Psychrometry

Lecture -11

Atmospheric air

- Psychrometry is the study of dry air and water vapour mixture.

- It can be seen that oxygen and nitrogen are the major constituents of air and in psychrometry, air is assumed to be a mixture of these two gases only.

- Psychrometry finds extensive application right from air conditioning to paper and textile industries involving hygroscopic materials like paper and textiles.

- The study of the properties of humid air is also useful in metrology and design of air conditioning equipment and cooling towers in power plants.

- The following assumptions are made in psychrometry;

(a) The gas mixture of interest is assumed to be composed of dry air and water vapour, each of which are considered to behave as ideal gases.
(b) The specific heats of air are assumed to be constant
(c) Enthalpy of water vapour depends only on temperature

The above assumptions are justified for psychrometry engineering applications fall in the temperature range of 0-50^{o}C and the total pressure of the mixture about 1 standard atmosphere (101.32 kPa).

A few important terms of psychrometry are given below:
1. Dry air
2. Dry bulb temperature
3. Wet bulb temperature
4. Dew point temperature
5. Absolute humidity
6. Relative humidity

Dry Air

- It is a mixture of oxygen, nitrogen, carbon dioxide, hydrogen and other gases like Argon, helium, krypton, xenon. Dry air is assumed to have no water vapour. But, it is impossible to get dry air without moisture. The sum of pressure of dry (p_a) are and water vapour (p_v) is equal to the barometric pressure (p).

- $p = p_a + p_v$

Constituents of Dry Air (Gravimetric and Volumetric analyses) and Their Composition

Constituent	**Volumetric %**	**Gravimetric %**	**Molecular mass**
Nitrogen	78.03	75.46	28
Oxygen	20.99	23.18	32
Argon	0.94	1.3	40
Carbon dioxide	0.03	0.06	44
Others	0.01	0.02	----

Dry Bulb Temperature

The temperature measured by a thermometer with a dry bulb is called dry bulb temperature. This is purely free from the influence of moisture present in air. It is denoted as T_{db}.

Wet Bulb Temperature

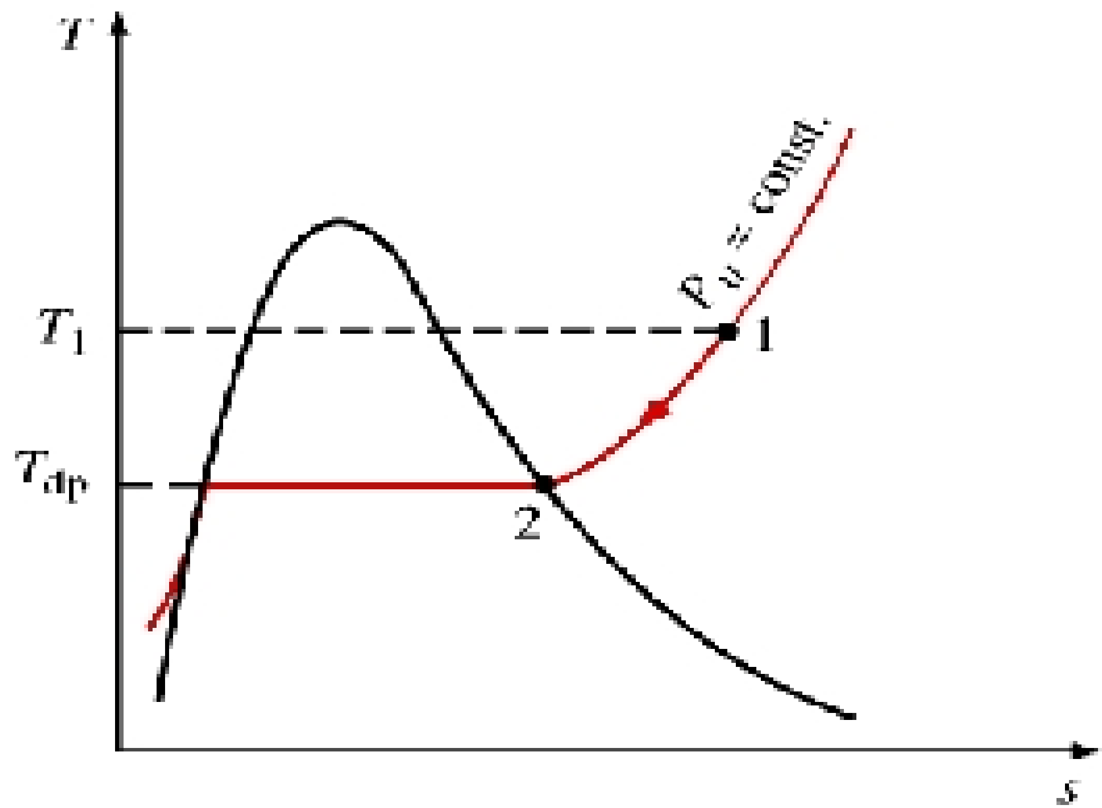
When a thermometer is covered by a wet wick, or cloth and it measures the temperature of air then the temperature is called wet bulb temperature. It is denoted as T_{wb}. The difference between the dry bulb temperature and wet bulb temperature is called wet bulb depression and it is a measure of the relative humidity.

Dew Point Temperature

It is defined as the temperature of moist air, in which water vapour starts to condense continuously at constant pressure. It is denoted as T_{dp}.

The partial pressure of water vapour in the air is equal to the saturation pressure of water at the dew point temperature.

Generally the state of water vapour in atmospheric air is superheated as shown as state 1 in Fig. When cooled at constant temperature of a sample of such air will decrease until it reaches the saturation temperature of steam corresponding to partial pressure Pv. This temperature is known as dew point temperature.



Moist air in T-*s* diagram

Specific Humidity or Humidity Ratio

The amount of water vapour present in the moist air (atmospheric air) per unit mass of dry air is also known as absolute humidity or the humidity ratio. It is denoted as ω.

$$\omega = \frac{\text{mass of water vapour present in moist air in a given volume}}{\text{mass of dry air in same volume}}$$

$$= \frac{\frac{m_v}{v}}{\frac{m_a}{v}} = \text{mass of water vapour per kg of dry air}$$

where,

m_v = mass of water vapour in moist air

m_a = mass of dry air

v = volume of given mixture

$$\omega = \frac{v_a}{v_v} \qquad \left[\frac{V}{m_v} = v_v, \frac{V}{m_a} = v_a\right]$$

Consider the perfect gas equation for water vapour

$$p_v V = m_v R_v T \qquad \textbf{(1)}$$

Similarly, for dry air

$$p_a V = m_a R_a T \qquad (2)$$

Dividing Eqn. (2) by Eqn. (1)

$$\frac{p_a V}{p_v V} = \frac{m_a R_a T}{m_v R_v T} \qquad (3)$$

$$\frac{p_a}{p_v} = \frac{m_a R_a}{m_v R_v}. \qquad (4)$$

The values of the gas constants for dry air and water vapour are taken as

$$R_a = \frac{8.314}{28.9} = 0.287 \ \text{kJ/kgK}$$

$$R_v = \frac{8.314}{18.05} = 0.4615 \ \text{kJ/kgK}$$

$$\frac{p_a}{p_v} = \frac{m_a}{m_v} \times 0.622 \qquad (5)$$

$$\frac{m_v}{m_a} = 0.622 \frac{p_v}{p_a} \qquad (6)$$

If the barometric pressure (p) is considered then

$$p = p_a + p_v$$

or, $$p_a = p - p_v \qquad (7)$$

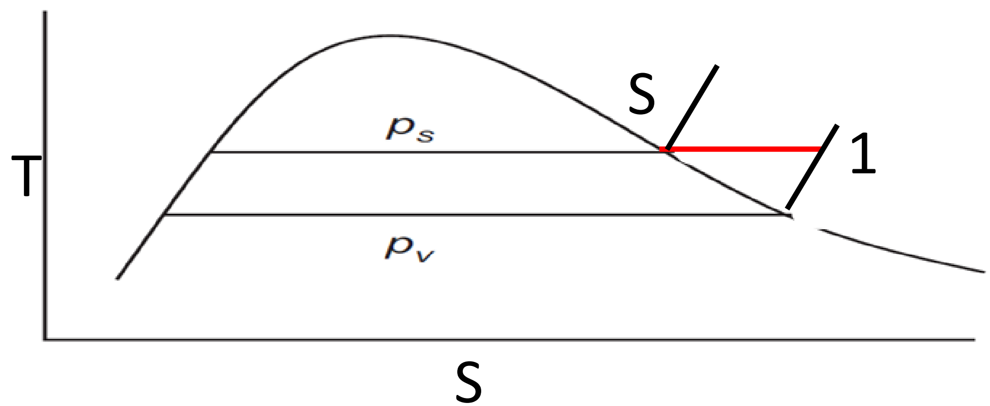
So, $$\frac{m_v}{m_a} = 0.622 \frac{p_v}{(p - p_v)} \qquad (8)$$

$$\omega = 0.622 \frac{p_v}{(p - p_v)} \qquad (9)$$

Relative Humidity

This is the ratio of actual partial pressure of water vapour present to the saturation pressure of water vapour at the same temperature and pressure. It is expressed in percentage. It is denoted as φ .

$$\varphi = \frac{\text{Actual partial pressure of water vapour present in moist air taken}}{\text{Partial pressure of water vapour in saturated air taken at same pressure and temperature}}$$



Partial pressure of moist air and water vapour in the T-*s* diagram

$$\varphi = \frac{p_v}{p_s} \qquad (10)$$

Since ideal gas behaviour is considered for both dry air and water vapour;

$P_v = m_v RT/V$

$P_s = m_s RT/V$

Substituting the above expressions and simplifying the relative humidity(RH) equation (10)

We get $\varphi = m_v/m_s$

Degree of Saturation

The ratio of the mass of water present in the unit mass of moist air to the mass of water vapour present in the unit mass of moist air saturated at same temperature is called the degree of saturation or the saturation ratio. The degree of saturation is denoted as μ.

