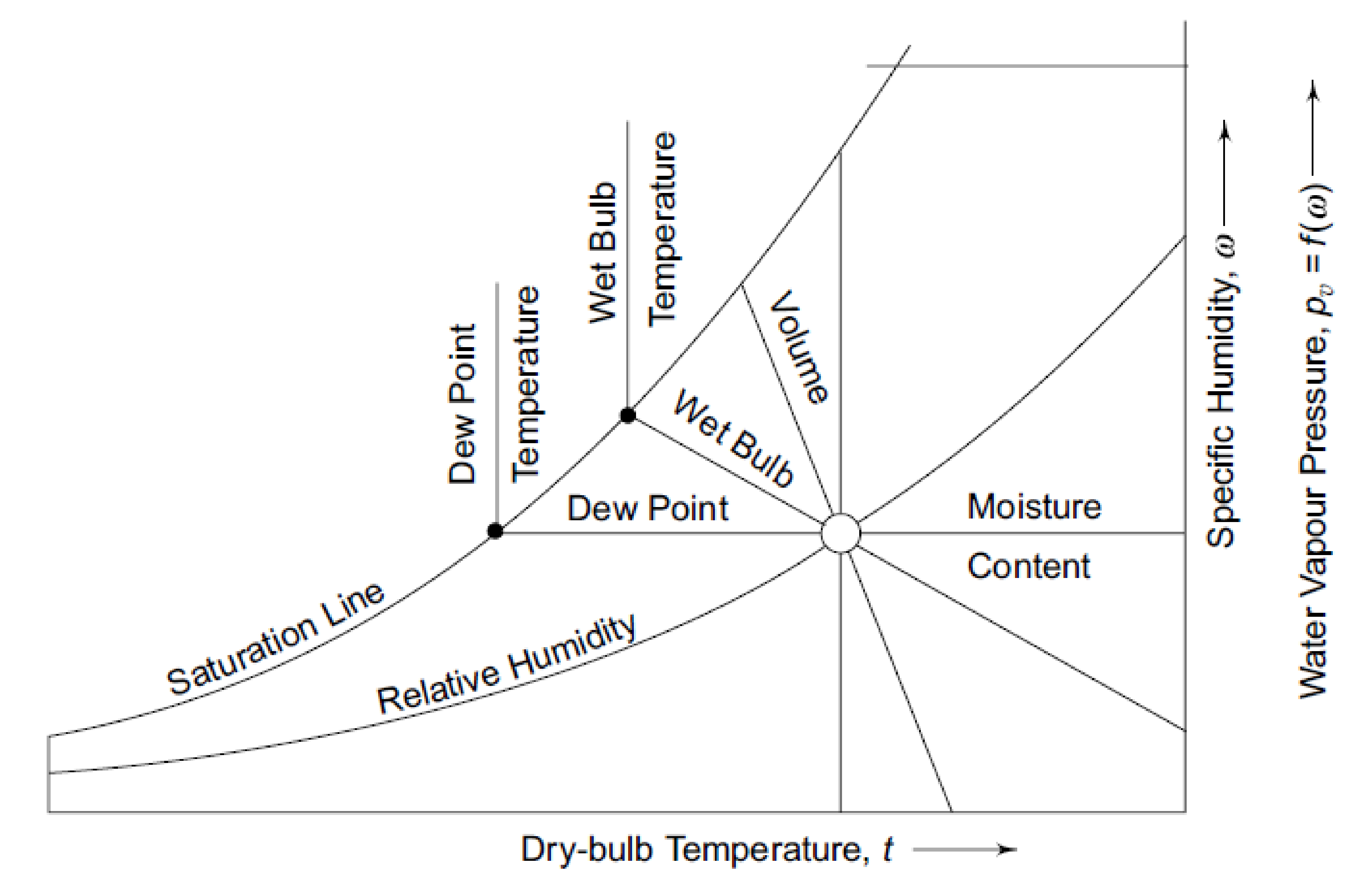
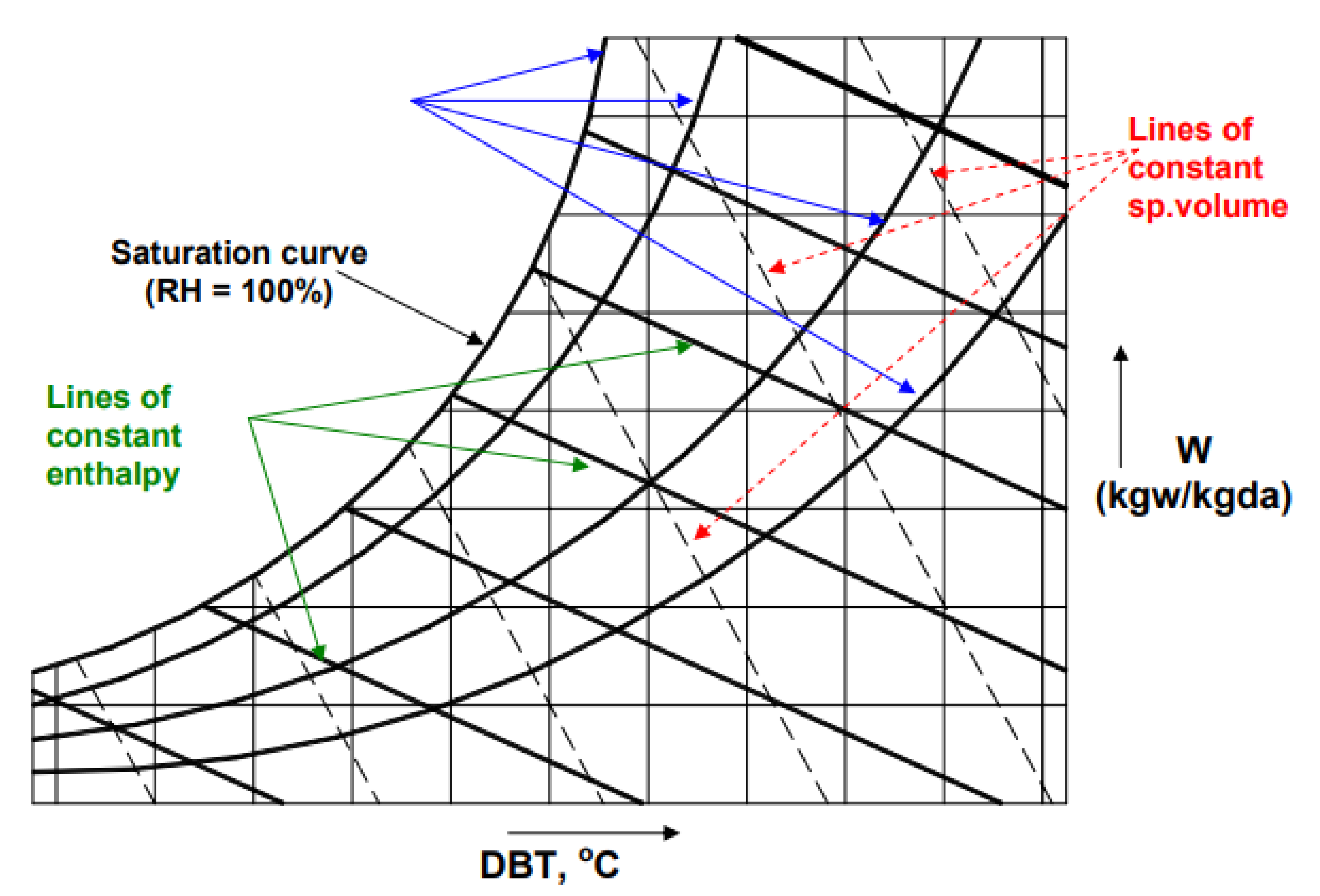
Psychrometric Processes and Air Conditioning

Psychrometric Chart



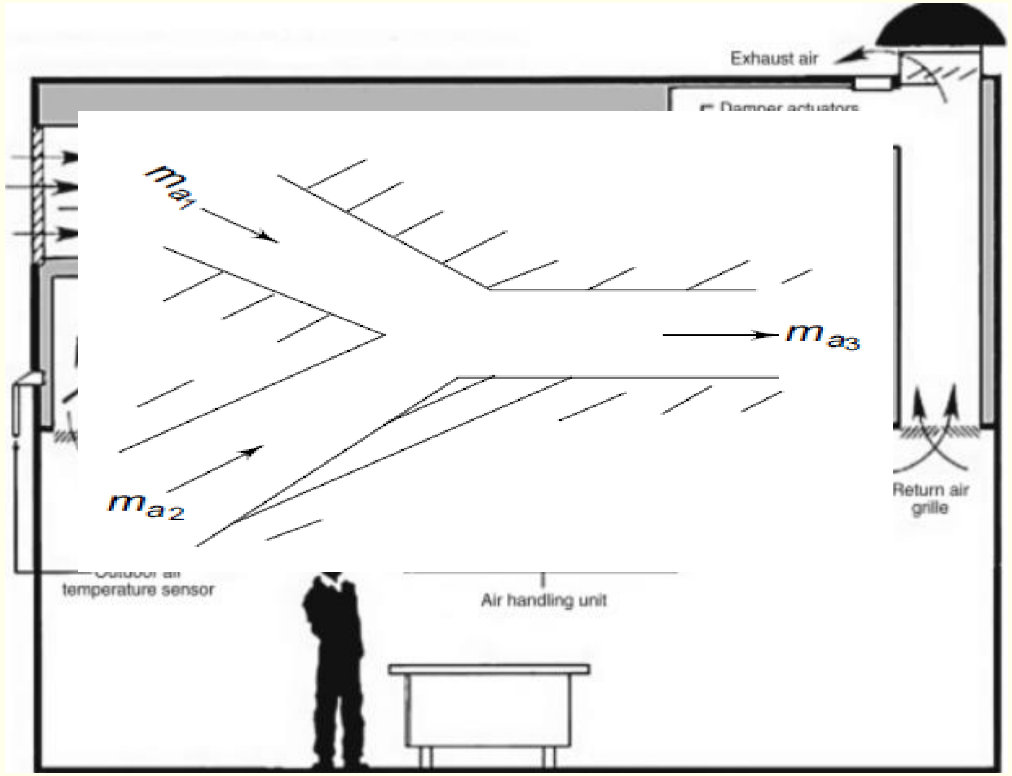
Psychrometry chart



Psychrometry of Air-Conditioning Processes - Mixing process

- State point of mixture lie on the straight line joining the two states.

- Position of mixture state divides the straight line at inverse ratio of masses m_{a_1} & m_{a_2} of dry two streams.



Mixing process

- Let us Adiabatic mixing of air at 2 different states at const pressure, by moisture balance

$$m_{a_3}\omega_3 = m_{a_1}\omega_1 + m_{a_2}\omega_2$$

$$\omega_3 = \frac{m_a\omega_1 + m_{a_2}\omega_2}{m_{a_3}}$$

Where m_a mass of dry air

- By dry air mass balance

$$m_{a_3} = m_{a_1} + m_{a_2}$$

- By energy balance, enthalpy of mixture

$$h_3 = \frac{m_{a_1}h_1 + m_{a_2}h_2}{m_{a_3}}$$

$$\Rightarrow \left(C_p t_3 + h_{fg}\omega_3\right) = \frac{m_{a_1}}{m_{a_3}}\left(C_p t_1 + h_{fg}\omega_1\right) + \frac{m_{a_2}}{m_{a_3}}\left(C_p t_2 + h_{fg}\ \omega_2\right)$$

Mixing process

- The temperature of mixture

$$t_3 = \frac{m_{a_1} t_1 + m_{a_2} t_2}{m_{a_3}} + \frac{h_{fg_0}}{C_P}\left[\frac{m_{a_1}}{m_{a_3}}\omega_1 + \frac{m_{a_2}}{m_{a_3}}\omega_2 - \omega_3\right]$$

- The second term negligible, hence

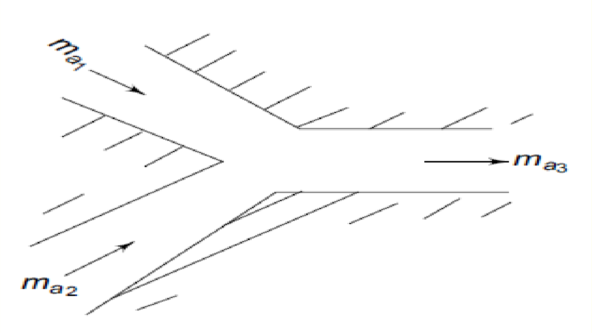
$$t_3 \approx \frac{m_{a_1} t_1 + m_{a_2} t_2}{m_{a_3}}$$

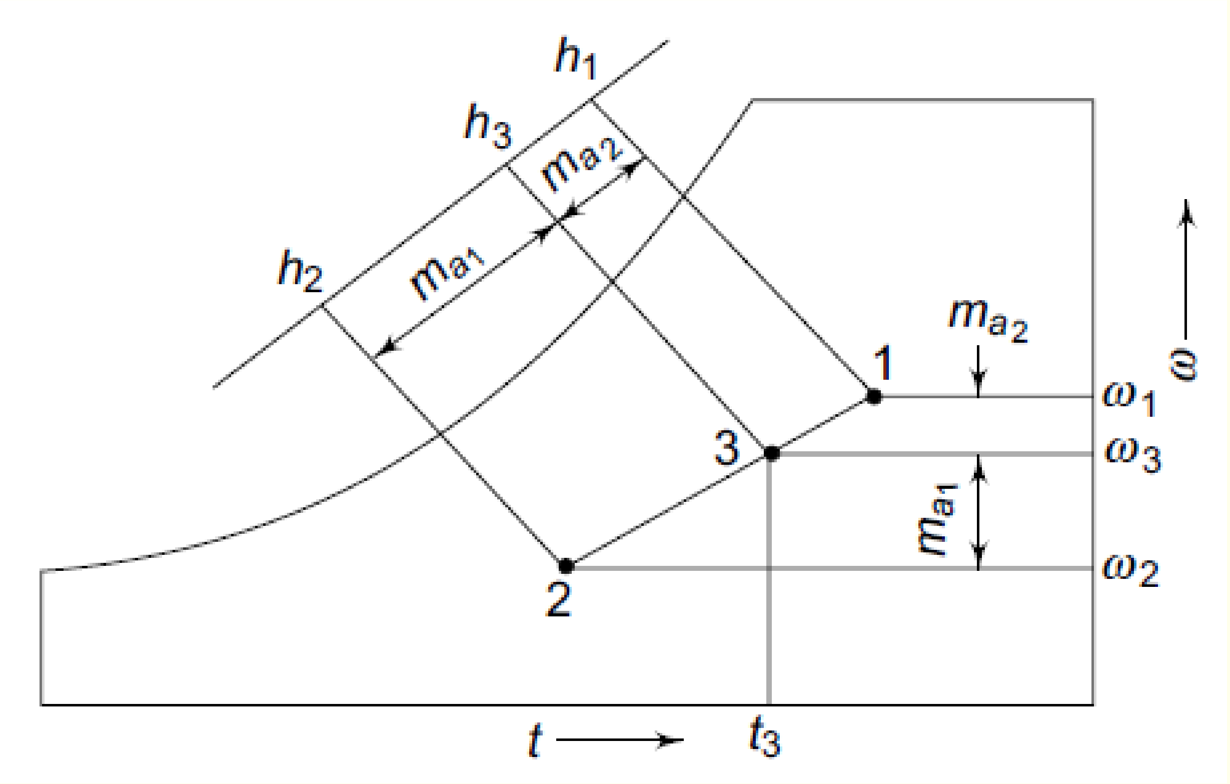
- The approximation sign used since specific heat same for all three streams.

