

**24AG301- APPLIED THERMODYNAMICS AND THERMAL
SYSTEMS IN AGRICULTURAL ENGINEERING**

**UNIT 4 PSYCHROMETRICS AND CONTROLLED
ATMOSPHERE APPLICATIONS**

HANDLED BY

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UNIT IV - PSYCHROMETRICS AND CONTROLLED ATMOSPHERE APPLICATIONS

4.1 Introduction

The science dealing with properties of air and vapour mixture is known as psychrometry. The knowledge of fundamental laws of gaseous mixture is necessary for understanding psychrometry.

PSYCHROMETRIC PROPERTIES:

The definitions of different psychrometric properties of air are given below :

a) Dry air

The dry air is considered as a mixture of nitrogen and oxygen and small percentages of other gases. The volumetric composition of air is 79% nitrogen and 21 % oxygen and the molecular weight of dry air is taken as 29 approximately .

b) Moist air

It is a mixture of dry air and water vapour . The quantity of water vapour present in the air depends upon the temperature of the air and its quantity may change from zero to maximum (the maximum amount depends on saturation condition).

c) Water vapour

The moisture present in the form of vapour is known as water vapour. The relative humidity of air is an important factor in all air - conditioning systems.

d) Dry bulb temperature

The temperature of air measured by ordinary thermometer is known as dry bulb temperature (dbt) . . .

e) Wet-bulb temperature

The temperature measured by the thermometer when its bulb is covered with wet cloth and is exposed to a current of moving air is known as wet bulb temperature (wbt) . The difference between the dry bulb and wet bulb temperature is known as wet bulb depression (wbd) . Wet bulb depression becomes zero when the air is fully saturated.

f) Dew Point temperature

The temperature of the air is reduced by continuous cooling than the water vapour in the air will start condensing at a particular temperature. The temperature at which the condensing starts is known as Dew point temperature. Dew point temperature is equal to the steam table saturation temperature corresponding to the actual partial pressure of the water vapour in the air . The difference between dry bulb temperature and dew point temperature is known as dew point depression (dpt).

g) Specific humidity (Humidity ratio)

It is defined as the mass of water vapour present per kg of dry air . It is expressed as g/kg dry air or kg/ kg dry air.

h) Absolute humidity

The weight of water vapour present in unit volume of air is known as absolute humidity.

i) Degree of Saturation

The degree of saturation is defined as the ratio of mass of water vapour associated with unit mass of dry air to mass of water vapour associated with unit mass of dry air saturated at the same temperature.

j) Relative Humidity

The relative humidity is defined as the ratio of actual mass of water vapour in a given volume to the mass of water vapour if the air is fully saturated at the same temperature .

k) Sensible Heat of air

The quantity of heat which can be measured by measuring the dry bulb temperature of the air is known as sensible heat of the air.

i) Total heat of air

The total heat of the humid air is the sum of the sensible heat of the dry air and sensible and latent heat of water vapour associated with dry air.

m) Humid specific volume:

The volume of the air per kg of dry air in the mixture is known as humid specific volume of the air. It is expressed as m³/kg dry air.

DEGREE OF SATURATION (μ)

Where, ω_s is the specific humidity of air when air is fully saturated.

$$\mu = \frac{\text{mass of water vapour in unit mass of dry air}}{\text{mass of water vapour in saturated unit mass of dry air}} = \frac{\omega}{\omega_s}$$

Where, ω_s is the specific humidity of air when air is fully saturated.

$$\therefore \mu = \frac{0.622 \left(\frac{P_v}{P - P_v} \right)}{0.622 \left(\frac{P_{vs}}{P - P_{vs}} \right)} = \frac{P_v}{P_{vs}} \left(\frac{P - P_{vs}}{P - P_v} \right) = \frac{P_v}{P_{vs}} \left[\frac{1 - \frac{P_{vs}}{P}}{1 - \frac{P_v}{P}} \right]$$

Where, P_{vs} is the partial pressure of water vapour when the air is fully saturated at the same temperature of the air. This can be calculated from steam table corresponding to the dry-bulb temperature of the air.

26.4. RELATIVE HUMIDITY (ϕ)

As per the definition of relative humidity,

As per the definition of relative humidity,

$$\phi = \frac{\text{mass of water vapour in a given volume}}{\text{mass of water vapour in same volume if saturated at the same temperature}}$$

$$= \frac{m}{m_s} = \frac{\frac{P_v V}{R T}}{\frac{P_{vs} V}{R T}} = \frac{P_v}{P_{vs}}$$

Relative humidity plays very important role in comfort air conditioning and deciding the performance of many unit operations such as drying, evaporative cooling etc.

ENTHALPY OF MOIST AIR

The enthalpy of moist air is the sum of the enthalpy of one dry air and the enthalpy of water vapour associated with one kg dry air.

$$\begin{aligned} \text{Enthalpy of moist air} &= \text{Enthalpy of one kg of dry air} + \text{Enthalpy of water vapour associated with one kg of dry air.} \end{aligned}$$

Thus,

$$h = h_a + \omega h_v$$

Where, h_a is the enthalpy of dry air and ωh_v is the enthalpy of water vapour associated with one kg of dry air.

$$h = C_{pa}(T_{db} - 0) + \omega [C_{pv}T_{dp} + (h_{fg})_{dp} + C_{pv}(T_{db} - T_{dp})]$$

Where, C_{pa} = specific heat of dry air, kJ/kg K

C_{pv} = specific heat of water

T_{db} = Dry bulb temperature of air

T_{dp} = Dew point temperature of air

$(h_{fg})_{dp}$ = Latent heat of vaporization at dpt

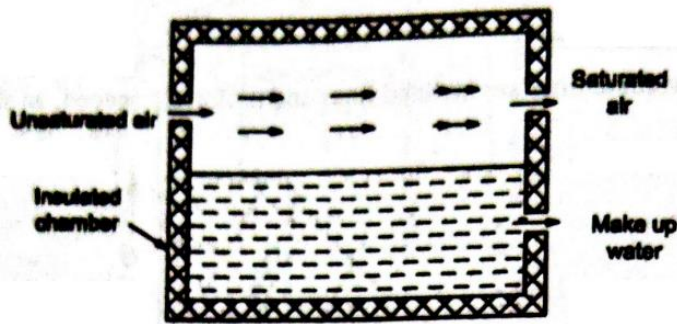
C_{pv} = Specific heat of superheated vapour

The values of C_{pv} and C_{pa} used in deriving the equation are 4.186 kJ/kg K and 1.88 kJ/kg K respectively. The value of C_{pa} is taken as 1.005 kJ/kg K.

