

Mass Transfer Operations II
Professor Chandan Das
Department of Chemical Engineering
Indian Institute of Technology Guwahati
Lecture 01 - Humidification and Air Conditioning

Now, I will be discussing on the Humidification and Air Conditioning.

Basic concepts

When a gas is brought in contact with a pure liquid in which it is essentially insoluble, interphase mass and heat transfer takes place. The term humidification is used to characterize these in a general fashion.

Four major applications of humidification operations (simultaneous heat and mass transfer) are as follows:

- a) Humidification of gases for controlled drying of wet solids
- b) Dehumidification and cooling of gas in air conditioning
- c) Gas cooling with the help of water
- d) Cooling of liquid (e.g. water) before reuse

Terminologies and definitions

Three most important quantities, namely, '**temperature**', '**humidity**' and '**enthalpy**', are essential terminologies in dealing humidification.

- 1) **Dry-bulb temperature:** It is true temperature of air measured by a thermometer whose bulb is dry.
- 2) **Wet-bulb temperature:** It is the steady-state temperature attained by a small amount of evaporating water in a manner such that the sensible heat transferred from the air to the liquid is equal to the latent heat required for evaporation.

(Refer Slide Time: 04:39)

Relative humidity: It is the ratio of partial pressure of water vapor (p_A) in air at a given temperature to the vapor pressure of water (p_A^0) at the same temperature.

$$\% \text{relative humidity} = \frac{p_A}{p_A^0} \times 100$$

“Relative humidity does not ‘explicitly’ give the moisture content of a gas, but gives the ‘degree of saturation’ of the gas at a given temperature.

Absolute humidity (simply humidity): It is the direct measurement of moisture content in a gas. The mass of water vapor per unit mass of dry gas is called absolute humidity, Y' .

$$Y' = \left(\frac{p_A}{P - p_A} \right) \frac{18.02}{28.97} \times 100$$

It is occasionally called ‘*Grosvenor humidity*’ after the name of the inventor.



Three most important quantities, namely, ‘**temperature**’, ‘**humidity**’ and ‘**enthalpy**’, are essential terminologies in dealing humidification.

- 3) **Dry-bulb temperature:** It is true temperature of air measured by a thermometer whose bulb is dry.
- 4) **Wet-bulb temperature:** It is the steady-state temperature attained by a small amount of evaporating water in a manner such that the sensible heat transferred from the air to the liquid is equal to the latent heat required for evaporation.
- 5) **Relative humidity:** It is the ratio of partial pressure of water vapor (p_A) in air at a given temperature to the vapor pressure of water (p_A^0) at the same temperature.

$$\% \text{relative humidity} = \frac{p_A}{p_A^0} \times 100 \quad (1)$$

“Relative humidity does not ‘explicitly’ give the moisture content of a gas, but gives the ‘degree of saturation’ of the gas at a given temperature.

- 6) **Absolute humidity (simply humidity):** It is the direct measurement of moisture content in a gas. The mass of water vapor per unit mass of dry gas is called absolute humidity, Y' .

$$Y' = \left(\frac{p_A}{P - p_A} \right) \frac{18.02}{28.97} \times 100 \quad (2)$$

It is occasionally called ‘*Grosvenor humidity*’ after the name of the inventor.

7) % Humidity or % Saturation: It is the ration of absolute humidity to that of saturated humidity at the same temperature and pressure.

$$\% Humidity = \frac{Y'}{Y'_s} \times 100 \quad (3)$$

where, Y' is absolute humidity of sample of air and Y'_s is humidity at same temperature and pressure if saturated with water vapor.

$$Y'_s = \left(\frac{p_A^v}{P - p_A^v} \right) \frac{18.02}{28.97} \quad (4)$$

and vapor pressure of water can be calculated by Antoine Equation:

$$\ln p_A^v = 11.96481 - \frac{3984.923}{(T - 39.97)} \text{ where, pressure is in bar and temperature is in K.}$$

8) Dew point: Dew point is a temperature at which a vapor-gas mixture must be cooled (at constant humidity) to become saturated. The dew point of a saturated gas equals the gas temperature. If a vapor-gas mixture is gradually cooled at a constant pressure, the temperature at which it just becomes saturated is also called its dew point.

9) Humid volume: The humid volume, v_H , is defined as the volume of unit mass of dry air with accompanying water vapor at a given temperature and pressure.

$$v_H = \left(\frac{1}{28.97} + \frac{1}{18.02} \right) \times 22.4 \times \left(\frac{T_G + 273}{273} \right) \text{ m}^3/\text{kg dry air} \quad (5)$$

assuming ideal gas behavior. T_G is gas temperature in °C.

10) Humid heat: The humid heat, c_H , is the heat energy required to raise the temperature of unit mass of dry air with the accompanying water vapor by one (1) degree.

$c_H = 1.005 + 1.88Y'$ kJ/(kg dry air)(K); first part of right hand side is heat capacity of dry air in kJ/kg.K and second part is heat capacity of water vapor in kJ/kg.K.

11) Enthalpy: The enthalpy of a vapor-gas mixture is the sum of the relative enthalpies of gas and vapor content.

$$H' = c_H(T_G - T_0) + Y' \lambda_0 = (1.005 + 1.88Y')(T_G - T_0) + 2500Y' \text{ kJ/kg} \quad (6)$$

where λ_0 is latent heat of vaporization of water, 2500 kJ/Kg.

(Refer Side Time: 06:16)

% Humidity or % Saturation: It is the ratio of absolute humidity to that of saturated humidity at the same temperature and pressure.

$$\%Humidity = \frac{Y'}{Y'_s} \times 100$$

where, Y' is absolute humidity of sample of air and Y'_s is humidity at same temperature and pressure if saturated with water vapor.

$$Y'_s = \left(\frac{p'_A}{P - p'_A} \right) \frac{18.02}{28.97}$$

and vapor pressure of water can be calculated by Antoine Equation:

$$\ln p'_A = 11.96481 - \frac{3984.923}{(T - 39.97)}$$

where, pressure is in bar and temperature is in K.



(Refer Slide Time: 07:18)

Dew point: Dew point is a temperature at which a vapor-gas mixture must be cooled (at constant humidity) to become saturated.

