MODULE 6

HUMIDIFICATION AND AIR CONDITIONING

LECTURE NO. 5

6.6 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 enthalpy balance of cooling tower is shown in Figure 6.10.

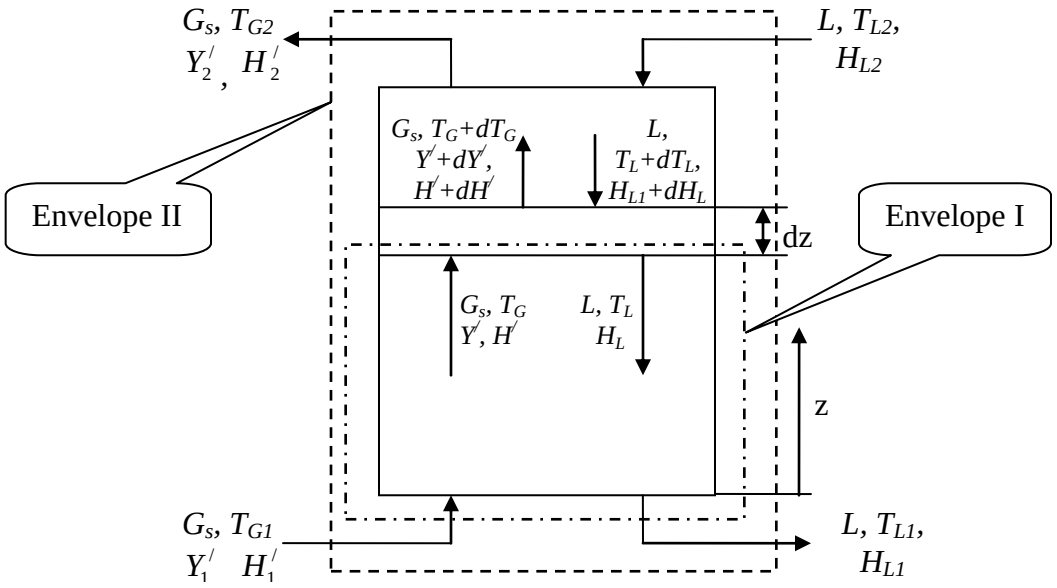

Figure 6.10: Enthalpy balance diagram of water cooling tower

Let, L is the constant water flow rate (kg/m^{2}s) and G_s is the air rate (kg dry air/m^{2}s). Across a differential thickness dz of the bed, temperature of water is decreased by dT_L and the enthalpy of air is increased by dH'.

Hence, change in enthalpy of water=$L.c_{WL}.dT_L$

and, change in enthalpy of air =$G_s.dH'$

Differential enthalpy balance over dz is $L.c_{WL}.dTL=G_s.dH'$ (6.16)

Enthalpy balance over *envelope I*,

$$Lc_{WL}(T_L - T_{L1}) = G_s(H' - H_1') \quad (6.17)$$

This is the operating line for air-water contact.

Enthalpy balance over entire tower (*envelope II*)

$$Lc_{WL}(T_{L2} - T_{L1}) = G_s(H_2' - H_1') \quad (6.18)$$

The equilibrium curve for air-water system on T_L-H' plane is the plot of enthalpy of saturated air versus liquid temperature at equilibrium.

Rate of transfer of water vapor to air in the differential volume is

$$G_s dY' = k_Y' \bar{a}(Y_i' - Y') \quad (6.19)$$

The decrease in temperature of air for sensible heat transfer to water is

$$-G_s c_H dT_G = h_G \bar{a}\, dz(T_G - T_i) \quad (6.19)$$

Differentiation of Equation (6.6) and multiplication with G_s gives

$$G_s dH' = G_s c_H dT_G + G_s dY' \lambda_0 \quad (6.20)$$

$$= -h_G \bar{a}\, dz(T_G - T_i) + k_Y' \bar{a}\, dz(Y_i' - Y')\lambda_0$$

$$= k_Y' \bar{a}\, dz\left\{\frac{h_G}{k_Y'}(T_i - T_G) + (Y_i' - Y')\lambda_0\right\} \quad (6.21)$$

$$= k_Y' \bar{a}\, dz\{c_H(T_i - T_G) + (Y_i' - Y')\lambda_0\} \quad (6.22)$$

$$= k_Y' \bar{a}\, dz\{c_H(T_i - T_0) + c_H(T_0 - T_G) + Y_i'\lambda_0 - Y'\lambda_0\} \quad (6.23)$$

$$= k_Y' \bar{a}\, dz\{c_H(T_i - T_0) + Y_i'\lambda_0 - [c_H(T_G - T_0) + Y'\lambda_0]\} \quad (6.24)$$

$$= k_Y' \bar{a}\, dz(H_i' - H') \quad (6.25)$$

The height (*z*) of the packing in the cooling tower is obtained by

$$\int_{H_1'}^{H_2'} \frac{dH'}{(H_i' - H')} = \frac{k_Y' \bar{a}}{G_s} \int_0^z dz = \frac{k_Y' \bar{a}}{G_s} z \qquad (6.26)$$