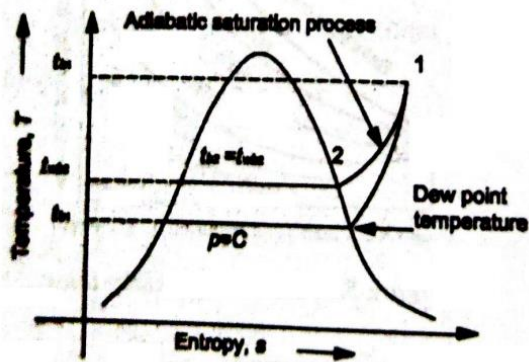
$$\begin{aligned} \therefore h &= 1(T_{db} - 0) + \omega [4.18T_{dp} + (h_{fg})_{dp} + 1.88(T_{db} - T_{dp})] \\ &= T_{db} + \omega [h_{fg})_{dp} + 1.88T_{db} + 2.3T_{dp}] \\ &= T_{db} + \omega [(h_{fg})_{dp} + 1.88T_{db}] \quad \text{kJ/kg dry air} \\ &= 1.005T_{db} + \omega [2501 + 1.88T_{db}] \quad \text{kJ/kg dry air} \end{aligned}$$

Adiabatic saturation process

When unsaturated air flows over a long sheet of water in an insulated chamber, the water is evaporated and specific humidity of air is increased. Both air and water are cooled as the evaporation takes place. The process continues until the energy transformed from the air to the water is equal to the energy required to vaporize the water.



When this point is reached, thermal equilibrium exists with respect to the water, air and water vapour, the air attains consequently the saturation point. The equilibrium temperature is called *adiabatic saturation temperature* of thermodynamic wet bulb temperature. The make-up water is introduced at this temperature to keep the water level constant. The adiabatic cooling process is shown in Figure for the vapour in the air-vapour mixture. Although the total pressure of the mixture is constant, the partial pressure of vapour increases corresponding to the adiabatic saturation temperature.



Vapour initially t_{bd1} is cooled adiabatically to t_{bd2} which is equal to adiabatic saturation temperature t_{wb2} . WBT lies between DBT and DPT. System is insulated and no work is done.

$$Gh_{a_1} + m_1h_{w_1} + (m_2 - m_1)h_{f_2} = Gh_{a_2} + m_2h_{w_2}$$

where

$(m_2 - m_1)$ be the mass of water added

h_{f_2} be the enthalpy of liquid water at $t_2 = t_{wb2}$

h_a is the specific enthalpy of dry air

h_w is the specific enthalpy of water vapour in air.

Dividing by G on both sides, and since $h_{w_2} = h_{g_2}$,

$$h_{a_1} + \omega_1h_{w_1} + (\omega_2 - \omega_1)h_{f_2} = h_{a_2} + \omega_2h_{g_2}$$

$$\omega_1 = \frac{(h_{a_2} - h_{a_1}) + \omega_2(h_{g_1} - h_{f_1})}{h_{w_1} - h_{f_2}} = \frac{C_{p_a}(T_2 - T_1) + \omega_2h_{f_{g_2}}}{h_{w_1} - h_{f_2}}$$

$$\text{where } \omega_2 = \frac{m_2}{G} = \frac{m_s}{G}$$

$$\text{Specific humidity, } \omega = 0.662 \frac{P_s}{p - P_s}$$

Problem

A sling psychrometer reads 40° C DBT and 30° C WBT .Calculate specific humidity,relative humidity, dew point temperature, enthalpy and specific volume of air mixture. Assume atmospheric air pressure as 1.0132 bar.

Solution

1. Specific humidity:

$$\omega = 0.622 \frac{P_v}{P_b - P_v}$$

Partial vapour pressure, $P_v = P_{sw} - \frac{(P_b - P_{sw})(t_d - t_w)}{1527.4 - 1.3t_w}$

where

P_{sw} = Saturation pressure corresponding to wet bulb temperature.

P_b = barometric pressure = 1.0132 bar

From Steam Table, for 30°C wet bulb temperature, the corresponding pressure is 0.04242 bar

i.e. $P_{sw} = 0.04242 \text{ bar}$

$$P_v = 0.04242 - \frac{(1.0132 - 0.04242)(40 - 30)}{1527.4 - 1.3 \times 30} = 0.035897 \text{ bar}$$

Substituting P_v and P_b value in equation for ω

$$\omega = 0.622 \times \frac{0.035897}{1.0132 - 0.035897}$$

Humidity ratio, $\omega = 0.0228 \text{ kJ/kg of dry air}$

Ans.

2. Relative humidity:

$$\phi = \frac{P_v}{P_s}$$

where, P_s - Saturation pressure corresponding dry bulb temperature.

From Steam Table, for 40°C dry bulb temperature, the corresponding pressure is 0.07375 bar

i.e. $P_s = 0.07375 \text{ bar}$

$$\phi = \frac{0.035897}{0.07375} = 0.487 = 48.7\%$$

Ans.

3. Dew point temperature (t_{dp}):

From Steam Table, corresponding to partial vapour pressure, $P_v = 0.035897 \text{ bar}$, temperature is 27°C. So, the dew point temperature (t_{dp}) is 27°C

Ans.