The dew point of a saturated gas equals the gas temperature.

If a vapor-gas mixture is gradually cooled at a constant pressure, the temperature at which it just becomes saturated is also called its dew point.

Humid volume: The humid volume, v_H , is defined as the volume of unit mass of dry air with accompanying water vapor at a given temperature and pressure (m^3/kg dry air).

$$v_H = \left(\frac{1}{28.97} + \frac{1}{18.02} \right) \times 22.4 \times \left(\frac{T_G + 273}{273} \right)$$

Assuming ideal gas behavior. T_G is gas temperature in $^{\circ}\text{C}$.



Three most important quantities, namely, '**temperature**', '**humidity**' and '**enthalpy**', are essential terminologies in dealing humidification.

- 1) Dry-bulb temperature:** It is true temperature of air measured by a thermometer whose bulb is dry.
- 2) Wet-bulb temperature:** It is the steady-state temperature attained by a small amount of evaporating water in a manner such that the sensible heat transferred from the air to the liquid is equal to the latent heat required for evaporation.
- 3) Relative humidity:** It is the ratio of partial pressure of water vapor (p_A) in air at a given temperature to the vapor pressure of water (p_A^0) at the same temperature.

$$\% \text{ relative humidity} = \frac{P_A}{P_A^0} \times 100 \quad (1)$$

“Relative humidity does not ‘explicitly’ give the moisture content of a gas, but gives the ‘degree of saturation’ of the gas at a given temperature.

4) Absolute humidity (simply humidity): It is the direct measurement of moisture content in a gas. The mass of water vapor per unit mass of dry gas is called absolute humidity, Y' .

$$Y' = \left(\frac{P_A}{P - P_A} \right) \frac{18.02}{28.97} \times 100 \quad (2)$$

It is occasionally called ‘*Grosvenor humidity*’ after the name of the inventor.

5) % Humidity or % Saturation: It is the ration of absolute humidity to that of saturated humidity at the same temperature and pressure.

$$\% \text{ Humidity} = \frac{Y'}{Y'_s} \times 100 \quad (3)$$

where, Y' is absolute humidity of sample of air and Y'_s is humidity at same temperature and pressure if saturated with water vapor.

$$Y'_s = \left(\frac{P_A^v}{P - P_A^v} \right) \frac{18.02}{28.97} \quad (4)$$

and vapor pressure of water can be calculated by Antoine Equation:

$$\ln P_A^v = 11.96481 - \frac{3984.923}{(T - 39.97)} \text{ where, pressure is in bar and temperature is in K.}$$

6) Dew point: Dew point is a temperature at which a vapor-gas mixture must be cooled (at constant humidity) to become saturated. The dew point of a saturated gas equals the gas temperature. If a vapor-gas mixture is gradually cooled at a constant pressure, the temperature at which it just becomes saturated is also called its dew point.

7) Humid volume: The humid volume, v_H , is defined as the volume of unit mass of dry air with accompanying water vapor at a given temperature and pressure.

$$v_H = \left(\frac{1}{28.97} + \frac{1}{18.02} \right) \times 22.4 \times \left(\frac{T_G + 273}{273} \right) \text{ m}^3/\text{kg dry air} \quad (5)$$

assuming ideal gas behavior. T_G is gas temperature in °C.

8) Humid heat: The humid heat, c_H , is the heat energy required to raise the temperature of unit mass of dry air with the accompanying water vapor by one (1) degree.

$c_H = 1.005 + 1.88Y'$ kJ/(kg dry air)(K); first part of right hand side is heat capacity of dry air in kJ/kg.K and second part is heat capacity of water vapor in kJ/kg.K.

9) **Enthalpy:** The enthalpy of a vapor-gas mixture is the sum of the relative enthalpies of gas and vapor content.

$$H' = c_H(T_G - T_0) + Y'\lambda_0 = (1.005 + 1.88Y')(T_G - T_0) + 2500Y' \text{ kJ/kg} \quad (6)$$

where λ_0 is latent heat of vaporization of water, 2500 kJ/Kg.

(Refer Slide Time: 08:44)

Humid heat: The humid heat, c_H , is the heat energy required to raise the temperature of unit mass of dry air with the accompanying water vapor by one (1) degree.

$$c_H = 1.005 + 1.88Y' \text{ kJ/(kg dry air)(K)}$$

First part of right hand side is heat capacity of dry air in kJ/kg.K and second part is heat capacity of water vapor in kJ/kg.K.

Enthalpy: The enthalpy of a vapor-gas mixture is the sum of the relative enthalpies of gas and vapor content.

$$H' = c_H(T_G - T_0) + Y'\lambda_0 = (1.005 + 1.88Y')(T_G - T_0) + 2500Y'$$

where λ_0 is latent heat of vaporization of water, 2500 kJ/Kg.



Three most important quantities, namely, ‘**temperature**’, ‘**humidity**’ and ‘**enthalpy**’, are essential terminologies in dealing humidification.

10) **Dry-bulb temperature:** It is true temperature of air measured by a thermometer whose bulb is dry.

11) **Wet-bulb temperature:** It is the steady-state temperature attained by a small amount of evaporating water in a manner such that the sensible heat transferred from the air to the liquid is equal to the latent heat required for evaporation.

12) **Relative humidity:** It is the ratio of partial pressure of water vapor (p_A) in air at a given temperature to the vapor pressure of water (p_A^0) at the same temperature.

$$\% \text{ relative humidity} = \frac{p_A}{p_A^0} \times 100 \quad (1)$$

“Relative humidity does not ‘explicitly’ give the moisture content of a gas, but gives the ‘degree of saturation’ of the gas at a given temperature.

13) Absolute humidity (simply humidity): It is the direct measurement of moisture content in a gas. The mass of water vapor per unit mass of dry gas is called absolute humidity, Y' .

$$Y' = \left(\frac{p_A}{P - p_A} \right) \frac{18.02}{28.97} \times 100 \quad (2)$$

It is occasionally called '*Grosvenor humidity*' after the name of the inventor.

