UNIT – III

PART – A

1. Define humidity.

Humidity H is the mass of vapour carried by a unit mass of vapour – free gas. So defined, humidity depends only on partial pressure of the vapour in the mixture.

$$H = \frac{M_A P_A}{M_B(P - P_A)}$$

2. Define saturated gas.

Saturated gas is gas in which the vapour is in equilibrium with the liquid at the gas temperature.

3. Define Saturation humidity.

The partial pressure of vapour in saturated gas equals the vapour pressure of the liquid at the gas temperature. If its is the saturation humidity then $P^1{}_A$ is the vapour pressure of the liquid.

$$H_S = \frac{M_A P^1{}_A}{M_B(P - P^1{}_A)}$$

4. What is relative humidity?

Relative humidity H_R is defined as the ratio of the partial pressure of the vapour to the vapour pressure of the liquid at the gas temperature. It is usually expressed on percentage basis, 50, 100 percent humidity means saturated gas and 0 percent humidity means vapour – free gas.

$$H_R = 100 \frac{P_A}{P^1{}_A}$$

5. What is vapour-free gas?

If the humidity is 0 percent means, then it is said to be vapour-free gas.

6. What is percentage humidity?

Percentage humidity is denoted as H_A and it is the ratio of the actual humidity H to the saturation humidity H_S.

$$H_A = 100 \frac{H}{H_S} = 100 \left[\frac{P_A/(P - P_A)}{P^1 A/(P - P^1{}_A)} \right]$$

$$= \text{HR} \left[\frac{P - P^1{}_A}{P - P_A} \right]$$

7. What is humid heat?

Humid heat is denoted as C_S and it is the heat energy necessary to increase the temperature of 1 gm. Or 11b of gas plus whatever vapour it may contain by 1°C or 1°F. Thus,

$$C_S = C_P^B + C_P^A H.$$

8. What is humid volume?

Humid volume is denoted as V_H and it is the total volume of a unit mass of vapour-free gas plus whatever vapour it may contain at 1 atm and the gas temperature.

$$V_H = \frac{0.0224\ T}{273}\left(\frac{1}{M_B} + \frac{H}{M_A}\right)$$

In fPs units

$$V_H = \frac{359\ T}{492}\left(\frac{1}{M_B} + \frac{H}{M_A}\right)$$

9. What is saturated volume?

For vapour-free gas H=0 and V_H is the specific volume of the fixed gas. For saturated gas $H = H_S$ and V_H becomes the saturated volume.

10. What is a dew point?

Dew point is the temperature to which a vapour-gas mixture must be cooled to become saturated. The dew point of a saturated gas phase equals the gas temperature.

11. What is total enthalpy?

Total enthalpy, H_Y is the enthalpy of a unit mass of gas plus whatever vapour it may contain.

12. What is adiabatic saturation temperature?

If not all the water evaporates and there is sufficient time for the gas to come to equilibrium with the water, the exit temperature of the gas is called adiabatic saturation temperature.

13. What is humidity chart?

A convenient diagram showing the properties of the mixtures of a permanent gas and a condensable vapour is the humidity chart.

14. What are adiabatic cooling lines?

Humidity chart, the slanting lines running downward and to the right of the saturation line are called as adiabatic cooling lines.

15. What is wet-bulb temperature?

Under steady state a liquid temperature that the heat needed to evaporate the liquid and heat the vapour to gas temperature is exactly balanced by the sensible heat flowing from the gas to the liquid.

That steady-state temperature T_W is called the wet-bulb temperature.

16. What is dry-bulb temperature?

Commonly an unconverted thermometer is used along with the wet bulb to measure T, the actual gas temperature is usually called as dry-bulb temperature.

17. What are the methods for measuring humidity?

There are three methods used for the measurement of humidity. They are:-

a) Dew – point method
b) Psychometric method
c) Direct method

18. What are cooling towers?

When warm liquid is brought into contact with unsaturated gas, part of the liquid evaporates and the liquid temperature drops. The most important application of this principle is in the use of cooling tower.

19. What is Lewis relation?

For the system air-water at ordinary conditions; the humid heat C_S is almost equal to the specific heat C_P and the equation is $\frac{hy}{M_B Ky} \cong C_S$

This is Lewis relation.

20. What is a Psychometric line?

For a given wet-bulb temperature the equation can be plotted on the humidity chart as a straight line having a slope of $-hy/M_B\ Ky\ \partial w$ and intersecting the 100% line at T_w. This line is called the Psychometric line.

21. What is direct method in the measurement of humidity?

The vapour contest of a gas can be determined by direct analysis, in which a known volume of gas is drawn through as appropriate analytical device.

22. What type of packing is used is the cooling tower?

The most common type of packing for new installations is cellular film or film-type packing, which consists of corrugated sheets of plastic similar to those used is plate – type heat exchangers.

23. What is known as approach?

In practice, the discharge temperature of the water is 5 to 15° F above the wet-bulb temperature, and this difference is known as "approach".

24. What is Psychometric method?

A very common method of measuring the humidity is to determine simultaneously the wet-bulb and dry-bulb temperature. From there readings the humidity is found by locating the Psychometric line intersecting the saturation line at the observed wet-bulb temperature and the Psychometric line to its intersection with the ordinate of the observed dry-bulb temperature.

25. Give some examples of adiabatic operations.

Some examples of adiabatic operations are:

- ⇒ Cooling a liquid
- ⇒ Cooling a hot gas
- ⇒ Humidifying a gas
- ⇒ Dehumidifying a gas

26. Give some examples for non-adiabatic operations.

We have generally two non-adiabatic operations. They are :

- ⇒ Evaporative cooling
- ⇒ Dehumidifying a gas

27. Define the process "Cooling a liquid"

The cooling occurs by transfer of sensible heat and also by evaporation. The principal application is cooling of water by contact with atmospheric air.

28. Define "Cooling a hot gas".

Direct contact provides a non-fouling heat exchanges which is very effective, providing the presence of some of the vapour of the liquid is not objectionable.