4. Specific volume (v_a) of air:

From gas law, $p_a v_a = R_a t_a$

where,

Gas constant, $R = 0.287 \text{ kJ/kg}$

$$T_a = t_d + 273 = 40 + 273 = 313 \text{ K}$$

$$p_a = p_b - p_v = 1.0132 - 0.035897 = 0.977 \text{ bar}$$
$$= 0.977 \times 100 = 97.7 \text{ kN/m}^2$$

$$v_a = \frac{R_a T_a}{p_a} = \frac{0.287 \times 313}{97.7} = 0.919 \text{ m}^3/\text{kg} \quad \text{Ans.}$$

5. Density of air:

$$\rho_a = \frac{1}{v_a} = \frac{1}{0.919}$$

$$\text{Density of air } \rho_a = 1.087 \text{ kg/m}^3 \quad \text{Ans.}$$

6. Density of water vapour (ρ_v):

From Steam Table, corresponding to 40°C dry bulb temperature, the specific volume (v_g) is $19.546 \text{ m}^3/\text{kg}$

$$\rho_v = \frac{1}{v_g} = \frac{1}{19.546} = 0.05116 \text{ kg/m}^3$$

Vapour density of relative humidity, $\phi = 0.487$

$$\text{Vapour density, } \rho_v = 0.05116 \times 0.487 = 0.025 \text{ kg/m}^3 \text{ Ans.}$$

7. Total enthalpy:

$$h = C_p t_d + \omega h_g$$

where

C_p - Specific heat = 1.005 kJ/kgK

h_g - specific enthalpy of air corresponding dry bulb temperature.

From Steam Table, for 40°C dry bulb temperature, the corresponding specific enthalpy is 2574.4 kJ/kg

$$h = 1.005 (40) + 0.0232 (2574.4)$$
$$= 99.93 \text{ kJ/kg} \quad \text{Ans.}$$

Psychrometric Processes

(1) Sensible Heating or Cooling { $W = \text{constant}$ } Only the dry bulb temperature of air changes. Let us consider sensible heating of air

I. PSYCHROMETRIC PROCESSES

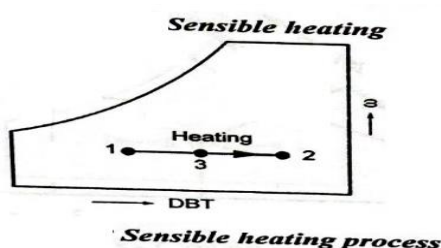
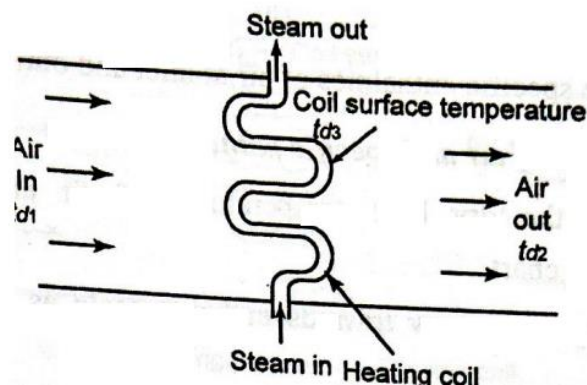
Maintaining a living space or an Industrial facility at the desired temperature and humidity requires some processes called *psychrometric processes*. These processes include simple heating, simple cooling, humidification, dehumidification or combination of these processes. The different types of psychrometric are as follows:

1. Sensible heating process ,
2. Sensible cooling process
3. Humidification process/
4. Dehumidification process ,
5. Heating and humidification process
6. Cooling and dehumidification process
7. Adiabatic mixing air streams process -
8. Evaporative cooling process.

Sensible Heating Process

Many residential systems consist of stove, heat pump or electric resistance heater. The air in these systems is heated by circulation through a duct. The duct contains tubes with hot gases such as steam.

In this case, air is heated at constant specific humidity. It means, heating is done without adding moisture. During heat addition, the dry bulb temperature increases from t_{d1} to t_{d2} . So, $w_1 = w_2$ but $t_{d2} > t_{d1}$. The heating coil is placed in air flow path. Heating is done by either electric resistance heating coils or steam coils. Steam is sent inside the heating coils. So, the heat present in the steam heats the air by convection. Finally, the steam coming out of the coil gets cooled. But, the air at outlet will be at increased dry bulb temperature. The heating process is shown in psychrometric chart below.



The efficiency of heating coil is measured in terms of by pass factor. *By pass factor* is defined as the portion of the air that passes through the coil without contacting the coil surface. It is denoted by BPF.

BPF is calculated by the formula

$$\text{BPF} = \frac{t_{d3} - t_{d2}}{t_{d3} - t_{d1}}$$

where, t_{d1} and t_{d2} are dry bulb temperatures of air at inlet and outlet in the duct.

t_{d3} is the coil surface temperature.

The outlet dry bulb temperature of air lies between air temperature at inlet and the coil surface temperature.

$$t_{d1} < t_{d2} < t_{d3}$$

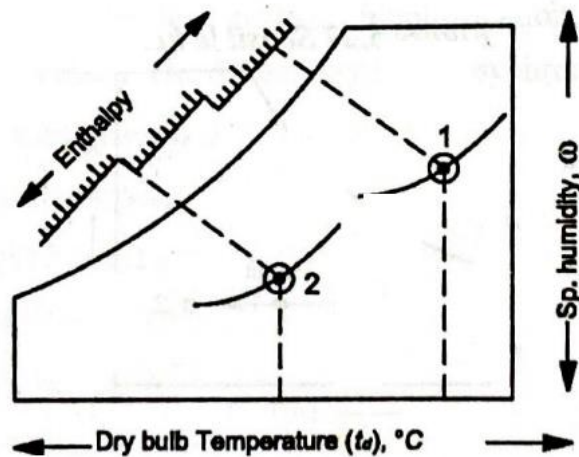
Heat supplied to air, $Q = m_a (h_2 - h_1)$

where $m_a = \text{mass of air in kg} = \frac{\text{Total volume}}{\text{Specific volume}} = \frac{V}{v}$

h_1 and h_2 are specific enthalpies of air at inlet and outlet.

Procedure to find mass of air and specific enthalpy:

1. First, locate the dry bulb temperatures of air at inlet and outlet on psychrometric chart.
2. From these points, draw towards enthalpy scale as shown in Figure below.



3. If volume of air is given at inlet 1, find specific volume at that point from the chart or if the volume of air at outlet 2 is given, find specific volume at that point.