Mixing process

- State point of mixture lie on the straight line joining the two states.

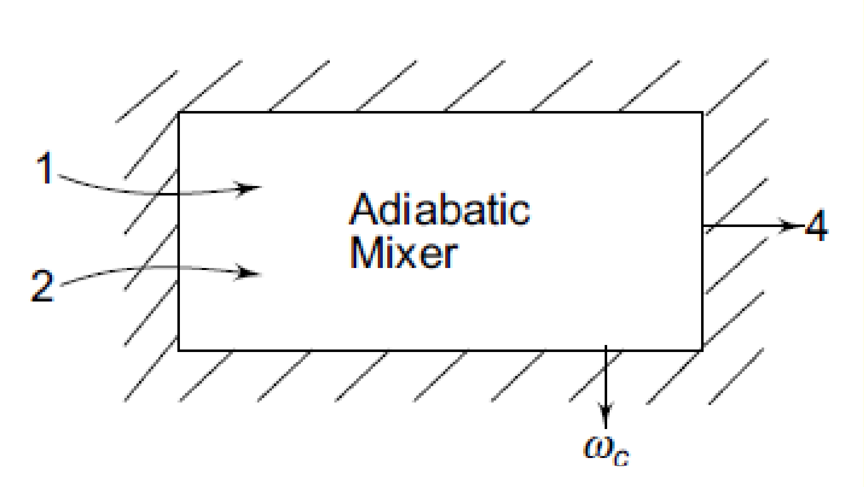
- Position of mixture state divides the straight line at inverse ratio of masses m_{a_1} & m_{a_2} of dry two streams.

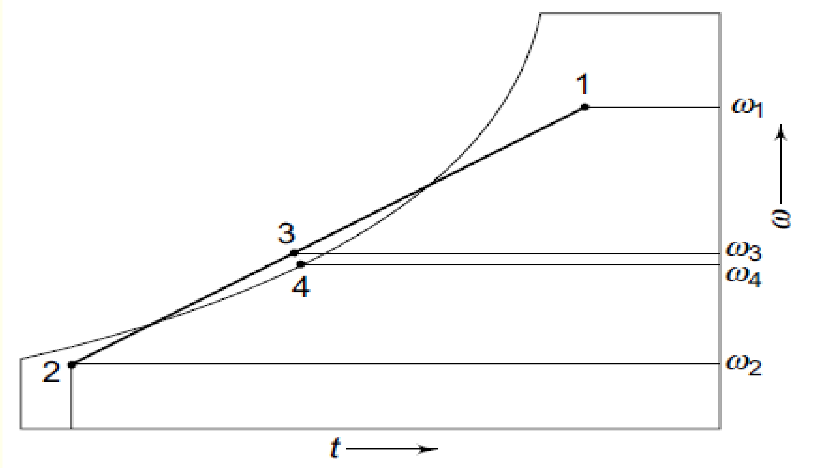




Mixing with Condensation

- When cold air mixes with warm air at high humidity, possibility of water vapour condensation.
- This mixture will have saturate air and condensate.
- Condensate can freeze when DBT of mixture fall below 0 $°C$.
- Due to condensation, the sp humidity (w) of the mixture w_3 gets reduced to w_4 .
- Also, the temperature of the air increases from t_3 to t_4 due to release of latent heat of condensate.





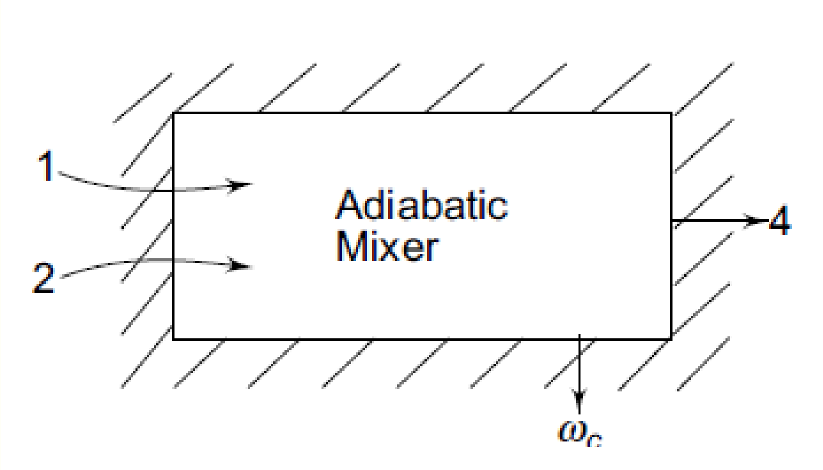
Mixing with Condensation

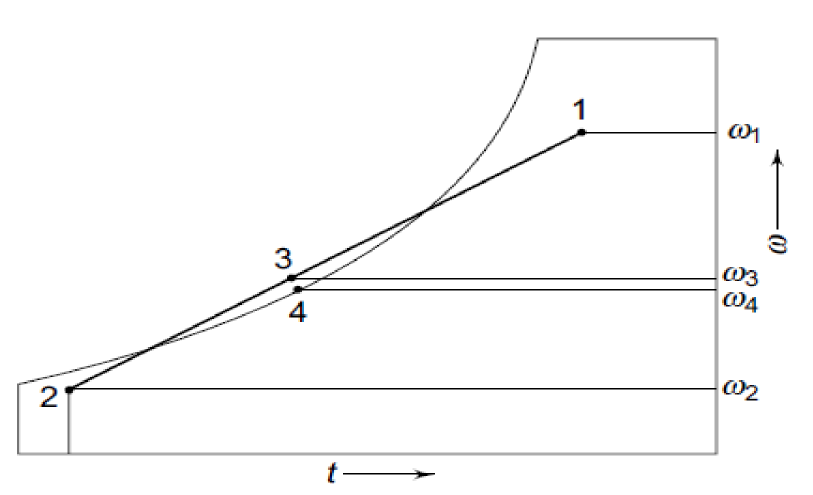
- Mass of condensate per unit mass of mixture ω_c, from moisture and energy balance

$$\omega_c = \omega_3 - \omega_4$$

$$\Rightarrow \omega_4 = \frac{m_{a_1}\omega_1 + m_{a_2}\omega_2}{m_{a_1} + m_{a_2}} - \omega_c$$

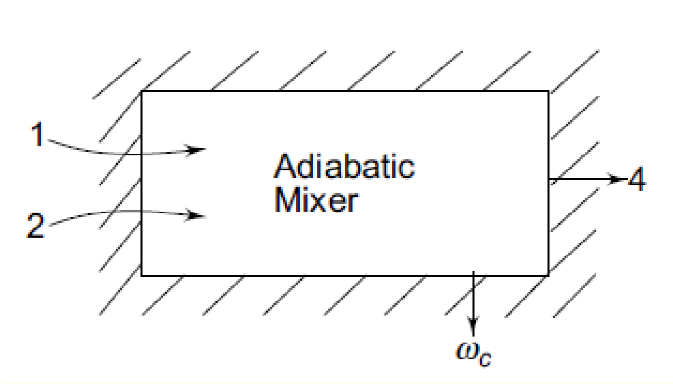
$$m_{a_4}h_4 + m_{a_4}\omega_c\, h_{f_4} = m_{a_4}h_3$$





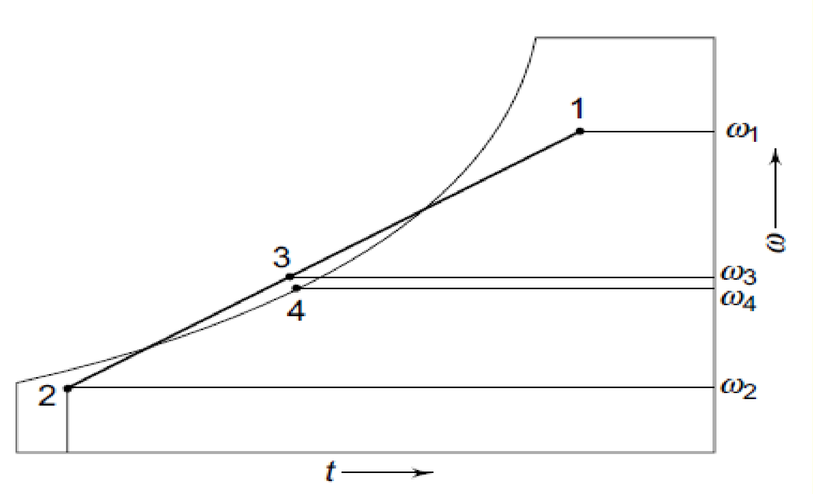
Mixing with Condensation

$$h_4 = \frac{m_{a_1} h_1 + m_{a_2} h_2}{m_{a_1} + m_{a_2}} - \omega_c h_{f_4}$$



- Where h_{f_4} → enthalpy of condensate at temperature t_4 of mixture.

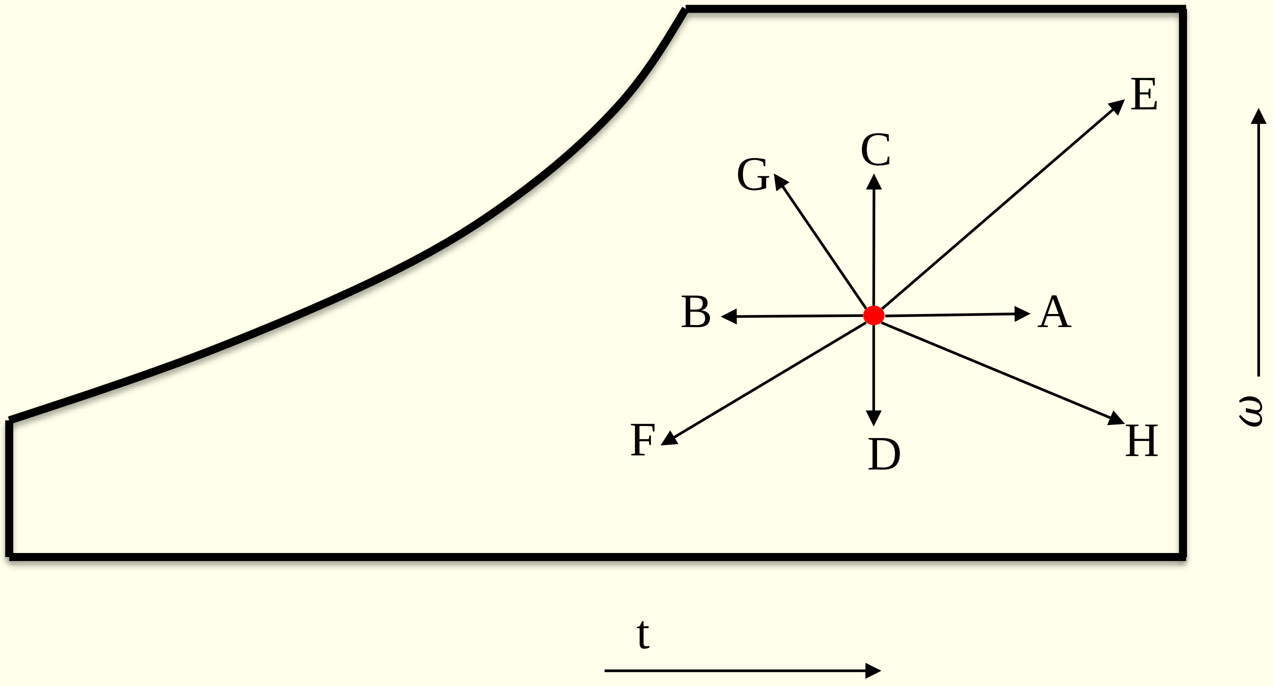
- Fog or frost formation due to mixing of cold air near earths surface with humid air developed towards evening of after rain.



Air-Conditioning Processes

Basic processes in conditioning of air

- Sensible heating – process OA
- Sensible cooling – process OB
- Humidifying – process OC
- Dehumidifying – process OD
- Heating and humidifying – process OE
- Cooling and dehumidifying – process OF
- Cooling and humidifying – process OG
- Heating and dehumidifying – process OH.