In other words, it is the ratio of specific humidity of the given unsaturated air to that of saturated air at the same temperature .

$$\mu = \omega / \omega_s \qquad (11)$$

ω = actual humidity ratio of given unsaturated air (moist air)

ω_s = humidity ratio of the same volume of air if it is saturated at the same temperature.

If the relative humidity φ= 0, p_v = 0 then μ = 0. If the air is saturated, then the relative humidity φ = 1, p_v = p_s and m= 1 .

It can be seen that μ also ranges from 0 to 1.

Carrier Equation for Partial Pressure of Water Vapour

An empirical relationship was formulated by Carrier, to calculate the partial pressure of water vapour in the moist or humid air corresponding to dry and wet bulb temperature.

$$P_v = P_s - \frac{(P - Ps)(Tdb - Twb)(1.8)}{2800 - 1.3(1.8Tdb + 32)}$$

, where Ps is the Saturation Pressure at WBT.

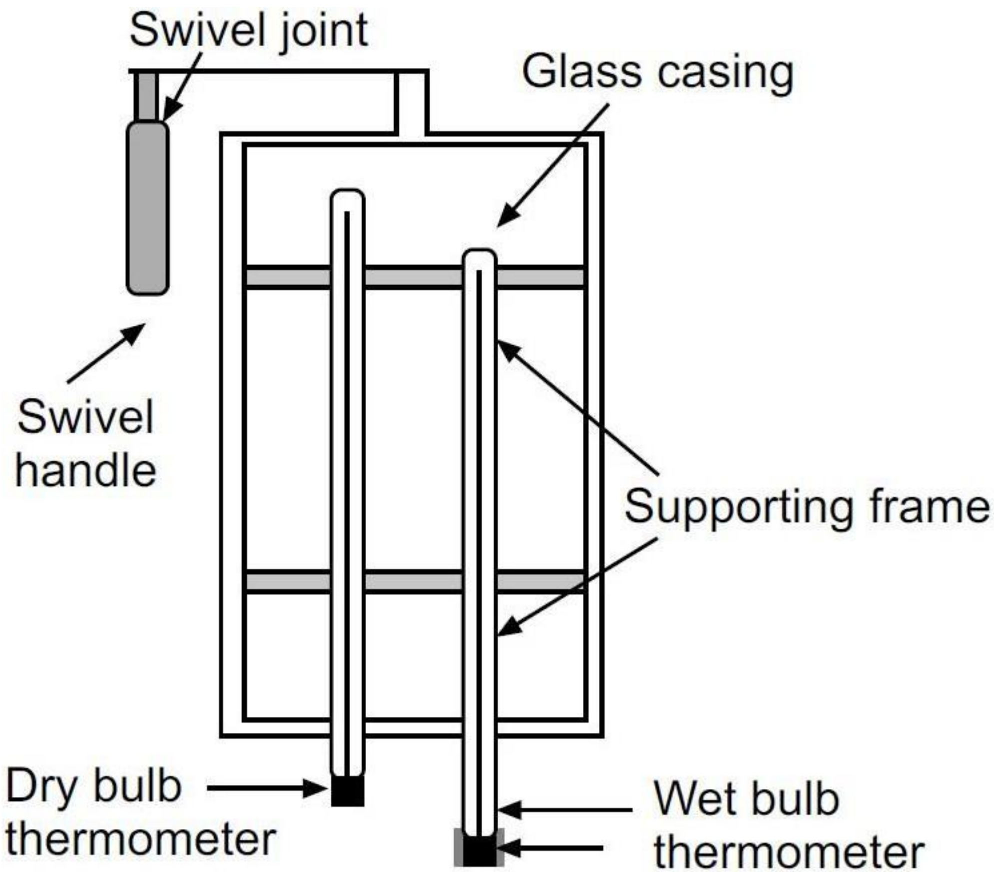
Eqn. (12)

PSYCHROMETER

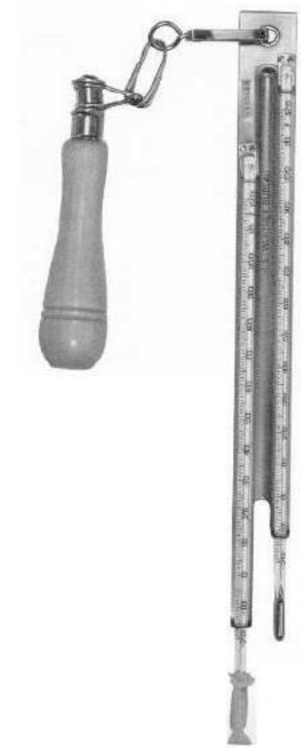
It is a device used to measure the dry and wet bulb temperatures of moist air. There are a few devices available to record the above quantities.

(i) Sling psychrometer
(ii) Modified psychrometer
(iii) Relative humidity sensor
(iv) Dew point sensor
(v) Hygrography recorder

Sling Psychrometer



Sling psychrometer



It consists of two thermometers.

- The thermometers contain mercury or alcohol. Both the thermometers are mounted on a wooden or steel plate.
- The bottom of the plate has a provision for a container filled up with water.
- One of the thermometers has a wick out of its bottom the which will be kept in water.
- This enables the thermometer to measure the wet bulb temperature. At the top of the plate a handle is provided.
- The handle rotates the psychrometer. When the psychrometer stops its rotation the wet bulb temperature and dry bulb temperature are measured.
- This enables the thermometer to give an accurate reading of the wet bulb temperature, which would be affected by air velocity across the wet bulb.

Specific enthalpy of moist air

The total heat or specific enthalpy of moist air is generally determined as the sum of the specific enthalpy of dry air and water vapour, which is normally in the superheated condition in air water vapour mixture.

Specific enthalpy $h = h_a + \omega h_v$ (13)

where, h_v = specific enthalpy of water vapour

h_a = specific enthalpy of dry air, kJ/kg
ω = specific humidity, kg/kg of dry air,
C_{pa} = specific heat of dry air, kJ/kgK

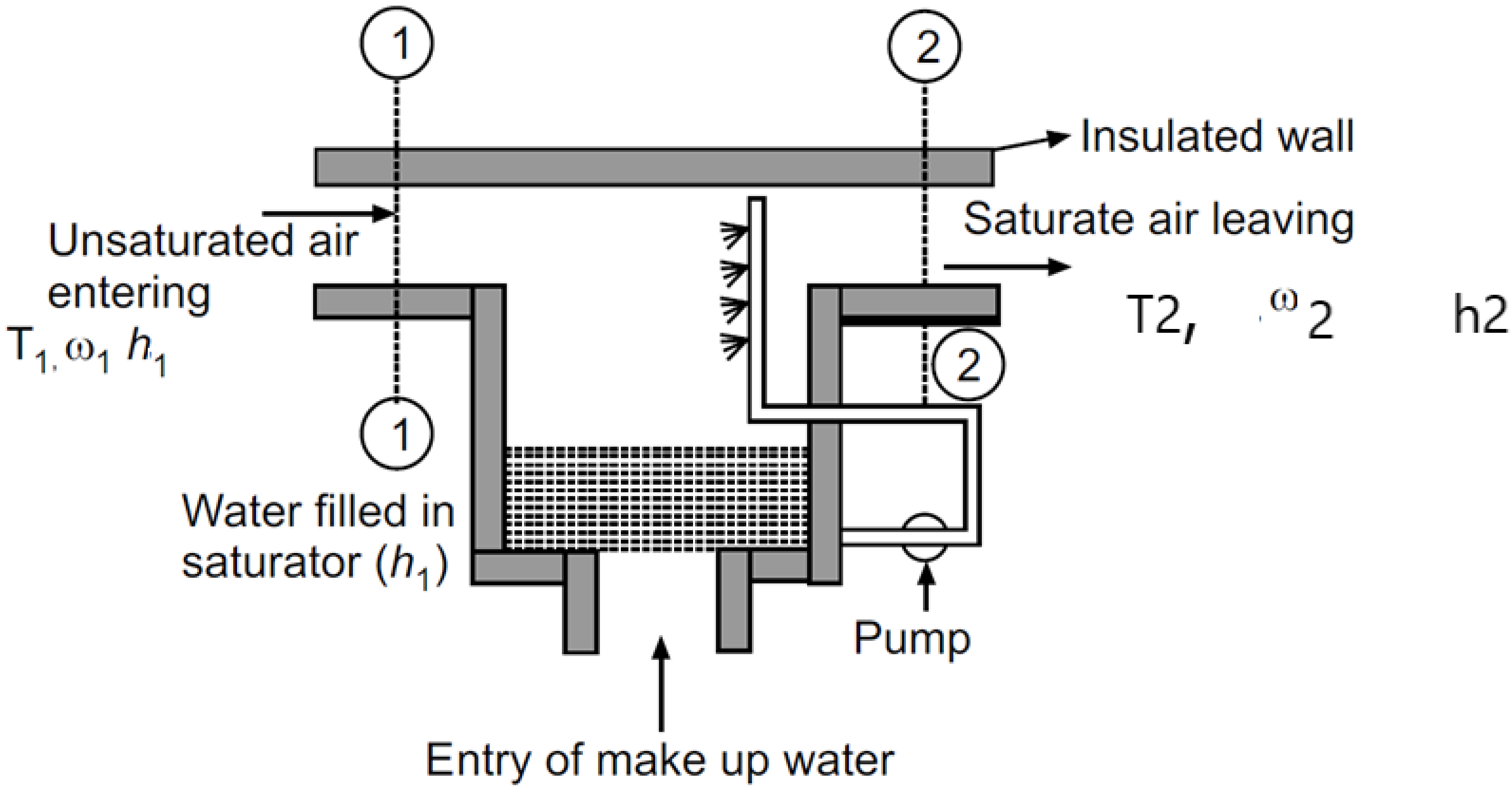
$h_a = C_{pa} T_{db}$ *or* $h_a = 1.005\ T_{db}$ (14)

h_v = specific enthalpy of water vapour per kg of moist air
T. temperature, kJ/kg
$h_v = 2500 + 1.88 T_{db}$ (15)

Therefore, $h = 1.005 T_{db} + \omega(2500 + 1.88 T_{db})$ kJ/kg of moist air (16)

Adiabatic saturation

An insulated device which is called the adiabatic saturator.



