CHAPTER THREE

Humidification, Dehumidification, and Cooling Tower

3.1 Introduction.

Humidification and dehumidification involves simultaneous transfer of material between a pure liquid phase and a fixed gas which is insoluble in the liquid.

Humidification: is a process to increase the amount of vapor present in the gas stream, by passing the gas over a liquid which then evaporates into gas stream. This transfer into the main stream takes place by diffusion, and at the interface simultaneous transfer of heat and mass. The drying of wet solid is an example of humidification process. *Dehumidification*: is a process to reduce the vapor present in gas stream. In this operation, partial condensation must be affected and the condensed vapor removed. Dehumidification has use in air conditioning.

3.2 Terminology and Definitions:

There are defined in pervious chapter.

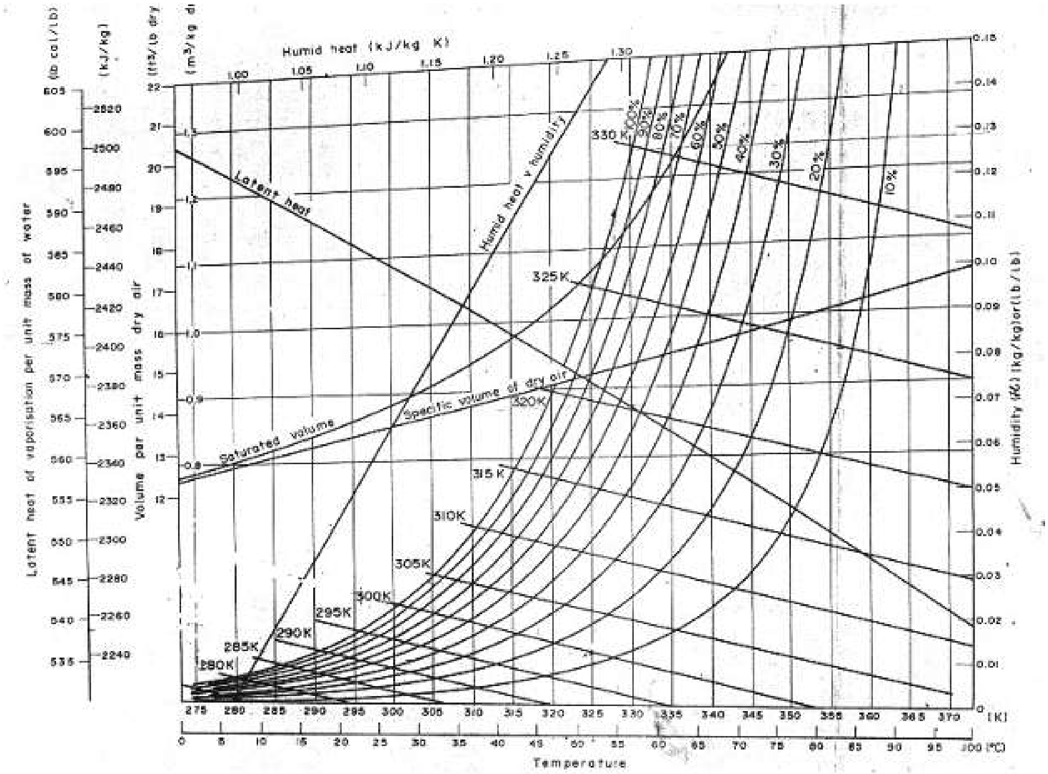
3.3 Humidity Data for Air – Water system.

Various type of humidity chart is available, based on either the temperature or enthalpy of the gas.

3.3.1Temperature –Humidity Chart (Psychrometric Chart).

From this chart (see figure 1) the following quantities can be estimated:

1. Humidity (absolute and relative H).
2. Specific volume of dry gas.
3. saturated volume.
4. Latent heat of vaporization.
5. Humid heat.
6. Dry and wet bulb temperature.
7. Dew and saturation temperature.



Figure(1) Temperature –Humidity Chart (Psychrometric Chart) for air-water system.

If any two of the above quantities are known the others can be readily obtained.

3.3.2 Enthalpy –Humidity Chart.

If **H** is the enthalpy of humid gas per unit mass of dry gas, $\mathbf{H_a}$ enthalpy of dry gas per unit mass. $\mathbf{H_w}$ the enthalpy of vapor per unit mass, H humidity of the gas, C_a the specific heat of dry gas at constant pressure, C_w the specific heat of vapor at constant pressure, Θ is the temperature of humid gas, Θ_0 the reference temperature, λ latent heat of vaporization liquid at reference temperature.