29. Define "humidifying a gas"

This can be used for controlling the moisture contest of air for drying.

30. Define "De-humidifying a gas".

Contact of a warm vapour-gas mixture with a cold liquid results in condensation of the vapour. There are applications in air-conditioning, recovery of solvent vapours from gases used in drying.

31. What is evaporative cooling?

A liquid (or) a gas inside a pipe is cooled by water flowing is a film about the outside, the water in turn being cooled by direct contact with air.

32. What is dehumidifying a gas in non-adiabatic operation?

A gas-vapour mixture is brought into contact with refrigerated pipes, and the vapour condenses upon the pipes.

33. Give the equation used frequently in cooling-tower operations.

The water – cooling tower industry frequently uses,

$$\frac{Ky\ a^2}{L^1} = \int_{tL_1}^{tL_2} \frac{dt_L}{H^{'X} - H^{'}}$$

34. Give the enthalpy balance equation for adiabatic saturated?

The total enthalpy of the entering gas is C_S $(T - T_S) + H\ \partial_S$ and the enthalpy balance equation is

$$C_S(T - T_S) + H\partial_S = H_S\partial_S$$

$$\frac{H_S - H}{T - T_S} = \frac{C_S}{\partial_S} = \frac{C_P B + C_{PA} H}{\partial_S}$$

35. What for the humidity charts are used other than air-water?

A humidity chart may be constructed for any system at any desired total pressure. The data required are the vapour pressure and latest heat of vaporization of the condensable component.

36. What are the precautions in the measurement of wet-bulb temperature?

- ⇒ Wick must be completely wet.
- ⇒ Velocity of the gas should be large enough to ensure that the rate of heat flow by radiation from warmer surrounding to the bulb.
- ⇒ If make-up liquid is supplied to the bulb, it should be at the wet-bulb temperature.

37. What are the types of flow in cooling towers?

The flow types are,

⇒ Parallel flow

⇒ Counter flow

⇒ Cross flow

38. What will happen in a counter flow cooling tower?

In the counter-flow tower, air enters below the layer of fill and passes upward counter flow to the flow of descending water.

39. Give the use of humidity chart.

The usefulness of the humidity chart as a source of data on a definite air-water mixture can be shown which is a portion of the chart. Assume, for example, that a given stream of under saturated air is known to have a temperature T, and a percentage humidity H_A.

40. Write the equation of humid volume in fps unit.

In fps unit the equation is,

$$V_H = \frac{359T}{492}\left(\frac{1}{M_B}+\frac{H}{M_A}\right)$$

Where V_H is in cubic feet per pound and T is in degrees Ronkire. For vapour-free gas H = 0 and V_H is the specific volume of the fixed gas.

41. What is the difference between vapour and gas?

Vapour means the gaseous form of the component that is also present as liquid.

Gas is the component present only is gaseous form.

42. Give the humidity mole fraction equation.

The humidity is related to the mole fraction in the gas phase by the equation,

$$Y = \frac{H / M_A}{1/M_A + H/M_A}$$

43. What are tray towers?

These are very effective but are not commonly used is humidification, dehumidification or gas-cooling operations for reasons of cost and relatively high pressure – drop except under special conditions.

44. What are Spray Chambers?

There are essentially horizontal spray towers and may be arranged. They are frequently used for adiabatic humidification cooling operations with re-circulating liquid.

45. Write the formula for absolute humidity?

Absolute Humidity or Molar Absolute Humidity:

(a) Molar: $$Y = \frac{\text{moles A}}{\text{moles B}} = \frac{y_A}{y_B} = \frac{\bar{p}_A}{\bar{p}_B} = \frac{\bar{p}_A}{p_t - \bar{p}_A}$$

(b) Mass: $$Y' = \frac{\text{mass A}}{\text{mass B}} = Y\left(\frac{M_A}{M_B}\right) = \left(\frac{M_A}{M_B}\right)\frac{\bar{p}_A}{p_t - \bar{p}_A}$$

46. State the relative saturation?

$$\phi = \frac{\text{mole fraction of A at T and } p_t \text{ in gas-vapour phase}}{\text{mole fraction of A at T and } p_t \text{ in saurated gas-vapour phase}}$$

$$\phi = \frac{\bar{p}_A}{p_A} \rightarrow \phi_{\%} = 100\frac{\bar{p}_A}{p_A}$$

47. What humid volume?

Humid volume v_H: Volumes – always associated with 1 kg of dry gas.

Dry Volume: $$v_G = \frac{RT}{p_t M_B} (=) \left[\frac{m^3 \text{ of dry gas}}{\text{kg of dry gas}}\right]$$

Humid Volume = volume of 1 kg of dry gas + volume of associated vapour

$$V_H = \frac{RT}{p_t M_B} + Y'\frac{RT}{p_t M_A} = \frac{RT}{p_t}\left(\frac{1}{M_B} + \frac{Y'}{M_A}\right) (=) \left[\frac{m^3 \text{ of mixture}}{\text{kg of dry gas}}\right]$$

$$V_H = 9315\frac{t_G + 273}{p_t}\left(\frac{1}{M_B} + \frac{Y'}{M_A}\right)$$ for ideal gas

$$V_H = (0.00283 + 0.00456\,Y')(t_G + 273)$$

For the air (B) – water (A)

system at 1 std. atm. Pressure.

$$V_{H3} = \frac{RT}{p_t}\left(\frac{1}{M_B} + \frac{Y_S}{M_A}\right)(=)\left[\frac{m^3 \text{ of mixture}}{\text{kg of dry gas}}\right]$$

48. What is dew point?

The temperature at which condensation begins (i.e. the vapour-gas mixture is saturated) when cooled at constant total pressure.