Adiabatic saturation

- Let us consider that ambient air steadily enters the adiabatic saturator. It passes through the water vapour sprayer.

- Now, assume that equilibrium is attained between the air and water droplets in the saturator. The saturated air and water vapour will leave the saturator, so that both the temperatures of the air and water vapour are the same.

- The temperature at which the mixture of air and water vapour leaving the saturator is equal to the water in the saturator, is called the adiabatic saturation temperature.

- Let us assume that the saturator is a control volume.

Mass balance:
The mass of air entering the saturator – m_{a1}
The mass of air leaving the saturator – m_{a2}
From conservation of mass;

The mass of air entering the separator = mass of air leaving the separator

So, $m_{a1} = m_{a2}$ (17)

The mass of water vapour in the entry air=m_{w1}
The mass of water consumed from the make up water=m_{ws}
The mass of water vapour in the exit air=m_{w2}

$$m_{w2} = m_{w1} + m_{ws} \tag{18}$$

Energy balance:

(Enthalpy of air)$_2$ = [Enthalpy of air]$_1$ + Enthalpy of make up water

$$m_2 h_2 = m_1\, h_1 + \mathrm{m_w h_w} \qquad (19)$$

$h_1 = h_{a1} + \omega_1 h_{w1}$

$h_2 = h_{a2} + \omega_2 h_{w2}$

$$m_1(h_{a1}+\omega_1 h_{w1}) + m_w h_w = m_2(h_{a2}+\omega_2 h_{w2}) \qquad (20)$$

$m_2(h_2 - h_1) = m_1(\omega_2 - \omega_1)\, h_w$ $\qquad$ $(h_2 - h_1) = (\omega_2 - \omega_1)\, h_w$

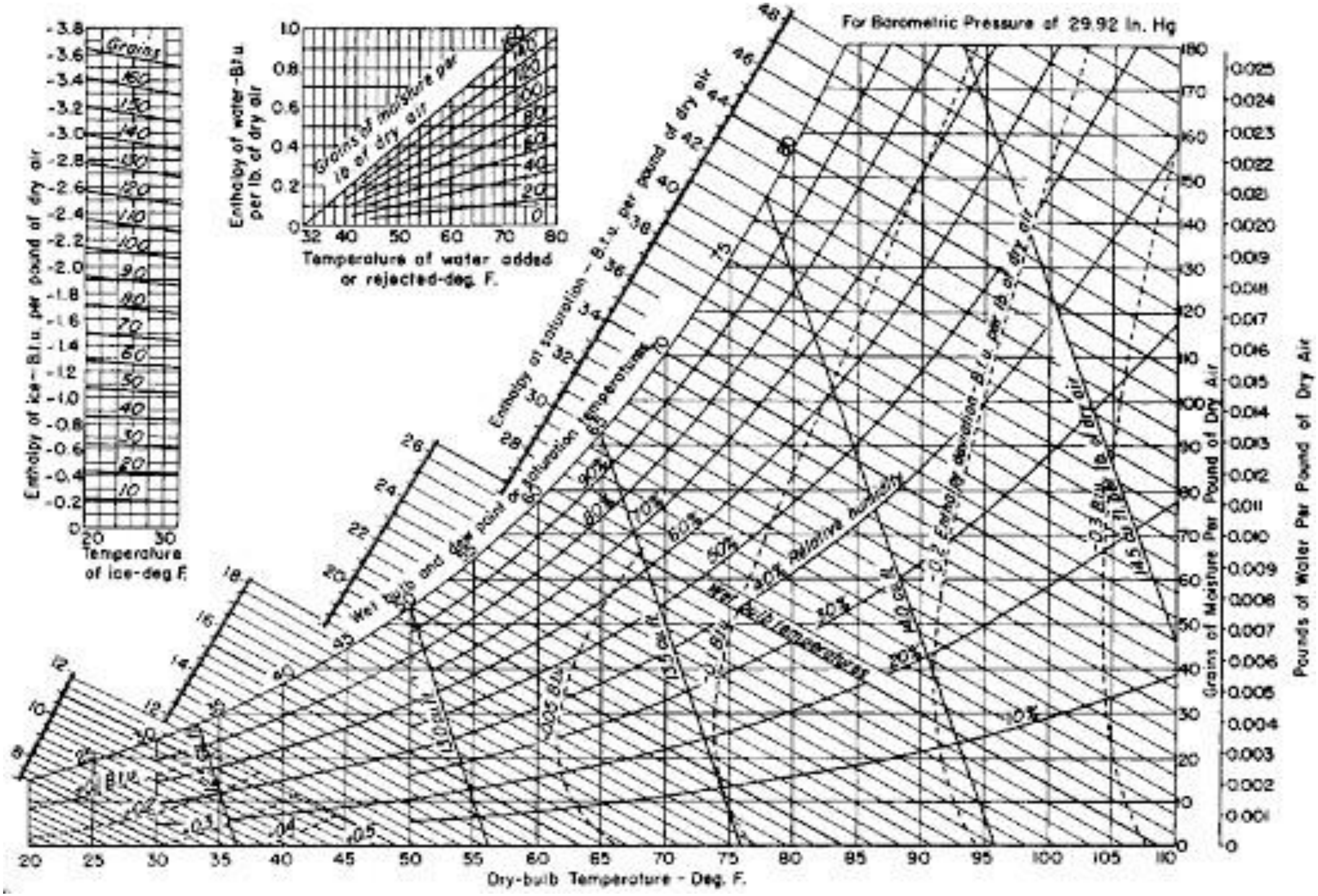
$$h_1 = C_{pa}\, t_1 + \omega_1 h_{w1} \qquad (21)$$

$$h_2 = C_{pa}\, t_2 + \omega_1 h_{w2} \qquad (22)$$

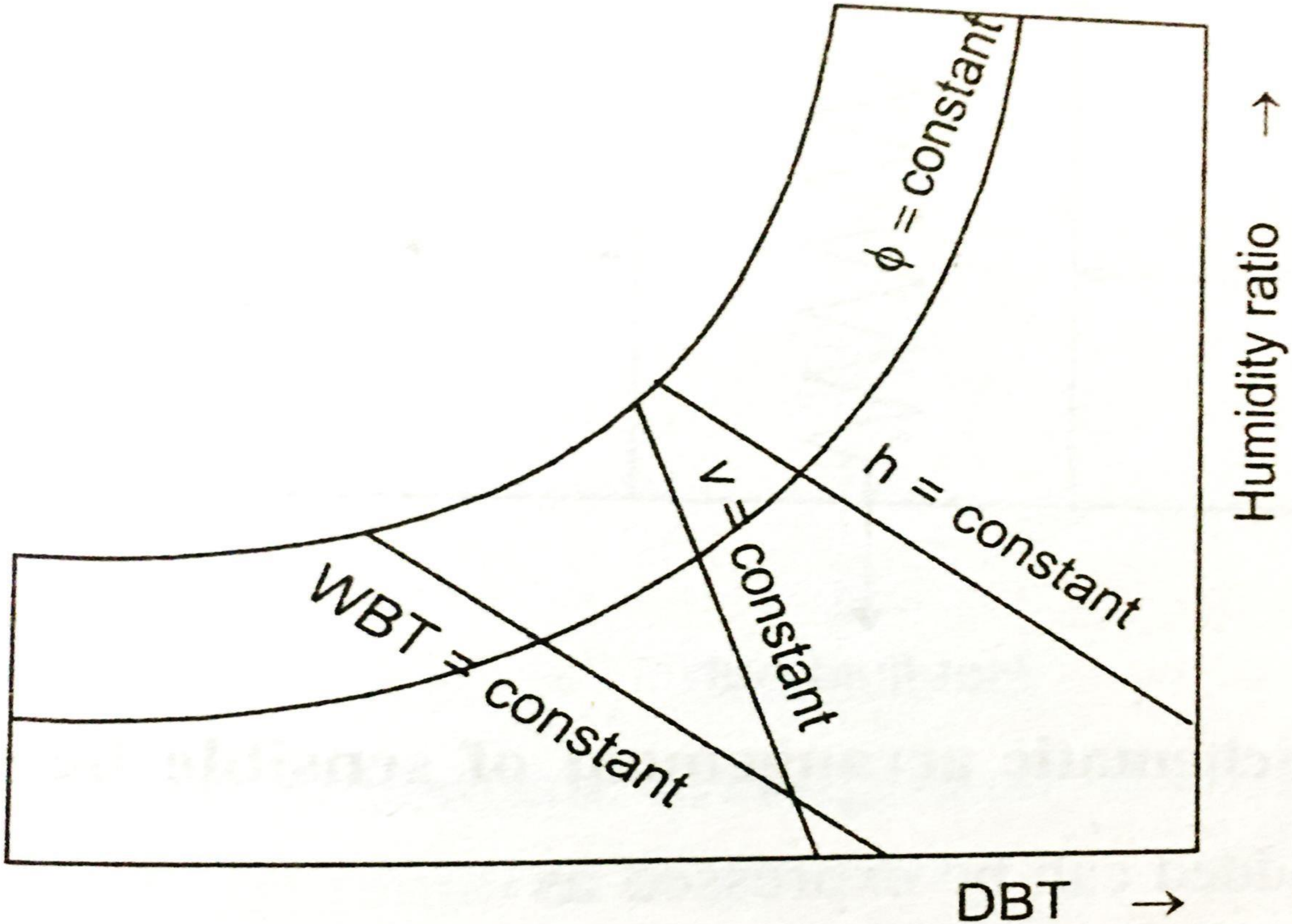
$$\omega_1 = [C_{pa}(t_2 - t_1) + \omega_1(h_{w2} - h_{w1})] \;/\; [h_{w1} - h_w] \qquad (23)$$

$\omega_1 = [C_{pa}(t_2 - t_1) + \omega_2(h_{w2} - h_w)] \;/\; (h_{w1} - h_w)$

The adiabatic saturation temperature is denoted as T_{as}. The adiabatic saturator may be used to determine the specific humidity and relative humidity of moist air. The temperature of the air entering the saturator, and the specific humidity of the air entering are the influencing parameters of the adiabatic saturation temperature.



