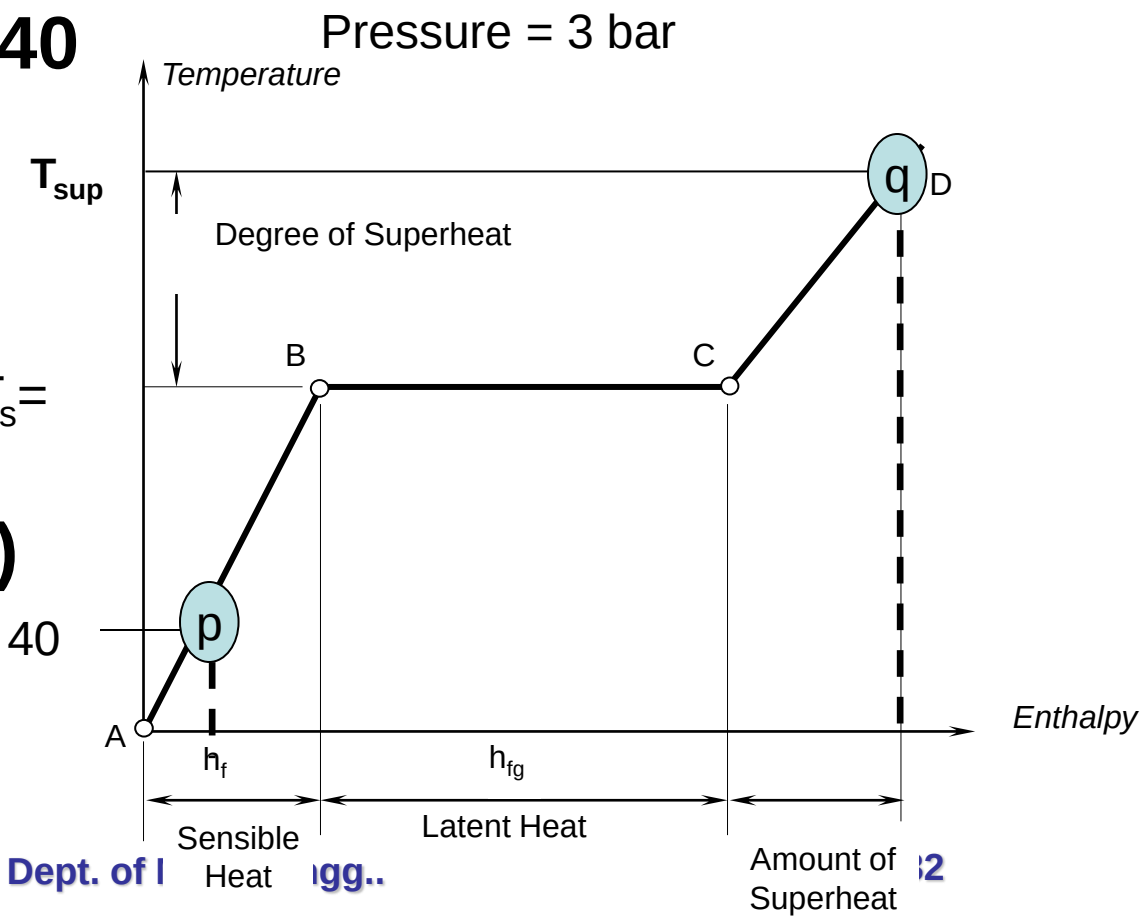
$= 1 \times 4.1868 \times 40$

$= 167.2$ kJ/kg.

Enthalpy at "q"

$= h_g + C_{sup}(T_{sup} - T_{sat})$

$= 2761.82$ kJ/kg.