Sensible Heat Process-Heating or Cooling

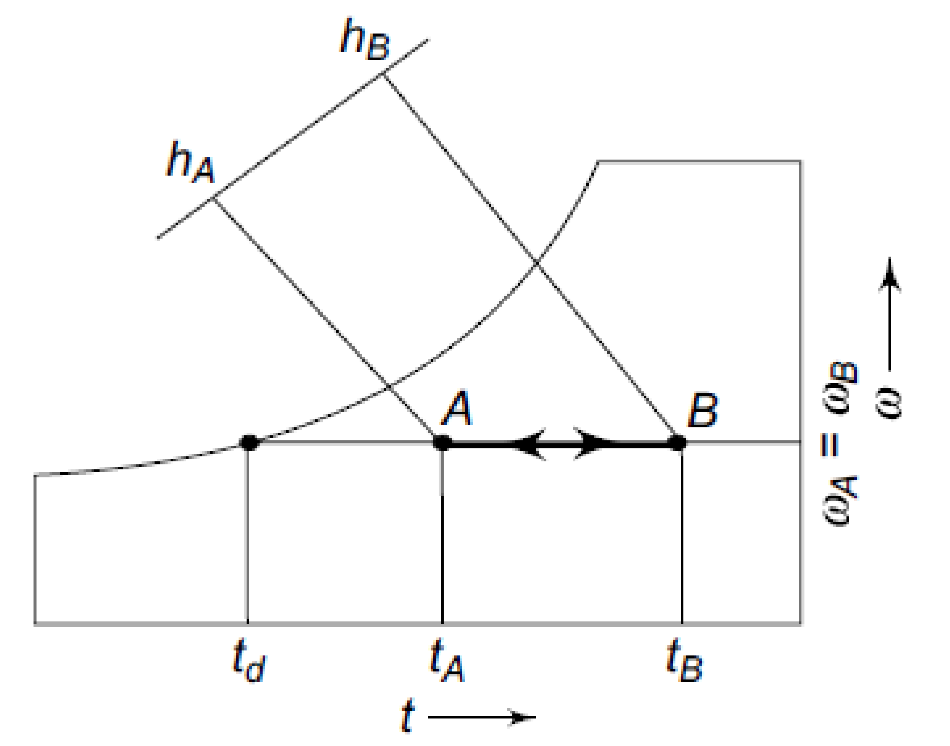
- The heat transferred to change temperature of air

$$Q_s = m_a(h_B - h_A) = m_a C_p(t_B - t_A)$$

$$= m_a C_{p_a}(t_B - t_A) + m_a \omega C_{p_v}(t_B - t_A)$$

$$= m_a(1.005 + 1.88\omega)(t_B - t_A)$$

- Where C_p is humid specific heat.



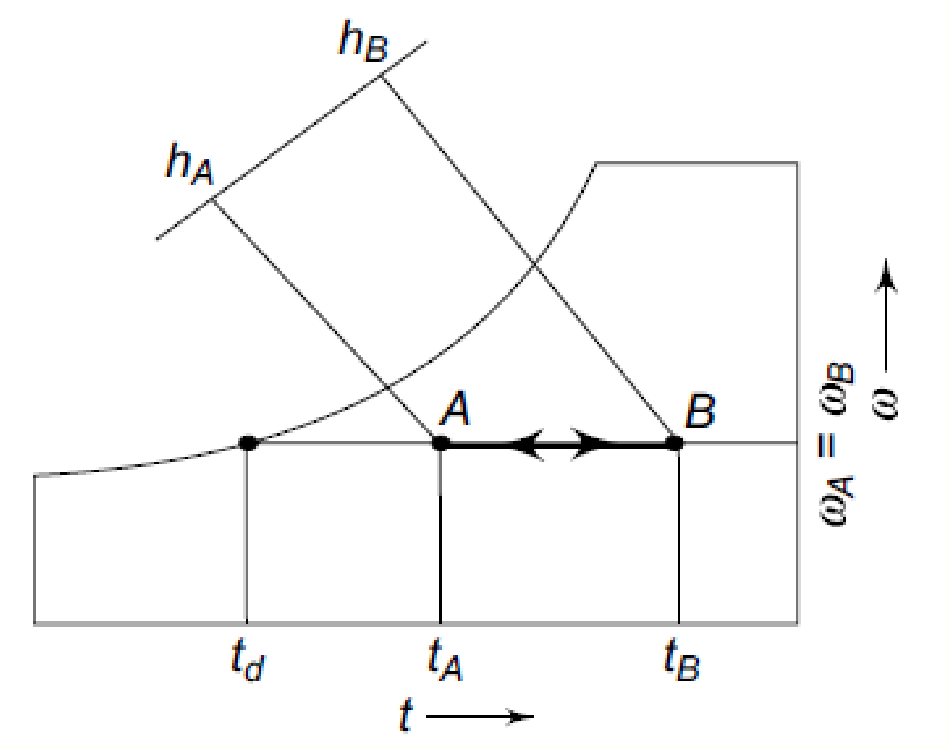
Sensible Heat Process-Heating or Cooling

Mass flow rate of air in cubic meters of air per minute

$$\dot{m}_a = \dot{Q}_v \rho$$

$$\dot{m}_a = \frac{(cmm)\rho}{60} \quad \frac{kg\ d.a.}{s}$$

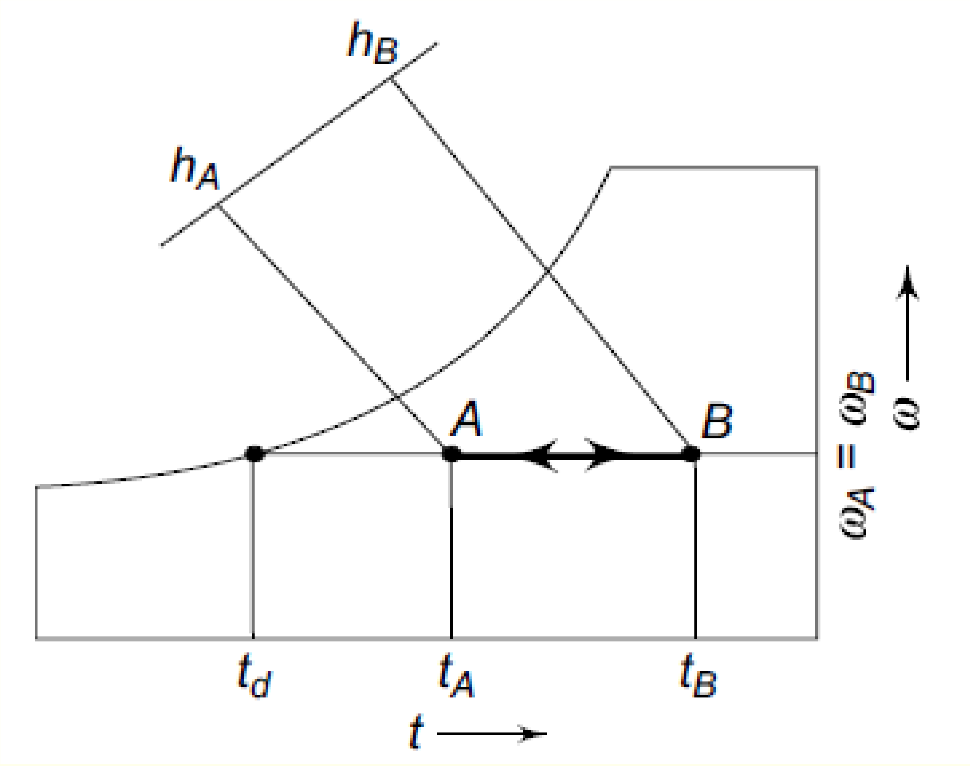
$$\dot{Q}_s = \frac{(cmm)(1.2)(1.0216)}{60}\Delta t = 0.0204\ (cmm)\Delta t, kW$$



- (for standard air at RH=50% and 20 C; density =1.2, humid sp heat =1.02)

Sensible Heat Process-Heating or Cooling

- Simple heating of moist air can be done to any desired temperature.
- Simple cooling can be done up to dew point temperature i.e., t_d
- Cooling below t_d will result in condensation of moisture.



Latent Heat Process-Humidification or Dehumidification

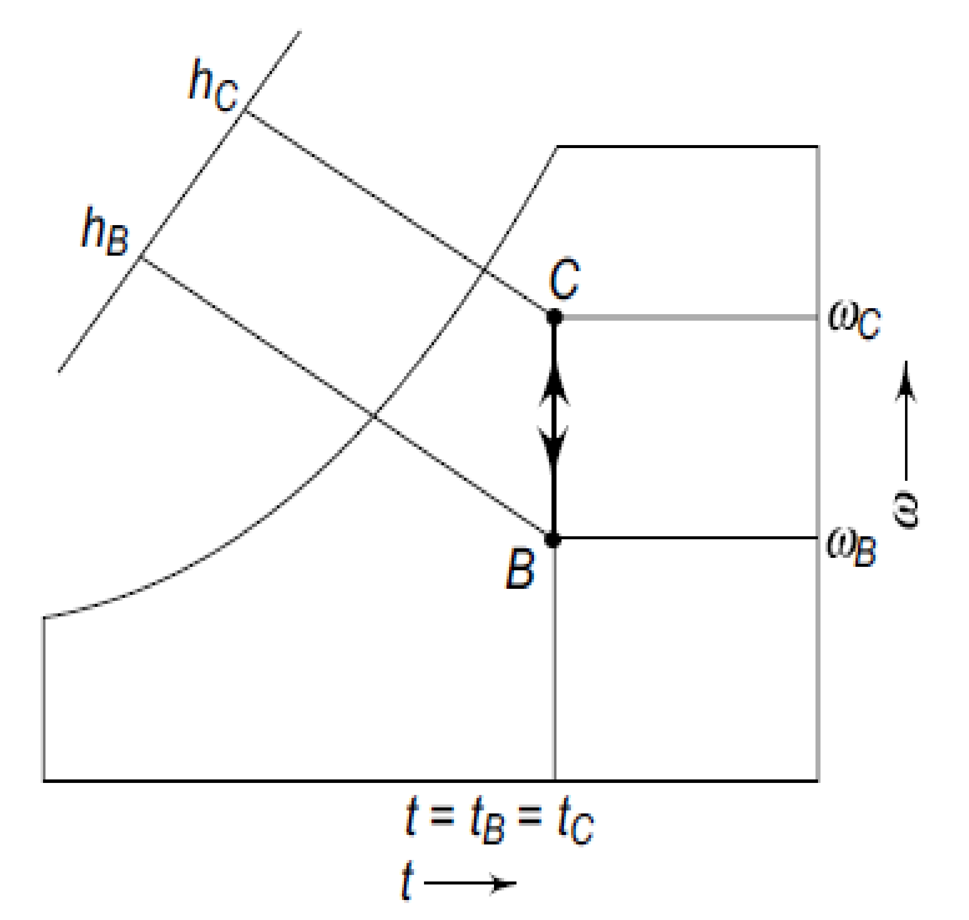
- The state of air altered along BC, The moisture transfer G

$$G = m_a(\omega_C - \omega_B)$$

- The change in enthalpy due to change in humidity ratio
- $(h_C - h_B)$

- The latent heat transfer Q_L

$$Q_L = m_a(h_C - h_B) = m_a[(C_p t_C + h_{fg_0}\omega_C) - (C_p t_B +$$



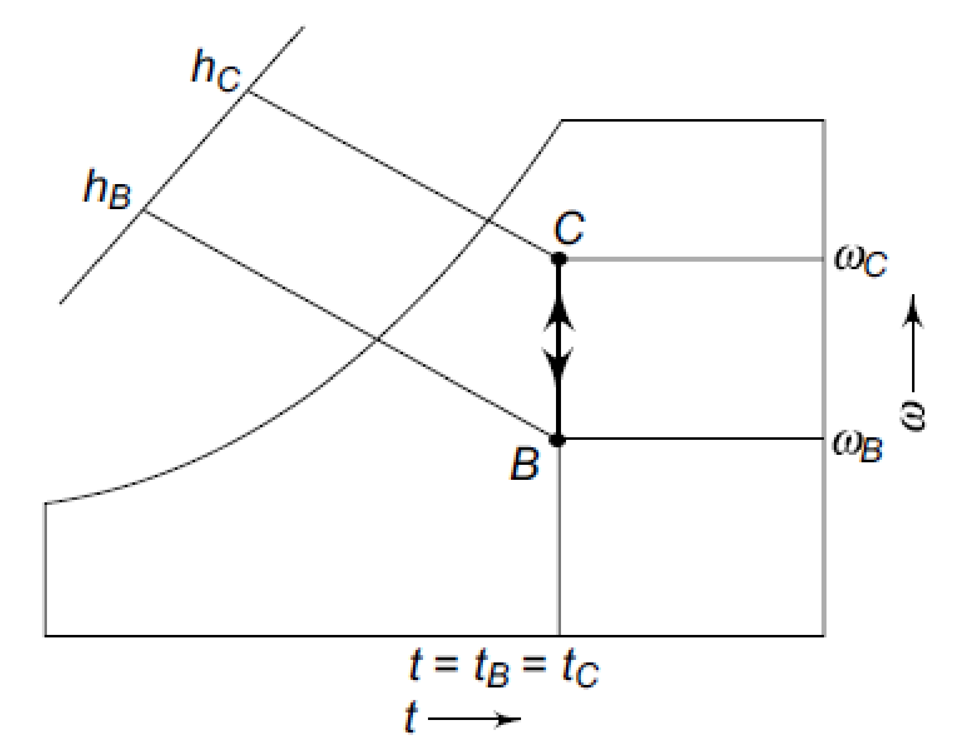
Latent Heat Process-Humidification or Dehumidification

$$Gh_{fg_0} = 2500G$$

- C_p is same for states B & C. Thus $Q_L \propto h_{fg_o}$

- Therefore if water evaporated or condensed at temperature of air, required heat transfer would be Q_L

- $\dot{Q}_L = \frac{(cmm)(1.2)(2501)}{60}\Delta\omega = 50(cmm)\Delta\omega, kW$



