NUMERICALS ON PROPERTIES OF STEAM

1) Determine the condition and related parameter of the steam in the following cases: (i) Pressure of 10 bar and temperature of 200ºC and (ii) Pressure of 8 bar and enthalpy of 2500kJ/kg. (iii) Steam at 20bar and 300ºC is cooled at constant pressure during which the heat lost is 400kJ/kg. Assume specific heat of superheated steam as 2.25kJ/Kg K.

Solution:

i) Pressure = 10 bar and T = 200 °C

From steam tables at a pressure of 10 bar,

T_{sat} = 179.9 °C, h_f = 762.6 kJ/kg

h_{fg} = 2013.6 kJ/kg, h_g = 2776.2 kJ/kg

Sincet the temperature of the steam is greater than the saturation temperature the steam sample is superheated.

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

$= 2776.2 + 2.25(200 - 179.9)$

hsup = 2821.43 kJ/kg

Degree of Superheat (DOS)

$$DOS=(Tsup-Tsat)$$

$= 200 – 179.9$

$= 20.1$ºC

ii) Pressure = 8 bar and h = 2500 kJ/kg

From steam tables at a pressure of 8 bar,

T_{sat} = 170.4 °C, h_f = 720.9 kJ/kg

h_{fg} = 2046.5 kJ/kg, h_g = 2767.4 kJ/kg

Since enthalpy of dry saturated steam (hg = 2767.4 kJ/kg) is greater than the enthalpy of steam sample (h = 2500 kJ/kg) the given sample of steam is wet Steam.

Dryness fraction of the steam (X):

$h = h_f + X\ h_{fg}$

$2500 = 720.9 + X * 2046.5$

$X = 0.8693$ or 86.93 %

iii) Pressure = 20 bar, T = 300 °C, Heat loss = 400 kJ/kg

From steam tables at a pressure of 20 bar,

$T_{sat} = 212.4$ °C $h_f = 908.5$ kJ/kg

$h_{fg} = 1888.7$ kJ/kg $h_g = 2797.2$ kJ/kg

Sincet the temperature of the steam is greater than the saturation temperature the steam sample is superheated.

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

$= 2797.2 + 2.25(300 – 212.4)$

$h_{sup} = 2994.3$ kJ/kg

Enthalpy after heat loss of 400 kJ/kg = 2994.3 – 400

= 2594.3 kJ/kg

Since the enthalpy after heat loss (2594.3 kJ/kg) is less than the enthalpy of dry saturated steam (hg = 2797.2 kJ/kg), the steam is Wet.

Dryness fraction of the steam (X):

$h = h_f + X * h_{fg}$

$2594.3 = 908.5 + X \times 1888.7$

$X = 0.8926$ or 89.26%

2) 2 Kg of water at 30ºC is heated at a constant pressure of 5 bar. The total amount of heat added is 500 KJ. Determine the condition and related parameter of water after heat addition. Assume specific heat of water as 4.187kJ/Kg K.

At P= 5 bar T_{sat} = 151.9^{O}C, h_f = 640.1 KJ/Kg,

h_{fg} = 2107.4 KJ/Kg, h_g = 2747.5 KJ/Kg.

Solving on a per kg basis

Enthalpy of water at 30ºC

$$h = mCp(T - 0)$$

= 1 x 4.187 x (30-0)

= 125.61 kJ/Kg

Heat added on per kg basis

=500/2

= 250kJ/kg

Enthalpy after heat addition

= 125.61+250

= 375.61 kJ/kg < h_f

Since enthalpy after heat addition is less than sensible heat the resulting condition after heat addition is unsaturated water**.**

Temperature of unsaturated water after heat addition

$$h = mCp(T - 0)$$

375.61= 1 x 4.187 x (T-0)

T= 89.71ºC

OR

Considering the actual mass of water

Enthalpy of water at 30ºC

$$h = mCp(T - 0)$$

= 2 x 4.187 x (30-0)

= 251.22 kJ/2Kg

Enthalpy after heat addition

= 251.22 + 500

= 751.22 kJ/2kg

∴Sensible heat for 2 Kg = h_f x 2

= 640.1 x 2 = 1280.2 KJ

Since enthalpy after heat addition is less than sensible heat the resulting condition after heat addition is unsaturated water.