49. What is humid heat?

The heat capacity of 1 kg of dry gas + the associated vapour. The heat required to raise the temperature of 1 kg of dry gas and its accompanying vapour one degree at constant pressure.

$$C_S = C_B + Y'C_A(=)\left[\frac{\text{J for mixture}}{\text{kg dry gas } ^\circ\text{C}}\right]$$

50. What is wet bulb temperature?

If air is not saturated, liquid will evaporate from wick and wick will cool. We then have a temperature difference between the air and the wick, so heat transfer occurs. Eventually, a steady state will be reached there the heat transfer from the air to the wick just supplies the energy needed for vaporization. The temperature of the wetted wick as indicated by the thermometer is the wet-bulb temperature, t_{WB}.

51. Write the Humidification equipment?

- Cooling Tower
- Tray Towers
- Spray Chambers
- Spray Ponds

PART – B

1. In a mixture of benzene vapour (A) and nitrogen gas (B) at a total pressure of 800mm Hg and a temperature of 60°C, the partial pressure of benzene is 100 mm Hg. Express the benzene concentration in other terms.

Solution:

$$\bar{P}_A = 100$$

$$\bar{P}_B = 800 - 100$$

$$= 700 \text{ mm Hg.}$$

(a) **Mole fraction**

Since the pressure fraction and mole fraction are identical for gas mixtures,

$$\bar{Y}_A = \frac{\bar{P}_A}{P_t} = \frac{100}{800} = 0.125 \text{ mole fraction benzene}$$

The mole fraction of nitrogen = Y_B = 1 – 0.125

$$= \frac{700}{800} = 0.875$$

(b) Volume fraction of benzene equals the mole fraction, 0.125

(c) Absolute humidity

$$Y = \frac{Y_A}{Y_B}$$

$$= \frac{\bar{P}_A}{\bar{P}_B}$$

$$= \frac{0.125}{0.875} = \frac{100}{700}$$

= 0.143 mol benzene / mol nitrogen.

$$Y' = Y \frac{M_A}{M_B}$$

$$= 0.143 \left(\frac{78.05}{28.08}\right)$$

= 0.398 Kg benzene / Kg nitrogen.

2. A gas (B) = benzene (A) mixture is saturated at 1std atm, 50°C. Calculate the

absolute himidity if B is (a) nitrogen (b) carbon dioxide.

Solution:

Since the mixture is saturated, the partial pressure of benzene, $\hat{P}_A$ equals the equilibrium vapour pressure P_A of benzene at 50°C, from the chart,

$$\hat{P}_A = 275 \text{ mm Hg}$$

(or) 0.362 Std atm.

(a) $$Y_S = \left(\frac{P_A}{P_t - P_A}\right)$$

$$= \frac{0.362}{(1-0.362)}$$

$= 0.567$ Kmol C_6H_6/Kmol N_2

$$Y'_S = \left(\frac{Y_S M_A}{M_B}\right)$$

$$= \frac{0.567\ (78.05)}{28.02}$$

$= 1.579$ Kg $C_6\ H_6$ / Kg N_2.

(b) $$Y_S = \left(\frac{P_A}{P_t - P_A}\right)$$

$$= \frac{0.362}{(1-0.362)}$$

$= 0.567$ Kmol C_6H_6/Kmol Co_2

$$Y'_S = \left(\frac{Y_S M_A}{M_B}\right)$$

$$= \frac{0.567\ (78.05)}{44.01}$$

$= 1.006$ Kg C_6H_6/Kg Co_2.

3. Write a note on measurement of humidity in detail.

The humidity of a stream or mass of gas may be found by measuring either the dew point or the wet-bulb temperature or by direct absorption methods.

⇒ **Dew – Point methods:-**

If a cooled, polished disk is inserted into gas of unknown humidity and the temperature of the disk gradually lowered, the disk reaches a temperature at which mist condenses on the polished surfaces. The temperature at which this mist just forms is the temperature of equilibrium between the vapour in the gas and the liquid phase. It is therefore the zero point. A check on the reading is obtained by slowly increasing the disk temperature and noting the temperature at which the mist just disappears. From the average of the temperatures the humidity can be read out.

⇒ **Psychometric methods:-**

A very common method of measuring the humidity is to determine simultaneously the wet-bulb and dry-bulb temperatures. From there readings the humidity is found by locating the psychometric line intersecting the saturation line at the observed wet-bulb temperature and following the Psychometric line to its intersection with the ordinate of the observed dry-bulb temperature.

⇒ **Direct methods:**

The vapour contest of a gas can be determined by direct analysis, in which a known volume of gas is drawn through an appropriate analytical device.

4. Explain in detail about cooling towers.

When warm liquid is borough into contact with unsaturated gas, part of the liquid evaporates and the liquid temperature drops. The most important application of this principle is in the use of cooling towers to lower the temperature of recirculated water used for condenses and heat exchangers in chemical plants, power plants, and air-conditioning units.

Cooling towers are large – diameter columns with special types of packing designed to give good gas-liquid contact with low pressure drop.

Two of the major types are cross-flow and counter flow. In the counter flow tower, air enters below the layer of fill and passes upward counter current to the flow of descending water. This is a more efficient arrangement for heat transfer and permits a closer temperature approach.

In older towers, the packing consisted of horizontal redwood or cypress slats spaced so that water falling on the slats would splash and the droplets be intercepted by next layer of packing. Splash-type fill is still used in some cross-flow towers, but V-shaped bars of polyvinyl chloride are used instead of wooden slats.

The most common type of packing for new installations is cellular fill or film-type packing, which consists of corrugated sheets of plastic similar to those used in plate-type heat exchangers.

The reduction in water temperature in the cooling tower comes mainly from evaporation, although when the air temperature is low, there is also some sensible heat transfer to the air.

Cooling towers are generally selected after consultation with equipment suppliers and consideration of factors such as the average and maximum heat duty, the required temperature range, the availability and quality of make up water and the local weather conditions.