Total Heat Process

- Sensible heat load due to change in temperature

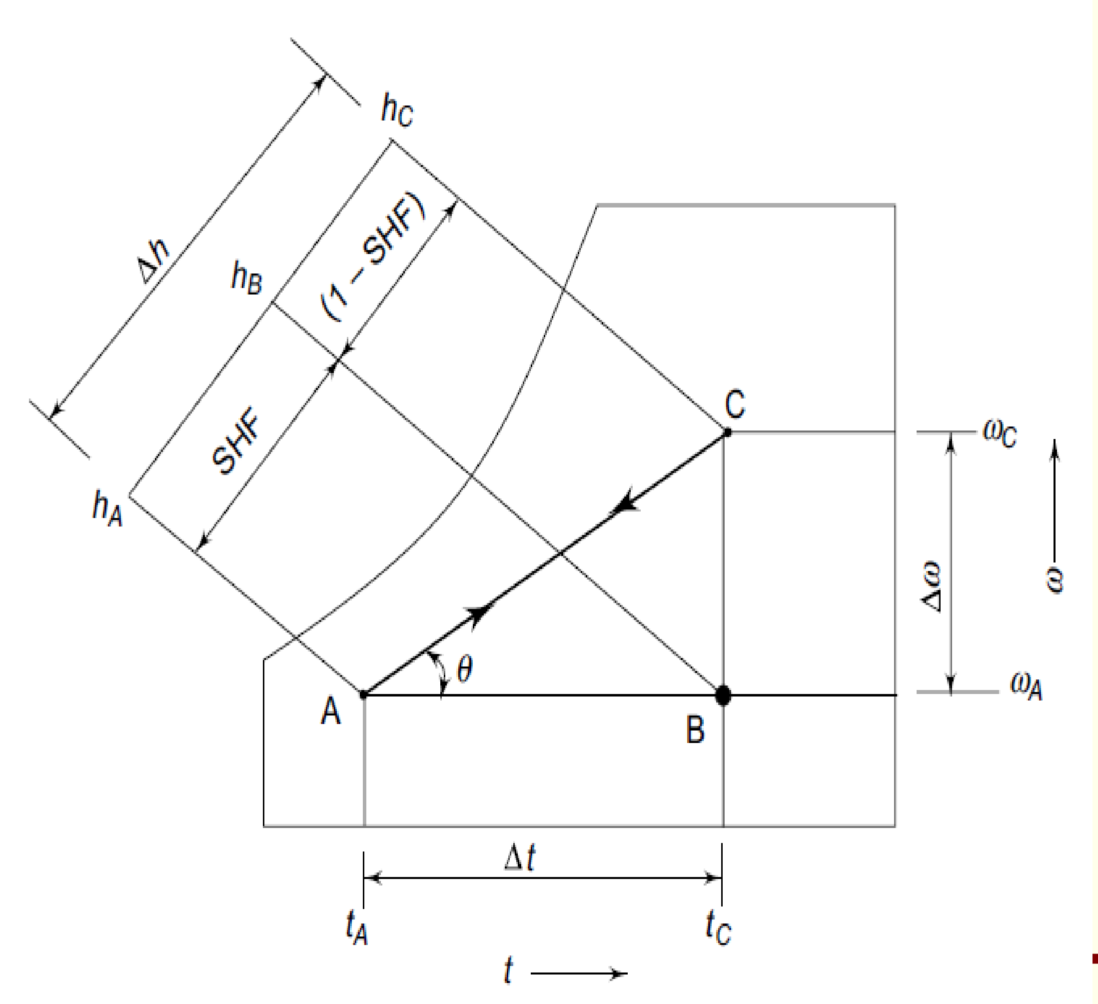
$$Q_s = m_a(h_B - h_A) = m_a C_p(t_C - t_A)$$

- Moisture transfer due to change in humidity ratio

$$G = m_a(\omega_C - \omega_A)$$

- Latent heat load

$$Q_L = m_a(h_C - h_B) = m_a h_{fg_0}(\omega_C - \omega_A)$$



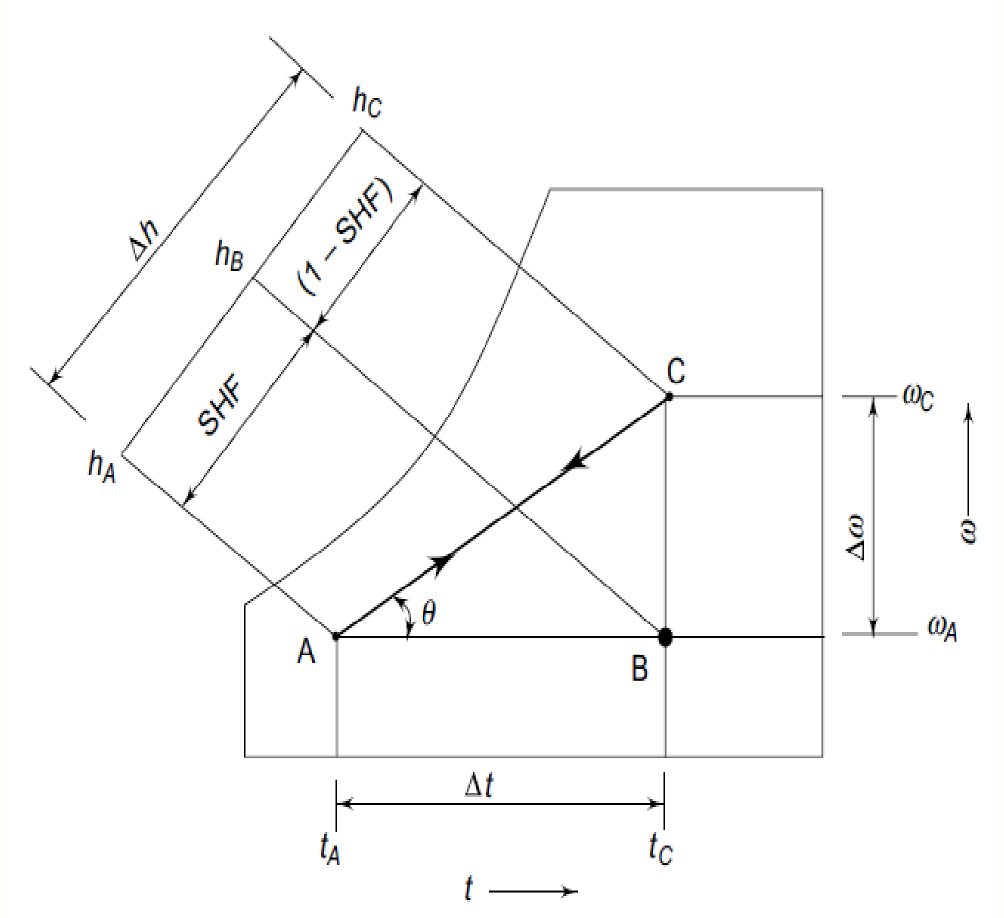
Total Heat Process

- Total heat load
- $$Q = Q_s + Q_L = m_a(h_C - h_A)$$

$$= m_a\left[C_p(t_C - t_A) + h_{fg_0}(\omega_C - \omega_A)\right]$$

- Mass flow rate in cmm
- $$\dot{Q} = \frac{(cmn)(1.2)}{60}\Delta h = 0.02(cmm)\Delta h$$

$$\Rightarrow \dot{Q} = (cmm)(0.0204\Delta t + 50\Delta\omega)kW$$



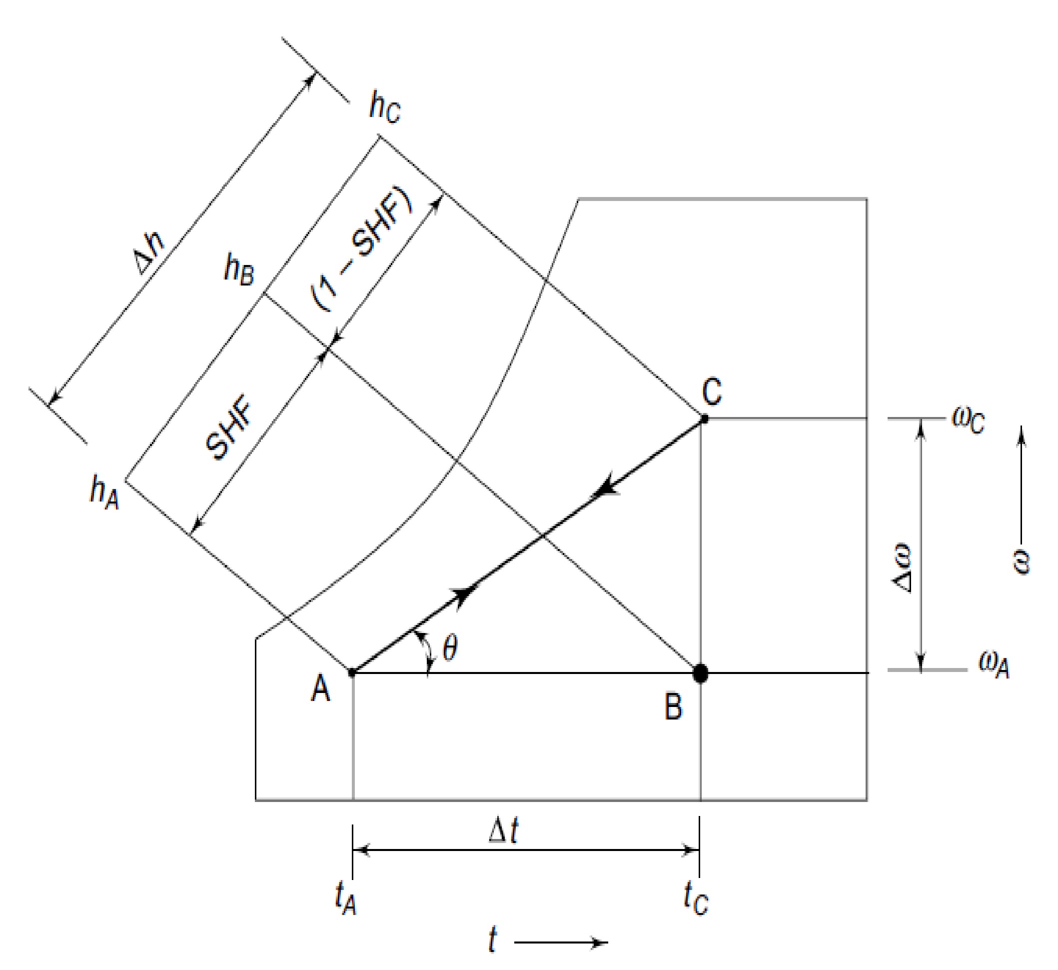
Sensible Heat Factor (SHF)

- Ratio of sensible heat transfer to total heat transfer

$$SHF = \frac{Q_s}{Q_s + Q_L} = \frac{Q_s}{Q}$$

- $SHF = \frac{h_B - h_A}{(h_B - h_A) + (h_C - h_B)} = \frac{h_B - h_A}{h_C - h_A} = \frac{0.0204\Delta t}{0.0204\Delta t + 50\Delta\omega}$

$$= \frac{0.0204\Delta t}{0.02\Delta h}$$



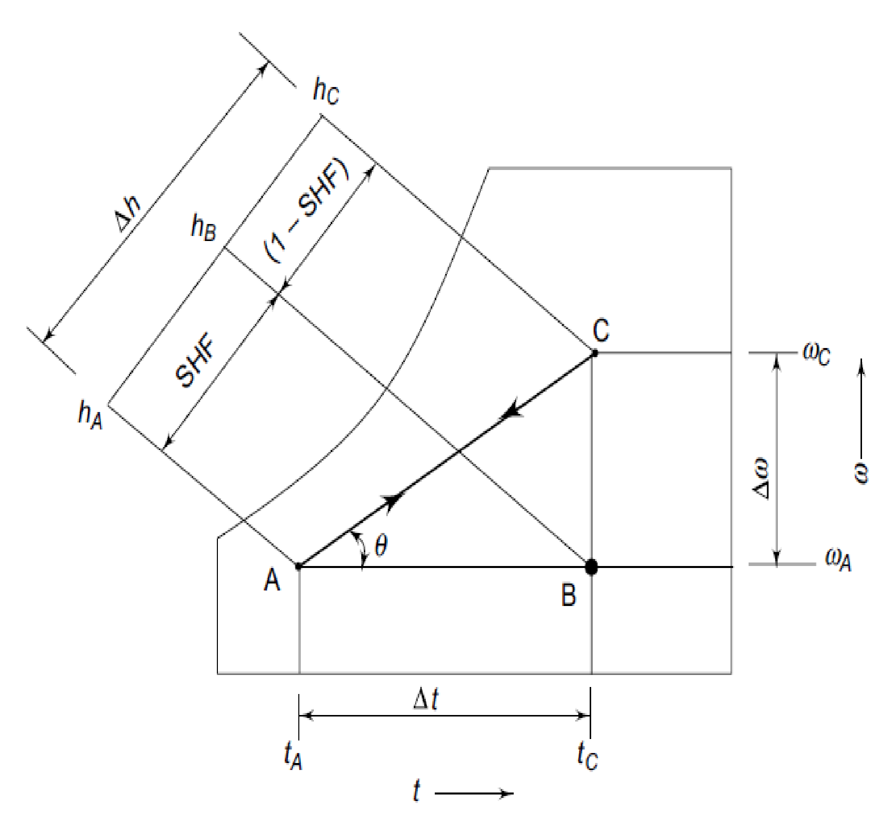
Sensible Heat Factor (SHF)

- SHF of unity ⇒ no latent heat transfer & SHF line is horizontal in chart

- SHF = 0 ⇒ no sensible heat transfer

$$SHF = \frac{1}{1+2451\frac{\Delta\omega}{\Delta t}} = \frac{1}{1+2451\tan\theta} \quad , \tan\theta = \frac{\Delta\omega}{\Delta t} \ ,$$

$$\tan\Theta = \frac{1}{2451}\left[\frac{1}{SHF} - 1\right]$$

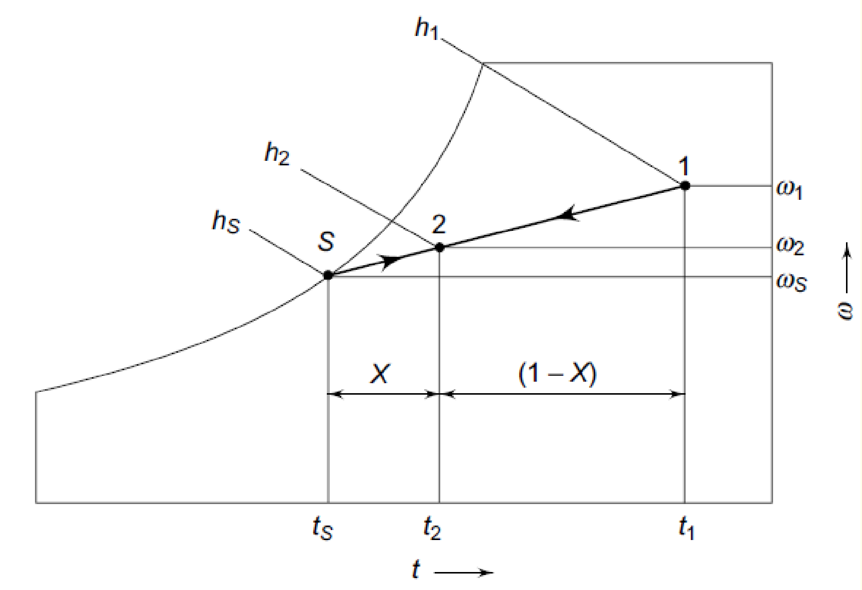


Bypass factor

- The limitations of practical psychrometric processes and equipment is given by Bypass factor.