The amount of heat added in the heating process

$$= h_q - h_p$$

$$= 2594.62 \text{ kJ/kg.}$$

$\therefore$ **For 5 Kg, heat added = 5 x 2594.62**

$$= 12973.125 \text{ kJ}$$

Amount of superheat $= C_{sup} (T_{sup} - T_{sat}) \times 5$

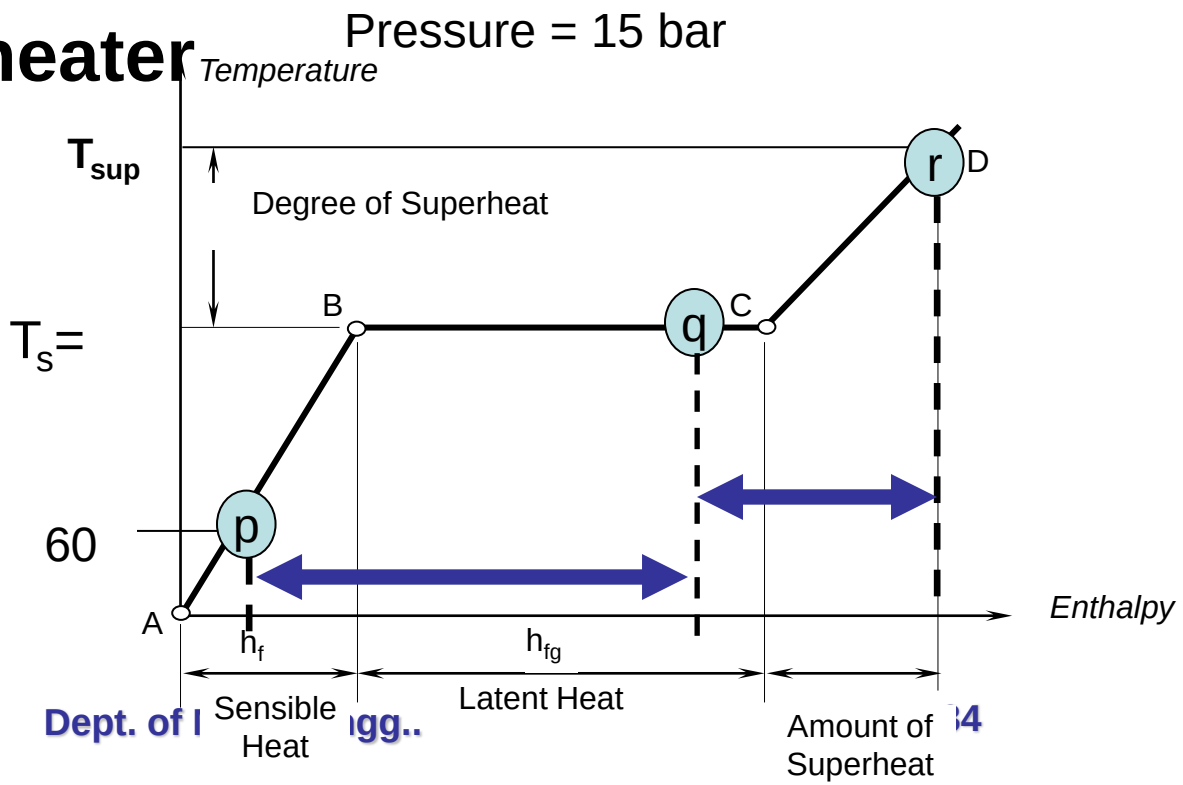
$$= 2.25(150 - 133.5) \times 5$$

$$= 185.625 \text{ kJ}$$

Problem 10: **Feed water enters the boiler at 60°C at a pressure of 15 bar, it leaves the boiler with 20% wet to enter a superheater, where it is superheated to 350°C. Find the heat supplied per kg of steam,**

- **In the boiler**
- **In the superheater**

Solution:

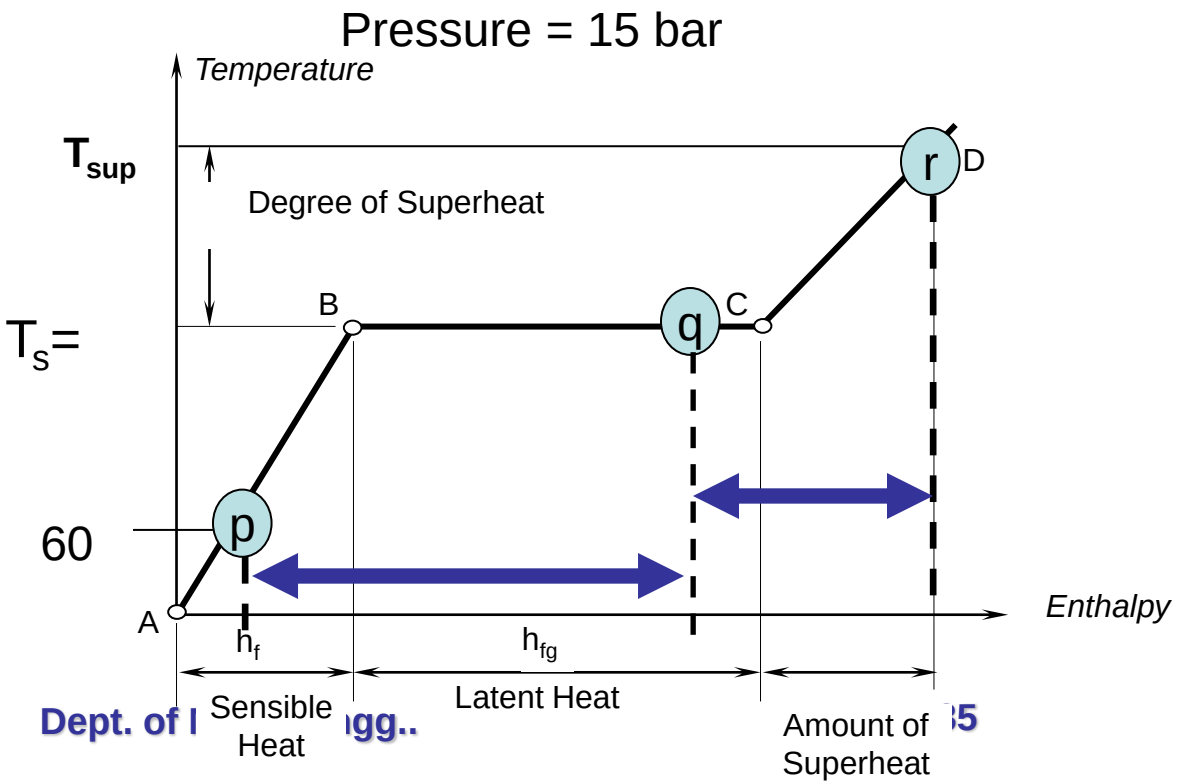


Total heat supplied to feed water in the boiler =

$h_q - h_p = 2538.7$ kJ/kg

Total heat supplied in the superheater =

$h_r - h_q = 730.38$ kJ/kg



Problem 11: Dry saturated steam at a pressure of 16 bar is generated in a boiler. Dry saturated steam leaves the boiler to enter a superheater, where it looses heat equal to 600 kJ/kg. And in the superheater, steam is superheated to temperature of 380^{o}C. If temperature of feed water is 30^{o}C, determine:

- Total heat supplied to feed water in the boiler
- Dryness fraction of steam at the entry of superheater
- Total heat supplied in the superheater.

At 16 bar pressure,

T_{sat} = 201.4°C,

h_f = 858.5 kJ/kg,

h_{fg} = 1933.2 kJ/kg,

h_g = 2791.7 kJ/kg.

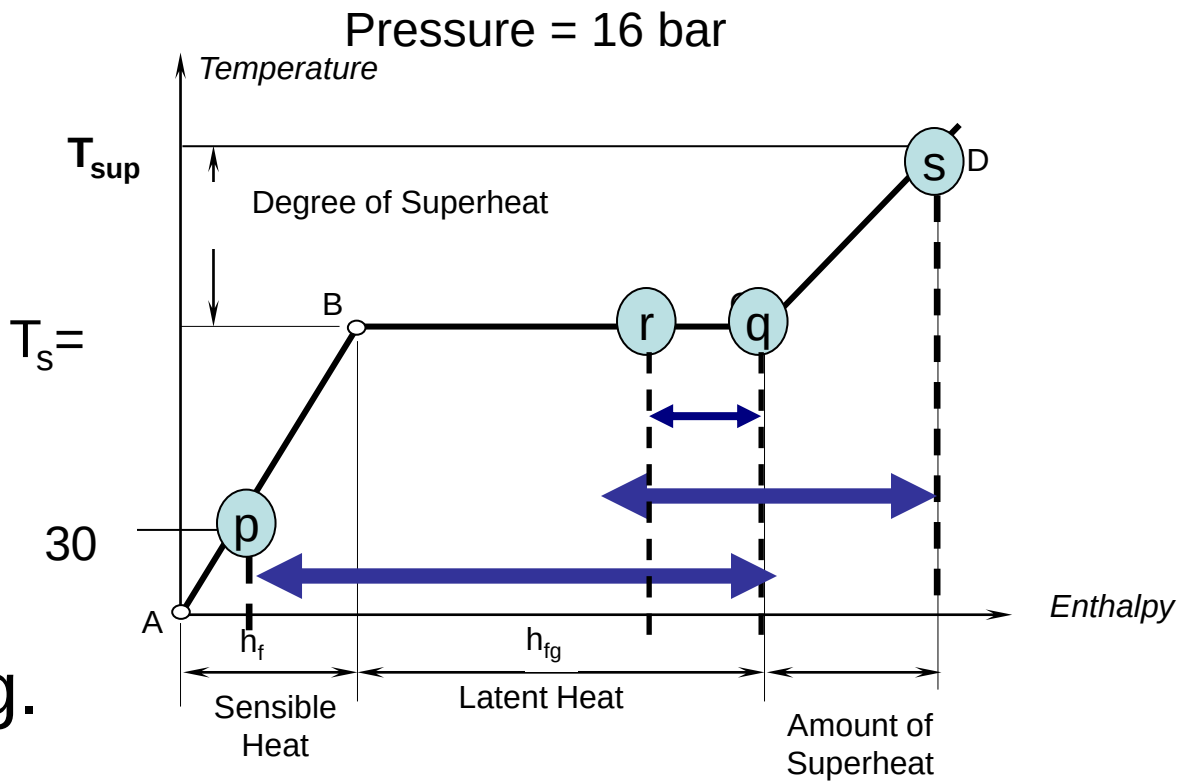
∴ Enthalpy at "p"

