INTERCOMPANY MEMORANDUM

CAL CHEM CORPORATION

To: CHE Seniors

Date: Fall Quarter
File: CHE 435

From: CHE faculty
Laboratory Managers

Subject: **Cooling Tower**

You are to determine the number of overall gas transfer units and the overall gas mass transfer coefficients for a small cooling tower (designed and constructed by a Chemical Engineering student at Cal Poly Pomona, Chris Kaya) in the Unit Operation Laboratory. You should find the maximum cooling rate provided by the tower. It is probably best to use various water rates and vary the air flow for each water rate.

For this experiment you also need to measure the inlet and outlet air temperatures, the inlet air wet bulb temperature, and the inlet and outlet water temperatures. The wet bulb temperature of the inlet air can be assumed to be the wet bulb temperature of the air inside the lab at a location far away from the outlet air of the cooling tower.

Cooling Tower

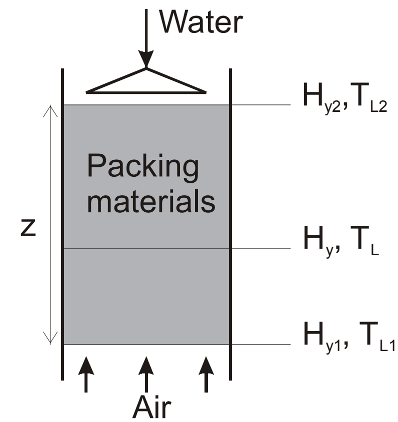

Fig. 1 Schematic representation of the cooling tower in the lab.

The height of contact between water and air can be obtained from the following equation

$$z = \frac{G}{M_B K_G a P} \int_{H_{y1}}^{H_{y2}} \frac{dH_y}{H_y^* - H_y}$$

In this equation, H_y^* is the enthalpy (kJ/kg dry air) of saturated air corresponding to the liquid temperature T_L. H_y is the enthalpy of the air in the tower at the location in the tower where the liquid temperature is T_L. H_y^* versus T_L is the equilibrium curve in Figure 2.

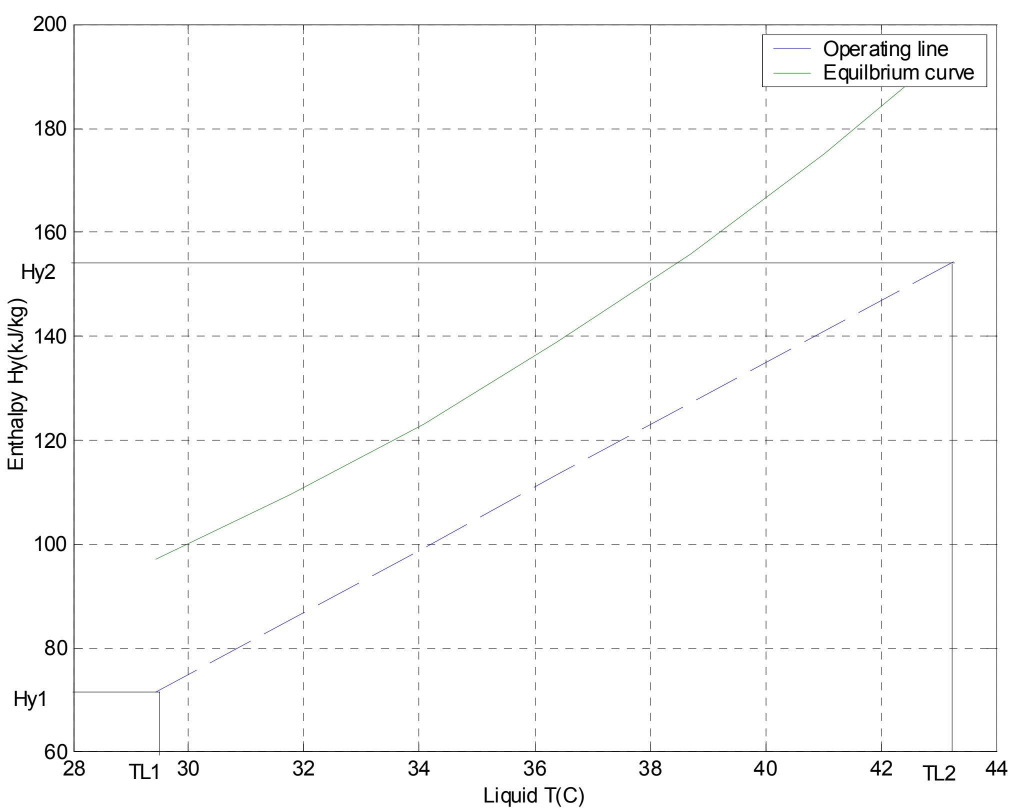

Figure 2. Temperature enthalpy diagram and operating line for cooling tower.