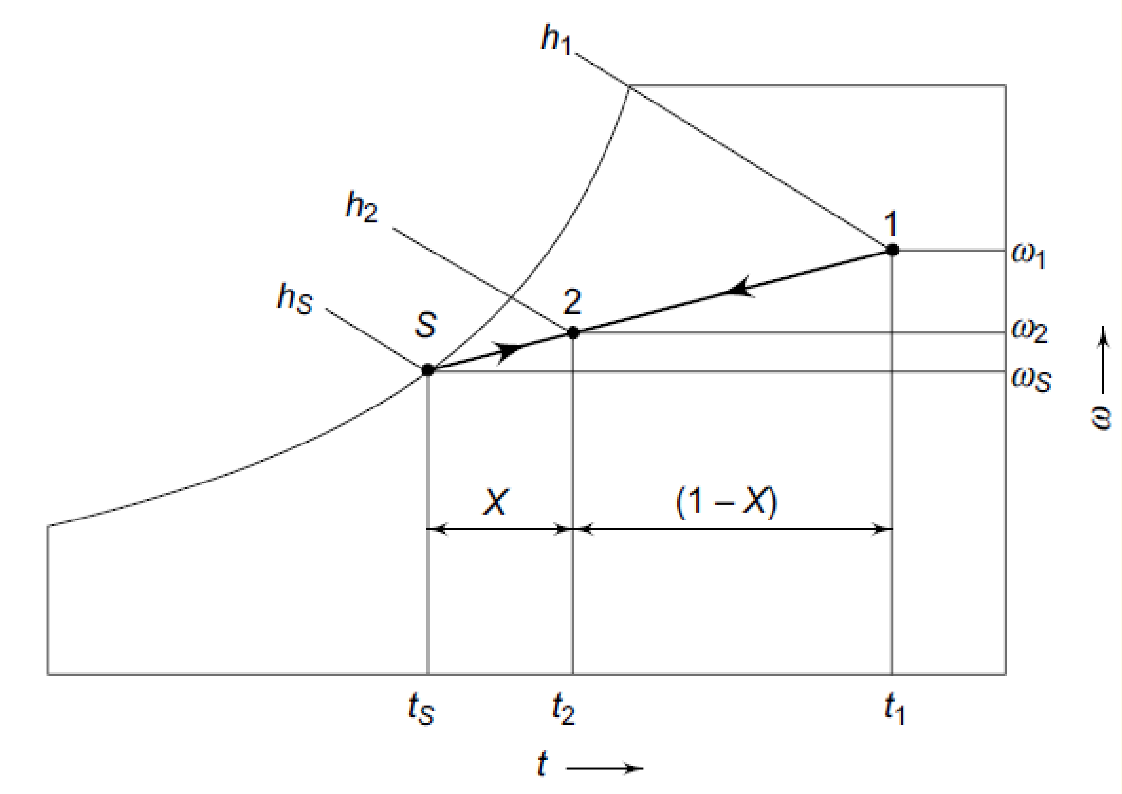
- The moist air enters at 1 and leaves at 2 when surface maintained at S

- Air stream particle come in contact with surface. State of contacted air is same as saturated air at surface at the temperature



Bypass Factor

- Thus equivalent of perfect contact of definite portion of air particles with the surface or no contact or equivalent bypass of remaining particles.
- Uncontacted air remains at the entering state.
- End state of air same as complex mixing of contacted and uncontacted particle at 2.



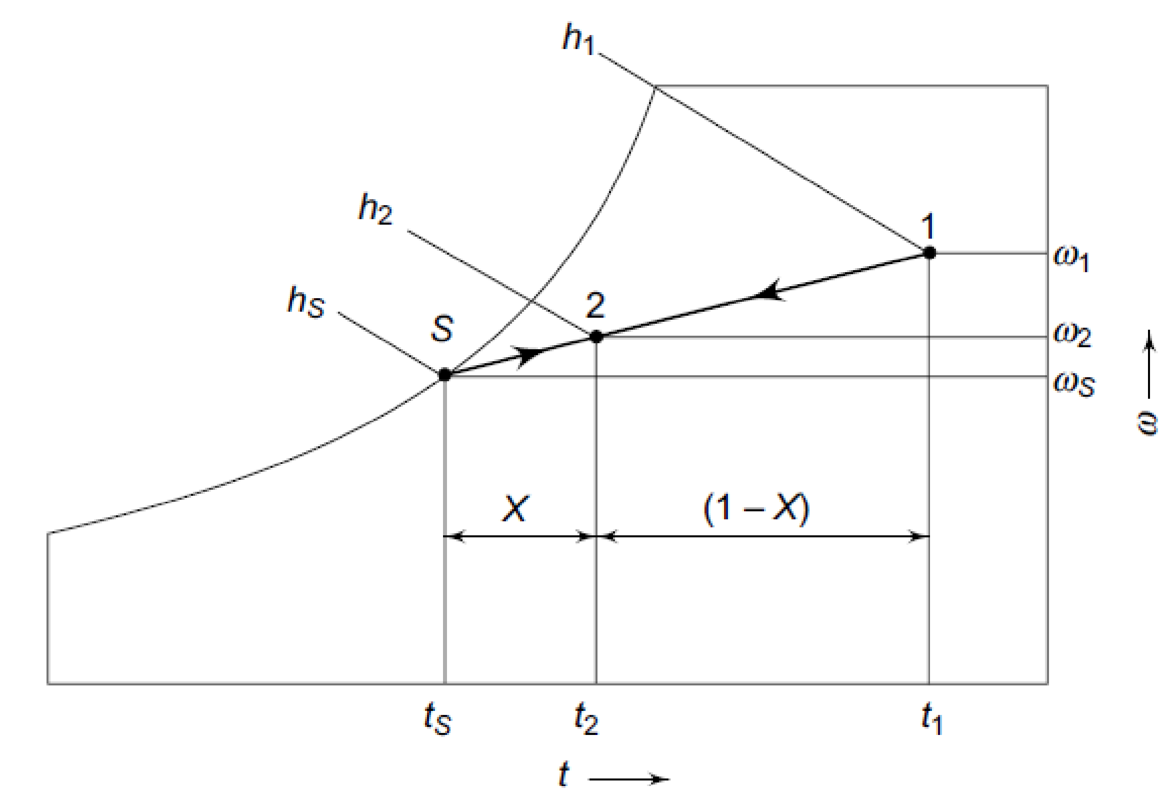
Bypass Factor

- BPF can be defined as representing fraction of uncontacted air in terms of 1, 2, S as

$$X = \frac{t_2 - t_s}{t_1 - t_s} = \frac{\omega_2 - \omega_s}{\omega_1 - \omega_s} = \frac{h_2 - h_s}{h_1 - h_s}$$

- Contact factor $(1 - X)$ represents a fraction of contacted air

- Bypass factor can be defined in terms of humidity ratio or temperature or enthalpy



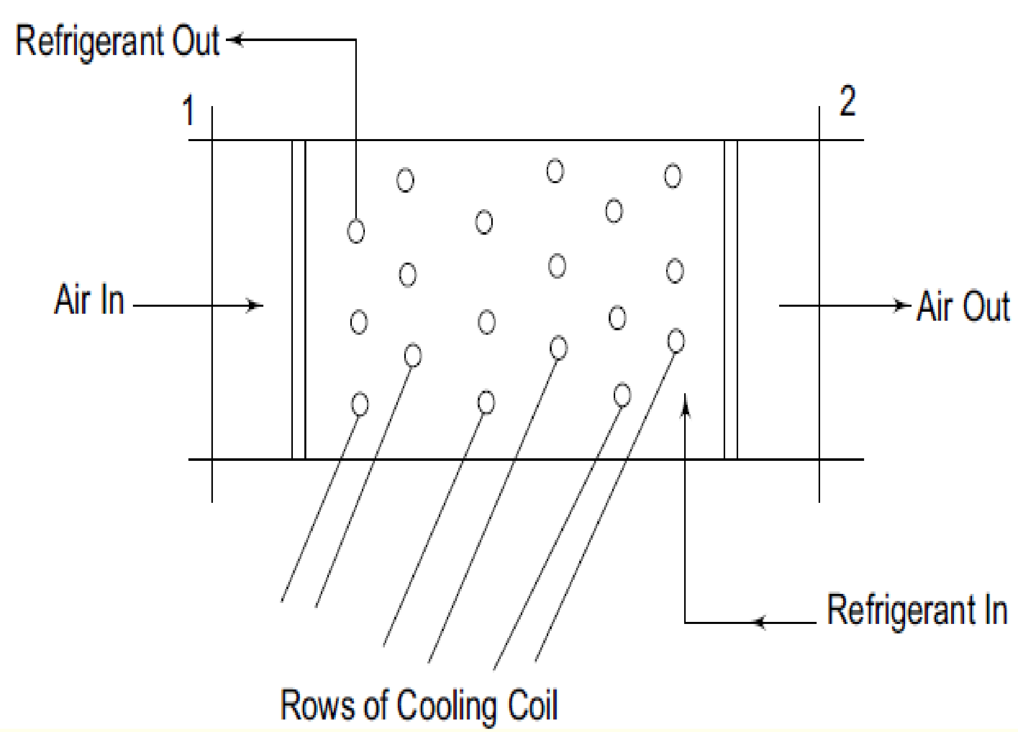
Cooling and Dehumidifying Coils

- Moist air is made to flow over coils carrying chilled water or brine as secondary refrigerant

- Sensible or simple cooling takes place at t_S (coil surface tempp) lower than DBT of air

- The air is cooled along DPT Line

- Leaving air state depends on BPF(by pass factor) of coil



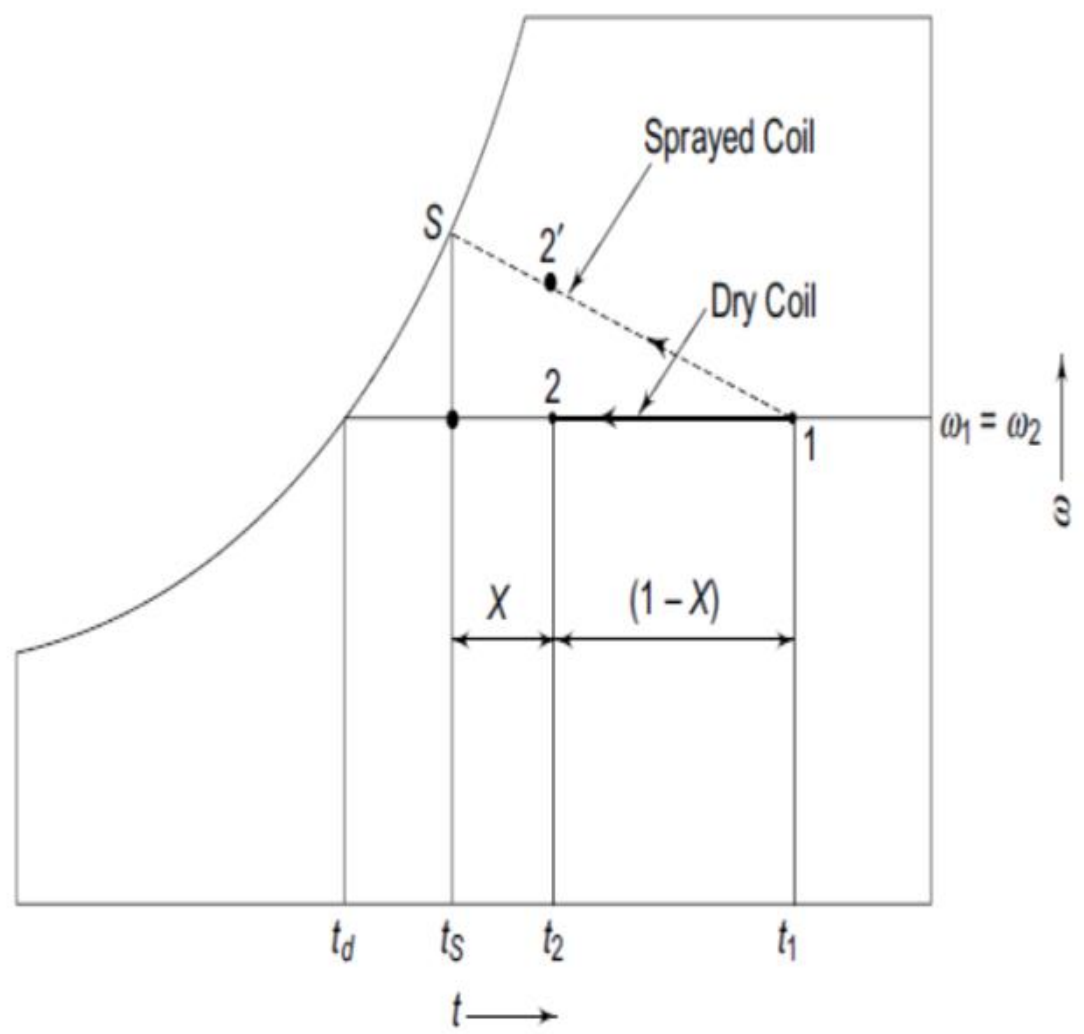
Cooling and Dehumidifying Coils

- Air Leaves at state 2 for BPF of X

- BPF can be decreased & leaving air state made to approach coil surface temperature by increasing number of coils