= $m.C_p.\Delta T$

= 125.4 kJ/kg.

At "q",

ie. h_g = 2791.7 kJ/kg.



Before it gets into superheater, it losses 600 kJ/kg heat.

$\therefore$ Enthalpy before it enters the superheater,

$h_r = 2791.7 - 600 =$ **2191.7 kJ/kg.**

$\therefore$ Quality of steam before entering the superheater, $h_r = h_f + x.h_{fg}$

$$2191.7 = 858.5 + x\ .1933.2$$

x = 0.6896

Enthalpy of superheated steam coming out from superheater,

$$h_s = h_g + C_{sup}\ (T_{sup} - T_{sat}\ )$$

= 3193.55 kJ/kg.

- **Total heat supplied to feed water in the boiler = $h_q - h_p$ = 2666.33 KJ/Kg.**
- **Dryness fraction of steam before entering superheater = 68.96%**
- **Total heat supplied in the superheater = $h_s – h_r$ = 1001.85 KJ/Kg**

- **Problem 12: The steam initially at a pressure of 9bar and dryness 0.98. Find the final quality and temperature of steam at each of the following operations.**
- **A) When steam loses 50 KJ/Kg at constant pressure**
- **B) When steam receives 150 KJ/Kg at constant pressure**

- **Solution:**
- At P = 9bar, T_{sat} = 175.4^{o}C, h_f = 742.6 KJ/kg, h_{fg} = 2029.5 KJ/kg, hg = 2772.1 KJ/kg,
- given x_1 = 0.98

- $h_i = h_f + x_1.h_{fg}$
- $= 742.6 + 0.98 \times 2029.5$
- $= 2731.5$ KJ/Kg
- A) When steam loses 50 KJ/Kg then resulting enthalpy is $= 2731.5 - 50$
  $= 2681.5$ KJ/Kg $< h_g$
- $\therefore h = h_f + x_2.h_{fg}$
- $2681.5 = 742.6 + x_2 . 2029.5$
- $\therefore \mathbf{x_2 = 0.9554}$
- B) When steam receives 150 KJ/Kg, then resulting enthalpy is $= 2731.5 + 150$
  $= 2881.5$ kJ/kg $> h_g$

