CL 332/334-UG LAB

Cooling Tower- MT 305

Objective:

1. To study the operation of cooling tower
2. To determine average heat and mass transfer coefficients and to estimate the tower height
3. To examine the effect of various parameters such as feed flow rate, air flow rate, inlet water temperature etc. on the performance of the cooling tower.

Theory:

When a component is transferred from a gas phase to solution in a liquid phase, the latent heat associated with the condensation is evolved. In the operations where mass transfer proceeds by equimolar counter diffusion, as in distillation or in operations where latent heat effect are small, as in liquid –liquid extraction, gas absorption in dilute solutions, and leaching, heat transfer is of minor importance as a rate controlling mechanism. In others, particularly where there is a net transfer of mass from gas phase to condensed phase or vice versa, the heat transfer rate is important. In these cases, heat transfer significantly limits the rate at which mass can be transferred.

Of those operations where both heat transfer and mass transfer affect the rate, humidification and dehumidification involve two components and two phases. The liquid phase, most often water, is single component, and the gas phase consists of a non-condensable gas, usually air, in which some vapor from the liquid phase is present.

HUMIDIFICATION: INDUSTRIAL APPLICATIONS

Humidification process may be carried out to control the humidity of a space or, more usually, to cool and recover water by contacting it with low humidity air. The water that has lost heat to the atmosphere can then be reused in heat exchanger throughout a plant. Alternatively, the water could be cooled in the surface heat exchanger. The choice is one of economics, with the designer balancing the loss of cooling water inherent in the air- water contact cooler against the cost of supplying and handling the cooling source to the surface cooler and the higher cost of surface units.

HUMIDIFICATION EQUIPMENT

The most obvious form of humidification equipment is the spray chamber. Here, the contacting liquid is sprayed as a mist into the gas stream. Gas velocity is kept low so that the contact time is high so that there will be only small amount of liquid physically entrained in the gas stream. These units are usually restricted to the small-scale operations and are frequently used in humidity control of a room or plant where either humidification or dehumidification of the inlet air is required.

Types of cooling towers

Cooling towers are generally used for humidification operations. 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 flow rates above 200,000 gal/min. Usually these types of towers are only used by utility power stations. 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 that help increase the contact time between the water and the air. This helps maximize heat transfer between the two. The experimental setup for UG lab uses mechanical draft cooling tower, which is shown in Fig.1.
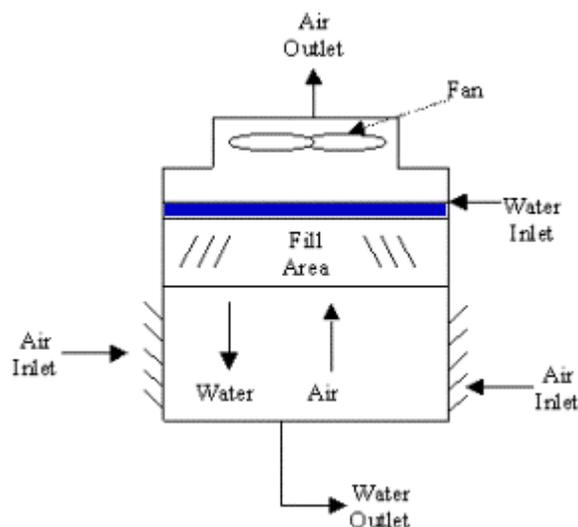
CALCULATIONS FOR HUMIDIFICATION AND DEHUMIDIFICATION OPERATIONS

The design of equipment to carry out humidification and dehumidification operations depends upon the concepts of the direction of the transfer processes and their rates (determined by writing enthalpy) and material balance equations and rate equations by combining these equations into the applicable design equations. In this section, these concepts will be applied to the special conditions surrounding the operation of humidification and dehumidification equipment.

In a dehumidification process, a warm vapor gas mixture is contacted with a cool liquid. Vapor condenses from the gas phase, the gas phase cools, and the liquid is warmed. Both sensible and latent heat are transferred toward the liquid phase. In the normal convention, the gas phase is chosen as the system, and heat and mass-transfer rates and quantities are positive when transfer is toward the gas phase. This sign convention is equivalent to measuring distance in the direction toward the gas phase. Then, heat- and mass-transfer quantities for this physical situation will be negative.