- There is a minimum limit to coil temperature for simple cooling t_d

- t_d equal to Dew point temperature (DPT) of entering air

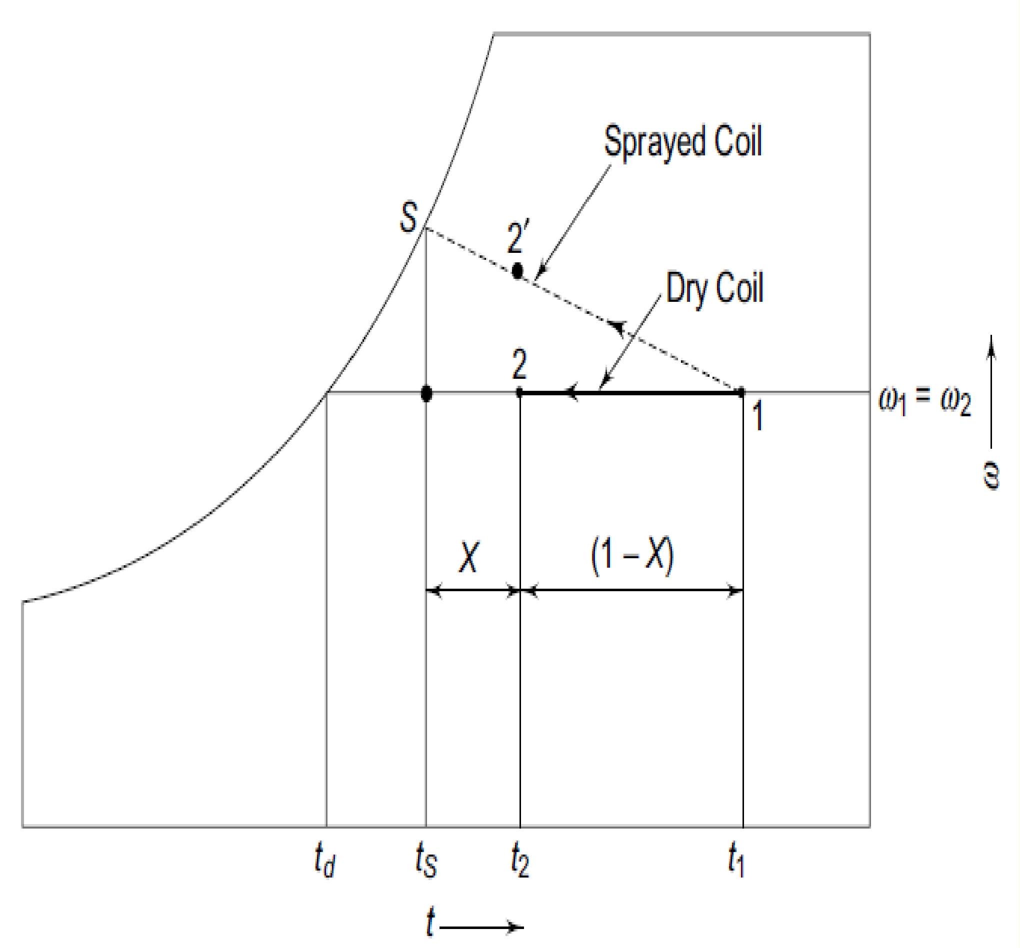


Cooling and Dehumidifying Coils

- Process along 1-S, air leaves at state 2’. This process occurs if the coil were wet, water sprayed over it, at temperature t_S.

- The cooling process accompanied with humidification, eg: air conditioning of textile mills.

- Dehumidification of air are accompanied with either simultaneous cooling or heating of air.

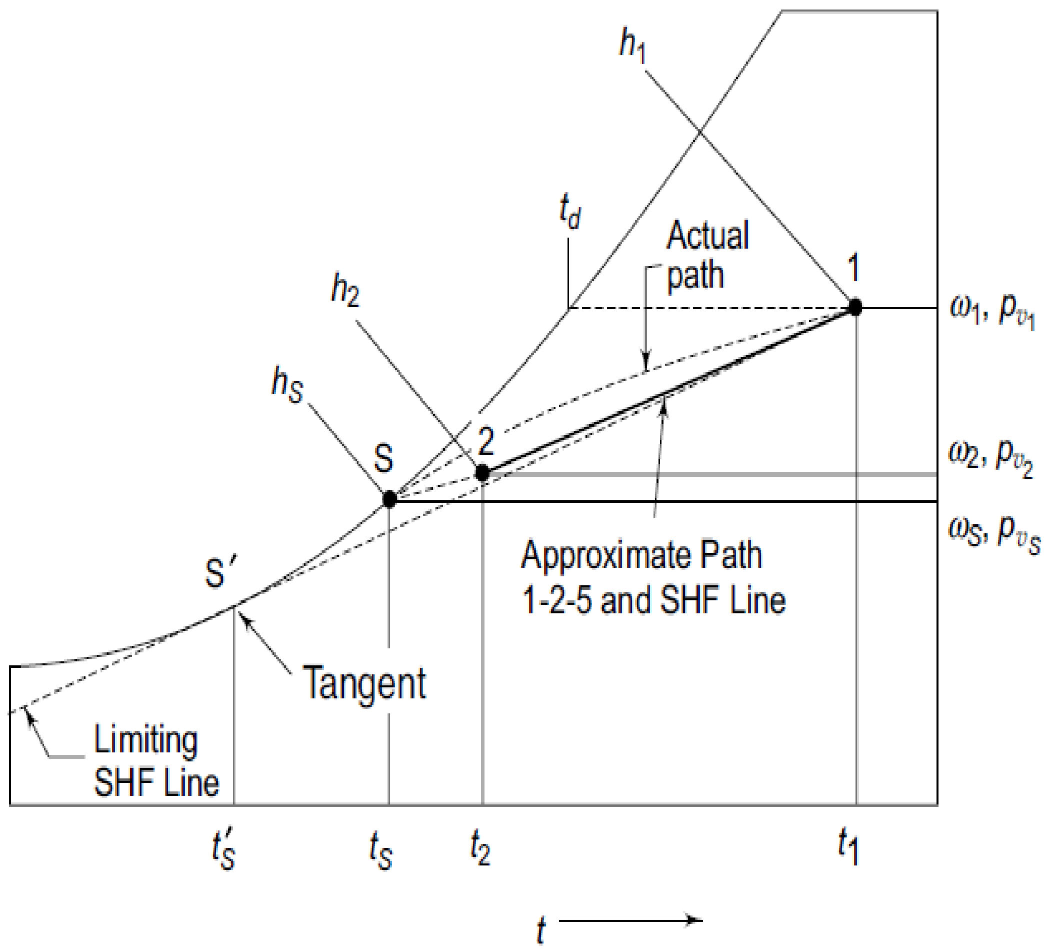


Cooling, Dehumidification and ADP

- Dehumidification with cooling happens if moist air flows over cooling coils maintained at mean surface temperature $t_s < t_d$ of entering air.

- t_s of cold surface is Apparatus Dew Point temperature of the coil(ADP)

- Between air and surface, sensible and latent heat transfer takes place.

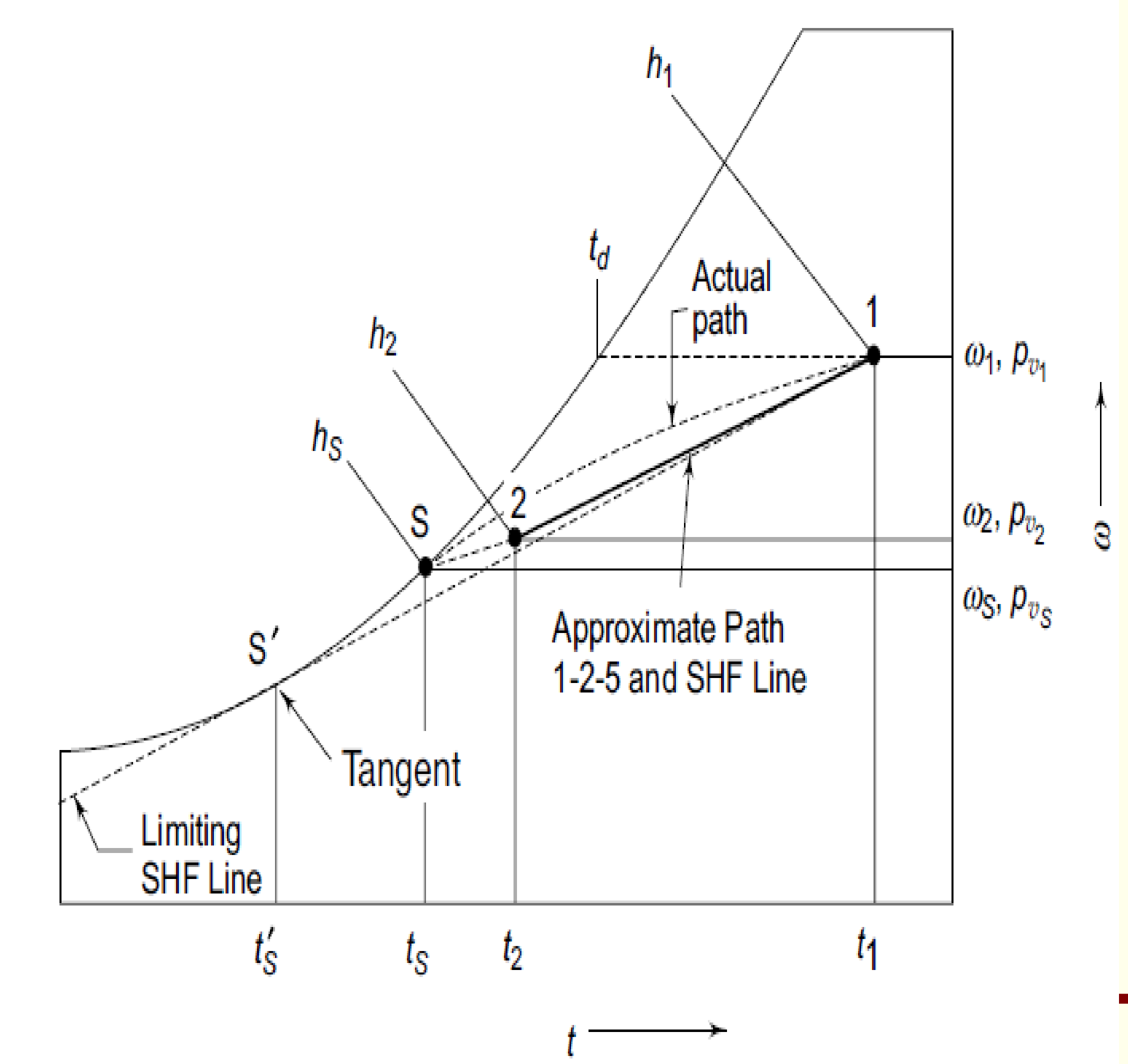


Cooling, Dehumidification and ADP

- The driving potential for sensible and latent heat transfer are $(t - t_s)$ & $(p_v - p_{v_s})$ or $(\omega - \omega_s)$ respectively.

- p_{v_s} partial pressure of water vapour in air at immediate vicinity of cold surface temperature t_s

- Actual path of process 1-S depends on heat and mass transfer coefficients.

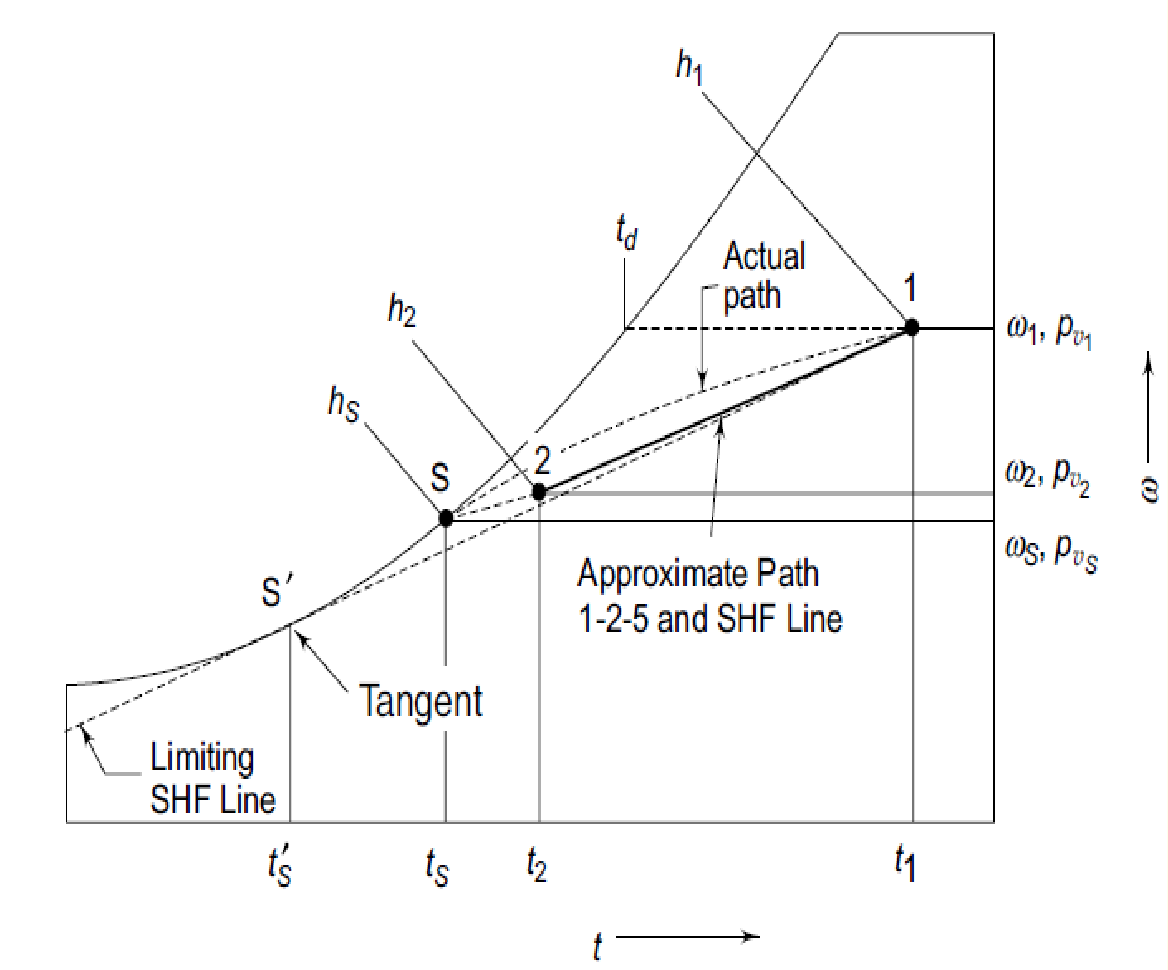


Cooling, Dehumidification and ADP

- Process 1-S assumed to be straight line & air leaving state at 2 as a result of BPF of coil.

- The limit to this process is up to 1-S'. SHF lower than that of 1-S' cannot be achieved with air entering at state 1.