4. Calculate mass of air circulated around the coil by the formula

$$m_a = \frac{V_1}{v_1} \text{ or } \frac{V_2}{v_2}$$

Sensible Cooling Process

In sensible cooling processes, refrigerant is sent inside the coil instead of steam to cool the air. During this process, the dry bulb temperature reduces from t_{d1} to t_{d2} . So,

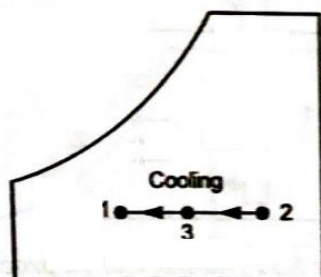
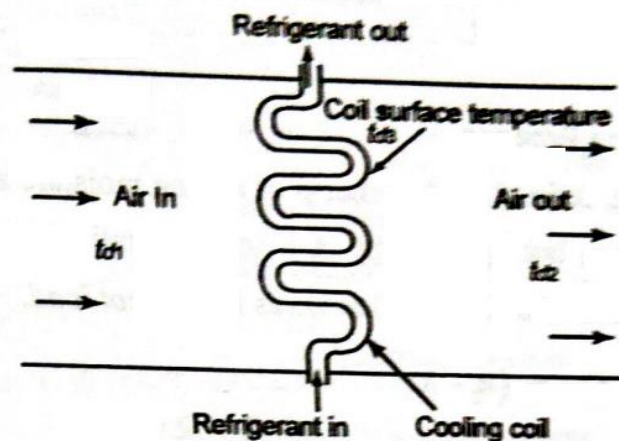
4. Calculate mass of air circulated around the coil by the formula

$$m_a = \frac{V_1}{v_1} \text{ or } \frac{V_2}{v_2}$$

Sensible Cooling Process

In sensible cooling processes, refrigerant is sent inside the coil instead of steam to cool the air. During this process, the dry bulb temperature reduces from t_{d1} to t_{d2} . So,

the heat present in the air is extracted by refrigerant. But, there is no addition of moisture in the air. So, $t_{d1} > t_{d2}$ and $\omega_1 = \omega_2$.



Sensible cooling process

In this case also, the efficiency of cooling coil is measured in terms of by-pass factor.

$$\text{RPF} = \frac{t_{d3} - t_{d2}}{t_{d1} - t_{d2}}$$

where, t_{d1} and t_{d2} are dry bulb temperatures of air at inlet and outlet in the duct
 t_{d3} is the coil surface temperature.

The outlet dry bulb temperature of air lies between air temperature at inlet and the coil surface temperature.

$$t_{d1} < t_{d2} < t_{d3}$$

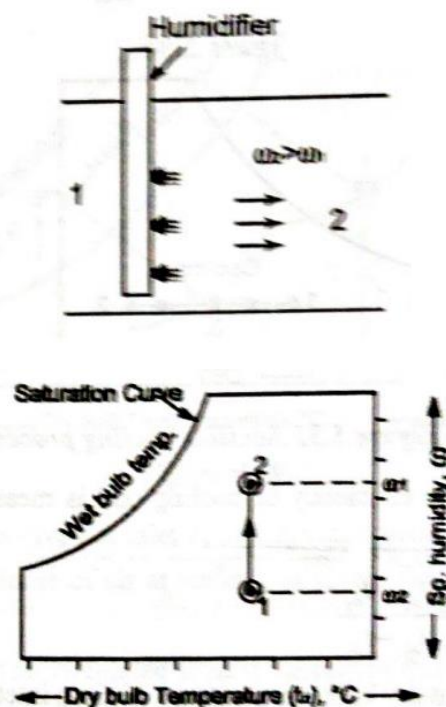
Amount of heat removed from air is calculated by

$$Q = m_a (h_1 - h_2)$$

Humidification Process

Humidification is defined as the process of adding moisture at constant dry bulb temperature. So, $\omega_2 > \omega_1$ but $t_{d1} = t_{d2}$. So, the humidity ratio increases from ω_1 to ω_2 . The heat due to addition of moisture is known as *latent heat load*.

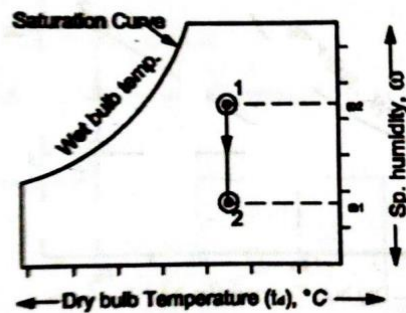
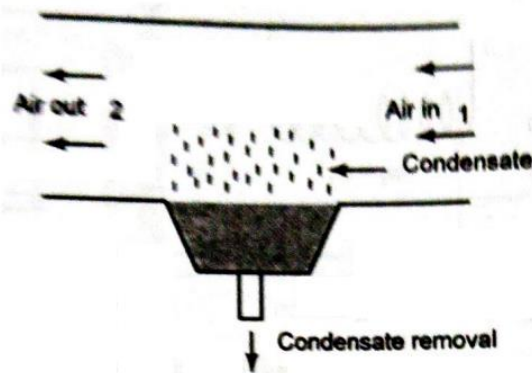
$$\text{Latent heat load, } Q = m_x (h_2 - h_1)$$



Dehumidification Process

In this case, the humidity ratio decreases by removing moisture from air. But this process is carried out at constant dry bulb temperature. So, $\omega_2 < \omega_1$, $\phi_1 > \phi_2$ but $t_{d1} = t_{d2}$. The heat involved in dehumidification is also called as *latent heat load*.