Temperature of unsaturated water after heat addition

$$h = mCp(T-0)$$

751.22= 2 x 4.187 x (T-0)

T= 89.71ºC

3) 10 Kg. of steam at a pressure of 1.15 MPa and temperature of 250°C loses 27578.2 kJ of heat at constant pressure. Determine the resulting temperature? Assume specific heat of water and superheated steam as 4.187 kJ/kg K and 2.25 kJ/kg K respectively.

P=1.15 MPa= 11.5bar,

T_{sat}= 186°C, h_f=789.9KJ/kg, h_{fg} = 1991.4kJ/kg, h_g=2781.3 kJ/kg.

Solving on a per kg basis

Enthalpy at 250°C

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

= 2781.3 +2.25(250 – 186)

= 2925.3KJ/kg

Enthalpy after heat loss. = 2925.3 – 27578.2/10

=167.48 kJ/kg < h_f

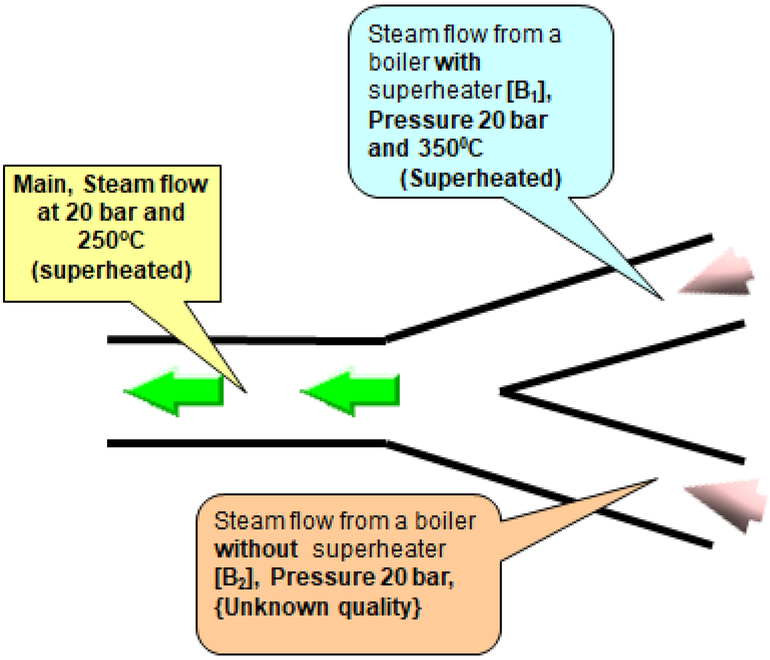
Resulting Temperature

$$hw = mCp(T - 0)$$

167.48= 1x4.187x (T-0)

T = 40°C

4) Two boilers one with super heater and another without super heater are delivering equal quantities of steam into a common main. The pressure in the boiler and in the main is 20 bar. The temperature of the steam from a boiler with a superheater is 350ºC and the temperature of steam in the main is 250ºC. Determine the quality of steam supplied by the other boiler. Assume specific heat of superheated steam as 2.25kJ/Kg K.



P= 20bar.

At 20 bar.

T_{sat} = 212.4ºC, h_f = 908.5 kJ/kg, h_{fg} = 1888.7 kJ/kg & h_g = 2797.2 kJ/kg

Enthalpy of steam generated in the boiler (B_1) having super heater

$T=350^{o}C > T_{sat}$, steam is superheated.