- Temperature required for 1-S' is very low result in low COP of refrigeration system.



- A mixture of dry air and water vapour is at a temperature of 21°C under a total pressure of 736 mm Hg. The dew-point temperature is 15°C. Find:

(i) Partial pressure of water vapour.
(ii) Relative humidity.
(iii) Specific humidity.
(iv) Specific enthalpy of water vapour
(v) Enthalpy of air per kg of dry air.
(vi) Specific volume of air per kg of dry air.

- Moist air at standard atmospheric pressure is passed over a cooling coil. The
  inlet and exit states are as follows:

Number	State	DBT or °C	RH %
1	Inlet	30	50
2	Exit	15	80

Show the process on a psychrometric chart. Determine the amount of heat and moisture removed per kg of dry air.

- 39.6 cmm of a mixture of recirculated room air and outdoor air enter a cooling coil at 31°C DB and 18.5°C WB temperatures. The effective surface temperature of the coil is 4.4°C. The surface area of the coil is such as would give 12.5 kW of refrigeration with the given entering air state. Determine the dry and wet bulb temperatures of the air leaving the coil and the coil bypass factor.

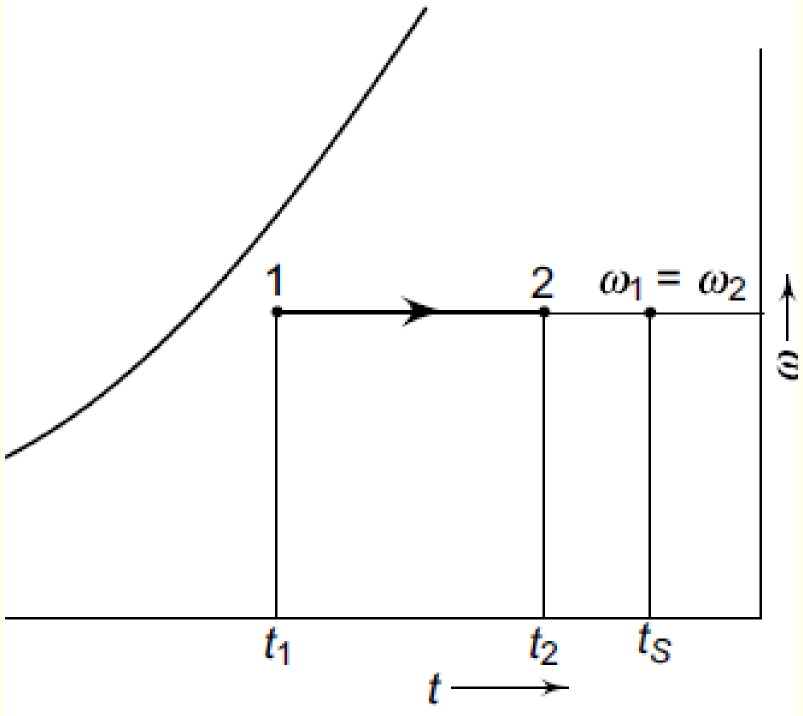
Heating Coils

- Sensible heating of air happen when air flow over heating coil whose surface temperature t_s higher than dry bulb temperature of air.

- No limit to the coil temperature for sensible heating.

- Heating medium in coil are steam or hot gas from furnace.

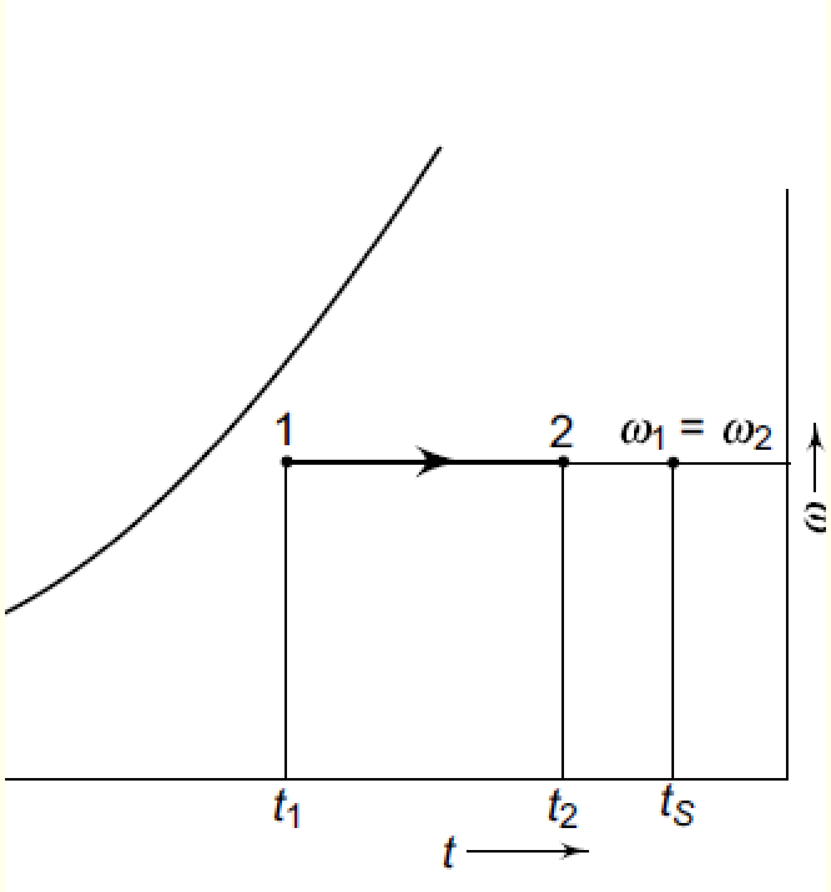
- For winter heating of air : hot water or steam coils, direct fired furnace gasses coil, finned electric strip heaters are used.



Heating Coils

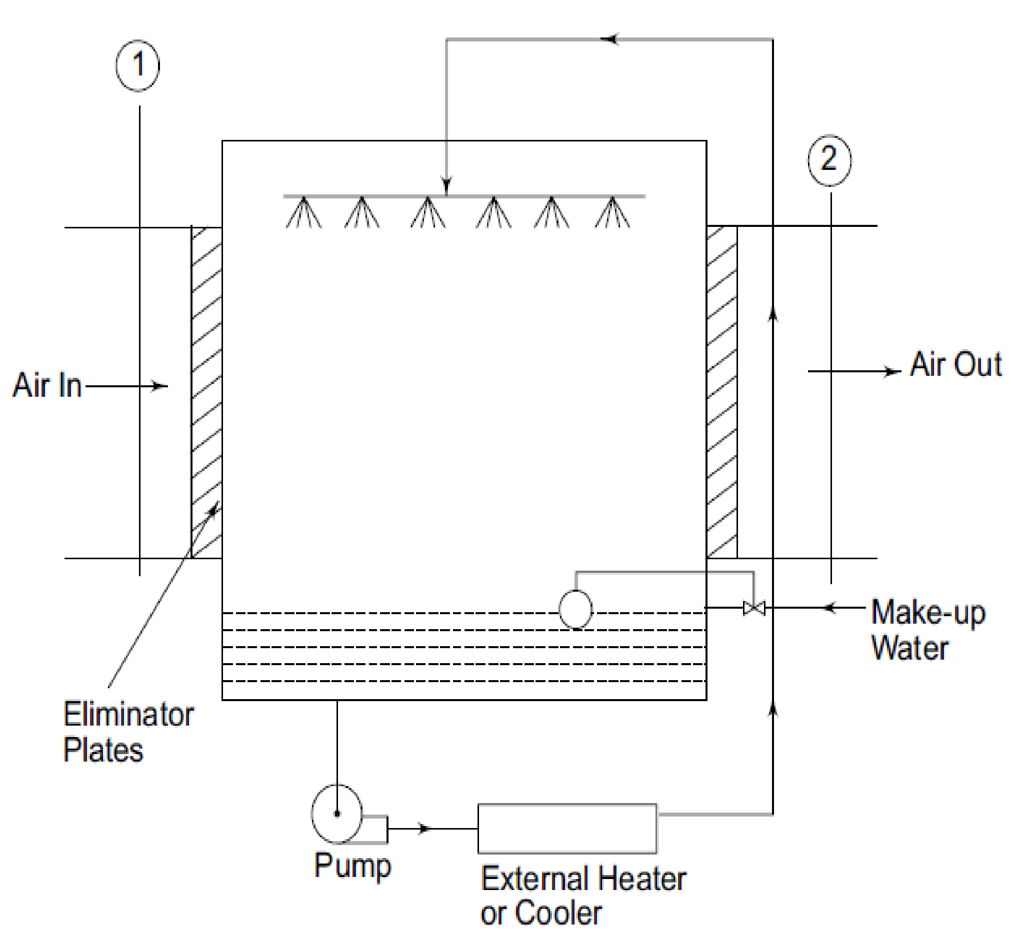
- In hot water coil: boilers run on fuel oil. Boiler provide hot water to coil at 92 $°C$ and returns at 70 $°C$.

- Furnaces are oil fired (75% efficiency) or gas fired(80-85% efficiency)



Air Washer

- Air pass through spray of water. The air may be cooled or heated, humidified or dehumidified or adiabatically saturated depending on mean temperature of water.
- Water cooled or heated or recirculated by a pump.
- Make up water added for humidification.
- Eliminator are used to minimize loss of water droplets.

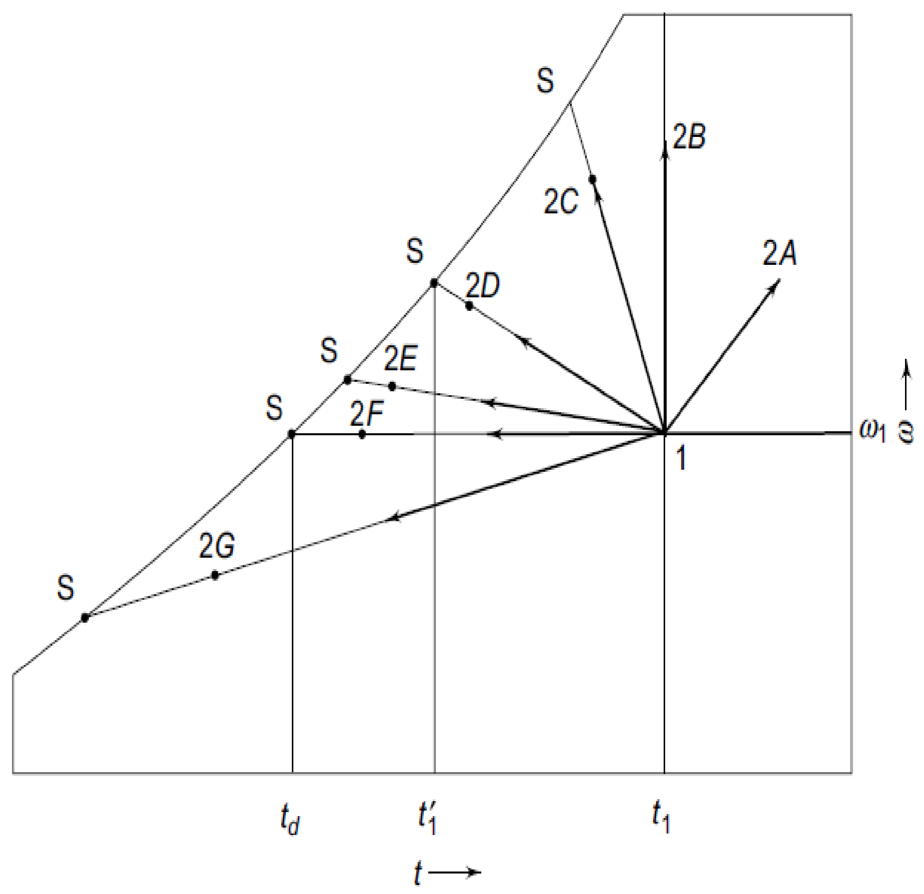


Air Washer

- Process 1-2A: heating and humidification $(t_S > t_1)$
- Process 1-2B: humidification $(t_S = t_1)$
- Process 1-2C: cooling and humidification $(t_1' < t_S < t_1)$

  Though the air is cooled its enthalpy increases due to humidification. The water therefore needs to be externally heated.
- Process 1-2D: adiabatic saturation $(t_1' = t_S)$
- Process 1-2E : cooling and humidification $(t_d < t_S < t_1')$

  Enthalpy decreases. Water is externally cooled.
- Process 1-2F: cooling $(t_S = t_d)$
- Process 1-2G: cooling and dehumidification $(t_S < t_d)$