In a water-cooling process, warm water is contacted by a cooler gas-vapor mixture. Mass and heat are transferred toward the gas phase. As a result, the signs of the driving-force terms and transfer rates are positive based upon the convention described above.
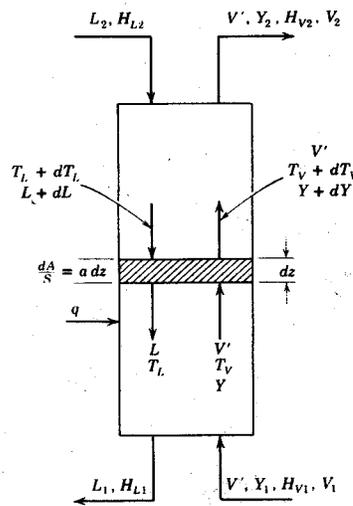

Figure 2: Representation of the general humidification process

The physical arrangement is shown in Fig.2. The subscripts 1 and 2 refer to the bottom and top of the column.

On the basis, for a tower of constant cross section, an overall material balance gives

$$L_1 - L_2 = V_1 - V_2 \qquad \qquad ...(1)$$

a material balance for the condensable component gives

$$V^1 (Y_2 - Y_1) = L_2 - L_1 \qquad \qquad ...(2)$$

and an enthalpy balance gives

$$L_2 H_{L2} + V^1 H_{V1} + Q = L_1 H_{L1} + V^1 H_{V2} \qquad \qquad ...(3)$$

Most commonly, the column will operate nearly adiabatically with $q \rightarrow 0$. The approach to adiabatic operation will be closer the larger the column diameter. For this situation, similar balances for the differential height (dz) will be written. The condensable component balance becomes

$$V^1 dY = dL \qquad \qquad ...(4)$$

The corresponding enthalpy balance is

$$V^1 dH_V = d(Lh_L) \qquad \qquad ...(5)$$

If the rate of solute transfer between phases is small compared to the total flow stream, an average value of L may be used, and the change in enthalpy of the liquid phase may be expressed as if it resulted solely from the change in temperature at constant specific heat. Thus,

$$d(LH_L) = L_{av} c_L dT_L \qquad \qquad ...(6)$$

where

$$L_{av} = (L_1 + L_2)/2 \qquad \qquad ...(7)$$

For the change in gas–phase enthalpy, the expression in terms of temperature is rigorous if c_h is constant.

$$V^1 dH_V = V^1 d[c_h (T_V - T_0) + Y\lambda_0] = V^1 c_h d T_V + V^1 \lambda_0 dY \qquad \qquad ...(8)$$

Rate equations for heat and mass transfer can also be written. Here, however, complications arise because of the fact that heat is transferred from the bulk of the liquid phase to the liquid-gas interface entirely as a result of the temperature potential, but from the interface to the bulk of the gas phase, heat is transferred as the result by two mechanisms. On the gas-phase side of the interface, heat is transferred as the result of a temperature potential, and the latent heat

associated with the mass transfer is transferred by these two mechanisms are separated as the two terms on the right side of the equation (8).

With these ideas, equations for the heat- transfer processes indicated in equations (6) and (8) can be written separately. For the liquid phase transfer

$$\frac{L_{av}}{S} c_L dT_L = hLa(T_L - T_i)dz \qquad \ldots(9)$$

where T_i = the interfacial temperature, ^0F

For the gas-phase sensible-heat transfer,

$$V^1 c_h dT_V = h_c a(T_i - T_V)dz \qquad \ldots(10)$$

And, for the gas-phase latent heat transfer,

$$\frac{V^1}{S} \lambda_0 dY = \lambda_0 k_y a(Y_i - Y)\,dz \qquad \ldots(11)$$

where

Y_i = the gas –phase mole ratio of solute to solvent at the interface

Development of the Design Equation

The enthalpy-balance equations are the rate equations given above can be combined to give a design equation. These equations will relate the change in gas-phase temperature and molal humidity to the rates of heat and of mass transfer to, or from, the gas-phase. Thus, combining equation (8) with equations (10) and (11).