Psychrometry chart



Psychrometry chart

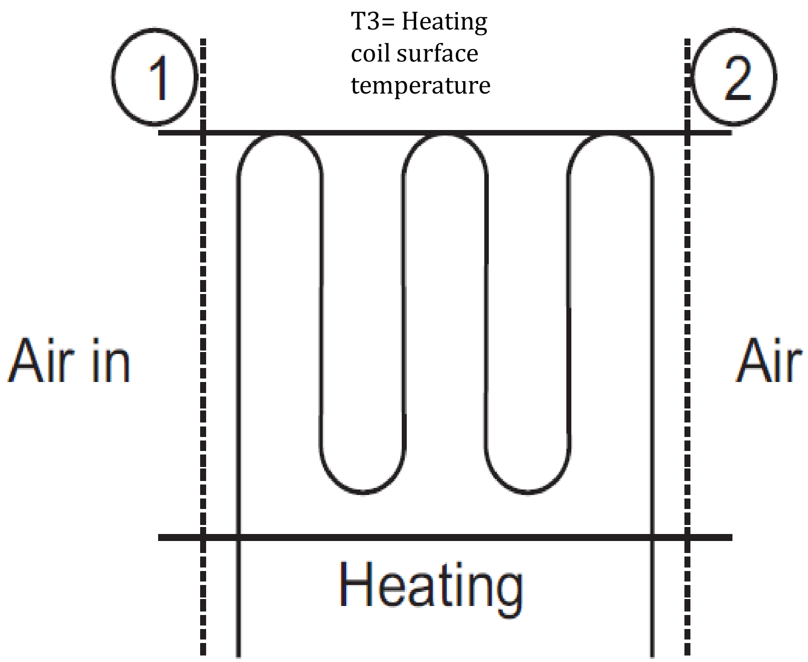
Psychrometry Processes

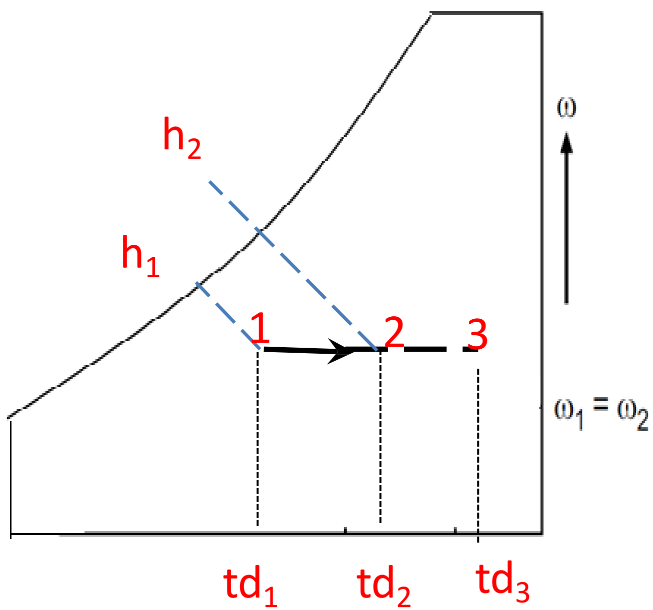
1. Sensible heating
2. Sensible cooling
3. Dehumidification by cooling
4. Cooling and dehumidification
5. Adiabatic humidification
6. Heating and humidification
7. Adiabatic mixing.

Sensible Heating

Sensible heating is the process in which the air is heated without any change in the specific humidity, but, the temperature changes.

The heating of air is done by passing the moist air over a heating coil, through which hot fluid or water is circulated .





The changes are the following;

Dry bulb temperature : Will increase
Wet bulb temperature : Will increase
Specific enthalpy : Will increase
Specific volume : Will increase
Relative humidity : Will decrease

The enthalpy of air during sensible heating is given by;

$$h = h_2 - h_1$$

$$h = C_{pm} (T_2 - T_1)$$

$$h = 1.002 \ (T_2 - T_1) \text{ kJ/kg}$$

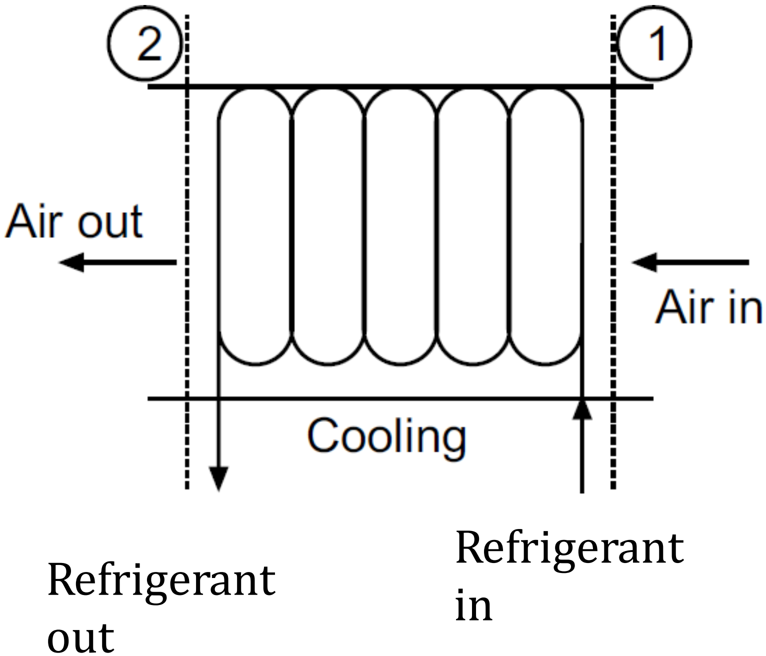
Bypass Factor

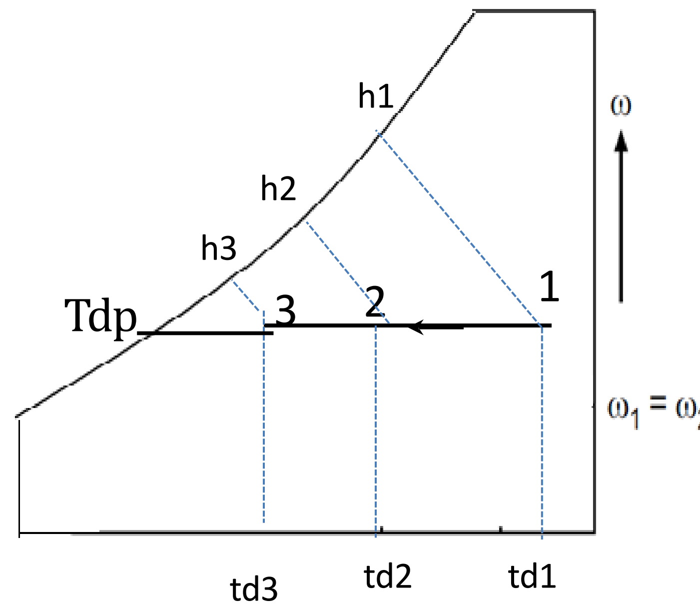
In the case of sensible heating, the bypass factor is given as:

$$\text{BPF} = \frac{(\text{Heating coil temp} - \text{Dry bulb temperature of air at the exit})}{\text{Heating coil temp} - \text{Dry bulb temperature of air at the inlet})}$$

$$\text{BPF} = \frac{(T_3 - T_2)}{(T_3 - T_1)}.$$

Sensible Cooling





The changes are the following;

Dry bulb temperature : Will decrease
Wet bulb temperature : Will decrease
Specific enthalpy : Will decrease
Specific volume : Will decrease
Relative humidity : Will increase

- The sensible cooling of air is done by passing the air over a cooling coil through which cold fluid or water would be circulated.

- When the temperature on a cooling surface is above or equal to the dew point temperature of the surrounding air, the air will be cooled without any change in the specific humidity.

- This process is called sensible cooling. In this process the sensible heat in the air is removed.

- The air gets cooled along a constant specific humidity.

Let us consider the following;
Temperature of air at the inlet = T_1
Temperature of air at the outlet = T_2
Temperature of the cooling coil = T_3
The temperature of air leaving at the outlet (T_2) is greater than the temperature of cooling coil (T_3).

Dry bulb temperature

Amount of heat rejected in the cooling process;

$h = h_1 - h_2$

$h = C_{pm}(T_1 - T_2)$

where C_{pm} = specific heat of moist air

= 1.002 kJ/kg K.