Air Washer

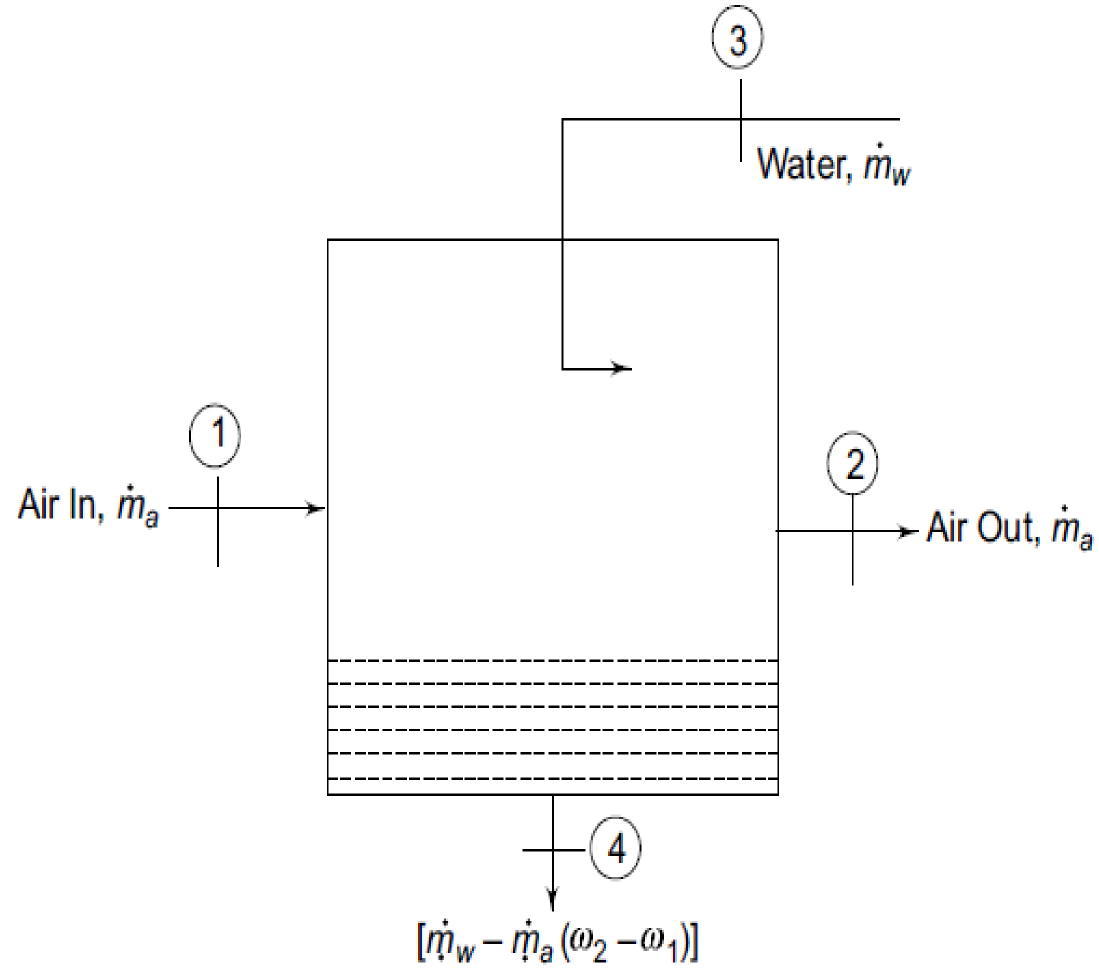
- The energy balance :

$$\dot{m}_a(h_2 - h_1) = \dot{m}_w c_{p_w} t_{w_3} - [\dot{m}_\omega - \dot{m}_a(\omega_2 - \omega_1)]C_{p_w} t_{w_4}$$

$$\dot{m}_a(h_2 - h_1) = \dot{m}_w C_{p_w}\left(t_{w_3} - t_{w_4}\right) + \dot{m}_a(\omega_2 - \omega_1)C_{p_w} t_{w_4}$$

- *Neglecting effect of water temperature in the last term,*

$$\dot{m}_a(\Sigma_2 - \Sigma_1) = \dot{m}_w C_{p_w}\left(t_{w_3} - t_{w_4}\right)$$



Air Washer

- For any section of air washer

$$\dot{m}_a \, d\Sigma = -\dot{m}_n C_{p_w} dt_w$$

- For adiabatic saturation process :

$$d\Sigma = 0$$

$$dt_w = o, \qquad t_{\omega_3} = t_{w_4}$$

- If the spray water is heated external to the washer, WBT of air increases
- If the spray water is cooled external to the washer, WBT of air decreases
- If the spray water is neither heated nor cooled, WBT of air does not change – Adiabatic saturation

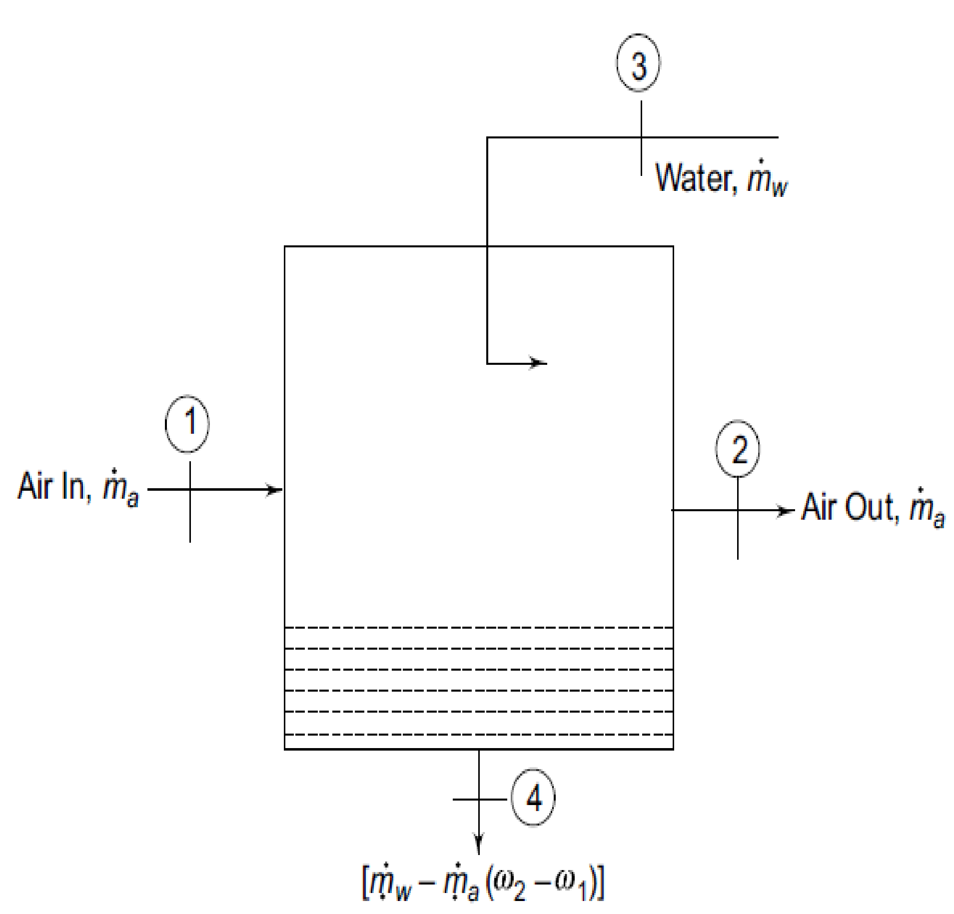
Air Washer

- Humidifying efficiency of air washer

$$\eta_H = \frac{h_2 - h_1}{h_s - h_1} = \frac{\omega_2 - \omega_1}{\omega_s - \omega_1}$$

- Bypass factor X expressed as

$$X = \frac{\omega_s - \omega_2}{\omega_s - \omega_1} = 1 - \frac{\omega_2 - \omega_1}{\omega_s - \omega_1} = 1 - \eta_H$$



Water Injection

- Water at temperature t_f injected and sprayed into flowing air by nozzles
- Condition of air changes depending on amount of water evaporated
- Enthalpy of vapourization will come from enthalpy of air

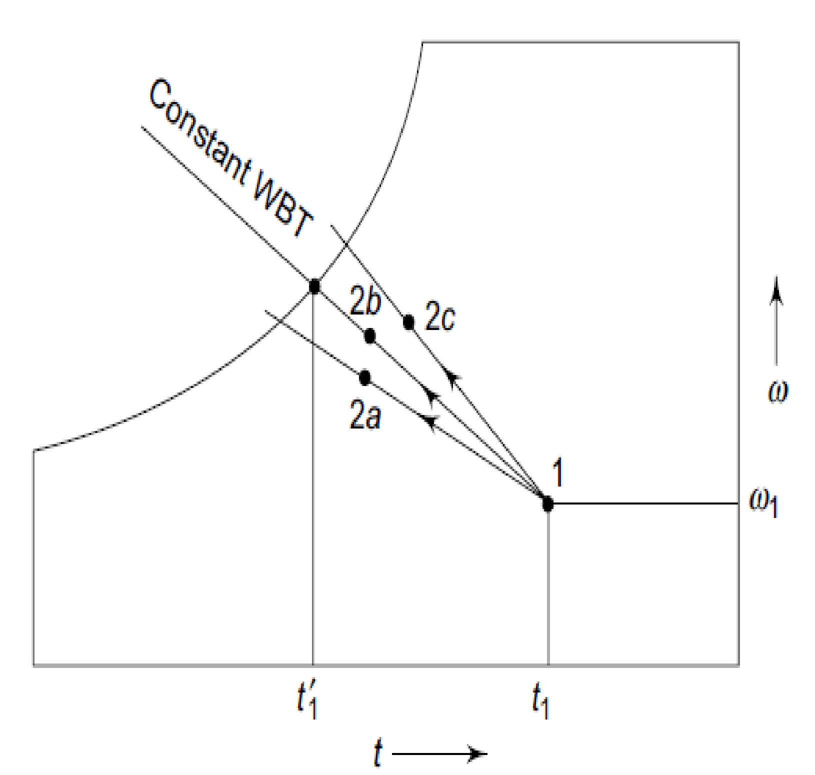
Water Injection

- m_v be amount of water has been evaporated is equal to amount of injected

- m_a be air flow rate. Mass and enthalpy given by

$$\omega_2 = \omega_1 + \frac{m_v}{m_a}$$

$$h_2 = h_1 + \frac{m_v}{m_a} h_f = h_1 + (\omega_2 - \omega_1) h_f$$



Water Injection

- If water injected at wet bulb temperature of air, sigma heat function constant & process follow constant WBT line 1-2b

- Process 1-2a or 1-2c follow depending on water temperature lower or higher than WBT of air

- $(\omega_2 - \omega_1)$ is very small compared to $(h_2 \,\&\, h_1)$, lines 1-2a & 1-2c very close to 1-2b irrespective of temperature of injected water.

Steam Injection

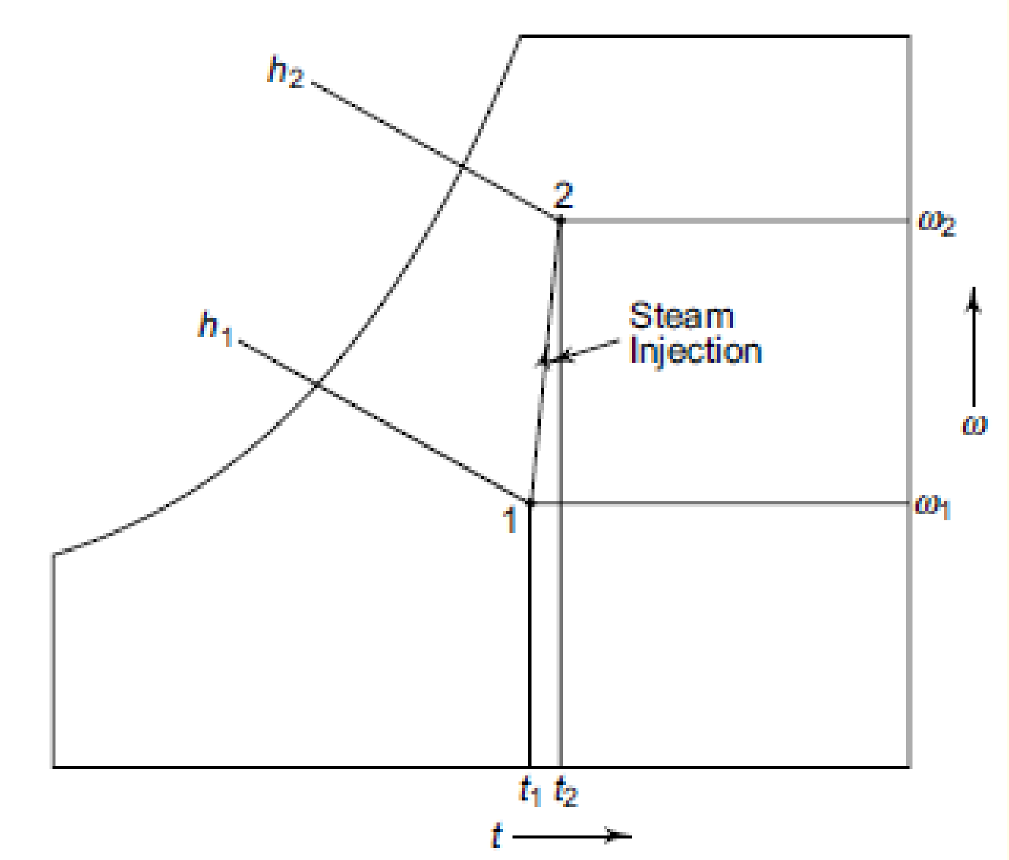
- Steam injection used where high humidity need to be maintained

- Process analysed by mass and energy balance

- State of leaving air given by

$$\omega_2 = \omega_1 + \frac{m_v}{m_a} \qquad h_2 = h_1 + \frac{m_v}{m_a} h_v$$

- Dry bulb temperature of air changes very little during process



Q.1 The air-handling unit of an air-conditioning plant supplies a total of 4500 cmm of dry air which comprises by weight 20 per cent fresh air at 40°C DBT and 27°C WBT, and 80 per cent recirculated air at 25°C DBT and 50 per cent RH. The air leaves the cooling coil at 13°C saturated state. **Calculate the total cooling load, and room heat gain.**

Q.2 An air-conditioned space is maintained at 27°C DBT and 50 per cent RH. The ambient conditions are 40°C DBT and 27°C WBT. The space has a sensible heat gain of 14 kW. Air is supplied to the space at 7°C saturated.

Calculate: (i) Mass of moist air supplied to the space in kg/h.
(ii) Latent heat gain of space in kW.
(iii) Cooling load of the air washer in kW if 30 per cent of the air supplied to the space is fresh, the remainder being recirculated.

Q.3 A building has the following calculated cooling loads: RSH gain = 310 kW RLH gain = 100 kW The space is maintained at the following conditions: Room DBT = 25°C Room RH = 50% Outdoor air is at 28°C and 50% RH. And 10% by mass of air supplied to the building is outdoor air. If the air supplied to the space is not to be at a temperature lower than 18°C, find:

(a) Minimum amount of air supplied to space in m3 /s.
(b) Volume flow rates of return (recirculated room) air, exhaust air, and outdoor air.
(c) State and volume flow rate of air entering the cooling coil.
(d) Capacity, ADP, BPF and SHF of the cooling coil.

Example 18.14. *Air flowing at the rate of 100m³/min at 40°C dry bulb temperature and 50% relative humidity is mixed with another stream flowing at the rate of 20m³/min at 26°C dry bulb temperature and 50% relative humidity. The mixture flows over a cooling coil whose apparatus dew point temperature is 10°C and by-pass factor is 0.2. Find dry bulb temperature and relative humidity of air leaving the coil. If this air is supplied to an air-conditioned room where dry bulb temperature of 26°C and relative humidity of 50% are maintained, estimate : 1. Room sensible heat factor ; and 2. Cooling load capacity of the coil in tonnes of refrigeration.*