Latent heat load, $Q = m_a (h_1 - h_2)$

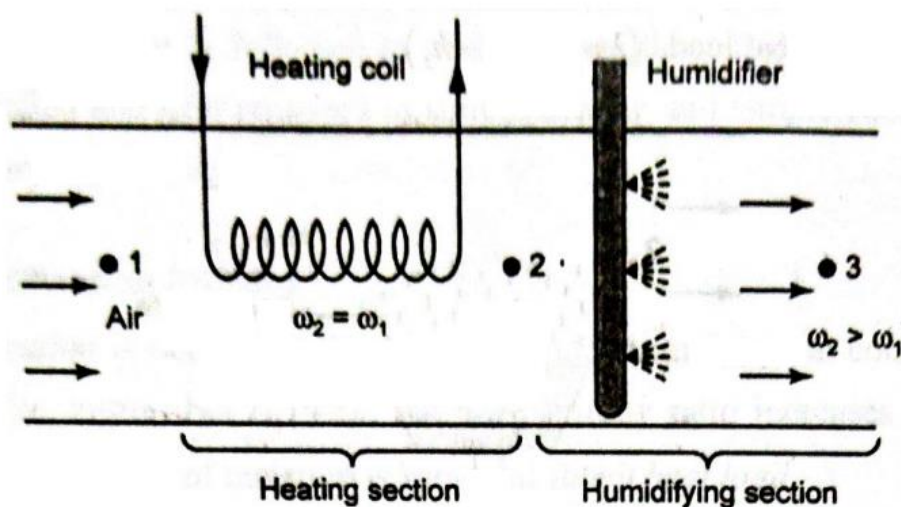


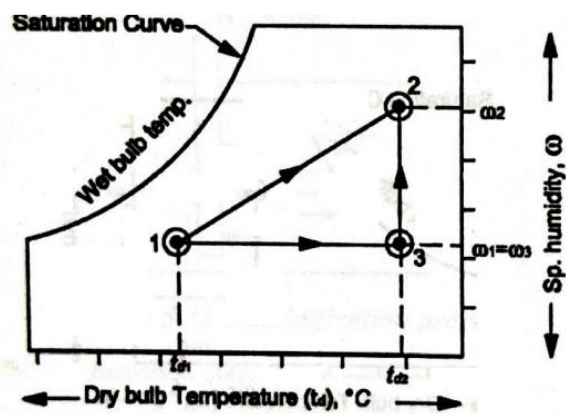
Heating and Humidification Process

Practically, winter air-conditioning systems require heat and more moisture. So, both heating and humidification processes are carried one after the other. First, heating is done. By heating, the dry bulb temperature increases from t_{d1} to t_{d3} . Next, humidification is done by adding moisture. Due to this, only humidity increases from $\omega_1 = \omega_3$ to ω_2 . But, the dry bulb temperature is constant ($t_{d1} = t_{d3}$).

Total heat load on the heating coil, $THL = \text{Sensible heat load, } SHL + \text{Latent heat load, } LHL$

$$THL = (h_3 - h_1) + (h_2 - h_3)$$





Sensible heat factor:

The ratio of sensible heat load to the total heat load is known as *sensible heat factor* or *sensible heat ratio*.

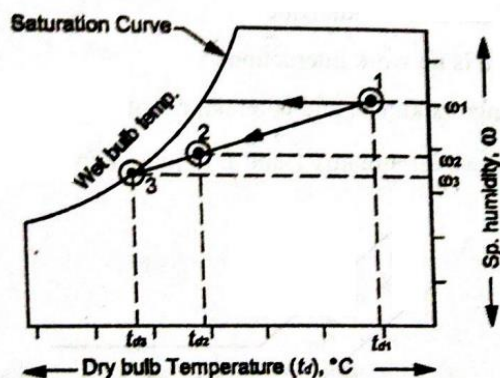
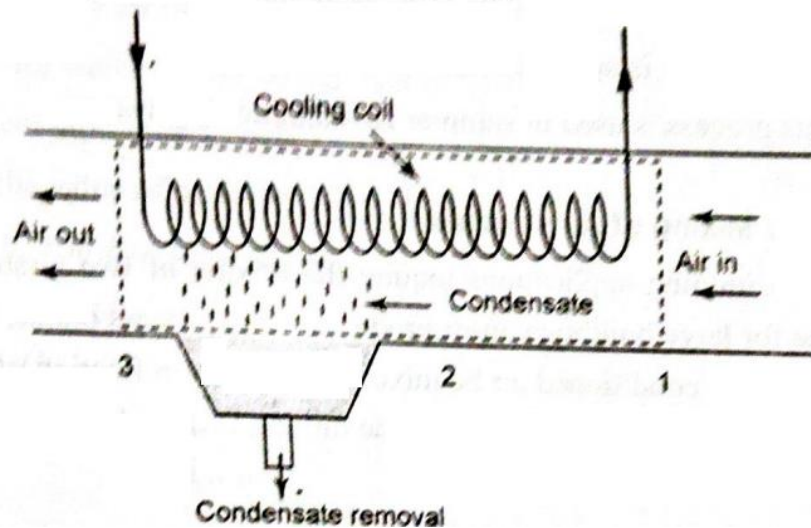
$$SHF = \frac{SHL}{SHL + LHL} = \frac{h_3 - h_1}{(h_3 - h_1) + (h_2 - h_3)}$$

Cooling and Dehumidification Process

In this case, both cooling and dehumidification are carried out one by one. First, cooling is done by passing refrigerant inside the coil tube. During this time, dry bulb temperature decreases from t_{d1} to t_{d3} but specific humidity is constant. Then,

dehumidification is done by removing moisture from the air. Due to this, specific humidity decreases but dry bulb temperature remains constant.

$$\therefore \omega_1 = \omega_3 < \omega_2 \text{ but } t_{d1} > t_{d3} < t_{d2}$$



Total heat load on the heating coil, $THL = \text{Sensible heat load, } SHL + \text{Latent heat load, } LHL$

$$THL = (h_1 - h_3) + (h_3 - h_2)$$

SHF is calculated by using the same formula discussed above.

By pass factor is calculated by the formula

$$BPF = \frac{t_{d2} - t_{d3}}{t_{d1} - t_{d3}} = \frac{t_{d2} - t_{ADP}}{t_{d1} - t_{ADP}}$$

where t_{d1} and t_{d2} are dry bulb temperatures of air at inlet and outlet in the duct

$t_{d3} = t_{ADP}$ is apparatus dew point temperature.

Mainly, this process is used in summer air-conditioning systems.

Adiabatic Mixing of Air streams

Many air conditioning applications require the mixing of two airstreams. This is particularly true for large buildings, most production and process plants, and hospitals, which require that the conditioned air be mixed with a certain fraction of fresh outside air before it is routed into the living space. The mixing is done by simply merging the two airstreams.