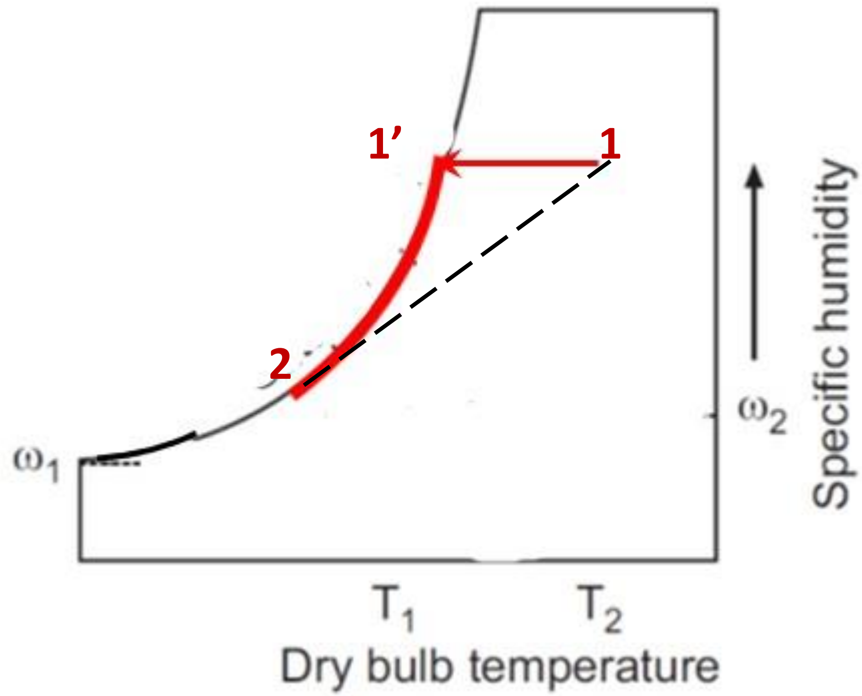
In the case of sensible cooling, the bypass factor is given as:

$$\text{BPF} = \frac{(\text{Dry bulb temperature of air at the exit} - \text{Coil temp.})}{(\text{Dry buld temperature of air at the inlet} - \text{Coil temp.})}$$

$$\text{BPF} = \frac{(T_2 - T_3)}{(T_1 - T_3)}$$

Where T_1 and T_2 are dry bulb temperatures of air at the inlet and the exit

Dehumidification by cooling



When moist air is cooled below its dew point temperature water vapour is removed from air.

Heat removal rate is given as;

$Q = m(h_1 - h_{1'}) + m(\omega_{1'} - \omega_2)h_f$

The changes are the following;

Dry bulb temperature : Will decrease
Wet bulb temperature : Will decrease
Specific enthalpy : Will decrease
Moisture content : Will decrease
Relative humidity : Will increase

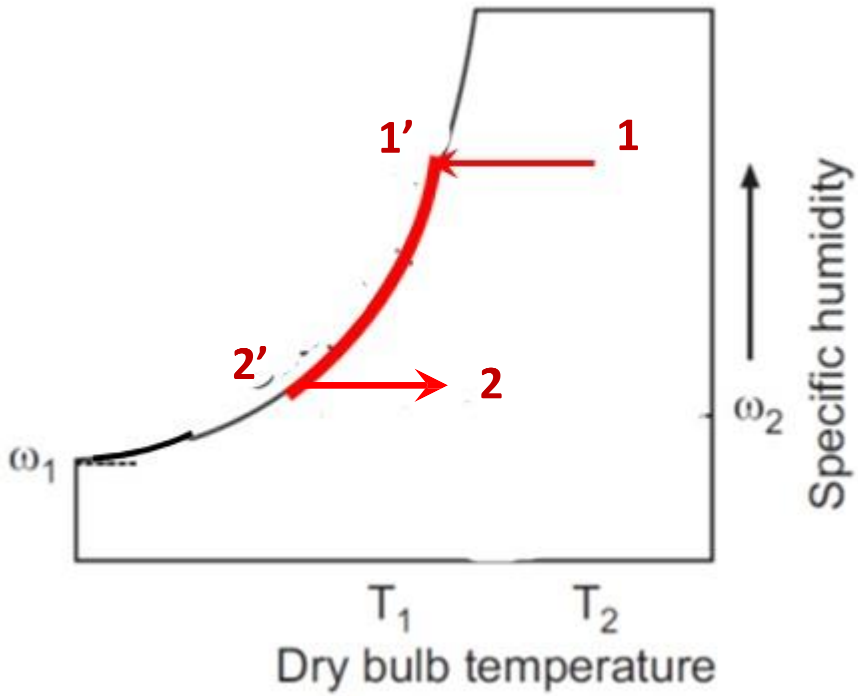
Sensible heat factor = Sensible heat / Total heat

Sensible heat factor = Sensible heat / Sensible heat+ latent heat

Sensible heat factor (SHF)= SH/ SH+LH

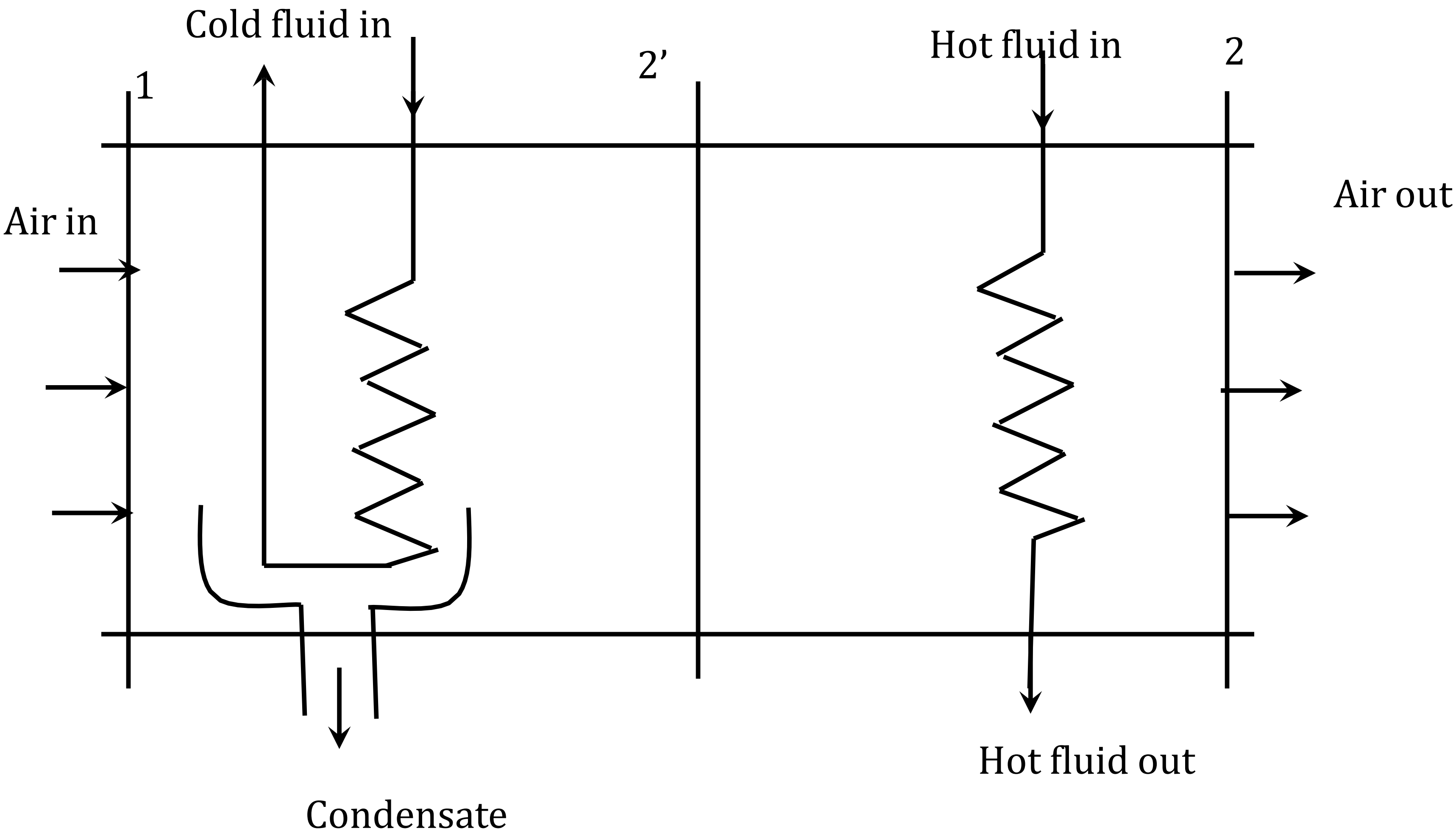
Sensible heat factor (SHF)= $(h_1-h_1')/(h_1-h_2)$

Cooling and dehumidification



Let us consider conditioning of air existing at state 1 and state 2 as shown in Figure. To remove the necessary quantity of moisture, air is cooled to a state 2'.

From this state it is heated sensibly to state 2. The schematic arrangement of a such a process is shown in Figure.



Heat load on the cooling coil is given as

$$Q = m(h_1 - h_2') + m(\omega_1 - \omega_2)h_f$$

Heat load on the heater is given as;