$$\frac{V^1}{S} dH_V = h_c a(T_i - T_V)dz + \lambda_0 k_y a(Y_i - Y)\,dz \qquad \ldots(12)$$

for the gas phase. Separating $k_y a$ from the right side of the equation and designating $h_c/k_y c_h$ as r, the psychrometric ratio, give

$$\frac{V^1}{S} dH_V = k_y a[(c_h r T_i + \lambda_0 Y_i) - (c_h r T_V + \lambda_0 Y)] \qquad \ldots(13)$$

In putting r into this equation for $h_c a/ k_y a c_h$, the assumption is made that a, the area per unit volume of tower, is the same for heat transfer as it is for mass transfer. This will be true only at such high liquid rates that the tower packing is completely wet. If r is equal to 1, as it is for the air-water system under normal conditions, the terms within parentheses in equation (13) are enthalpies as defined by equation (13a).

$$H = C_b(T-T_0)+Y[\lambda_0+C_a(T-T_0)] \qquad \ldots(13a)$$

$$\frac{V^1}{S} dH_V = k_y a(H_i - H_V)dz \qquad \ldots(14)$$

$$\int_{H_{V1}}^{H_{V2}} \frac{V^1 dH_V}{S k_Y A (H_i - H_V)} = \int_0^z dz = z \qquad \dots (15)$$

Equation (15) is a design equation; the driving force is expressed as an enthalpy difference. Enthalpy is an extensive thermodynamic property. As such, it cannot be a driving force for any transfer operation. Thus, the mathematical treatment that leads to equation (15) should be examined. First, in the energy balances, the total flow per unit time is fixed. The enthalpy terms are then "specific enthalpy", based upon a fixed mass of material. Second, in the basic design equation, Equation (13), the driving force is a function of T and Y, the quantities that would be expected to control rates of heat and of mass transfer. Only in the fortuitous case that $r=1$ can H be substituted for these T and Y functions. In all other cases, Equation (15)would be written as

$$\int \frac{V^1 d(c_h r T_V + \lambda_0 Y)}{S k_y a[(c_h r T_i + \lambda_0 Y_i) - (c_h r T_V + \lambda_0 Y)]} = \int dz \qquad \dots (16)$$

Integration of the Design Equation

Integration indicated by equation (15) is usually performed by values of V^1 and $k_y a$ averaged over the column height. This introduces small error in light of the low concentration of water vapor in the gas stream. Beyond this, knowledge of the relation between the enthalpy in the main gas phase and that at the gas-liquid interface is necessary. Such a relation can be obtained by now considering the transfer process on the liquid side of the interface. Combining the enthalpy balance (Equation (5)) with the liquid transfer rate (Equation (9)) gives

$$\frac{V^1}{S} dH_V = h_L a(T_L - T_i)dz \qquad \dots (17)$$

and combining this equation with Equation (14) gives

$$- \frac{h_L a}{k_y a} = \frac{H_V - H_i}{T_L - T_i} \qquad \dots (18)$$

Equation (18) applies at any point in an air-water contacting device. From it, the temperature and the enthalpy of the interface can be determined at any point for which the liquid temperature (T_L), the gas enthalpy (H_V), and the ratio of the liquid-phase heat transfer coefficient to the gas-

phase heat transfer coefficient to the gas-phase mass transfer coefficient based upon mole-ratio driving forces are known.

The interface conditions can be obtained through equation (18) using a graphical method. A plot is drawn with coordinates of liquid-phase temperature versus enthalpy of the gas phase. On it, the locus of interface H_i and T_i values can be plotted by realizing that at the interface the vapor phase will be saturated at the interface temperature if the assumption that equilibrium exists at a phase boundary is tenable. From the saturation curve on the air-water humidity chart, the saturation molal humidity can be obtained for any desired temperature. The saturation, or interface, enthalpy can then be calculated or read from the humidity chart.