5. Write the use of humidity chart.

The usefulness of the humidity chart as a source of data as a definite air-water mixture can be shown by reference, which is a portion of the chart. Pressure for example, that a given stream of under saturated air is known to have a temperature T, and a percentage humidity H_{A1}. Point a represents these air on the chart. This point is the intersection of the constant – temperature line for T_1 and the constant-percentage – humidity line H_{A1}. The humidity H_1 of the air is given by point b, the humidity coordinate of point a. The dew point is found by following the constant – humidity line through a point a to the left to point C on the 100 percent line. The dew point is then read at point d on the temperature axis.

The adiabatic saturation temperature is the temperature applying to the adiabatic cooling line through point a. The humidity at adiabatic saturation is found by following the adiabatic line through point a to its intersection e on the 100% line and reading humidity H_S at point f on the humidity scale.

Interpolation between the adiabatic lines may be necessary. The adiabatic saturation temperature T_S is given by point g.

If the original air is subsequently saturated at constant temperature, the humidity after saturation is found by following the const – temperature line though point a to point h and the 100% line and reading the humidity at point j. Refer to humidity chart.

6. The temperature and dew point of the air entering a certain dryer are 150 & 60°F respectively. What additional data for this air can be read from the humidity chart?

<u>Solution:-</u>

The dew point is the temperature co-ordinate on the saturation line corresponding to the humidity of the air. The saturation humidity for a temperature of 60°F is 0.011 lb of water per pound of dry air, and this is the humidity of the air. From the temperature and humidity of the air, the point on the chart for this air is located.

At H = 0.011 and T = 150°F. The percentage humidity H_A is found by interpolation to be 5.2%. The adiabatic cooling line through this point intersects the

100% line at 85°F and this is the adiabatic saturation temperature. The humidity of saturated air at this temperature is 0.026 lb of water per pound (0.026 g/g) of dry air. The humid heat of the air is 0.245 Btu/ lb dry air °F. The saturated volume at 150°F is 20.7 ft^3/lb of dry air, and the specific volume of dry air at 150°F is 15.35 ft^3/lb. The humid volume is,

$$V_H = 15.35 + \frac{0.011 \times 359}{18}\left(\frac{610}{492}\right)$$

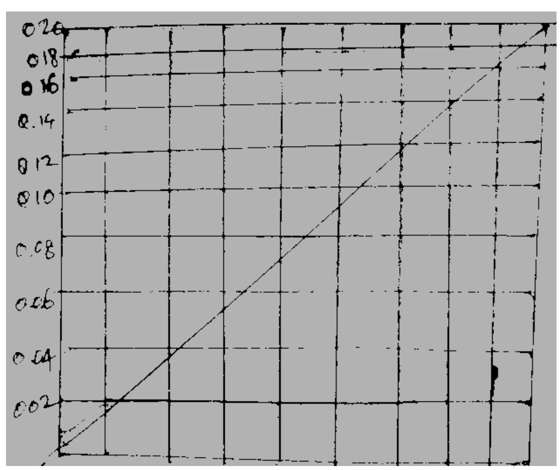
$$= 15.62 \text{ ft}^3/\text{lb dry air } (0.978 \text{m}^3/\text{kg})$$

7. Write a note on Phase – equilibrium.

In humidification and dehumidification operations the liquid phase is a single pure component. The equilibrium partial pressure of solute in the gas phase is therefore a unique function of temperature when the total pressure on the system is held constant. Also, at moderate pressures the equilibrium partial pressure is almost independent of total pressure and is virtually equal to the vapour pressure of the liquid. By Dalton's law the equilibrium partial pressure may be converted to the equilibrium mole fraction y_e in the gas phase. Since the liquid is pure, x_e is always unity.

Equilibrium data are often presented as plots of y_e versus temperature at a given total pressures, as shown for the system air-water at 1 atm. The equilibrium mole fraction y_e is related to the saturation humidity and the equation is

$$y_e = \frac{H_S/M_A}{1/M_B + H_S/M_A}$$



8. Explain about adiabatic saturator.

Water is often sprayed into a stream of gas in a pipe or spray chamber to bring the gas to saturation. The pipe or chamber is insulated so that the process is adiabatic.

The gas, with an initial humidity H and temperature T Q is cooled and humidified. If not all the water evaporates and there is sufficient time for the gas to come to equilibrium with the water, the exit temperature of the gas is called the adiabatic saturation temperature T_S. The remaining liquid is also at T_S and can be recirculated to the spray nozzles.

The value of T_S depends on the temperature and initial humidity of the air and to a minor extent on the initial water temperature. To simplify the analysis, the water is often assumed to enter at T_S.

An enthalpy balance can be written over this process. Pump work is neglected, and the enthalpy balance is based on temperature T_S as a datum. Then the enthalpy of the makeup liquid is zero and the total enthalpy of the entering gas equals that of the leaving gas. Since the latter is at datum temperature, its enthalpy is simply $H_S \partial_S$, where H_S is the saturation humidity and ∂_S is the latest heat, both at T_S.

Then, the total enthalpy of the entering gas is $C_S (T - T_S) + H \partial_S$ and the enthalpy balance is,

$$C_S (T - T_S) + H \partial_S = H_S \partial_S \quad \text{(or)}$$

$$\frac{H_S - H}{T - T_S} = \frac{C_S}{\partial_S} = \frac{C_{P^B} + C_{P^{AH}}}{\partial_S}$$

To find the adiabatic saturation temperature for gases other than air, a heat balance equation similar to the above equation is used.

It may be more convenient however, to use molar heat capacities, as discussed.

9. Flues gas at 320°F and 1 atm is to be cooled by a water spray. The gas contains 14% Co_2, 7%, H_2O, 3% O_2 and 76% N_2. (a) Calculate the adiabatic saturation temperature if the water spray enters at 80°F.