Number of gas-enthalpy transfer units

$$N_{tG} = \int_{H_1'}^{H_2'} \frac{dH'}{(H_i' - H')} \qquad (6.27)$$

Height of gas-enthalpy transfer units

$$H_{tG} = \frac{G_s}{k_Y' \bar{a}} \qquad (6.28)$$

Hence, height of cooling tower (packing section), *z*

$$z = H_{tG} . N_{tG} \qquad (6.29)$$

Volumetric mass or enthalpy transfer coefficient ($k_Y' \bar{a}$) should be known. Then H_{tG} can be estimated from given mass flow rate.

There is no direct relation available between enthalpy of bulk gas H' and that of H_i'. So, integral cannot be evaluated analytically. For numerical or graphical evaluation of the integral, we have to know the values H_i' (interfacial enthalpy) for a set of values of H'.

Let, $h_L \bar{a}$ is volumetric heat transfer coefficient on the water side,

$$G_s dH' = L c_{WL} dT_L = h_L \bar{a} (T_L - T_{Li}) \qquad (6.30)$$

$$k_Y' \bar{a}\, dz (H_i' - H') = -h_L \bar{a}\, dz (T_{Li} - T_L) \qquad (6.31)$$

$$\frac{(H_i' - H')}{(T_{Li} - T_L)} = -\frac{h_L}{k_Y'} \qquad (6.32)$$

A point (T_L, H') on the operating line meets the equilibrium line at the point (T_{Li}, H_i').

Substituting $G_s dH' = L c_{WL} dT_L$ in Equation (6.25) we have,

$$L c_{WL} dT_L = k_Y' \bar{a}\, dz (H_i' - H')$$

and

$$\int_{T_{Li}}^{T_{L0}} \frac{dT_L}{(H_i^{/} - H^{/})} = \frac{k_Y^{/}\bar{a}}{Lc_{WL}} \int_0^z dz = \frac{k_Y^{/}\bar{a}}{Lc_{WL}} z \tag{6.33}$$

Equation (6.33) is called '***Merkel Equation***'.

A simplified design equation based on overall enthalpy transfer coefficient:

If overall enthalpy transfer coefficient $K_Y^{/}$ is used, differential mass balance equation becomes

$$G_s dH^{/} = K_Y^{/}\bar{a}\, dz(H^{*/} - H^{/}) \tag{6.34}$$

Here, $H^{*/}$ is the enthalpy of saturated air at TL (bulk liquid temperature).

$$\int_{H_1^{/}}^{H_2^{/}} \frac{dH^{/}}{(H^{*/} - H^{/})} = \frac{K_Y^{/}\bar{a}}{G_s} \int_0^z dz = \frac{K_Y^{/}\bar{a}}{G_s} z \tag{6.35}$$

This is overall enthalpy transfer units (N_{toG}).

Expression of overall enthalpy transfer coefficient in terms of individual coefficients:

$$q = k_Y^{/}(H_i^{/} - H^{/}) = h_L(T_L - T_{Li}) = K_Y^{/}(H^{*/} - H^{/}) \tag{6.36}$$

$$(H^{*/} - H^{/}) = (H^{*/} - H_i^{/}) + (H_i^{/} - H^{/})$$

$$\frac{q}{K_Y^{/}} = q\frac{(H^{*/} - H_i^{/})}{h_L(T_L - T_{Li})} + \frac{q}{k_Y^{/}}$$

$$\frac{1}{K_Y^{/}} = \frac{(H^{*/} - H_i^{/})}{(T_L - T_{Li})} + \frac{1}{k_Y^{/}} \tag{6.37}$$

Equation (6.33) (Merkel Equation) is also expressed as:

$$\frac{K_Y^{/}\bar{a}V}{L} = \int_{T_{Li}}^{T_{L0}} \frac{dT_L}{(H_i^{/} - H^{/})} \tag{6.38}$$

The left hand side of the equation is called ***"tower characteristic"*** where, *V* is active cooling volume/plan area.