14) % Humidity or % Saturation: It is the ration of absolute humidity to that of saturated humidity at the same temperature and pressure.

$$\% \text{ Humidity} = \frac{Y'}{Y'_s} \times 100 \quad (3)$$

where, Y' is absolute humidity of sample of air and Y'_s is humidity at same temperature and pressure if saturated with water vapor.

$$Y'_s = \left(\frac{p_A^v}{P - p_A^v} \right) \frac{18.02}{28.97} \quad (4)$$

and vapor pressure of water can be calculated by Antoine Equation:

$$\ln p_A^v = 11.96481 - \frac{3984.923}{(T - 39.97)} \text{ where, pressure is in bar and temperature is in K.}$$

15) Dew point: Dew point is a temperature at which a vapor-gas mixture must be cooled (at constant humidity) to become saturated. The dew point of a saturated gas equals the gas temperature. If a vapor-gas mixture is gradually cooled at a constant pressure, the temperature at which it just becomes saturated is also called its dew point.

16) Humid volume: The humid volume, v_H , is defined as the volume of unit mass of dry air with accompanying water vapor at a given temperature and pressure.

$$v_H = \left(\frac{1}{28.97} + \frac{1}{18.02} \right) \times 22.4 \times \left(\frac{T_G + 273}{273} \right) \text{ m}^3/\text{kg dry air} \quad (5)$$

assuming ideal gas behavior. T_G is gas temperature in °C.

17) Humid heat: The humid heat, c_H , is the heat energy required to raise the temperature of unit mass of dry air with the accompanying water vapor by one (1) degree.

$c_H = 1.005 + 1.88Y'$ kJ/(kg dry air)(K); first part of right hand side is heat capacity of dry air in kJ/kg.K and second part is heat capacity of water vapor in kJ/kg.K.

18) Enthalpy: The enthalpy of a vapor-gas mixture is the sum of the relative enthalpies of gas and vapor content.

$$H' = c_H(T_G - T_0) + Y'\lambda_0 = (1.005 + 1.88Y')(T_G - T_0) + 2500Y' \text{ kJ/kg} \quad (6)$$

where λ_0 is latent heat of vaporization of water, 2500 kJ/Kg.

Adiabatic saturation temperature:

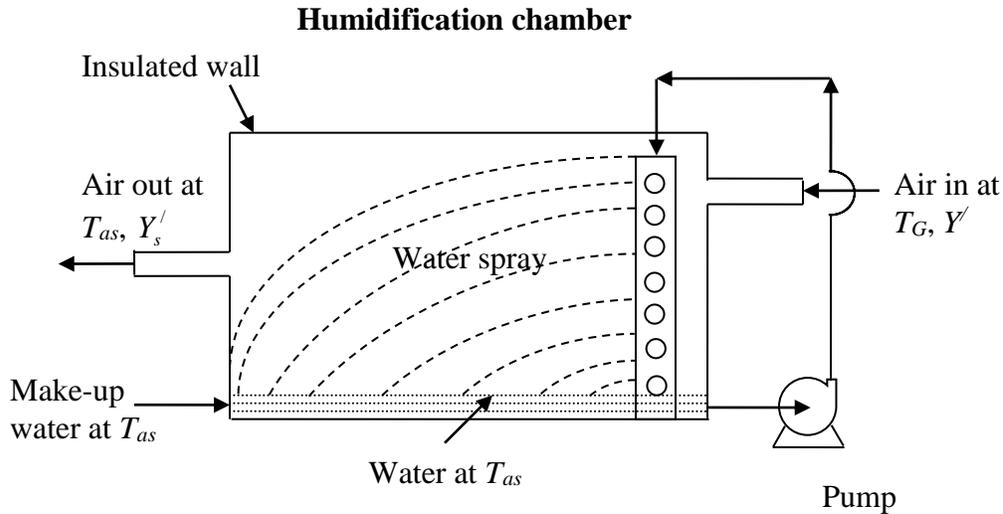


Figure 1. Schematic representation of adiabatic saturation of air.

The schematic of the adiabatic saturation of air by water is shown in Figure 1. The air stream attains thermal equilibrium with water at temperature T_{as} and also gets saturated with water vapor at that temperature before it leaves. A small quantity of water at the temperature T_s is fed to the humidification chamber continuously in order to compensate for the vaporization loss of water. The chamber operates adiabatically, wall is well-insulated. The temperature T_{as} attained by air (same as water) is called “**adiabatic saturation temperature, T_{as}** ”.

Now we will be leaning another important terminology that is adiabatic saturation temperature. So before understanding this adiabatic saturation temperature we will be discussing on the one adiabatic container, this one chamber is maintained adiabatically means no heat is taken in inside this chamber or no heat is lost also from the chamber or we can say it is encircled with the this insulated wall. And say from the right hand side suppose air is entering this one through, we can say this one through this air entering at T_G or gas temperature with humidity is Y prime and this

one water is we can say spread from the sprayer inside this we can say humidification chamber and this the entire chamber is maintained let us say T_{as} .

We say this one temperature as T_{as} and again the water is recycled to the we can say this one from the chamber again to the chamber and say some amount of this air is we can say this one is coming out at T_{as} because our target is to maintain this entire chamber this one the temperature of T_{as} and that time we can say this one humidity will be increased from Y' to Y_s' . And as some amount of water will be evaporated during this we can say this one during maintaining the entire temperature at T_{as} some amount of water will be evaporated. That is why some amount of makeup water is fed at T_m to maintain the temperature of the entire chamber at T_{as} .

So that we can say this one the temperature T_{as} is called this adiabatic saturation temperature, we will be discussing in detail about this temperature that what is really the adiabatic saturation temperature.