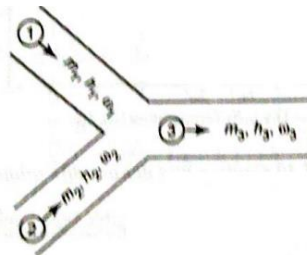
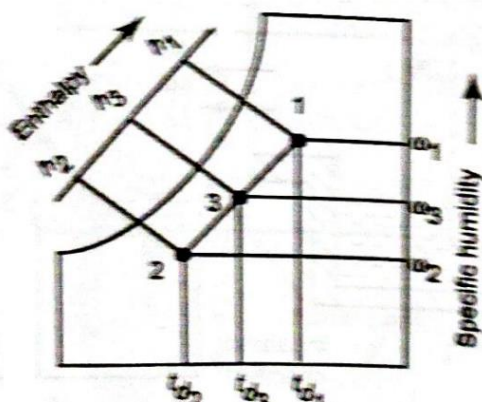


Figure 5.40 Adiabatic mixing

Let, m_1 = Mass of air entering at 1
 h_1 = Enthalpy of air entering at 1

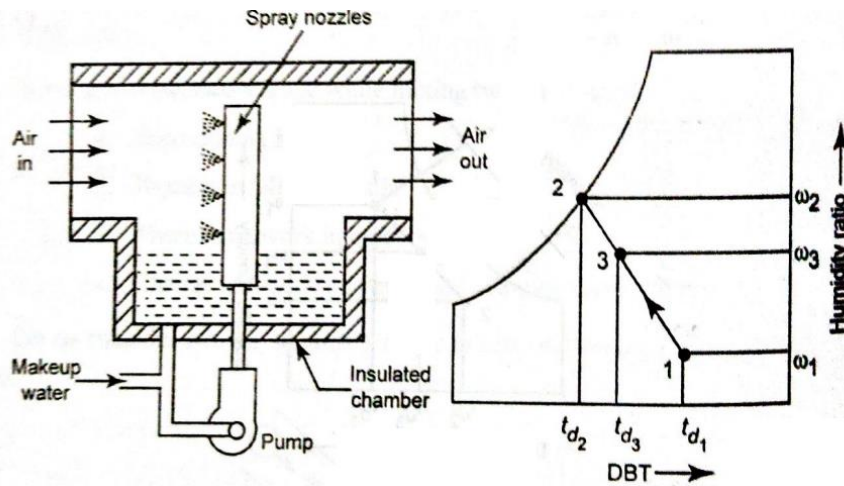


$$m_1/m_2 = (h_3 - h_2) / (h_1 - h_3)$$

$$\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3} = \frac{w_3 - w_2}{w_1 - w_3}$$

Adiabatic Evaporative Cooling

In this type of cooling, the air is passed through an insulated chamber. This insulating chamber has sprays in which water is maintained at a temperature higher than the dew point temperature of entering air but lower than its dry bulb temperature. So, both cooling and humidification are done without supplying or rejecting heat from the water spray. At the same time, the same water is recirculated again and again. The main disadvantage in this method is, perfect humidification of air is not possible.



Problem

Atmospheric air with dry bulb temperature of 40°C and wet bulb temperature of 20°C is cooled to 15°C without changing its moisture content calculate the following

1. Original relative humidity
2. Final relative humidity
3. Final wet bulb temperature.
4. Heat removed.

Given data:

Initial dry bulb temperature, $t_{d1} = 40^\circ\text{C}$

Initial wet bulb temperature, $t_{w1} = 20^\circ\text{C}$

Final dry bulb temperature, $t_{d2} = 15^\circ\text{C}$

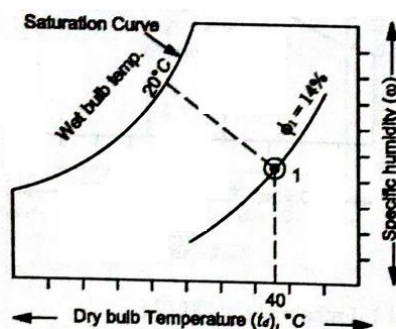


Figure 5.58

The initial condition of air i.e., 40°C dry bulb temperature and 20°C wet bulb temperature is marked on the psychrometric chart at point 1. From psychrometric chart we know that, relative humidity (ϕ_1) passing through point 1 is 14%

i.e. $\phi_1 = 14\%$

Ans. $\phi_1 = 14\%$

Step 2

Draw a vertical line from 15°C (final dry bulb temperature) and draw a horizontal line from point 1. Both lines intercept at point 2 as shown in Figure 5.59.

Step 3:

From psychrometric chart, the relative humidity (ϕ) passing through point 2 is 55%.

$$\text{i.e. } \phi_2 = 55\%$$

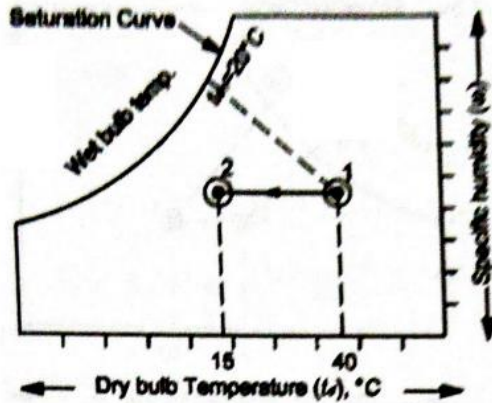
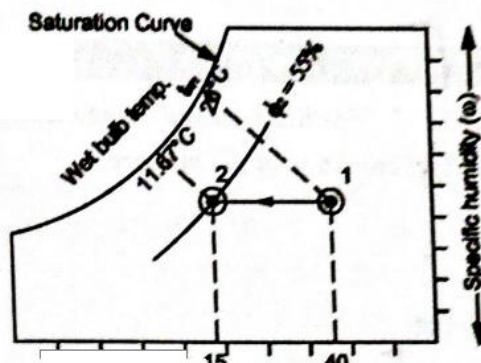