On the same plot, an "operating line" of H_V versus T_L can be plotted by combining equations (5) and (6) and integrating. This curve represents the path of bulk-phase conditions as the fluids pass through the unit. Thus,

$$\int_{H_{V1}}^{H_{V2}} V^1 \, dH_V = \int_{T_{L1}}^{T_{L2}} L_{av} c_L \, dT_L \qquad \qquad \ldots(19)$$

where the limits again refer to the bottom and top of the column. Integrating,

$$V^1 \, (H_{V2} - H_{V1}) = L_{aV} C_L \, (T_{L2} - T_{L1}) \qquad \qquad \ldots(20)$$

And rearranging,

$$\frac{H_{V1} - H_{V2}}{T_{L2} - T_{L1}} = \frac{L_{aV} c_L}{V^1} \qquad \qquad \ldots(21)$$

This equation gives the slope of the H_V versus T_L "operating" line as $L_{aV} C_L / V^1$. For the air-water system and for most other dilute gas-solution systems, this ratio is constant over a moderate humidity range, and the straight H_V versus T_L line can be determined from knowledge of the liquid- and gas-phase flow rates and the conditions of both streams at one end of the column, or alternatively the line can be located from the conditions at both ends of the column.
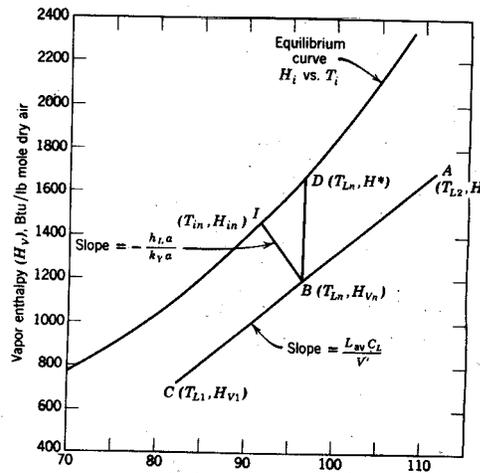
Figure 3: Graphical representation of adiabatic gas-liquid contacting operation

Fig.3 shows graphical representation of adiabatic gas-liquid contacting operation (humidification operation). The equilibrium curve represented on it was obtained from data on the air-water psychometric chart. On this curve are located all possible conditions of T_i, H_i throughout the column. Line ABC is the operating line containing all values of H_V corresponding to liquid temperature (T_L) throughout the column. This line could have been obtained from knowledge of the two end conditions, (T_{L1}, H_{V1}) and (T_{L2}, H_{V2}), or from either one of these two plus the slope ($L_{av}C_L/V^I$). On this line, point B represents an arbitrary point in the column at which the liquid temperature and gas enthalpy have the values of T_{Ln} and H_{Vn}. The interface conditions at this point can be found by using Equation (18). Thus, a tie line starting at point B and having a slope equal to $-h_La / k_Ya$ will intersect the equilibrium curve at the interface conditions corresponding to point B. Point l represents the interphase conditions designated by (T_{in}, H_{in}). In this way, interphase conditions can be found corresponding to any point between A and C on the operating line. Of course, values of k_Ya and h_La applicable to the column conditions are necessary. Usually, these values must be obtained experimentally.

From this construction, Equation (15) can now be integrated graphically. The necessary driving force in terms of enthalpy is determined for representative points throughout the column. For point B on Fig.3, this would be ($H_{in} - H_{Vn}$). Values of $V^I/SK_Ya(H_i - H_V)$ are then plotted against H_V and the area under this curve determined between the limits of H_{V1} and H_{V2} in order to find the column height (z).

Psychrometric chart is shown in appendix at the end of this report. From the wet bulb and dry bulb temperature of the air, other air properties like absolute humidity, relative humidity, enthalpy of saturated and unsaturated air can be found out from the psychrometric chart and are used for estimating the tower height.