(Refer Slide Time: 12:35)

Enthalpy of inlet air,

$$H_i' = c_H(T_G - T_{as}) + \lambda_s Y_i'$$

Enthalpy of exit air,

$$H_o' = c_H(T_{as} - T_{as}) + \lambda_s Y_s' = \lambda_s Y_s'$$

At steady state, $H_i' = H_o'$

Hence,

$$c_H(T_G - T_{as}) + \lambda_s Y_i' = \lambda_s Y_s'$$

$$(T_G - T_{as}) = \frac{\lambda_s}{c_H}(Y_s' - Y_i')$$

So you see this whenever the enthalpy in with this air inlet that is we can say this one that will be like H_i' is equal to $c_H(T_G - T_{as}) + \lambda_s Y_i'$ because this air will be in at T_G temperature and the difference in the temperature will be $T_G - T_{as}$ and the enthalpy of the exit air from here actually what is coming out that is H_o' is equal to $c_H(T_{as} - T_{as}) + \lambda_s Y_s'$ because that is ultimately it is converted into the temperature is attained at T_{as} plus $\lambda_s Y_s'$ because that time we can say this time humidity has increased from Y_i' to Y_s' .

So at steady state we can say this one whatever the enthalpy in and whatever the enthalpy out, both will be same, so we can say this one $H_I = H_O$ and hence we can say this one. From these two equations, this equation and this equation we can say $CH + T_G - T_a + \lambda S = Y' - Y$ will be equal to $\lambda S = CH + Y' - Y$. And from here we can say this one $T_G - T_a$ is equal to $\lambda S / CH$. Just by manipulation we have arrived at this $T_G - T_a$.

This T_a actually is called adiabatic saturation temperature where this T_G is this gas temperature or we can say this one dry bulb temperature. That is the temperature of the air in the dry condition or without any we can say saturation.

(Refer Slide Time: 14:35)

Wet bulb temperature

When evaporation of water occurs?

If the vapor pressure of water is higher than the partial pressure of water vapor in the ambient air, evaporation occurs. The latent heat for evaporation will be supplied by (i) surrounding air and (ii) water drop itself.

Now, consider a drop of water at the tip of thin wire. As temperature of water drop decreases with time, vapor pressure decreases causing a reduction in partial pressure driving force. Temperature driving force for heat transfer from ambient air to water increases. If sufficient time is allowed, a steady state temperature will be attained by drop. This is wet bulb temperature.

Factors that have influence on wet-bulb temperature

- (i) Dry bulb temperature of air T_G
- (ii) Humidity, Y'
- (iii) Air velocity
- (iv) Shape of the thermometer bulb

The combination of a dry-bulb and wet-bulb thermometer is called a “psychrometer”.

Determination of relationship between wet-bulb and dry-bulb temperature

(Refer Slide Time: 18:51)

For any system,

$$\frac{h_G}{K_Y} = 1.2315c^{0.56} \text{ kJ/kg.K}$$

$$\text{Now Eq. } (T_G - T_w) = \frac{\lambda w(Y_w' - Y')}{\left(\frac{h_G}{K_Y}\right)} \text{ becomes } (T_G - T_w) = \frac{\lambda w(Y_w' - Y')}{c_H}$$

$$\text{Equations } \boxed{(T_G - T_{as}) = \frac{\lambda_s(Y_s' - Y')}{c_H}} \text{ and } \boxed{(T_G - T_w) = \frac{\lambda w(Y_w' - Y')}{c_H}}$$

are identical and $T_{as} = T_w$.

Adiabatic saturation temperature and wet-bulb temperature are nearly equal for air-water system.

④ $(T_G - T_w)$ is called wet-bulb depression.

$$\text{Heat flux, } q = h_G(T_G - T_w) \quad (11)$$

$$\text{Molar flux, } N_A = k_G(p_w - p_A) \quad (12)$$

Since, heat flux is sufficient to meet requirement of latent heat of vaporization at steady state.

$$\text{Hence, } h_G(T_G - T_w) = \lambda_w M_w k_G (p_w - p_A) = \lambda w K_Y' (Y_w' - Y') \quad (13)$$

$$(T_G - T_w) = \frac{\lambda w(Y_w' - Y')}{\left(\frac{h_G}{K_Y}\right)} \quad (14)$$

$$\frac{h_G}{K_Y} \approx c_H ; \frac{h_G}{c_H K_Y} \approx 1 \rightarrow \text{Lewis relation}$$

For any system,

$$\frac{h_G}{K_Y} = 1.2315c^{0.56} \text{ kJ/kg.K}$$

$$\text{Now Eq. (14) becomes, } (T_G - T_w) = \frac{\lambda w(Y_w' - Y')}{c_H} \quad (15)$$

Equations (10) and (15) are identical and $T_{as} = T_w$.

Adiabatic saturation temperature and wet-bulb temperature are nearly equal for air-water system.

$(T_G - T_w)$ is called wet-bulb depression.

The Psychrometric chart construction and its use

Seven important quantities, namely, dry-bulb temperature, wet-bulb temperature, relative humidity, absolute humidity, dew point, enthalpy and specific volume, are all inter-related. The psychrometric chart characterizes this interdependence. If any two of these quantities are known, the other five quantities can be readily obtained from this psychrometric chart.

The interdependency of these seven properties is presented in Figure 2. If T_G is the dry-bulb temperature of air and Y' is its humidity, its state is denoted by point 'a'. It falls on the constant humidity line, A%. The adiabatic saturation line through 'a' is 'ab'. 'c' point indicates its humidity, Y' . The adiabatic saturation temperature, T_{as} is obtained by drawing the vertical line through 'b'. For air-water system, wet-bulb temperature T_w is practically same as T_{as} . The humidity of the adiabatically saturated air is given by the point 'e'. The dew point T_d is given by the point 'd' that can be reached by moving horizontally from the point 'a' to 100% humidity line and then moving vertically down to the temperature axis. The humid volume of saturated air at T_G corresponds to the point 'f' and that of dry air at T_G is given by point 'g'. The point 'm' gives the humid volume if the humidity is Y' and it is reached by interpolation between 'g' and 'f'. Enthalpy of a sample of air can also be obtained from humidity chart.