<u>Solution:</u>

(a) Basis : 100 mol of gas

Guess that T_S is 120°F

Molar heat capacity C_P = 220°F

Gas	No. of moles	Molar specific heat C_P	nC_P
Co_2	14	9.72	136.08
H_2O	7	8.11	56.77
O_2	3	7.14	21.42

N_2	76	6.98	530.48
	$\Sigma c = 100$		ΣnC_P 744.75

Heat balance equation,

$$\Sigma nC_P (T - T_S) = 2\,\partial_S + 18z\,(120 - 80)$$
$$= Z\,(\partial_S + 720)$$
$$\partial_S = 1{,}025.5 \times 18$$
$$= 18{,}459 \text{ Btu/lb mol.}$$

Then, $744.75\,(320 - 120) = Z\,(18{,}459 + 720)$

$$= 19{,}179Z$$
$$Z = 7.77$$

Total moles of water in exit gas

$$7 + 7.77 = 14.77$$

Mole fraction of water in exit gas

$$Y = \frac{14.77}{107.77} = 0.137$$

Now we have,

$$744.75\,(320 - 126) = Z\,[18398 + 18\,(126 - 80)]$$

$$= 19{,}226\,Z$$

$$Z = 7.51.$$

Total moles of water

$$7 + 7.51 = 14.51$$

$$Y = \frac{14.51}{107.51} = 0.135$$

10. Flue gas at 320°F and 1 atm is to be cooled by a water spray. The gas contains 14% Co_2, 7% H_2O, 3% O_2 and 76% N_2. Find out the adiabatic saturation temperature when the water enters at T_S.

<u>Solution:</u>

Basis : 100 mol of gas. Guess that T_S is about 120°F and C_P for each gas

$$= \frac{(320 + 120)}{2} = 220°F$$

We have as similar to the above problem.

The last term of the heat balance is dropped if $T_{in} = T_S$. For $T_S = 126°F$.

Then, we have

$$744.75\ (320 - 126) = Z\ (18{,}398)$$

$$Z = 7.85$$

$$Y = \frac{7.85 + 7}{107.51}$$

$$= 0.138$$

The saturation temperature must be slightly higher than 126°F but the difference is negligible.

11. Explain about Gas-Liquid contact operations.

Direct contact of a gas with a pure liquid may have any of several purposes.

⇒ Adiabatic Operations:

(a) **Cooling a liquid:**

The cooling occurs by transfer of sensible heat and also by evaporation. The principle application is cooling of water by contact with atmospheric air.

(b) **Cooling a hot gas:**

Direct contact provides a non-fouling heat exchanger which is very effective, providing the presence of some of the vapour of the liquid is not objectionable.

(c) **Humidifying a gas:-**

This can be used for controlling the moisture contest of air for drying, for example.

(d) **Dehumidifying a gas:-**

Contact of a warm vapour – gas mixture with a cold liquid results in condensation of the vapour. There are applications in air conditioning, recovery of solvent vapours from gases used in drying and the like.

⇒ **Non – adiabatic operations:-**

a) **Evaporative Cooling:-**

A liquid or gas inside a pipe is cooled by water flowing in a film about the outside, the latter in turn being cooled by direct contact with air.

(b) **De-humidifying a gas:-**

A gas – vapour mixture is brought into contact with refrigerated pipes, and the vapour condenses upon the pipes.

12. In the cooler of above illustration, what temperature would the water be cooled if, after the tower was built and operated at the design L′ and G′s volumes, the entering air entered at dry-bulb temperature t_{G1} = 32°C

Wet – bulb temperature t_{W1} = 28°C?

<u>Solution:</u>

For the new conditions,

H'_1 = 90,000 J/Kg and the new operating line must originate on the broken line at M. Since in all likelihood the heat load on the plant condensers which is ultimately transferred to the air, will remain the same, the change in air enthalpy will be the same.

$H'_2 - 90{,}000 = 163600 - 72000$

$H_2 = 181600$ J/Kg.

The new operating line must therefore end on the broken line at e and because of the same ratio L′/G′s it must be parallel to the original line No. since of H_tOG remains the same, for the some packing depth N_tOG remains at 3.25. The new operating line R_S is therefore located by trial so that N_{tOG} = 3.25.

The temperature at R = t_H is 31.7°C, which is the temperature to which the water will be cooled.

13. Explain about Dehumidification of Air-water vapour.

If a water vapour – gas mixture is contacted with cold liquid so that the humidity of the gas is greater than that at the gas-liquid interface, vapour will diffuse toward the liquid and the gas will be dehumidified. In addition, sensible heat can be transferred as a result of temperature differences within the system. For air-water-vapour mixtures (Le = 1) contacted with cold water, the methods of water cooling apply with only obvious modification.

The operating line on the gas – enthalpy-liquid – temperature graph will be above the equilibrium curve, the driving force is $H' - H^{1*}$ and the equation

$$N_{tOG} = \int_{H_1^1}^{H_Z^1} \frac{dH^1}{H^{1*} - H^1} = \frac{K_Y a^2}{G^1 s}$$

$$= \frac{Z}{H_{tOG}}$$

Can be used with this driving force. For all the other systems, for which Le ≠ 1.

The general methods below must be used.

14. For an air-water vapour mixture of dry bulb temperature 65°C, wet-bulb temperature 35°C was determined under conditions such that the radiation coefficient can be considered negligible. The total pressure was 1std atm. Compute the humidity of the air.

Solution:

At t_W = 35°C

∂_W = 2419300 J/Kg.

Y^1_W = 0.0365 Kg H_2O/Kg dry air.

ha /Ky = 950 J/Kg

K, tG = 65°C

Then from equation

$$t_G - t_W = \frac{\partial w(y^1_w - y^1)}{ha/ky}$$

We have,

$$(65 - 35) = \frac{2419300\ (0.0365 - y^1)}{950}$$

Y_1 = 0.0247 Kg H_2O / Kg air.

Alternatively as an approximation, the adiabatic – saturation curve for t_{as} = 35°C is followed to a dry-bulb temperature 65°C, where Y^1 is read as 0.0238 Kg H_2O / Kg air.

15. Estimate the wet-bulb sati and adiabatic saturation temperature for a toluene – air mixture of 60°C dry-bulb temperature, Y^1 = 0.050 Kg vapour/Kg air, 1 std atm.