Then for an unsaturated gas: $\mathbf{H} = \mathbf{H_a} + \mathbf{H_w}\, H$

Where $\mathbf{H_a} = C_a\,(\Theta - \Theta_0)$

And $\mathbf{H_w} = C_w\,(\Theta - \Theta_0) + \lambda$

Thus, $\mathbf{H} = (\Theta - \Theta_0)\, S + \lambda\, H$

If the gas contains more liquid or vapor than is required to saturate it at the temperature in question, either the gas will be supersaturated or the excess material will be present in the form of liquid or solid according to whether the temperature Θ is greater or less than the reference temperature Θ_0.

If the temperature Θ is greater than Θ_0 and the H is greater than the humidity of saturated gas H_0 , the enthalpy **H** is given by:

$$\mathbf{H} = C_a(\Theta - \Theta_0) + [C_w(\Theta - \Theta_0) + \lambda]H_0 + C_L(H - H_0)(\Theta - \Theta_0)$$

C_L is the specific heat of liquid.

If the temperature Θ is greater than Θ_0, the enthalpy **H** is given by:

$$\mathbf{H} = C_a(\Theta - \Theta_0) + [C_w(\Theta - \Theta_0) + \lambda]H_0 + (H - H_0)[C_s(\Theta - \Theta_0) + \lambda_f]$$

C_f is the specific heat of solid and λ_f latent heat of freezing of the liquid.

Two cases may be considered to illustrate the use of enthalpy – humidity charts. These are the mixing of two streams of humid gas and the addition of liquid or vapor to a gas.

❖ *Mixing of Two Stream of Humid Gas*.

Consider the mixing of two gases of humilities H_1 and H_2, temperatures Θ_1 and Θ_2, masses m_1 and m_2, and the enthalpies $\mathbf{H_1}$ and $\mathbf{H_2}$ to give a mixed gas of temperature Θ, mass m, enthalpy **H** and humidity H. Taking a balance on the dry gas ,vapor and enthalpy :

$$m_1 + m_2 = m$$
$$m_1H_1 + m_2H_2 = mH$$
$$m_1\mathbf{H_1} + m_2\mathbf{H_2} = m\mathbf{H}$$

Elimination of m gives:

$$m_1(H - H_1) = m_2(H_2 - H)$$
$$m_1(\mathbf{H - H_1}) = m_2(\mathbf{H_2 - H})$$

Dividing these two equations:

$$\frac{\mathrm{H-H1}}{\mathbf{H-H1}} = \frac{\mathrm{H-H1}}{\mathbf{H-H1}}$$

❖ Addition of liquid or vapor to a gas.

Let a mass m_3 of liquid or vapor of enthalpy H_3 be added to a gas of humidity H_1 and enthalpy $\mathbf{H_1}$ and containing a mass m_1 of dry gas. Then:

$$m_1 (H-H_1) = m_3$$

$$m_1 (\mathbf{H}-\mathbf{H_1}) = m_3\ \mathbf{H_3}$$

Thus:
$$\frac{\mathbf{H-H1}}{\mathrm{H-H1}} = \mathbf{H_3}$$

Where H and **H** is the humidity and enthalpy of the gas produced in mixing.

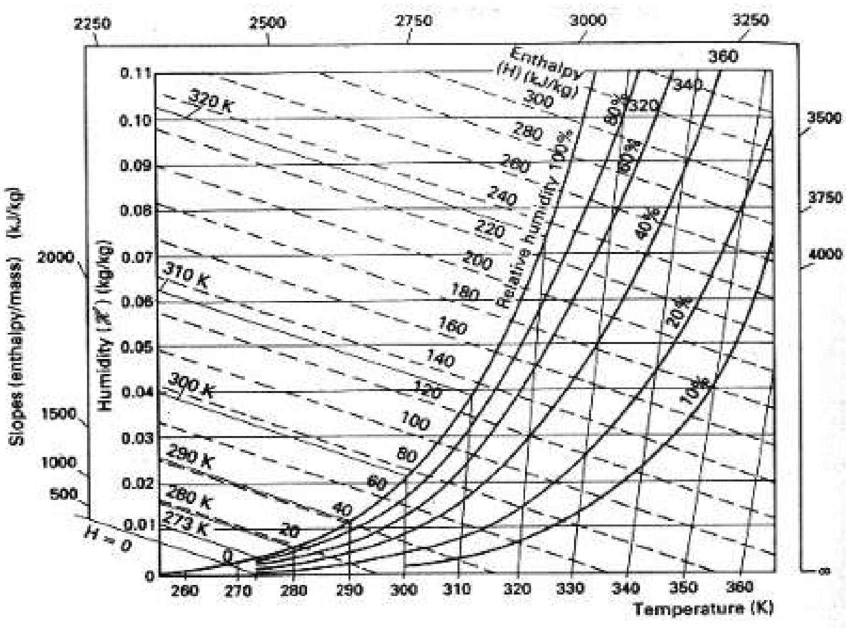


Figure (2) Enthalpy- Humidity chart for air-water system.