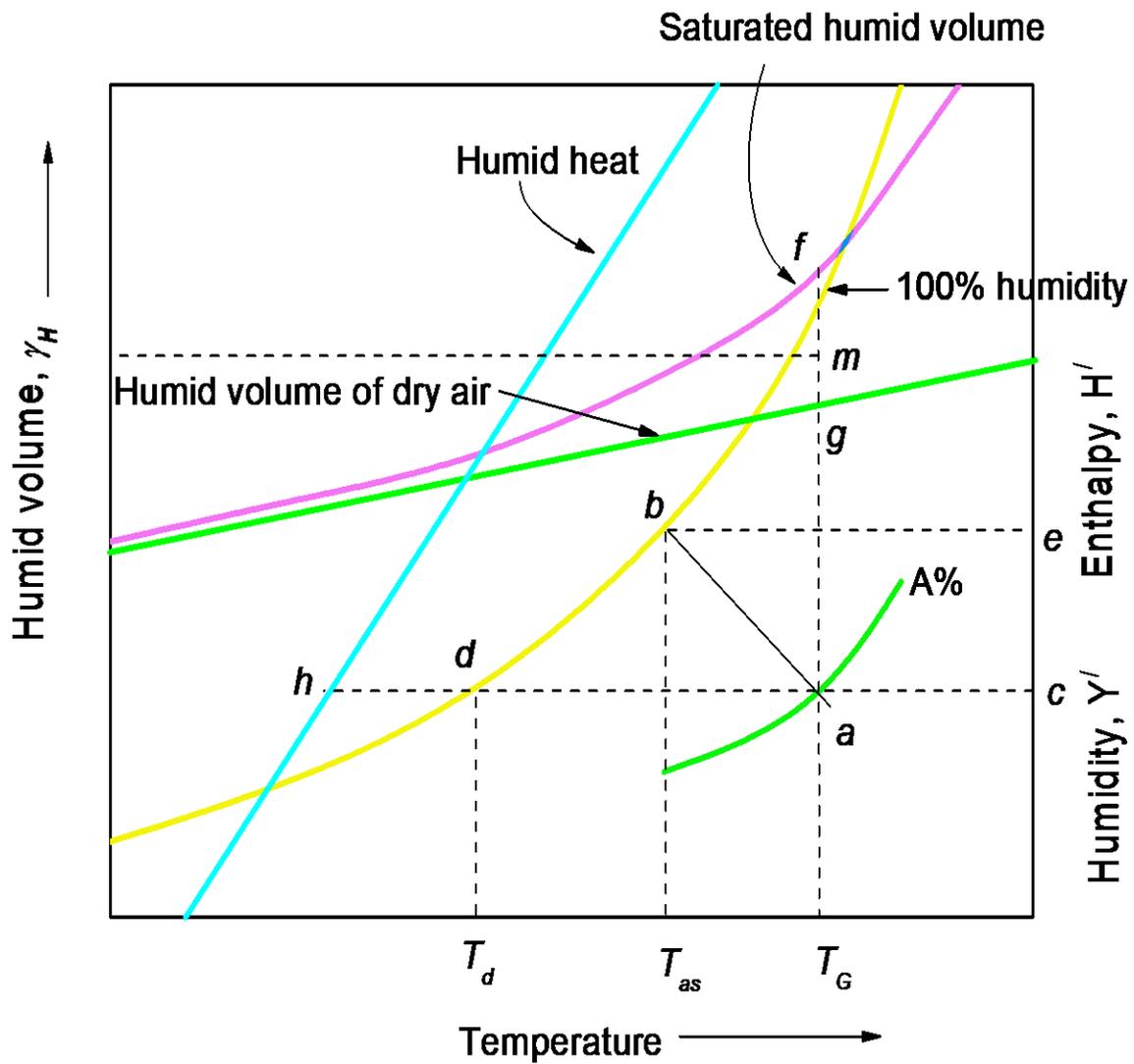


Figure 2. Determination of properties from the psychrometric chart.

Humidification and dehumidification operations and design calculations

Humidification operations: In this operation, water transfers from liquid phase to gas phase. Hence, moisture content of air increases. Air with particular moisture content is useful for drying of a solid under controlled condition.

Dehumidification operations: It is the reverse phenomena of humidification. A portion of water vapor from moist warm air is condensed by contacting cold water in air conditioning.

Cooling tower principle and operation

A cooling tower is a special type of heat exchanger in which the warm water and the air are brought in direct contact for '*evaporative cooling*'. It provides a very good contact of air and water in terms of the contact area and mass transfer co-efficient of water vapor while keeping air pressure drop low.

Enthalpy of air is lower than enthalpy of water. Sensible heat and latent heat transfer take place from water drop to surrounding air. Schematic of heat transfer from water drop to surrounding air is presented in Figure 3.

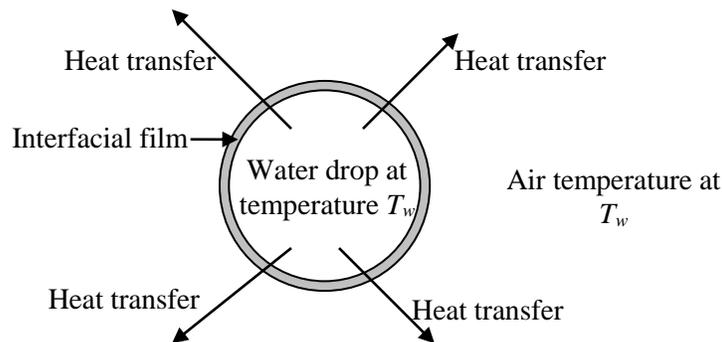


Figure 3. Schematic of heat transfer from water drop to surrounding air.

Thus, cooling is accomplished by sensible heat transfer from water to air and evaporation of a small portion of water. A generalized cooling tower system is shown in Figure 4. The hot water which is coming from heat exchanger is sprayed at the top of the cooling tower. Air enters through the louvers at the two opposite walls of the cooling tower. During cooling process of

water, around 2% water is evaporated. Make water is used to compensate the water loss due to evaporation. Blowdown is there to drain a part of water containing solid deposit. The exit cold water from the cooling tower is used in the heat exchanger or other unit operation.