Solution:

Wet – bulb temperature

t = 60°C

Y^1 = 0.050 Kg toluene / Kg air

D_{AB} = 0.92 × 10^{-5} Kg/ms.

S_C should be calculated for mean conditions between those of the gas –vapour mixture and the wet-bulb saturation conditions. However, for the dilute mixture considered here, the bulk – gas value of S_C is satisfactory and is essentially independent of temperature.

$$S_C = \frac{\mu}{\rho \Delta_{AB}} = \frac{1.95\times10^{-5}}{1.060\ (0.92\times10^{-5})}$$

= 2.00//

$$60 - t_w = \frac{\partial w}{1812}(y^1{}_w - 0.050)$$

⇒ Adiabatic saturation temperature.

t_{m1} = 60°C

Y_1 = 0.05

C for toluene vapour = 1256 J/Kg. K

C_{S1} = 1005 + 1256 (0.05)

= 1067.8 J/Kg.K

$$60 - t_{as} = (Y^1{}_{as} - 0.05)\ \frac{\partial_{as}}{1067.8}$$

In the some fashion, as the wet-bulb temperature, t_{as} is calculated by trial and found to be 25.7°C.

16. Briefly explain the cooling towers?

Cooling Tower Overview

The primary task of a cooling tower is to reject heat into the atmosphere. This heat rejection is accomplished through the natural process of evaporation that takes place when air and water are brought into direct contact in the cooling tower. The evaporation is most efficient when the maximum water surface area is exposed to the maximum flow of air, for the longest possible period of time.

Cooling towers are designed in two different configurations, Counterflow and Cross flow, specific configuration indicates the direction of airflow through the tower relative to the direction of the water flow. Cooling tower water and air distribution systems are designed in, with each playing an equally important role in determining the efficiency and proper application of the cooling tower.

Operating Principle of Cooling Towers

Just like air, water is one of our most important natural resources and vital to all our lives. The world's growing water consumption combined with its increasing scarcity is making it more important than ever to use water intelligently and carefully.

The re-cooling and recycling of water as a transport medium for waste heat for which there is no further in intelligent use should therefore be the first rules of economy and ecology.

Water cooling systems: Water cooling systems can be subdivided into various categories on the basis of the cooling water temperature they require. At temperatures of below approx, +20 °C refrigeration machines are generally used. Above this temperature cooling towers are used. At temperature over 45°C dry-type cooling units can also be employed.

Types of cooling towers: Cooling towers are distinguished according to various criteria:

(1) The forced of the air-stream: Naturally ventilated cooling towers (natural draught cooling towers). Artificially ventilated cooling towers (mechanical draught cooling tower). Fans may be of the induced or forced draught type design.

(2) The relationship of the air-stream to the water flow: Counter flow cooling towers, cross-flow cooling towers, combination of these two designs.

(3) The design of the fill material: Open systems in which the water is cooled by direct contact with the surrounding air (wet-type cooling towers).

Closed systems in which the medium to be cooled does not come into direct contact wit the surrounding air. Hybrid cooling towers, combustion of open and closed systems. Wet-type cooling towers are able to achieve water temperature below the ambient temperature, the decisive factor being the so-called wet bulb temperature. This represents a physical value for the relationship between ambient temperature and relative air humidity.

Wet type cooling towers can reach the minimum cold water temperature of approx. 3-4 K above the wet-bulb temperature. In India standard wet-bulb temperatures are dependent on the location.

(4) Open wet-type cooling towers: The water to be cooled is sprayed and trickled over fill material by a water distribution system, which, owing to its shape and position, guarantees high water and air contact times. At the same time, the surrounding air is fed through the tower is counter-flow, thereby evapourating a small part of the circulating water. The heat required for this evapouration process is drawn off by the cooling water and provides the majority of the cooling capacity. The remainder of the cooling capacity is created by the convection of the warm water to the cold air. The re-cooled water collects in the collecting basin from where it is fed back to the cooling can be up to 97% of the circulation water, the remainder being required to compensate for the water loss due to evaporation and bleed-off.

(5) Closed-type cooling towers and coolers: The medium to be cooled flows through a closed heat exchanger and does not come into direct contact with the surrounding air. Water is trickled over the heat exchanger by a water distribution system (secondary circuit) in order to use the evaporation heat.

(6) Dry-type coolers: The medium to be cooled flows through a heat exchanger just as for closed cooling towers. Heat is removed by means of convection to the surrounding air thus allowing the system to attain cooling water temperatures in excess of ambient temperature.

Cooling Tower Selection

Cooling towers are designed and manufactured in various sizes and configurations. Recognizing and understanding the different configurations and the advantages and limitations of each is essential to specifying the most cost effective solution for the end user. The purpose of this bulletin is to highlight the differences between Crossflow and Counterflow cooling towers and to describe applications where each configuration should be specified.

How Water Distribution Systems

The overall efficiency of a cooling tower is directly related to the design of the tower's hot water distribution system. The primary consideration in selecting the type of hot water distribution system for a specific application is pump head. The pump head imposed by a cooling tower consists of the static life (related to the height of the inlet) plus the pressure necessary to move the water through the distribution system and over the fill. The pump head varies according to the cooling tower configuration.

Counterflow towers use a high-pressure spray nozzle hot water distribution system to achieve water coverage of the fill. The nozzle spray pattern is sensitive to changes in water flow, and consequent change in nozzle pressure. The air movement is vertically upward through the fill, counter to the downward fall of the water (figure). Counter flow towers typically have a smaller footprint than Crossflow towers, but require additional height, static lift, and dynamic head to achieve the same cooling effect.

Cross flow towers utilize a distinctly different type of water distribution system. Hot water is distributed to the fill by gravity through metering orifices in the floor of the inlet basin. There is no pressure spray distribution system. The air movement is horizontally through the fill, across the downward fall of the water (figure). In crossflow towers, the internal pressure component of pump head is insignificant because maximum flow is achieved by gravity.