Figure 5.59



Draw an inclined line from point 2 along the constant wet bulb temperature line till it cuts saturation curve. At that point temp is 11.67°C .

$$\text{i.e. } t_{w2} = 11.67^{\circ}\text{C}$$

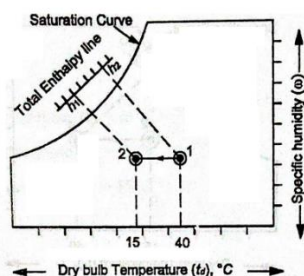
From chart, at point 1, Enthalpy $h_1 = 58\text{kJ/kg}$

At point 2, Enthalpy $h_2 = 32\text{kJ/kg}$

$$\text{Heat removed, } Q = m(h_1 - h_2) \quad (\because h_2 > h_1)$$

$$Q = (h_1 - h_2) = (58 - 32) [\because m = 1\text{kg}]$$

$$Q = 26\text{kJ/kg}$$



One kg of air at 24°C , 70% RH is mixed adiabatically with 2kg of air at 16°C , 10% RH. Determine final condition of the mixture.

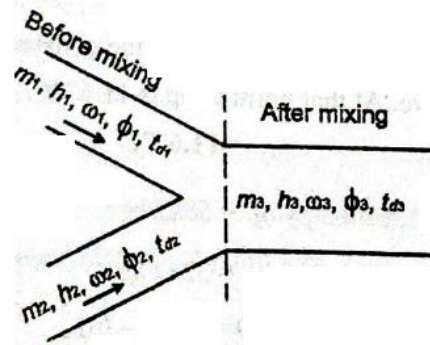
Given data:

First Stream:

Mass of air, $m_1 = 1\text{ kg}$

Dry bulb temperature, $t_{d1} = 24^{\circ}\text{C}$

Relative humidity $\phi_1 = 70\%$



Solution

Second stream:

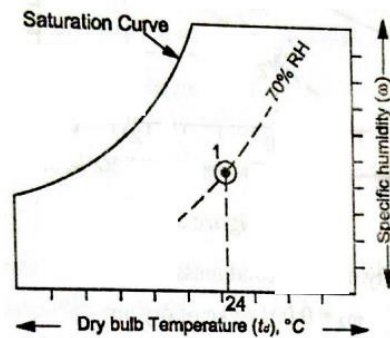
Mass of air, $m_2 = 2\text{ kg}$

Dry bulb temperature, $t_{d2} = 16^{\circ}\text{C}$

Relative humidity $\phi_2 = 10\%$

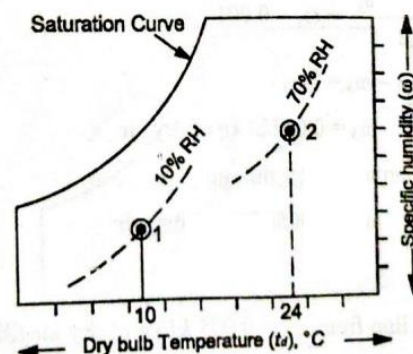
Step 1:

The first stream of air i.e. 24°C dry bulb temperature and 70% RH is marked on the psychrometric chart at point 1.



Step 2:

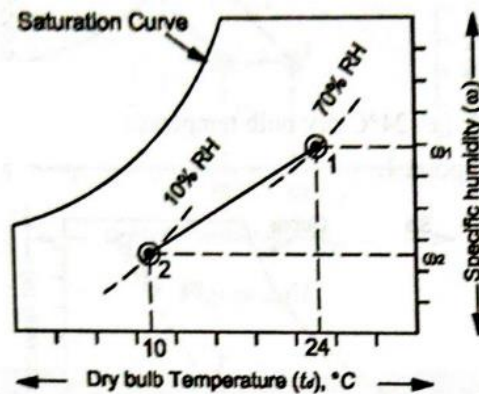
The second stream of air i.e. 16°C dry bulb temperature and 10% RH is marked on the psychrometric chart at point 2.



Step 3:

Join the points 1 and 2 from the psychrometric chart, the specific humidity of the first mass of air,

$$\omega_1 = 0.0134 \text{ kg/kg of dry air}$$



Specific humidity of the second mass of air

$$\omega_2 = 0.001 \text{ kg/kg of dry air}$$

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

$$\frac{1}{2} = \frac{\omega_3 - 0.001}{0.013 - \omega_3}$$

$$\frac{1}{2} = \frac{\omega_3 - 0.001}{0.013 - \omega_3}$$

$$\frac{0.013 - \omega_3}{2} = \omega_3 - 0.001$$

$$0.013 - \omega_3 = 2\omega_3 - 0.002$$

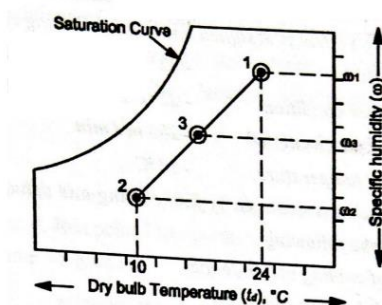
$$\omega_3 = 0.005 \text{ kg/kg of dry air}$$

Specific humidity after mixing

$$\omega_3 = 0.005 \text{ kg/kg of dry air}$$

Step 4:

Draw a horizontal line from $\omega_3 = 0.005 \text{ kg/kg of dry air}$ till it cuts 1.2 line. Note the point 3.