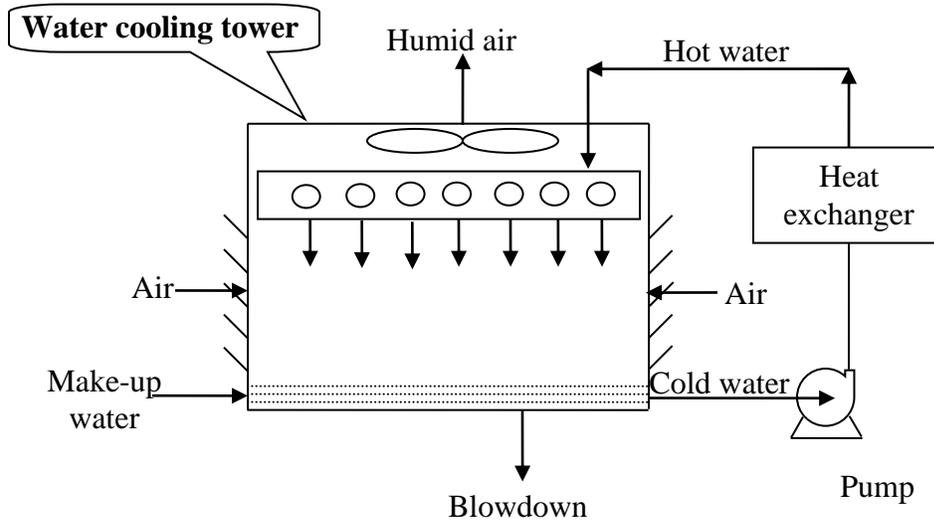
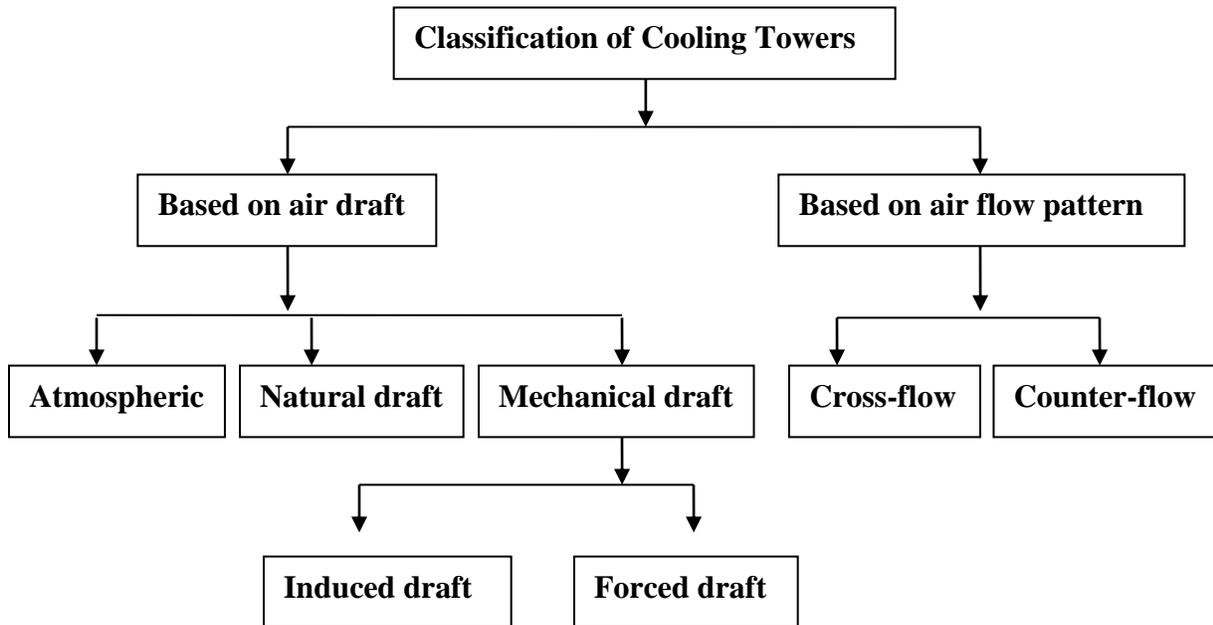


Figure 4. Generalized cooling tower system.

Factors govern the operation of cooling tower

- i. The dry-bulb and wet-bulb temperatures of air
- ii. Temperature of warm water
- iii. The efficiency of contact between air and water in terms of volumetric mass transfer coefficient ($k'_y \bar{a}$)
- iv. Contact time between air and water
- v. The uniformity of the distribution of the phases within the tower
- vi. Air pressure drop
- vii. Desired temperature of cooled water

Types of equipment



(A) Atmospheric Towers

It is a big rectangular chamber with two opposite ‘louvered’ walls. Tower is packed with a suitable ‘tower fill’. Atmospheric air enters the tower through louvers driven by its own velocity. Direction and velocity of wind greatly influence its performance. Figure 5 shows the schematic of the atmospheric cooling tower.

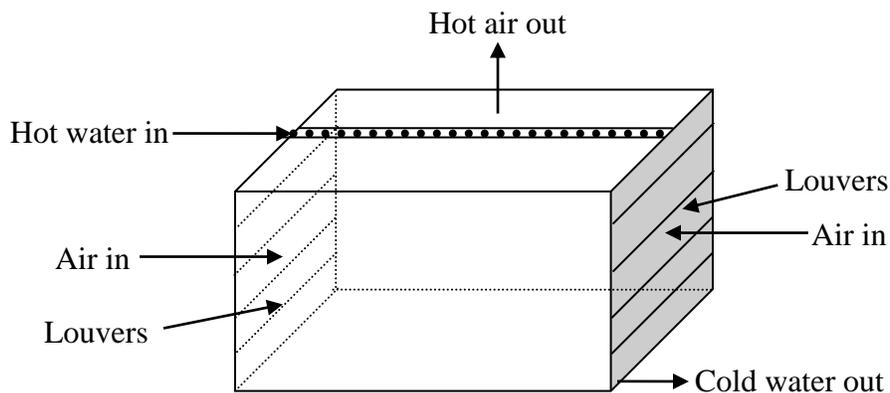


Figure 5. Schematic of atmospheric cooling tower.

(B) Natural Draft Towers

A natural draft cooling tower has a large reinforced concrete shell of hyperbolic shape (also called 'hyperbolic tower'). Natural flow of air occurs through the tower; hence it is called natural draft (refer Figure 6).

Factors responsible for creating natural draft

- (a) A rise in temperature and humidity of air in the column reduces its density
- (b) Wind velocity at the tower bottom

Fan is used to enhance the air flow rate in fan assisted natural draft tower. The typical diameter of tower is 150 m and capacity is 5,00,000 gallon/minute.