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

$= 2797.2 + 2.25 (350 - 212.4)$

$= 3106.8 kJ/kg$ --------(A)

Enthalpy of steam in the main

$T=250^{o}C > T_{sat}$, steam is superheated

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

$= 2797.2 + 2.25 (250 - 212.4)$

$= 2881.8 kJ/kg$

Total enthalpy in the main for 2kg of steam

$= 2x\ 2881.8$

$= 5763.6 kJ/2kg$ --------(B)

Enthalpy of steam generated in the boiler (B_2) without the super heater

$h = h_f + X. \ h_{fg}$

$= 908.5 + X^* 1888.7 kJ/kg$ -------(C)

For heat balance

(A) + (C) = (B)

$3106.8 + 908.5 + X^* 1888.7 = 5763.6$

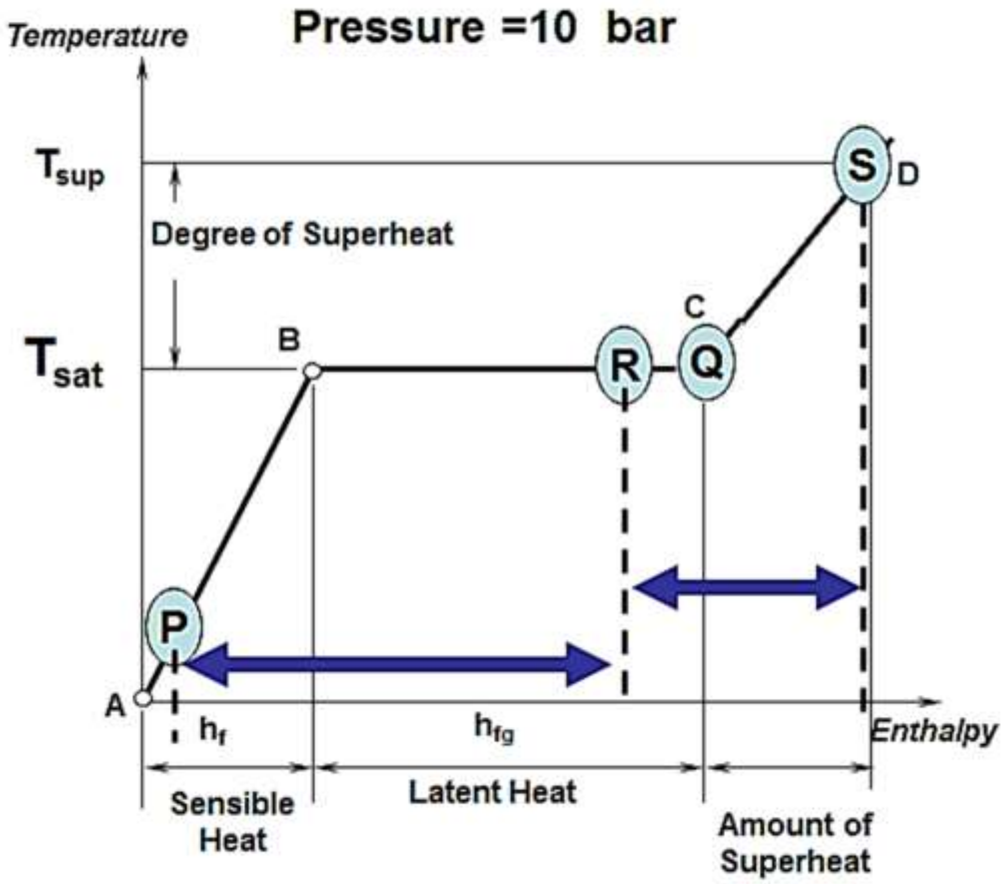
X= 0.9257 or 92.57%. Steam generated in the boiler without the super heater is 92.57% dry.

5) A dry saturated steam at a pressure of 1 MPa is generated in a boiler. Dry saturated steam leaves the boiler to enter a super heater, where it loses heat equal to 400 kJ/kg. In the super heater, steam is super-heated to temperature of 300ºC. If temperature of feed water is 28ºC, determine:

a) Total heat supplied to feed water in the boiler

b) Dryness fraction of steam at the entry of super heater

c)Total heat supplied in the super heater.
Assume specific heat of water as 4.187kJ/Kg K and that of superheated steam as 2.25kJ/Kg K



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Data: Pressure = 1 MPa = 10 bar, T_{sup} = 300 °C, T = 28 °C

Heat loss before entering superheater = 400 kJ/kg

Let

P – Point at which water enters the boiler

Q – Point at which steam leaves the boiler in dry saturated condition.

R – Point at which steam enters the superheater as wet steam

S – Point at which superheated steam leaves the superheater.