Step 5

From psychrometric chart,

1. Relative humidity (ϕ), passing through point 3 is 40%

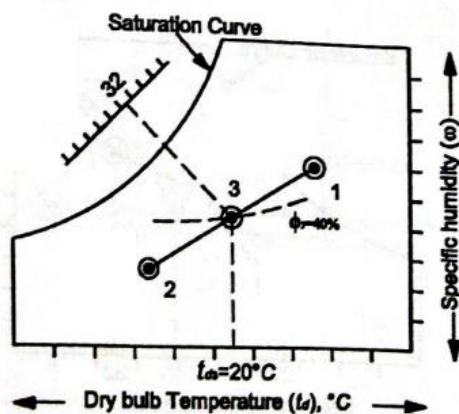
$$\text{i.e. } \phi_3 = 40\%$$

2. Draw a vertical line from point 3. Till it cuts dry bulb temperature line. At this point temperature is 20°C

$$\text{i.e. } t_{d3} = 20^\circ\text{C}$$

3. Draw a inclined line from point 3 along the constant wet bulb temperature line till it cuts total enthalpy line

$$\text{Enthalpy, } h_3 = 32\text{kJ/kg}$$



An air conditioning system is designed under the following condition

Outdoor condition	- 32°C DBT and 75% RH
Required Indoor condition	- 22°C DBT and 70% RH
Amount of free air circulated	- $200\text{ m}^3/\text{min}$
Coil dew point temperature	- 14°C

The required condition is achieved by first cooling and dehumidifying and then by heating. Calculate the following

1. Capacity of cooling coil in tonne
2. Capacity of heating coil in kW
3. Mass of water vapour removed in kg/s

Given data:

door conditions.

Dry bulb temperature, $t_{d1} = 32^\circ\text{C}$

Relative humidity, $\phi_1 = 75\%$

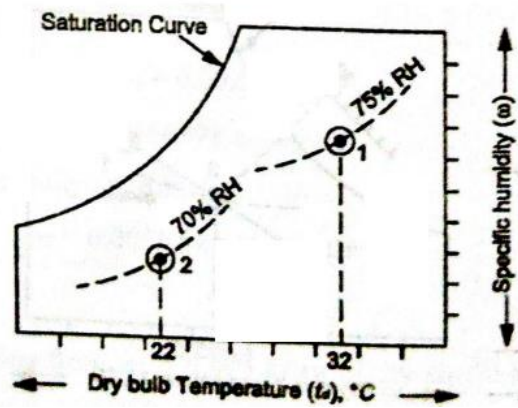
In door conditions:

Dry bulb temperature, $t_{d2} = 22^\circ\text{C}$

Relative humidity, $\phi_2 = 70\%$

Amount of free air circulated, $V = 200\text{ m}^3/\text{min} = 3.33\text{ m}^3/\text{s}$

Coil dew point temperature, i.e. surface temperature, $t_s = 14^\circ\text{C}$

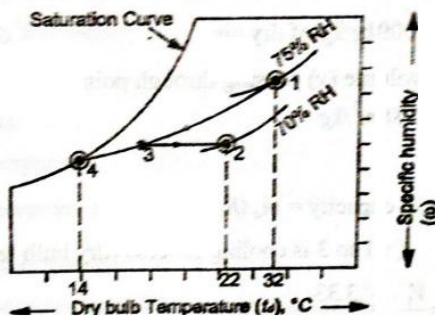


Step 1:

The outdoor conditions of air i.e. 32°C dry bulb temperature and 75% relative humidity are marked on the psychrometric chart at point 1. Indoor condition of air i.e. 22°C dry bulb temperature and 70% RH is marked on the psychrometric chart at point 2.

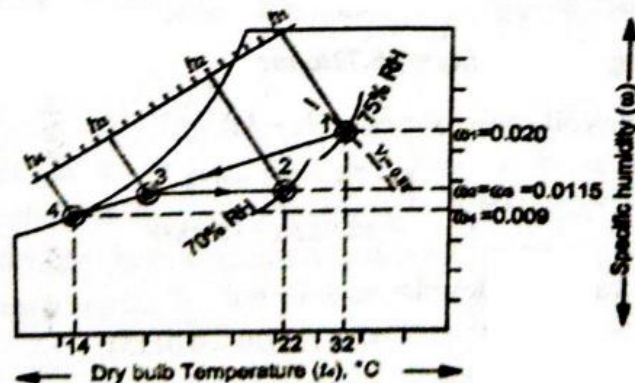
Step 2:

Draw a vertical line from 14°C (Dew point temperature) till it cuts saturation curve. Name the point 4. Join point 1 and point 4. Draw a horizontal line from point 2 till it cuts 1-4 line name the point 3.



Step 3:

Draw an inclined line from point 1, 2, 3 and 4 along constant wet bulb temperature line till it cuts total enthalpy line.



At point 1, enthalpy $h_1 = 82 \text{ kJ/kg}$

At point 2, enthalpy $h_2 = 53 \text{ kJ/kg}$

At point 3, enthalpy $h_3 = 48 \text{ kJ/kg}$

At point 4, enthalpy $h_4 = 41 \text{ kJ/kg}$

Draw a horizontal line from point 1, 2, 3 and 4 till it cuts specific humidity (ω) line

From chart,

$$\omega_1 = 0.020 \text{ kg/kg of dry air}$$

$$\omega_2 = \omega_3 = 0.0175 \text{ kg/kg of dry air}$$

$$\omega_4 = 0.009 \text{ kg/kg of dry air}$$

From chart, specific volume (v) passing through point 1 is $0.88 \text{ m}^3/\text{kg}$

$$\text{ie } v_1 = 0.88 \text{ m}^3/\text{kg}$$

Step 4:

$$\text{Cooling coil capacity} = m_a (h_1 - h_3)$$

($\because$ 1 to 3 is cooling process [dry bulb temperature decreases])

$$m_a = \frac{V_1}{v_1} = \frac{3.33}{0.88} = 3.78 \text{ kg/s}$$

Substituting m_a value in (5.22)

$$\text{Cooling coil capacity} = 3.78 (82 - 48) = 128.52 \text{ kW}$$

$$= \frac{128.52}{3.5} = 36.72 \text{ tonnes} \quad [\because 1 \text{ tonne} = 3.5 \text{ kW}]$$

$$\text{Cooling coil capacity} = \mathbf{36.72 \text{ tonne}}$$

$$\text{Heating coil capacity} = m_a \times (h_2 - h_3)$$

$$= 3.78 \times (53 - 48)$$

$$= 18.9 \text{ kJ/s} = \mathbf{18.9 \text{ kW}}$$

$$\text{Mass of water vapour removed} = m_a (\omega_1 - \omega_3)$$

$$= 3.78 (0.020 - 0.0115)$$

$$\text{Mass of water vapour removed} = \mathbf{0.03213 \text{ kg/s}}$$

Problem