$$Q = m(h_2 - h_2')$$

Sensible heat factor = Sensible heat / Total heat

Sensible heat factor = Sensible heat / Sensible heat+ latent heat

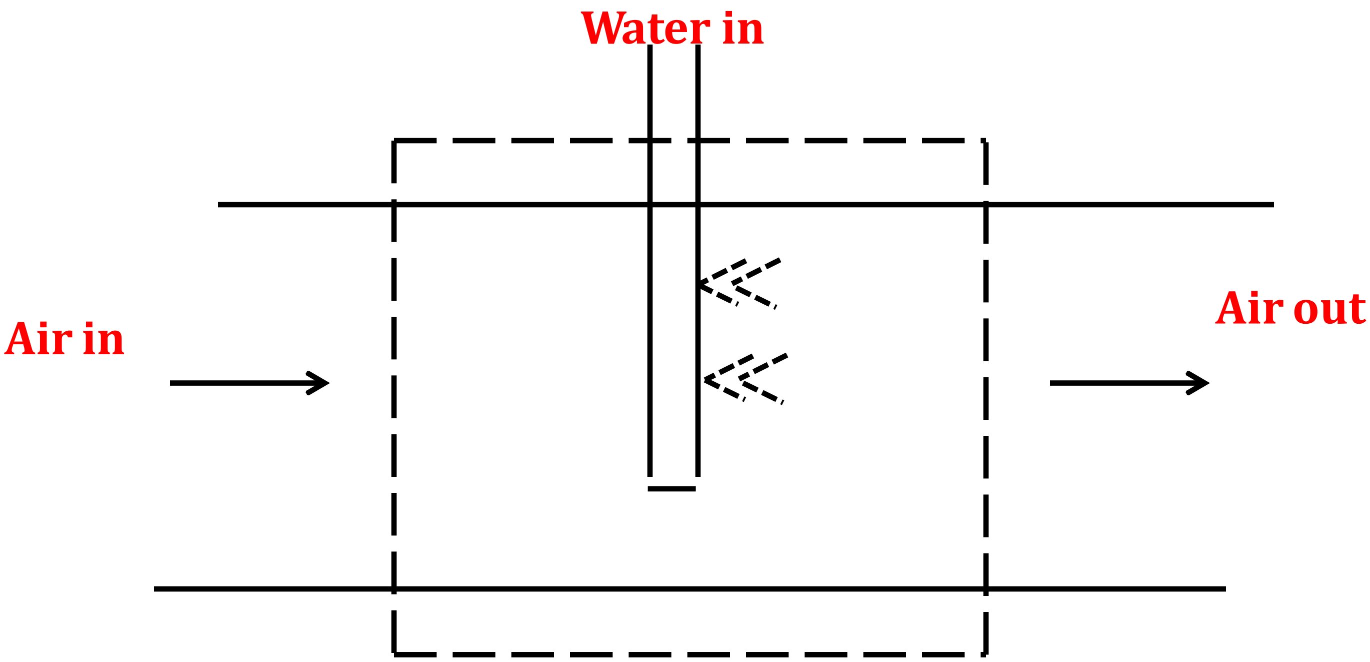
Sensible heat factor (SHF)= SH/ SH+LH

Sensible heat factor (SHF)= $(h_1-h_2)/ (h_1-h_1')+(h_1'-h_2)$

Sensible heat factor (SHF)= $(h_1-h_2)/ (h_1-h_2)$

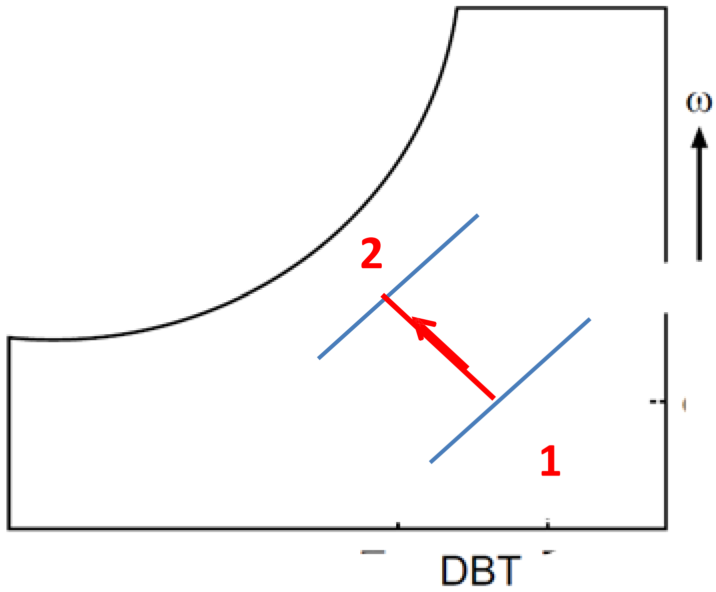
Adiabatic humidification

Increase in moisture content of air is known as humidification. If humidification is carried out adiabatically, the energy required for evaporation must be supplied by the entering air. Consequently, the dry bulb temperature of air must decrease.



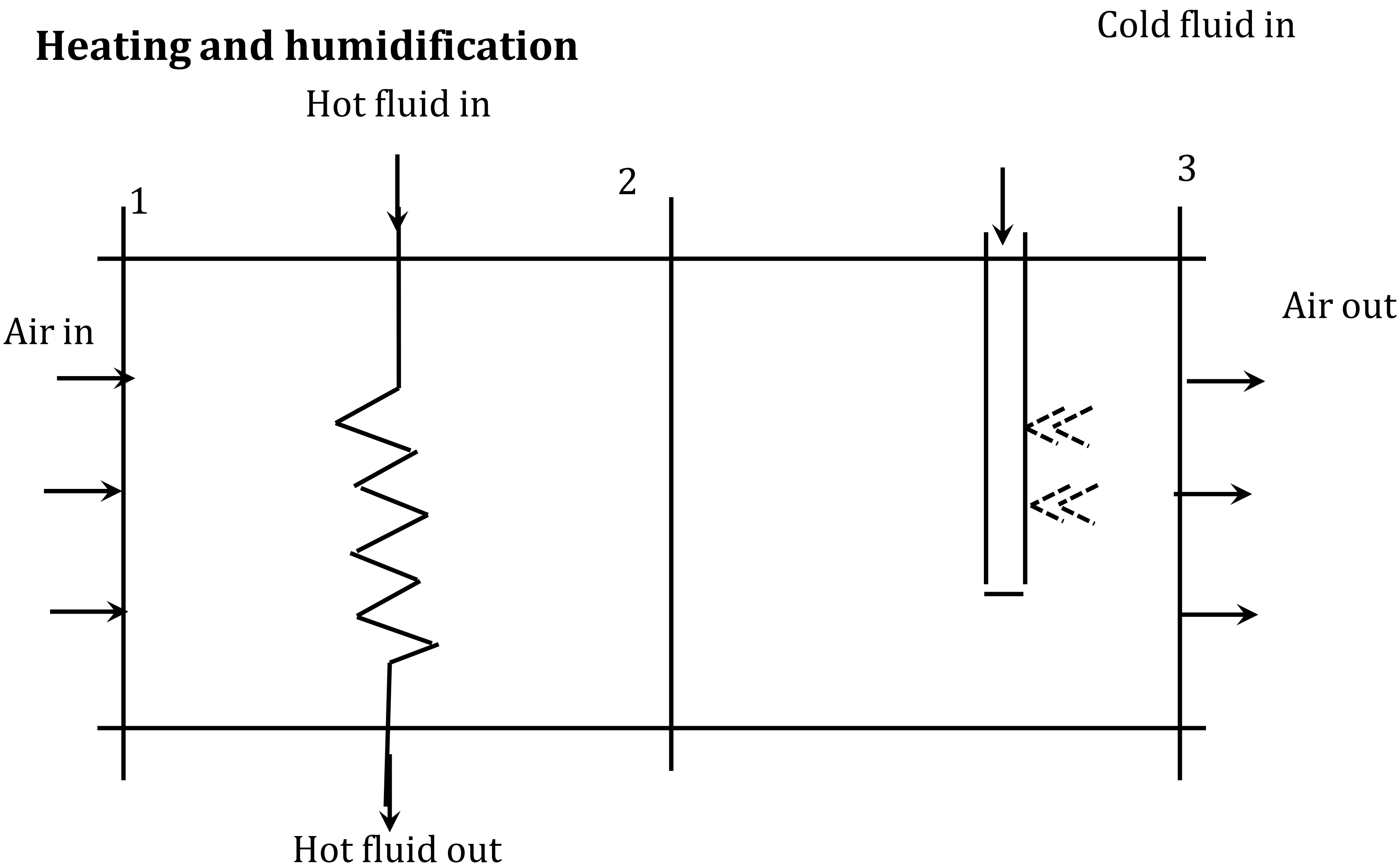
On the basis of unit mass of moist air, the energy equation is given as

$$h_1+m(\omega_2- \omega_1)h_f = h_2$$



In comparison with the magnitude of h_1 and h_2 , $(\omega_2- \omega_1)h_f$ is negligible. Therefore, it can be assumed that the specific enthalpy of air water vapour mixture remains constant during adiabatic humidification process.

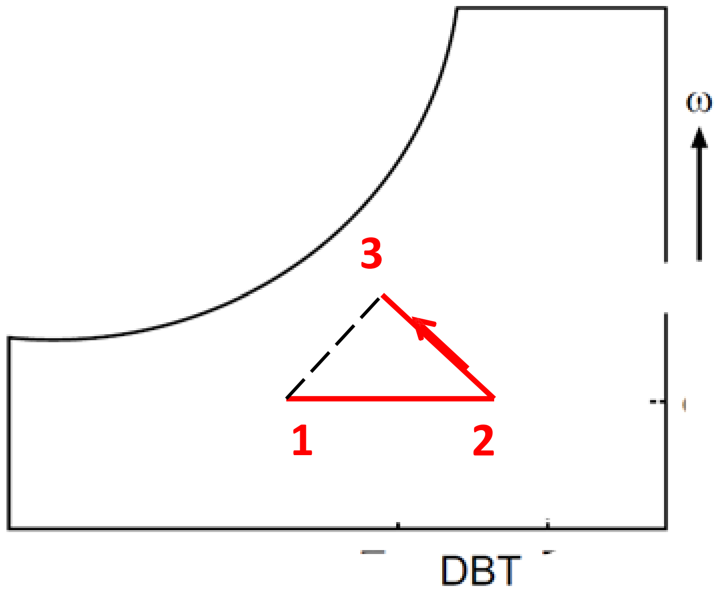
Heating and humidification



Moisture content and temperature are considerably less in winter. Air is to be heated and humidified in this condition.