At 10 bar,
T_{sat} = 179.9 °C, h_f = 762.6 kJ/kg, h_{fg} = 2013.6 kJ/kg h_g = 2776.2 kJ/kg

Enthalpy of water at 28ºC or enthalpy at P

$$h_P = mCp(T-0)$$

= 1 x 4.187 x (28-0)

= 117.24 kJ/Kg

Enthalpy at Q = h_Q = hg = 2776.2 kJ/kg

Enthalpy of steam at the entry point of superheater (R),

$h_R = h_Q - 400$

$= 2776.2 - 400$

$= 2376.2$ kJ/kg

Enthalpy of superheated steam (S),

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

$= 2776.2 + 2.25 (300 - 179.9)$

$= 3046.43$ kJ/kg

a) Total heat supplied to feed water in the boiler

$= h_Q - h_P$

$= 2776.2 - 117.24$

$= 2658.96$ kJ/kg

b) Dryness fraction of steam at the entry to the superheater (X)

$h = h_R =$ hf + X hfg

$2376.2 = 762.6 + X \times 2013.6$

X = 0.8014 or 80.14%

c) Total heat supplied in the superheater

$= h_S - h_R$

$= 3046.43 - 2376.2$

$= 670.23$ kJ/kg

6) 600 kg of 10% wet steam at a pressure of 16bar is generated in a boiler per hour. Steam leaves the boiler to enter a super heater. Steam loses heat equal to 300 kJ/kg before entering the super heater. In the super heater, steam is superheated to temperature of 375^0 C. If temperature of feed water is 40^0 C, determine

- **i) Total heat supplied to feed water per hour to produce wet steam in the boiler.**
- **ii) Total heat absorbed per hour in the super heater.**

Assume specific heat of water as 4.187kJ/Kg K and that of superheated steam as 2.25kJ/Kg K

P= 16bar.

From tables properties of steam at 16 bar.

T_{sat} = 201.4˚C, h_f = 858.5 kJ/kg, h_{fg} = 1933.2kJ/kg & h_g = 2791.7 kJ/kg

Solving on a per kg basis

Enthalpy of water at 40ºC

$$hw = mCp(T - 0)$$

$$= 1 \times 4.187 \times (40-0)$$

$$= 167.48 \text{ kJ/Kg}$$

Enthalpy of wet steam generated in the boiler

X= (1-0.1) = 0.9)

$h = h_f + X.\ h_{fg}$

h = 858.5 + 0.9 x 1933.2

h= 2598.38kJ/Kg

Enthalpy of the steam at the entry point of Super heater

h= 2598.38 – 300

h= 2298.38kJ/Kg

Enthalpy of the steam at the exit point of superheater

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

$$= 2791.7 + 2.25\,(375 - 201.4)$$

$$= 3182.3 \text{ kJ/Kg}$$

Total heat supplied to feed water per hour to produce 10% wet steam in the boiler.

= (2598.38-167.48) x 600

=1458540kJ

= 1458.54 MJ

Total heat absorbed per hour in the super heater.

=(3182.3-2298.38) x 600

=530352J

= 530.352MJ

7) A chemical company planning to install a coal fired boiler in its plant for process heating is weighing different technical options due to investment constraints. The steam generation capacity required is 5000kg per hour at a pressure of 0.56MPa and at a temperature of 220ºC. The feed water is available from a nearby reservoir at an average temperature 30ºC. The coal consumption is 1500 kg/hr, having a calorific value of 24MJ/kg. Assess the improvement in boiler efficiency if the following accessories are used.

i) Economizer which will increase the feed water temperature by 58ºC.and reduce the coal consumption by 14%.

ii) Air Preheater which will reduce the coal consumption by 20%.

iii) Both Economizer and Air Preheater whose combined effect will reduce the coal consumption by 30%.

Assume specific heat of water and superheated steam as 4.187kJ/kg K and 2.25kJ/kg k respectively.

T= 30ºC, T_{sup} = 220ºC, Q= 5000kg/hr, GCV= 24MJ/kg= 24000kJ/kg, m_{fu} = 1500 kg/hr

From Steam tables properties of steam at 0.56MPa or 5.6bar.