G is the dry air flow in kg/s·m^2. M_B is the molecular weight of air (28.97). K_G is the overall mass transfer coefficient based on the gas phase in kmol/s·m^2·atm. a is the interfacial area per unit volume of packed section in m^2/m^3. K_G and a are normally combined together as K_Ga since it is difficult to determine them separately. P is the operating pressure of the tower in atm. The number of overall gas transfer unit N_{OG} is defined as

$$N_{OG} = \int_{H_{y1}}^{H_{y2}} \frac{dH_y}{H_y^* - H_y}$$

H_{y1} is the enthalpy of the inlet air that can be determined from the following procedure:

1) Measure the dry bulb inlet air temperature T_1.

2) Measure the wet bulb inlet air temperature T_{w1} by using a sling thermometer at a location far away from the outlet air.

3) Determine the water vapor pressure, P_{vap}, at the wet bulb temperature T_{w1}. You can use the equation from the following Matlab program

--------- **Matlab function to determine water vapor pressure** ------------------

```
function ff=water_vap(T)
% Water vapor pressure in bar, T in C
%
TK=T+273.15;
Tc=647.3;Pc=221.2; % Tc in K, Pc in bar
vpa=-7.76451;vpb=1.45834;vpc=-2.7758;vpd=-1.23303;
x=1-TK/Tc;
tem=vpa*x+vpb*x.^1.5+vpc*x.^3+vpd*x.^6;
ff=Pc*exp(tem./(1-x));
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4) Determine the saturated humidity h_w at the wet bulb temperature T_{w1}.

$$h_w = \frac{M_A}{M_B} \frac{P_{vap}}{P - P_{vap}}$$

In this equation M_A is the molecular weight of water (18.02).

5) Evaluate the humidity h of the inlet air from

$$h = \frac{(1093 - 0.56T_{w1F})h_w - 0.24(T_{1F} - T_{w1F})}{1093 + 0.444T_{1F} - T_{w1F}}$$

In this equation T_{1F} and T_{w1F} are the dry and wet bulb temperatures of the inlet air in degree F. h_w is the humidity from step (4).

6) Determine H_{y1} (in kJ/kg dry air) from the following equation with the inlet air temperature in degree C.

$$H_{y1} = (1.005 + 1.88h)T_1 + 2501.4h$$

The air enthalpy at any location in the tower can be determined from an energy balance

$$G(H_y - H_{y1}) = LC_{pL}(T_L - T_{L1})$$

In this equation L is the water flow rate in kg/s·m^2 and is the heat capacity of water (4.187 kJ/kg·C). At T_{L2} we obtain H_{y2}.

We now need to evaluate H_y^* at T_L corresponding to H_y by

1) Evaluate the water vapor pressure P_{vap} at T_L.
2) Determine the saturated humidity h_w at the liquid temperature T_L.

$$h_w = \frac{M_A}{M_B}\frac{P_{vap}}{P - P_{vap}}$$

3) H_y^* is then evaluated from

$$H_y^* = (1.005 + 1.88h_w)T_L + 2501.4h_w$$

You need to integrate numerically the expression $\int_{H_{y1}}^{H_{y2}} \frac{dH_y}{H_y^* - H_y}$ using 7 points Simpson's rule.

$$N_{OG} = \int_{H_{y1}}^{H_{y2}} \frac{dH_y}{H_y^* - H_y}$$

$$N_{OG} = \frac{dH_y}{3}[f(1) + 4f(2) + 2f(3) + 4f(4) + 2f(5) + 4f(6) + f(7)]$$

where $f(1) = \frac{1}{H_{y1}^* - H_{y1}}$, $f(7) = \frac{1}{H_{y2}^* - H_{y2}}$

Minimum Data Analysis

1. Plot a graph of N_{OG} versus air flow rate at various water flow rates.
2. Plot a graph of K_Ga versus air flow rate at various water flow rates.
3. Determine the maximum cooling rate for the tower.

References

1. Geankoplis, C. J., Transport Processes & Separation Process Principles, Prentice Hall, 2003, pg. 565 & pg. 645
2. Mc Cabe W. L. et al , Unit Operations of Chemical Engineering, McGraw-Hill, 2001, pg. 608