On the basis of unit mass of moist air, the energy equation is given as

$Q = m(h_2 - h_1)$



Mass of water to be added by the sprayer

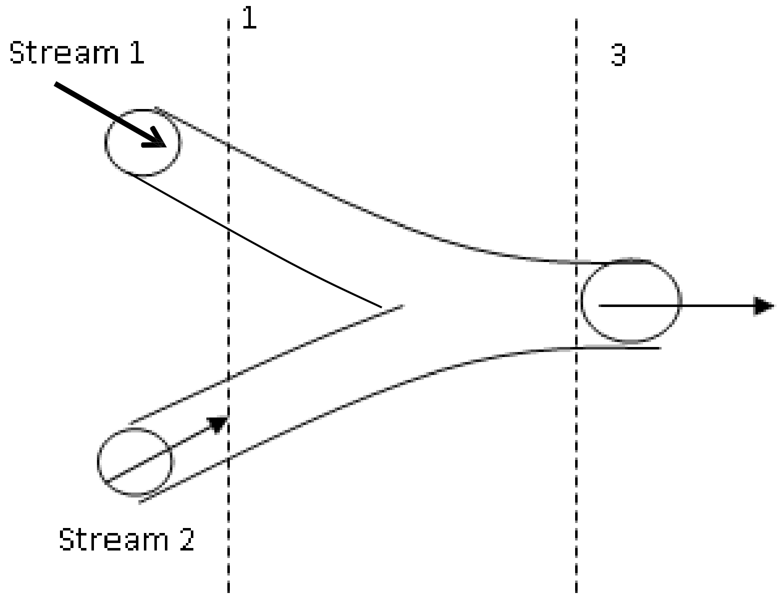
$(m_w) = m_a(\omega_3 - \omega_2)$

Sensible heat factor = Sensible heat / Sensible heat+ latent heat

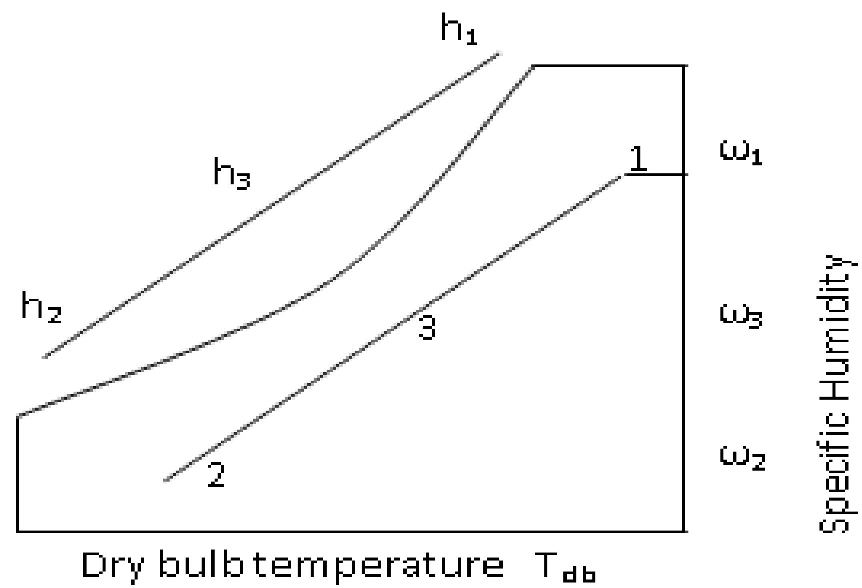
Sensible heat factor = $h_2 - h_3 / h_3 - h_1$

Mixing of air streams

In the psychometrics, there is an another important process considered which is known and as adiabatic mixing.



Mixing of two different air streams



Mixingof air streams in Psychormetry chart

The adiabatic process in which more than a stream of air are mixed together. The properties of the streams of air are different.

The specific application of such mixing of air stream is found in air conditioning, cold storage etc. Let us consider the air stream (1) enters through valve A, which has mass (m_1) specific enthalpy (h_1) and humidity ratio (ω_1) .

Similarly another air stream (2) enters through valve B. Stream (2) has similar properties m_2, h_2 and ω_2.

The mass of mixed air stream is m_3. The specific enthalpy and humidity of air after mixing were h_3 and ω_3 respectively.

Let us consider that two different masses of air are to be mixed.

mass of stream 1 = m_1

mass of stream 2 = m_2

mass of mixed stream 1 & 2 = m_3

Specific enthalpy of stream 1 = h_1

Specific enthalpy of stream 2 = h_2

Specific enthalpy of mixed stream 1 & 2 = h_3

mass balance of stream : $m_1 + m_2 = m_3$

Energy balance of stream : $m_1h_1 + m_2h_2 = m_3 h_3$

mass balance of water vapour : $m_1\omega_1 + m_2\omega_2 = m_3\omega_3$

$$m_1\omega_1 + m_2\omega_2 = (m_1 + m_2)\,\omega_3$$

Writing conservation of mass;

Total mass entering the system = Total mass leaving the system

$$m_1 + m_2 = m_3$$

Writing conservation of water vapour;

Total mass of water vapour

entering the systems = Total mass of water vapour leaving the system

$$m_1{*}\,\omega_1 + m_2{*}\,\omega_2 = m_3{*}\,\omega_3$$

Writing energy balance equation;

Energy entering before mixing of stream =Energy leaving after mixing of stream.

$$m_1h_1 + m_2h_2 = m_3h_3$$

$$\frac{m_1}{m_2} = \frac{h_3-h_2}{h_1-h_3}$$

Similarly we get

$$\frac{m_1}{m_2} = \frac{\omega_3-\omega_2}{\omega_1-\omega_3}$$

For determining dew point temperature:
Find partial pressure of water vapour (pv) from the steam tables with respect to wet bulb temperature.

Then find the partial pressure of water vapour using carrier gas equation.

Read the temperature corresponding to partial pressure of water vapour.

For relative humidity calculations;
To find saturation pressure ps, dry bulb temperature has to be considered.

Problem 1.The following observations were made during a testing of moist air

Dry bulb temperature T_{db}	=	29°C
Dew point temperature T_{dp}	=	15°C
Total pressure	=	1 bar

Determine the relative humidity and degree of saturation

Given

T_{db} = 29°C (or) 302 K

T_{dp} = 15°C (or) 288 K

Get the saturation pressure at T_{db} and T_{dp} from steam tables.

At 29°C	p_s	=	0.04004 bar
At 15° C	p_v	=	0.01704 bar

$$\text{Relative humidity} = \frac{p_v}{p_s} = \frac{0.01704}{0.04004}$$

$$= 0.4255$$

$$\text{Degree of saturation} = \mu = \frac{P_v}{P - P_v} \times \frac{P - P_s}{P_s}$$

$$= \frac{0.01704}{1 - 0.01704} \times \frac{1 - 0.04004}{0.04004}$$

$$= 0.4155.$$ kg/kg of dry air

2. A thermometer measures the dry bulb temperature of atmospheric air as 25°C. A wet bulb thermometer measures the wet bulb temperature of atmospheric air as 19°C. The total pressure is 1 bar. Calculate (i) the partial pressure of water vapour (ii) relative humidity (iii) specific humidity (iv) saturation ratio.

Given:

T_{db} = 25°C (or) 298 K

T_{wb} = 19°C (or) 292 K

Total pressure p = 1 bar

From steam tables, the saturation pressure of vapour is obtained corresponding to the wet bulb temp T_{wb} = 19 °C

p_s @ T_{wb} = 0.0316 bar

Carrier equation is used to calculate partial pressure of water vapour, corresponding to dry and wet bulb temperature

Carrier equation is used to calculate partial pressure of water vapour corresponding to dry and wet bulb temperature;

$$P_v = P_s - \frac{(P - P_s)(T_{db} - T_{wb})1.8}{2800 - 1.3(T_{db} - 32)}$$

$P_v = 0.02796$ bar

Dew point temperature;

It is understood that pressure of water vapour in the air is equal to the saturation pressure of vapour at dew point temperature. Therefore, corresponding to the pressure of water vapour (P_v= 0.02796), the temperature is obtained from steam table is T_{dp} = 22.8 ^oC.

Relative humidity (ϕ) = P_v/P_s

$\phi = 0.02796/0.03169$

$\phi = 0.8825$ or 88.25%

Specific humidity (ω) = $0.622\ P_v/\ P-P_v$

$\omega = 0.622\ P_v/\ P-P_v$

$\omega = 0.622\text{x}\ 0.02968/\ 1.0-\ 0.02968$
$\omega = 0.01789$ kg of water vapour/kg of air

Saturation ratio (μ) = $[P_v/\ P-P_v]\ \text{x}\ [P-P_s/\ P_s]$

Saturation ratio (μ) = 0.8788 kg/kg of air

3. A sling psychrometer reads the values of dry bulb and wet bulb temperature as T_{db} = 28°C, T_{wb}=18°C. The pressure measured is 740 mm of Hg. Calculate the following

(i) specific humidity (ii) relative humidity at dry bulb temp (iii) dew point temperature

Given:

Ambient pressure p = (740 / 760) x 1.013

Total pressure p = 0.9863 bar

T_{db} = 28°C = 301 K ; p_s = 0.03782 bar

T_{wb} = 18°C = 291 K

$$P_v = P_s - \frac{(P - P_s)(T_{db} - T_{wb})1.8}{2800 - 1.3(T_{db} - 32)}$$

P_v =0.03173 bar

Relative humidity (ϕ) = P_v/P_s

ϕ = 0.03173/0.03782

ϕ = 0.839 or 83.9 %

Specific humidity (ω) = 0.622 P_v/ P-P_v

ω = 0.622 P_v/ P-P_v
ω = 0.0206 kg of water vapour/kg of air

Saturation ratio (μ) = [P_v/ P-P_v] x [P-P_s/ P_s]

Saturation ratio (μ) = 0.8366 kg/kg of air

At P_v =0.03173 bar, the corresponding temperature obtained from the table is 25.03 ˚C .

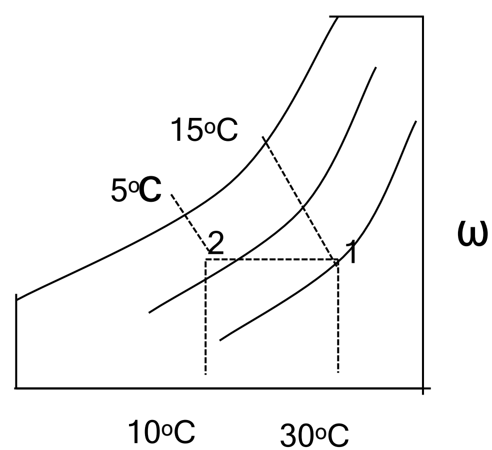
Problem 4 : The moist air with dry bulb temperature 30°C and a wet bulb temperature 15°C is cooled to 10°C without affecting the moisture content. Determine the following in the sensible cooling process.

a. Wet bulb temperature after cooling

b. Relative humidity after cooling

Given

Dry bulb temperature	T_{db1} =	30°C	=303 K
Wet bulb temperature	T_{wb1} =	15°C	= 288K
Dry bulb temperature after cooling	T_{db2} =	10°C	=283 K



a. Relative humidity after cooling

The wet bulb temperature at point 2 is 5 °C.