Procedure:

1. Start the fan.
2. Start water pump and adjust the flow rate to a desired value.
3. Start the water heater and set the inlet temperature to a desired value.
4. Measure wet bulb temperature and dry bulb temperature of outlet water.
5. Wait till the steady state is obtained. The attainment of the steady state is confirmed by the constancy in the outlet temperature.
6. Measure air velocity by anemometer.
7. Measure inlet temperature and outlet temperature of air.
8. Repeat steps 2 to7 by changing water flow rate or inlet temperature of water.

Calculations:

1. Verify the overall material and energy balance
2. Calculate heat and mass transfer coefficients by a graphical method described above.

Safety precautions:

1. Ensure the valve V_1(cooling tower inlet water valve) in partly open position and remaining valves in fully open position.
2. Restrict the flow rate of inlet water to cooling tower to 100 LPM.
3. Don't touch any electrical connections.
4. Don't put hands in any rotating equipment like fan, pump shaft etc.
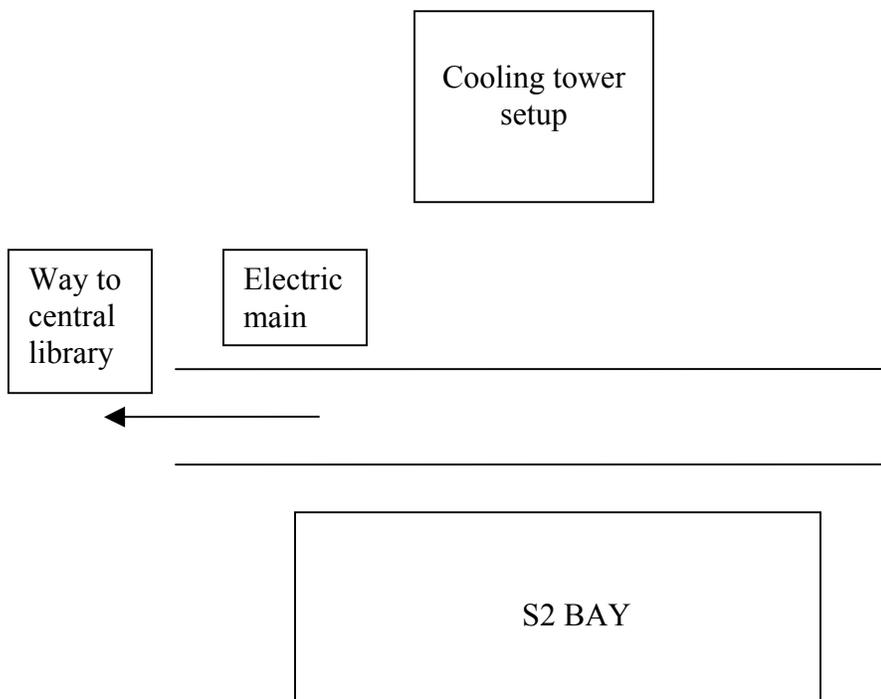5. If any equipment malfunctions, turn off electric mains immediately.

Figure 4. Location of cooling tower

Contact phone numbers:

S2 Bay: 4213

Main Security : 1122

Prof. Chandra Venkataraman: 7224

Nomenclature:

L_2 = liquid flow rate into the top of the column, lb mole/hr (or mol/s)

V_1 = flow rate of gas phase entering the column, lb mole/hr (or mol/s)

V^1 = flow rate of solvent, or "dry" gas, lb mole/hr (or mol/s)

Y_2 = mole ratio of solute to solvent gas at the top of the column

H_{V1} = enthalpy of gas phase entering the column, Btu/lb mole of "dry" gas
  (or joule/mol)

H_{L2} = enthalpy of liquid phase entering the top of the column, Btu/lb mole of liquid
  (or joule/mol)

q = heat transferred to the column from its surroundings, Btu/hr (or joule/s)

T_L, T_v = temperature of liquid and gas phases, respectively

dz = a differential height of column packing, ft (or m)

A = interfacial surface, ft^2 (or m^2)

a = interface area, ft^2/ft^3 of column volume (or m2/m^3 of column volume)

S = tower cross section, ft^2 (or m^2)

Appendix

Psychrometric chart