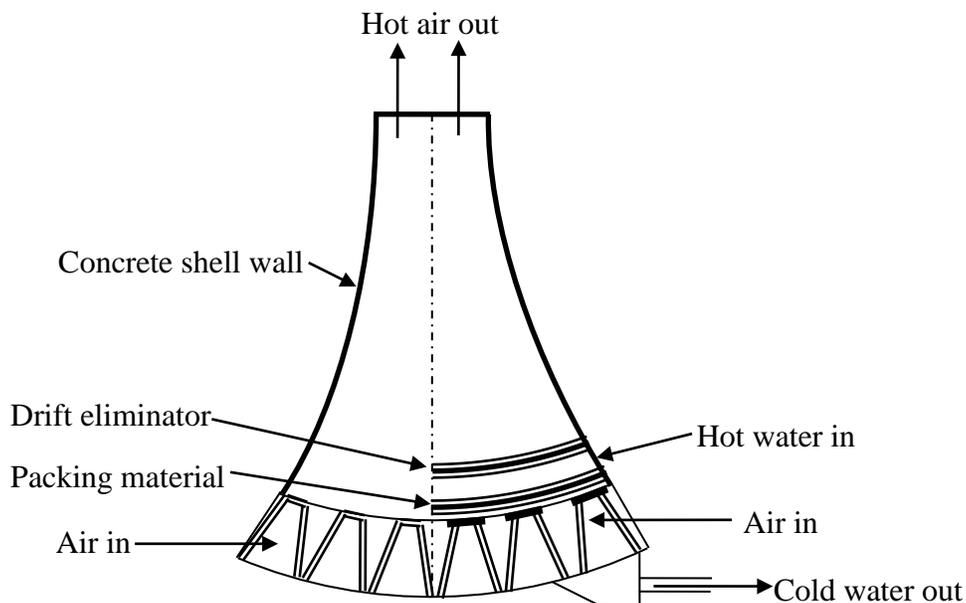


Figure 6. Schematic of natural draft tower.

Why hyperbolic shape?

- (i) *More packing materials can be placed at the bottom*
- (ii) *The entering air gets smoothly directed towards the centre*
- (iii) *Greater structural strength and stability*

(C) Mechanical Draft Towers: forced draft towers and induced draft towers

Fans are used to move air through the tower in mechanical draft cooling towers. Two types of mechanical draft towers are there, namely, forced draft tower and induced draft tower.

Forced draft towers: It can be seen from Figure 7 that it has one or more fans located at the tower bottom to push air into tower.

Advantages:

- (a) A part of the velocity head of air thrown by the blower is converted to pressure head on entering into the tower. It makes energy efficient than induced draft.
- (b) Less susceptible to vibrations as fans are installed near the ground.

Disadvantages:

- (a) Air flow through the packing may not be uniform
- (b) Some of the warm and humid air may be recirculated back. Recirculation rate becomes low if the wind velocity is high. It is not popular except for small capacities.

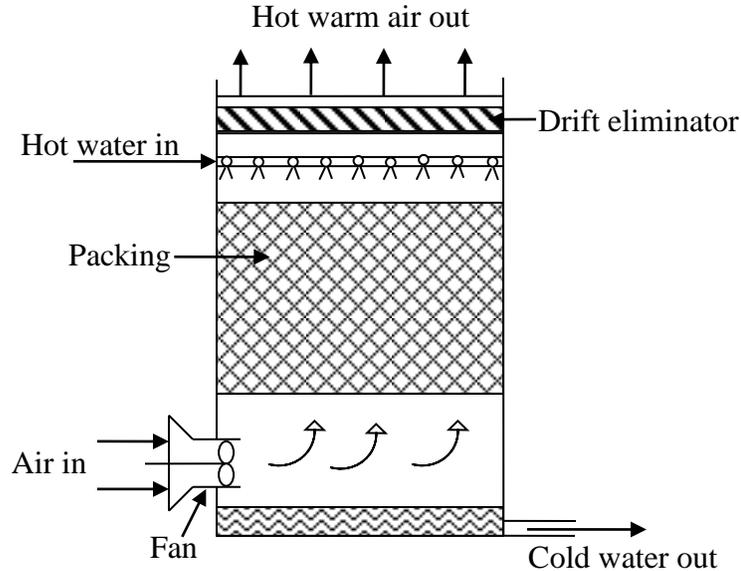


Figure 7. Schematic of forced draft towers.

Induced draft towers: One or more fans are installed at the top of the tower. Depending on the air inlet and flow pattern, induced draft towers are of two types, cross-flow and counter flow towers.

Major advantages of countercurrent induced draft cooling tower

- (a) Relatively dry air contacts the coldest water at the bottom of the cooling tower
- (b) Humid air is in contact with the warm water and hence maximum average driving force prevails for both heat and mass transfer.

Disadvantage of induced draft towers compared to forced draft towers

It consumes more horse power.

Cross-flow induced draft cooling tower requires less motor horse power than countercurrent induced draft cooling towers.

(D) Cross-current and counter-current

Cross-flow induced draft cooling tower supplies horizontal air flow along the packed height and requires less motor horse power than the counter-flow type. Additional 'cells' may be added to raise the capacity. The schematic of induced draft counter-flow and cross-flow cooling towers are presented in Figure 8 and Figure 9, respectively.