Locate dry bulb and wet bulb temperature in the chart at t_{db1} and t_{wb1} respectively and mark the point 1. From point 1 draw a horizontal line to intersect the curve at point 2 where the dry bulb temperature lies 10°C

b. Relative humidity before cooling :

Find out the relative humidity curve which is nearer to point 1.

$$\Phi_1 = 16\,\%$$

Relative humidity after cooling corresponding to point 2, the relative humidity from the psychometric chart is $\Phi_2 = 50\,\%$

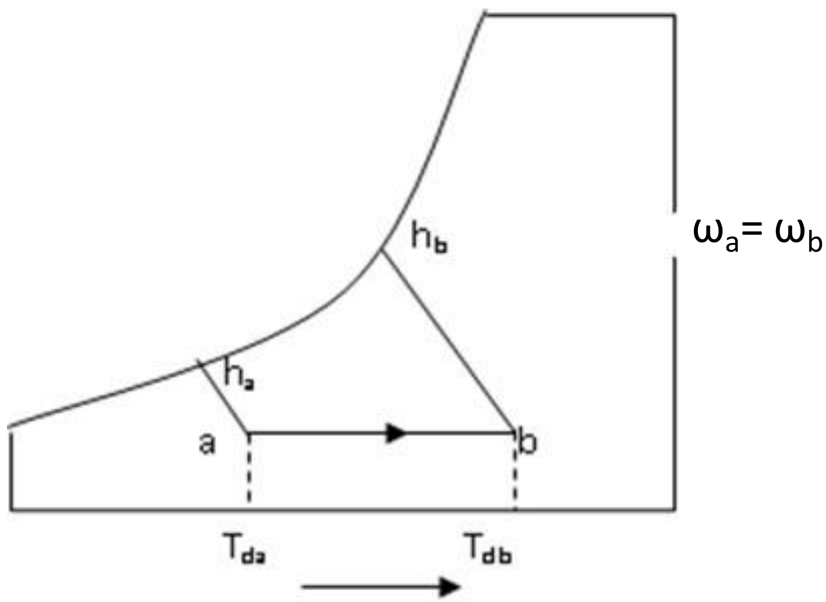
Problem 5. The moist air at 750mm of Hg is heated up by a heating coil. The following data were recorded in the heating process.

Dry bulb temperature before heating	T_{db1}	=	20°C
Dry bulb temp after heating	T_{db2}	=	35°C
Wet bulb temperature	T_{wb1}	=	15°C
By pass factor of heating coil	(BPF)	=	0.4

Calculate (i) Heating coil temperature (ii) Wet bulb temperature of air leaving the coil (iii) Relative humidity of air after heating. (iv) Sensible heat added per kg of air.

P=750mm of Hg

T_{db1}=20°C T_{db2}=35°C BPF =0.4



(i)Heating coil temperature:

$$\text{By pass factor} = \frac{T_{db3} - T_{db2}}{T_{db3} - T_{db1}}$$

$$0.4 = \frac{T_{db3} - 35}{T_{db3} - 20}$$

$$0.4\,(T_{db3} - 20) = (T_{db3} - 35)$$

$$0.4\,(T_{db3} - 10) = T_{db3} - 35$$

$$0.6\,T_{db3} = 27$$

$$T_{db3} = \frac{27}{0.6}$$

$$= 45.0\ ^{\circ}C$$

ii. Wet bulb temperature:

Locate the point 1 corresponding to dry bulb temperature, T_{b1}, T_{db2}, 35°C at point 2.
The wet bulb temperature corresponding to point 2 is T_{wb2} = 19°C

iii. Relative humidity of air after heating:

From the psychometric chart, the relative humidity of air after heating is obtained at point

$$\varphi_2 = 25\ \%$$

From psychometry tables the specific enthalpy values h1 and h2 are obtained

$$h_1 = 41\ \text{kJ/kg}$$
$$h_2 = 52\ \text{kJ/kg.}$$

$$\text{Added } h_2 - h_1 = 57\text{-}41$$
$$= 16\ \text{kJ/kg}$$

Problem 6. In a combined heating and humidification process, moist air enters heating coil with the dry bulb temperature 20°C and 30% R.H. After the process the dry bulb temperature and the RH of air were found to be 40°C and 55% RH. The air passes through the heating coil at the rate of 350 m^3/s. Calculate the following

- Moisture added to the air
- Heat added to the air if it enters the processor at a rate of 350 m^3/s.

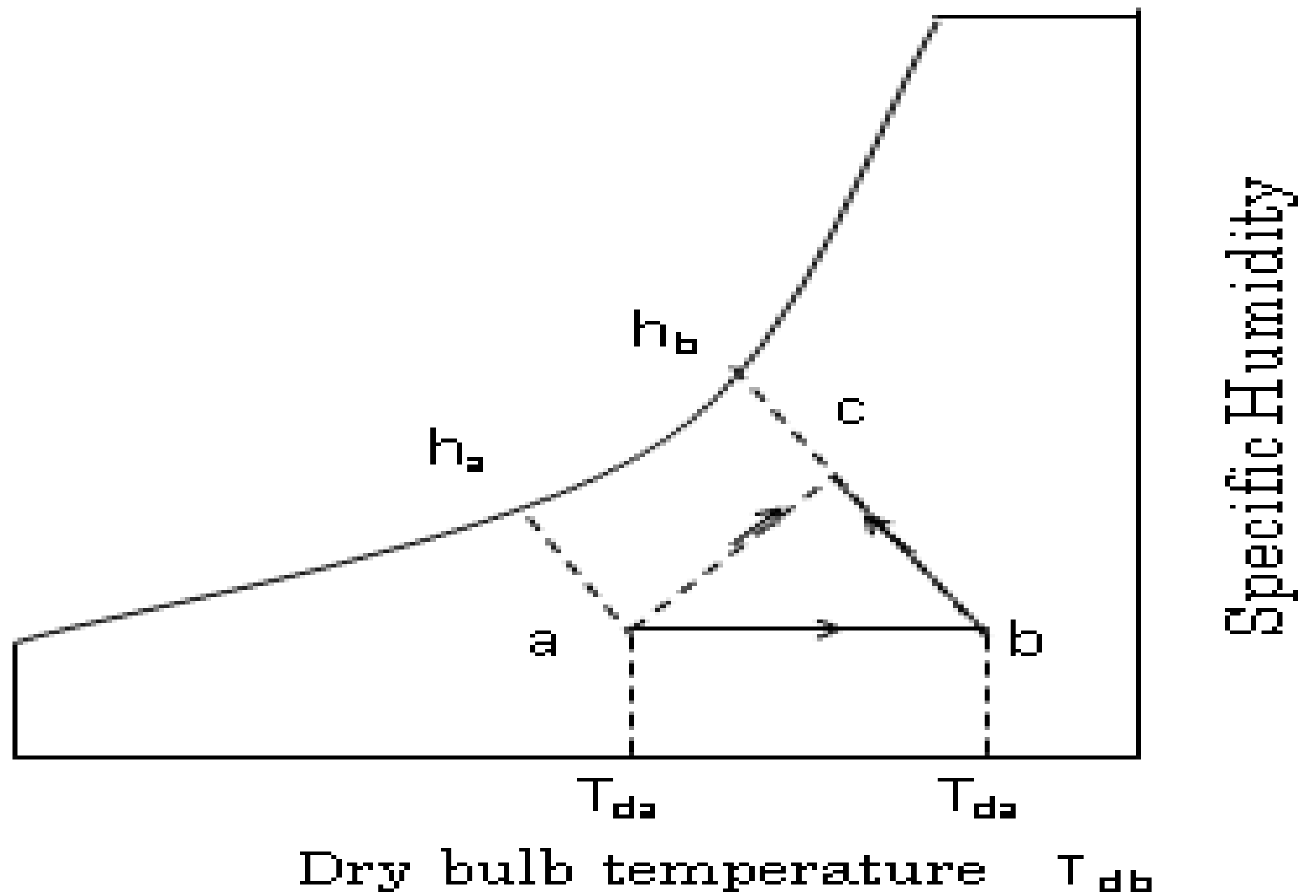
Given:-

T_{db1} = 20°C Φ_1 = 30 %

T_{db2} = 40°C Φ_2 = 55 %

Locate point 1 corresponding to T_{db1} = 20 °C and RH = 30%

Similarly locate point 2 correspondent to T_{db2} = 40°C and RH = 55% in the psychrometric chart.



h_b
c
h_a
a
b
T_da
T_da
Dry bulb temperature
T_db
Specific Humidity

Heat added during the process:

To find the mass flow rate of air we should know the specific volume of air. The specific volume of air is obtained from the chart corresponding to T_{db1} = 20°C.

$$\upsilon_1 = 0.635 \text{ m}^3/\text{kg}$$

$$\text{Therefore mass flow rate of air} = \frac{\text{Volume flow rate of air}}{\text{Specific volume of air}}$$

$$m = \frac{350}{\upsilon_1}$$

$$= \frac{350}{0.835} \text{ kg/sec}$$

Heat added during the process $=m(h_2-h_1)$ $=419.16$

Specific enthalpy at point 1 and 2 are obtained corresponding to T_{db1}, and T_{db2} respectively, from psychometric chart.

$h_1 = 32$ kJ/kg

$h_2 = 107$ kJ/kg

$$\text{Heat added to air per hour} = \frac{m(h_2-h_1)}{3600}$$

$$= \frac{419.16\ (107 - 32)}{60}$$

$$= 523.95\ kJ/kg$$

Sensible heat factor:

$$SHF = \frac{h_i - h_1}{h_2 - h_1}$$

Problem 7. 39.6 m^3 /min of a mixture of re-circulated room air and outdoor air enters cooling coil at 31°C dry bulb temperature and 18.5°C wet bulb temperature. 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 by-pass factor.