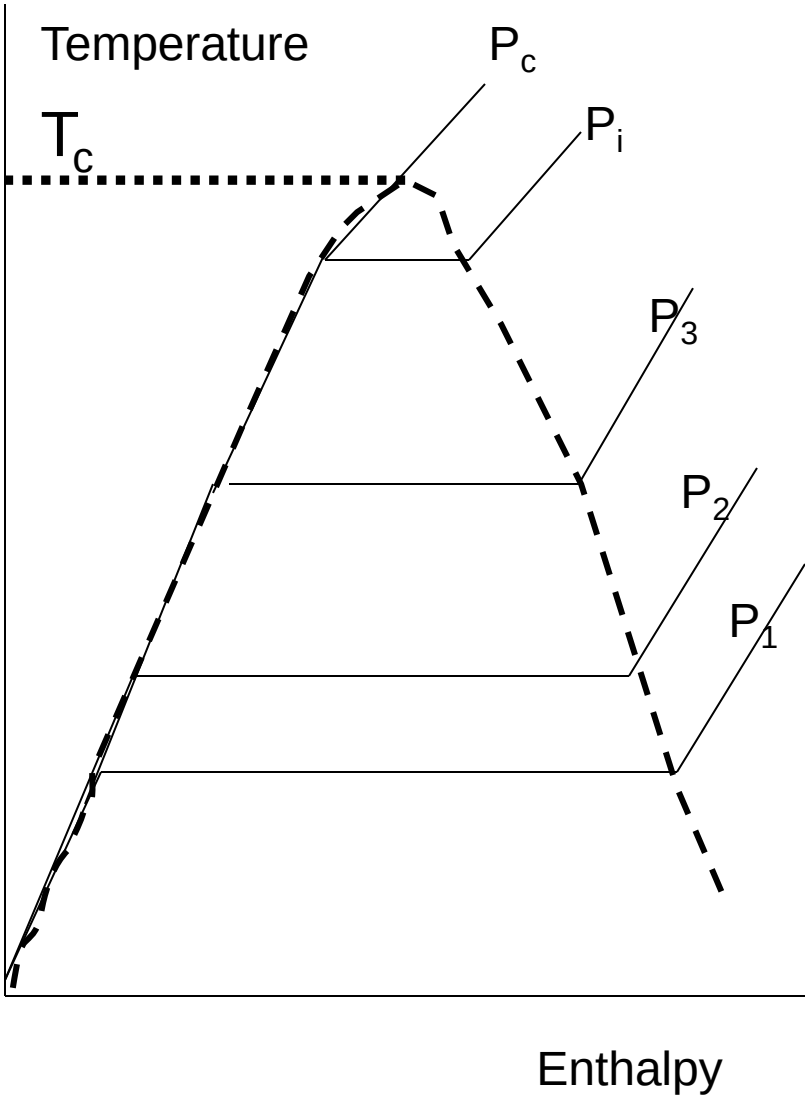
- ∴ **Steam is superheated.**
- **To find $T_{sup.}$,** $h_s = hg + C_{sup} (T_{sup} - T_{sat})$
- $2881.5 = 2772.1 + 2.25 (T_{sup} – 175.4)$
- ∴ $T_{sup} = 223.6^oC$