Compared to crossflow towers, Counterflow towers may require up to five or six psig adde pump head to achieve the proper spray distribution. The high Counterflow pumping head requirement (tower height plus nozzle pressure) leads to a higher may result in inadequate hot water flow, reducing tower efficiency and performance. First cost pumping system and significantly higher annual pump energy consumption and operating costs. If the system condenser pumps are not properly sized, the additional pump head required in Counterflow towers.

Air Flow Distribution Systems

Cooling tower performance is also related to the amount of air moving through the tower and coming into direct contact with the water. In Counterflow towers in the air movement is vertically upward through the fill, counter to the downward fall of the water. This configuration, along with the finer water droplet size available from pressurized spray nozzles, allows Counterflow towers to make more efficient use of available air. However, the resistance to upward air travels against the falling water results in higher static pressure loss and greater fan horse power than a Crossflow system.

Crossflow towers have a fill configuration through which air flows horizontally across the downward flow of the water. Crossflow tower utilize essentially the full tower height for inlet louvers, reducing air inlet velocity and minimizing recalculation and drift loss. The air inlet louvers in counterflow towers are restricted to the tower base, increasing inlet velocities and susceptibility to airborne trash and other debris.

Crossflow

Advantage of Crossflow: Cooling towers due to their gravity flow hot water distribution system:

- Low pumping head

- Lower first cost pumping systems
- Lower annual energy consumption and operating costs
- Accepts larger variation in water flow without adverse effect on the water distribution pattern (flat plate heat exchanger operation in winter).
- Easy maintenance access to distribution nozzles.

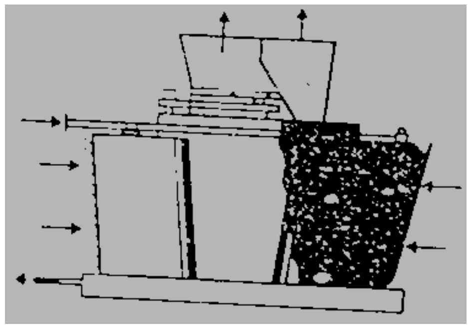


Figure: Crossflow cooling towers

Disadvantages of Crossflow: Cooling towers due to their gravity flow hot water distribution systems:

- Low pressure head on the distribution pan may encourage crifice clogging and less water breakup at spray nozzle.
- Exposure to air in the hot water basin may accelerate algae growth. Larger footprint.

Counterflow:

Advantages of Counterflow: Cooling towers due to their pressurized spray water distribution system:

- Increased tower height accommodates longer ranges and closer approaches.
- More efficient use of air due to finer droplet size from pressure sprays.

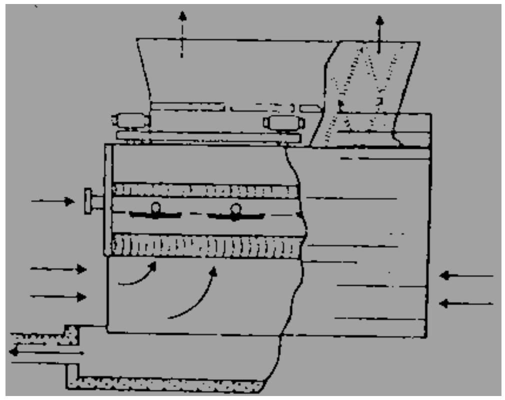


Figure: Counterflow cooling towers.

Disadvantages of Counterflow: Cooling towers due to their pressurized spray water distribution system:

- Increased system pumping head requirements.
- Increased energy consumption and operating costs.
- Distribution nozzles difficult to inspect and clean.
- Requires individual risers for each cell, increasing external piping costs.

Conclusions and Recommendations:

The air and water distribution systems for counterflow and crossflow cooling towers have advantages and disadvantages inherent in their respective designs. It cannot be said that one is better than the other. Rather, with the proper application, both configurations are cost effective and can serve the end user well.

Crossflow cooling towers should when the following criteria and limitations are important:

- To minimize pump head.
- To minimize pumping and piping first cost.
- To minimize operating costs.
- When condenser water flow variance is expected.
- When ease of maintenance is a concern.

COOLING TOWERS: DESIGN AND OPERATION CONSIDERATIONS

Cooling towers are a very important part of many chemical plants. They represent a relatively inexpensive and dependable means of removing low-grade heat from cooling water.

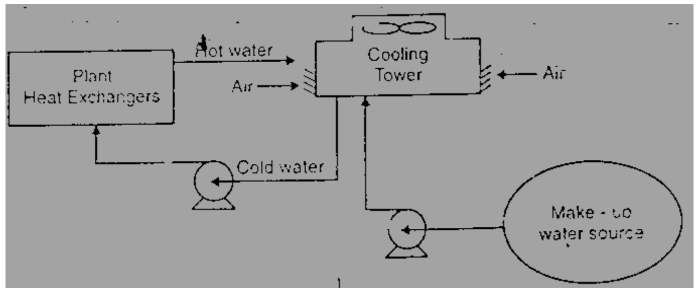


Figure: Closed Loop Cooling Tower System

The make up water source is used to replenish water lost to evaporations. Hot water from heat exchangers is sent to the cooling tower. The water exits the cooling tower and is sent back to the exchangers or to other units for further cooling.

Types of Cooling Towers

Cooling towers fall into two main sub-divisions: natural draft and mechanical draft. Natural draft designs use very large concrete chimneys to introduce air through the media. Due to the tremendous size of these towers (500 ft high and 400 ft in diameter at the base) they are generally used for water Flowrates above 200,000 gal/min. Usually these types of towers are only used by utility power stations in the United States. Mechanical draft cooling towers are much more widely used. These towers utilize large fans to force air through circulated water. The water falls downward over fill surfaces, which help, increase the contact time between the water and the air. This helps maximize heat transfer between the two.