3.4 Method of increasing humidity

1) Live steam may be added directly in the required quantity.
2) Water may be sprayed into gas at such a rate that it gives the required humidity.
3) The gas may be mixed with a stream of gas of higher humidity.
4) The gas may be brought into contact with water in such a way that only part of the liquid is evaporated.

3.5 Cooling Tower.

In a typical cooling tower, air and water are brought into countercurrent contact; the water flows down over a series of wooden slats or spry tower which gives a large interfacial area and promote turbulence in the liquid. The flow of air upward through the tower can be induced by the buoyancy of the warm air in the tower (natural draft) or by mechanical draft such as fan. Cooling takes place both by the transference of sensible heat and by evaporative cooling as a result of which sensible heat in the water provides the latent heat of vaporization. In the cooling tower the temperature of liquid is falls and the temperature and humidity of the air is rise, and its action is thus similar to that of an air humidifier. The enthalpy of the air stream dose not remains constant since the temperature of the liquid changes rapidly in the upper portion of the tower. Towards the bottom, however, the temperature of the liquid changes less rapidly because the temperature differences are smaller.

3.5.1 Height of packing tower:

The height of water cooling tower can be determined by setting up a material balance on the water, an enthalpy balance, and rate equations for the transfer of heat in the liquid and gas and for mass transfer in the gas phase. There is no concentration gradient in the liquid and therefore there is no resistance to mass transfer in the liquid phase.

Considering the countercurrent flow of water and air in a tower Z figure 3, the mass rate of flow of air per unit cross section G is constant throughout the whole height of the tower; the liquid rate per unit area L can be taken as constant, the temperature, enthalpy, and humidity will be denoted by symbols Θ, $\mathbf{H}$, H respectively, suffixes G, L and f being used to denote conditions in gas, liquid and of the air in contact with the water.

The five basic equations for an incremental height of column, dz, are as follows:

1) *Water balance :*

$$dL = G\, dH \ldots\ldots\ldots\ldots\ldots(1)$$

2) *Enthalpy balance:*

$$G\, d\mathbf{H}_G = L\, d\mathbf{H}_L \ldots\ldots\ldots (2)$$

Where**:** $\mathbf{H}_G = S\,(\Theta_G - \Theta_o) + \mathbf{H}\lambda$

and $\mathbf{H}_L = C_L(\Theta_L - \Theta_o)$

C_L: specific heat of liquid, S: humid heat

Thus: $G\, d\mathbf{H}_G = L\, C_L\, d\, \Theta_L \ldots\ldots\ldots (3)$

Integrating equation (3) over the entire tower, give:

$$G\,(\mathbf{H}_{G2} - \mathbf{H}_{G1}) = L\, C_L\,(\Theta_{L2} - \Theta_{L1}) \ldots\ldots\ldots (4)$$

Equation (4) is the *Operating Line* for air-water contact. Since L,G and C_L remain constant along the tower, it is a straight line on Θ_L-**H** plane having a slope of LC_L/G .From equation (4) it appears that the operating line may obtained by joining the terminal points (Θ_{L1}, $\mathbf{H}_1$) and (Θ_{L2}, $\mathbf{H}_2$). The equilibrium (saturation) curve for air-water system on the Θ_L-**H** plane is the plot of the enthalpy of saturated air vs. the liquid temperature at equilibrium.

3) *Heat transfer from the liquid to the interface:*

$$h_L\, a\, dz\,(\Theta_L - \Theta_f) = L\, C_L\, d\Theta_L \ldots\ldots\ldots(5)$$

Where: h_L: Individual heat transfer coefficient in the liquid phase. Θ_L: Bulk liquid temperature, Θ_f: Liquid temperature at the interface, a: interfacial area per unit volume of column.

4) *Heat transfer from the interface to the bulk of the gas.*

$$h_G\, a\, dz\,(\Theta_f - \Theta_G) = G\, S\, d\Theta_G \ldots\ldots\ldots (6)$$

5) *Mass transfer from the interface to the gas.*

$$h_D \rho a\, dz\,(H_f - H_G) = G\, dH \ldots\ldots\ldots\ldots(7)$$

h_D is mass transfer coefficient for gas, ρ is mean density.