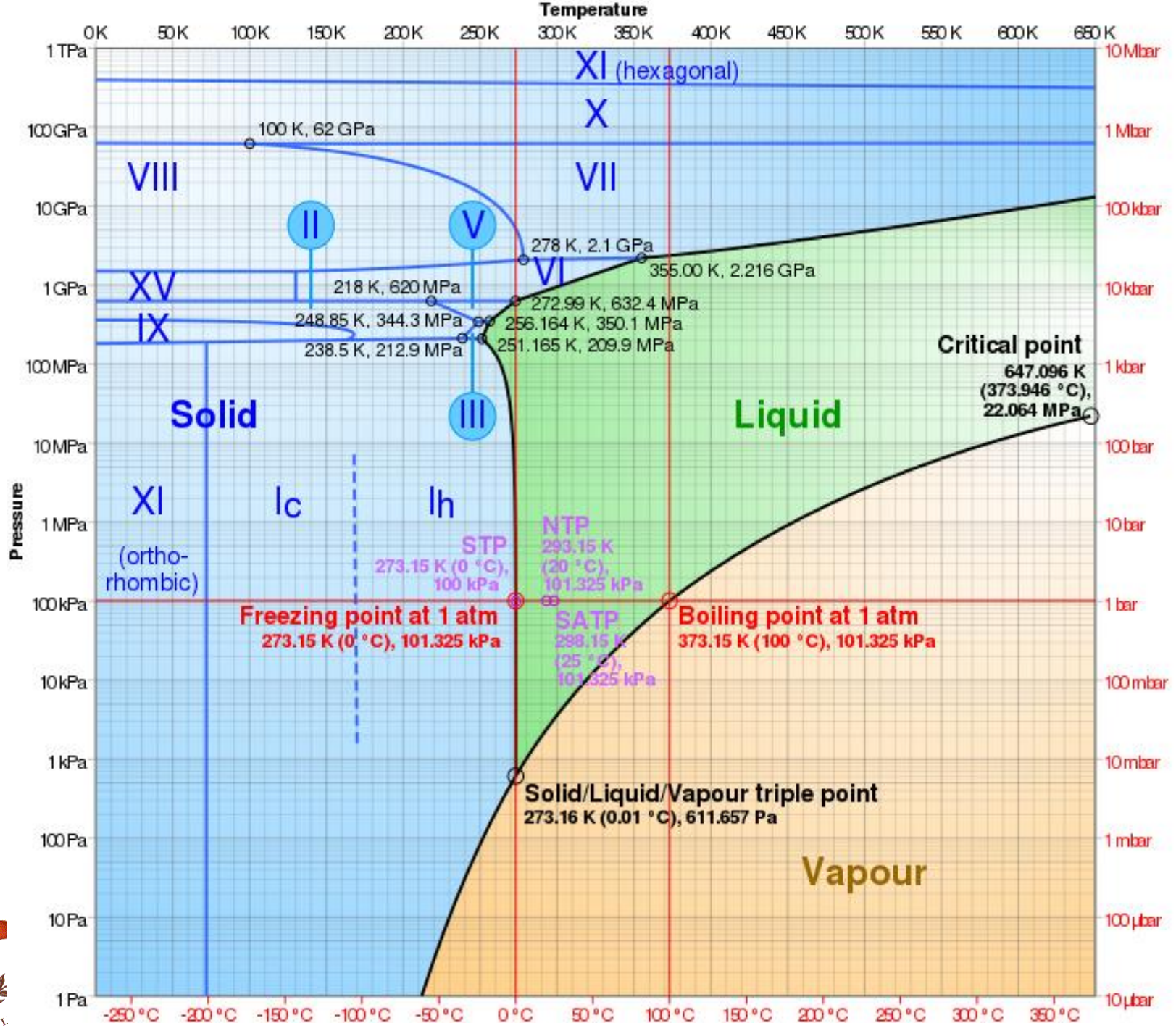
- **Problem 13: The steam initially at a pressure of 9bar and 98% dry expands in a turbine such that it losses 80 KJ/kg at a constant pressure. a) What is the quality of steam after expansion?**
- **B) If it receives 160 KJ/kg heat before expansion, what would be the final state and temperature of the steam?**
- **Solution:**
- **Answer a) x = 94 %**

  b) $T_{sup} = 192.9^{o}$ C

Critical Temperature & Pressure.

- T_c =374.15^{0}c
- P_c = 221.2 bar




Temperature
0K
50K
100K
150K
200K
250K
300K
350K
400K
450K
500K
550K
600K
650K
Pressure
1 TPa
100 GPa
10 GPa
1 GPa
100 MPa
10 MPa
1 MPa
100 kPa
10 kPa
1 kPa
100 Pa
10 Pa
1 Pa
10 Mbar
1 Mbar
100 kbar
10 kbar
1 kbar
100 bar
10 bar
1 bar
100 mbar
10 mbar
1 mbar
100 µbar
10 µbar
XI (hexagonal)
X
VIII
VII
VI
II
V
III
XV
IX
XI
(ortho-
rhombic)
Ic
Ih
Solid
Liquid
Vapour
100 K, 62 GPa
278 K, 2.1 GPa
355.00 K, 2.216 GPa
218 K, 620 MPa
272.99 K, 632.4 MPa
248.85 K, 344.3 MPa
256.164 K, 350.1 MPa
238.5 K, 212.9 MPa
251.165 K, 209.9 MPa
Critical point
647.096 K
(373.946 °C),
22.064 MPa
STP
273.15 K (0 °C),
100 kPa
NTP
293.15 K
(20 °C),
101.325 kPa
SATP
298.15 K
(25 °C),
101.325 kPa
Freezing point at 1 atm
273.15 K (0 °C), 101.325 kPa
Boiling point at 1 atm
373.15 K (100 °C), 101.325 kPa
Solid/Liquid/Vapour triple point
273.16 K (0.01 °C), 611.657 Pa
-250 °C
-200 °C
-150 °C
-100 °C
-50 °C
0 °C
50 °C
100 °C
150 °C
200 °C
250 °C
300 °C
350 °C