T_{sat} = 156.2ºC, h_f = 658.8 kJ/kg, h_{fg} = 2093.7 kJ/kg & hg = 2752.5 kJ/kg

Enthalpy of water at 30ºC

$$hw = mCp(T-0)$$

= 1 x 4.187 x (30-0)

= 125.61 kJ/kg.

Enthalpy at a temperature of 220ºC

$hsup = hg + Csup(Tsup - Tsat)$

= 2752.5 + 2.25x (220-156.2)

= 2896.05kJ/Kg

Boiler Efficiency without using the accessories

$$\eta = \frac{Q(h_s - h_w) * 100}{m_{fu} * GCV}$$

$$\eta = \frac{5000(2896.05 - 125.61) * 100}{1500 \quad * 24000}$$

η = 38.48%

i) Boiler Efficiency if Economizer is used.

T= 30+58 = 88ºC, m_{fu} = 1500 – 0.14x 1500 = 1290kg/hr

Enthalpy of water at 88ºC

$hw = mCp(T - 0)$

= 1 x 4.187 x (88-0)

= 368.46 kJ/kg.

$$\eta = \frac{5000(2896.05 - 368.46) * 100}{1290 \quad * 24000}$$

η = 40.52%

Improvement if efficiency= 40.52 – 38.48 = 2.05% in absolute terms.

OR

$$\frac{2.05}{38.48}x100 = 5.32\%$$ in percentage terms.

ii) Boiler Efficiency if Air Preheater is used.

m_f = 1500 – 0.2x 1500 = 1200 kg/hr

$$\eta = \frac{5000(2896.05 - 125.61) * 100}{1200 \quad * 24000}$$

η = 48.09%

Improvement if efficiency= 48.09 – 38.48 = 9.61% in absolute terms.

OR

$$\frac{9.61}{38.48}x100 = 24.97\%$$ in percentage terms.

iii) **Boiler Efficiency if both Economizer and Air Preheater are used.**

T= 30+58 = 88ºC, m_f = 1500 – 0. 3x 1500 = 1050kg/hr

Enthalpy of water at 88ºC

$$hw = mCp(T - 0)$$

= 1 x 4.187 x (88-0)

= 368.46 kJ/kg.

$$\eta = \frac{5000(2896.05 - 368.46) * 100}{1050 \quad * 24000}$$

η = 50.15%

Improvement if efficiency= 50.15 – 38.48 = 11.67% in absolute terms.

OR $$\frac{11.67}{38.48}x100 = 30.33\%$$ in percentage terms.

8) A restaurant, daily uses 600 kg of 95% dry steam produced at a pressure of 3bar. The boiler is fitted with an economizer which increases the feed water temperature to 94º C and is fired using wood and paddy husk in equal proportions. The gross calorific values of wood and paddy husk are15500kJ/kg and 12600 kJ/kg respectively. The boiler has been operating with an average efficiency of 78%. Calculate the daily consumption of wood and paddy husk?

P = 3bar, T= 94ºC, X = 0.95, Q= 600kg/day,

GCV(wood) = 15500kJ/kg, GCV(husk) = 12600kJ/kg , η = 78%, m_{fu} = ?

From Steam tables at P= 3bar.

T_{sat} = 133.5ºC, h_f = 561.5 kJ/kg, h_{fg} = 2163.2 kJ/kg & hg = 2724.7 kJ/kg

Enthalpy of water at 94ºC

$$hw = mCp(T-0)$$

= 1 x 4.187 x (94-0)

= 393.58kJ/kg

Enthalpy at X= 0.95

h = h_f + X h_{fg}

= 561.5 + 0.95 * 2163.2

= 2616.54 kJ/kg

$$\eta = \frac{Q(h_s - h_w) * 100}{m_{fu} * GCV}$$

$$78 = \frac{600(2616.54 - 393.58) * 100}{0.5 * m_{fu} * 15500 + 0.5 * m_{fu} * 12600}$$

m_{fu} = 121.71kg/day

Quantity of wood and paddy husk consumed= 0.5* 121.71

= 60.86kg each/day