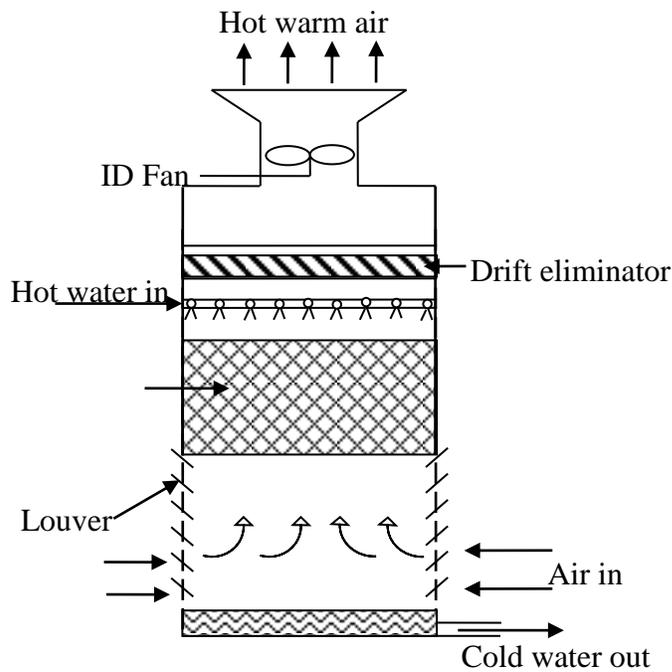


Figure 8. Schematic of mechanical draft counter-flow tower.

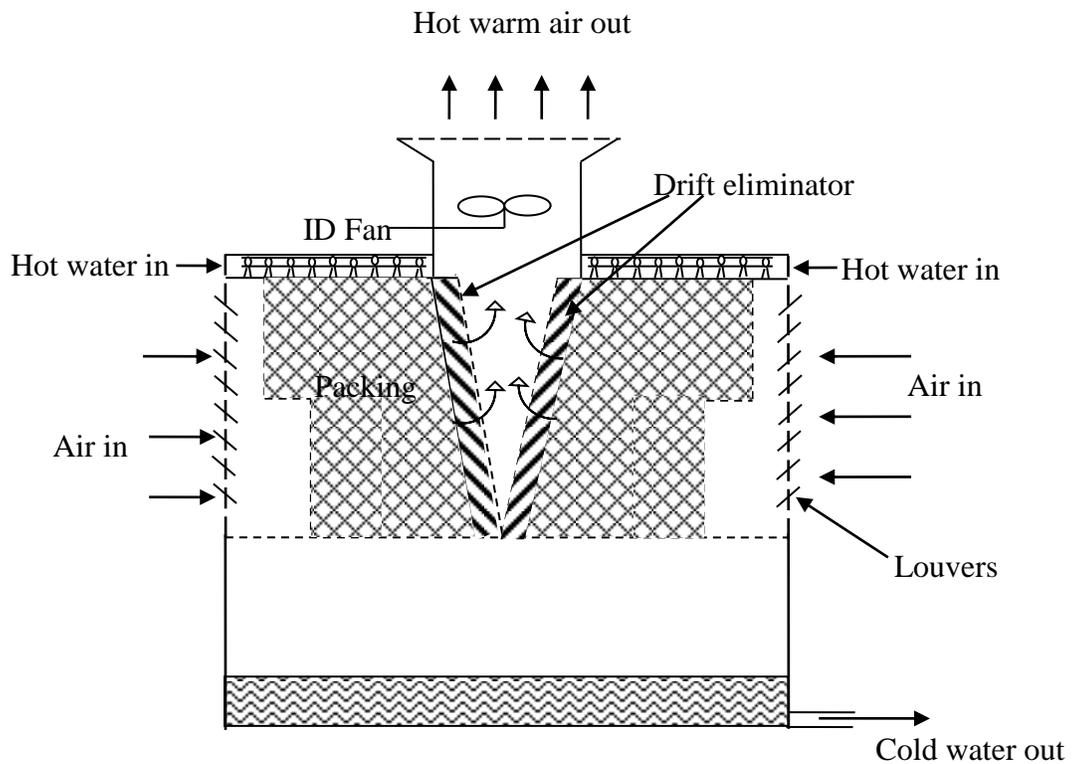


Figure 9: Schematic of mechanical draft cross-flow tower.

Design calculations of cooling tower

Primarily we need to calculate,

- (i) tower cross-section required to take the given load of warm water
- (ii) height of the packing required to achieve the desired cooling

Basic assumptions for the design of cooling tower are as follows:

- (i) the rate of vaporization of water is much less than the rate of water input to the tower (about 1% loss of feed water)
- (ii) evaporative or adiabatic cooling of water occurs in the tower

The schematic of cooling tower is shown in Figure 10.

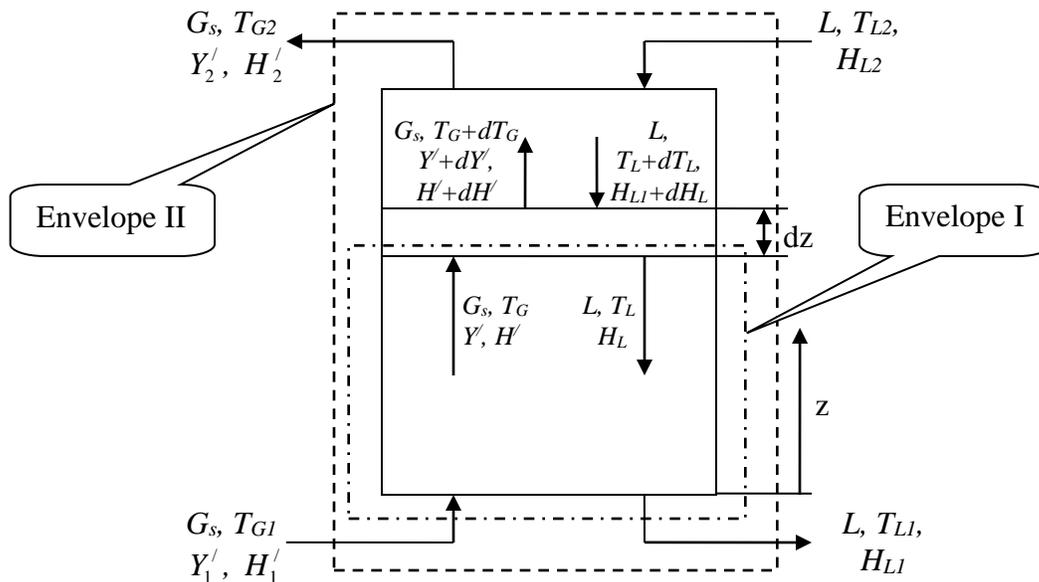


Figure 10. Schematic of water cooling tower

Thank you. In the next class we will be discussing on cooling tower design by step by step procedure.