Types of Mechanical Draft Towers:

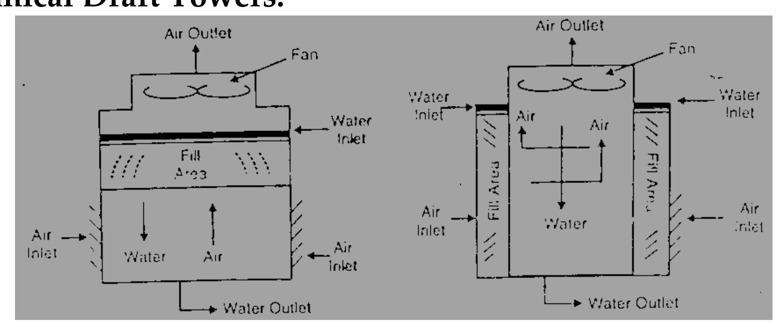


Figure: Mechanical draft counterflow tower **Figure: Mechanical draft cross flow tower**

Mechanical draft towers offer control of cooling rates in their fan diameter and speed of operation. These towers often contain several areas (each with their own fan) called cells.

19. A mixture of air and water vapour has a dry bulb temperature of 60 °C and an absolute humidity of 0.03 kg water vapour/kg dry air. The system pressure is at 1 atmosphere absolute. Evaluate.
(a) Saturation absolute humidity
(b) Relative humidity or relative saturation
(c) Dew point temperature
(d) Humid volume
(e) Humid heat
(f) Enthalpy
(g) Heat required to heat 1.2 m³ of this mixture to 120 °C
(h) Adiabatic saturation temperature
(i) Wet-bulb temperature

Solution:
(a) Saturation absolute humidity:

Use the Psychometric chart

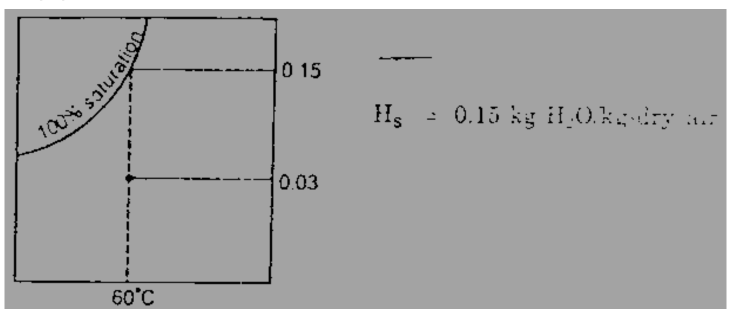


Figure:

(b) Relative humidity:

$$H_R = \frac{P_A}{P_A^{\circ}} \times 100\%$$

$$H = \frac{P_A M_A}{(P_t - P_A) M_B} \Rightarrow P_A = \frac{M_B H}{M_A + M_B H} . P_t$$

$$H_S = \frac{P_A^{\circ} M_A}{(P_t - P_A^{\circ}) M_B} \Rightarrow P_A^{\circ} = \frac{M_B H_S}{M_A + M_B H_S} . P_t$$

Thus,
$$H_R = \frac{M_A + M_B H_S}{M_A + M_B H} \times \frac{H}{H_S} \times 100\%$$

$$= \frac{18.02 + 28.97 \times 0.15}{18.02 + 28.97 \times 0.03} \times \frac{0.03}{0.15} \times 100\%$$

$\Rightarrow \qquad \boxed{H_R = 23.68\%}$

(b) Dew point temperature:

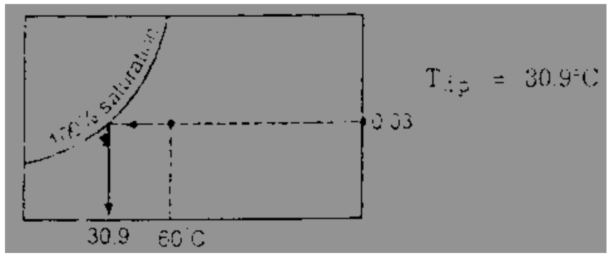


Figure:

(d) $\upsilon_H = 8314\left(\frac{1}{M_B}+\frac{H}{M_A}\right).\frac{T}{P_t}$

$$\upsilon_H = 8314\times\left(\frac{1}{28.97}+\frac{0.03}{18.02}\right)\times\frac{60+278.15}{101325}\,\text{m}^3 \text{ mixture/kg-dry air}$$

$$= 0.9831\ \text{m}^3 \text{ mixture/kg-dry air}$$

(e) Humid heat:

$$C_S = 1.005 + 1.884\ H \text{ kJ/kg-dry air.K}$$
$$= 1.005 + 1.884 \times .003 \text{ kJ/kg-dry air.K}$$
$$= 1.0615 \text{ kJ/kg-dry air.K}$$

(f) Enthalpy:

$$H_y = C_S(T - T_0) + H\lambda_0$$
$$H_y = 13.0165\times(60-0) + 2501.4\times0.03 \text{ kJ/kg-dry air}$$
$$H_y = 138.73 \text{ kJ/kg-dry air}$$

(g) $Q = W_B.C_S\,\Delta T$

$$= \frac{1.2}{0.9891}\times1.0615\times(120-60)\ \text{kJ}$$
$$= 77.27\ \text{kJ}$$

(h) Adiabatic saturation temperature:

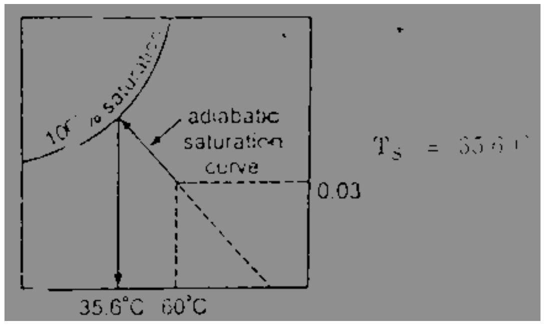


Figure:

(i) Wet bulb temperature:

For air water system $T_{wb} \approx T_S$

$\Rightarrow$ $T_{wv} = 35.6$ °C