PDHonline Course K113 (2 PDH)

Cooling Towers: Design and Operation Considerations

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Cooling Towers: Design and Operation Considerations

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COURSE CONTENT

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.

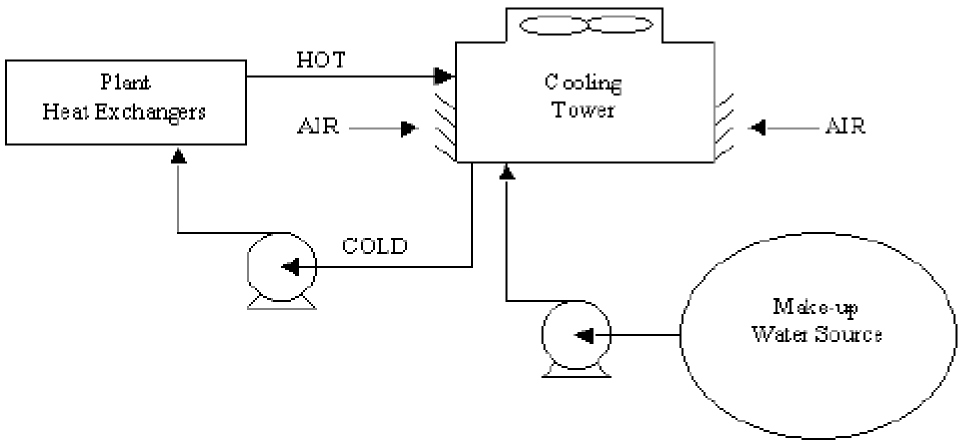

Figure 1: Closed Loop Cooling Tower System

The make-up water source is used to replenish water lost to evaporation. 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 flow rates 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

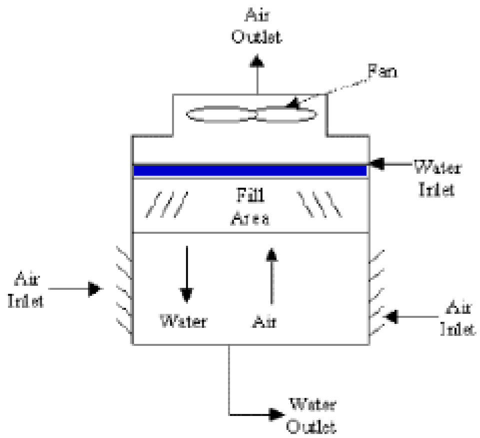

Figure 2: Mechanical Draft Counterflow Tower

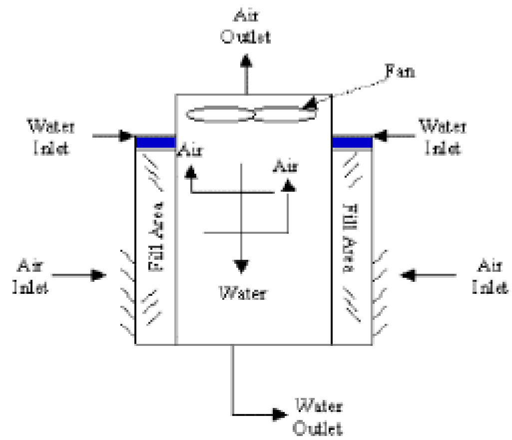

Figure 3: Mechanical Draft Crossflow Tower

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

Cooling Tower Theory

Heat is transferred from water drops to the surrounding air by the transfer of sensible and latent heat.

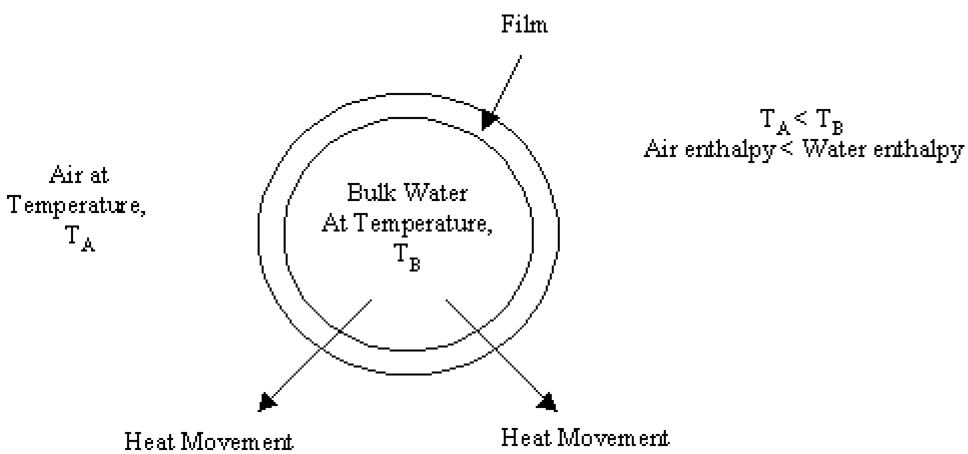

Figure 4: Water Drop with Interfacial Film

This movement of heat can be modeled with a relation known as the Merkel Equation:

$$\frac{KaV}{L} = \int_{T_2}^{T_1} \frac{dT}{h_w - h_a} \qquad (1)$$

where:

KaV/L = tower characteristic
K = mass transfer coefficient (lb water/h ft^2)
a = contact area/tower volume
V = active cooling volume/plan area
L = water rate (lb/h ft^2)
T_1 = hot water temperature (^{0}F or ^{0}C)
T_2 = cold water temperature (^{0}F or ^{0}C)
T = bulk water temperature (^{0}F or ^{0}C)
h_w = enthalpy of air-water vapor mixture at bulk water temperature
(J/kg dry air or Btu/lb dry air)
h_a = enthalpy of air-water vapor mixture at wet bulb temperature
(J/kg dry air or Btu/lb dry air)

Thermodynamics also dictate that the heat removed from the water must be equal to the heat absorbed by the surrounding air:

$$L(T_1 - T_2) = G(h_2 - h_1) \qquad (2)$$

$$\frac{L}{G} = \frac{h_2 - h_1}{T_1 - T_2} \qquad (3)$$

where:

L/G = liquid to gas mass flow ratio (lb/lb or kg/kg)
T_1 = hot water temperature (^{0}F or ^{0}C)
T_2 = cold water temperature (^{0}F or ^{0}C)
h_2 = enthalpy of air-water vapor mixture at exhaust wet-bulb temperature (same units as above)
h_1 = enthalpy of air-water vapor mixture at inlet wet-bulb temperature (same units as above)

The tower characteristic value can be calculated by solving Equation 1 with the Chebyshev numerical method:

$$\frac{KaV}{L} = \int_{T_2}^{T_1} \frac{dT}{h_w - h_a} = \frac{T_1 - T_2}{4}\left(\frac{1}{\Delta h_1} + \frac{1}{\Delta h_2} + \frac{1}{\Delta h_3} + \frac{1}{\Delta h_4}\right) \quad (4)$$

Where:

$\Delta h_1 =$ value of $h_w - h_a$ at $T_2 + 0.1(T_1 - T_2)$

$\Delta h_2 =$ value of $h_w - h_a$ at $T_2 + 0.4(T_1 - T_2)$

$\Delta h_3 =$ value of $h_w - h_a$ at $T_1 - 0.4(T_1 - T_2)$

$\Delta h_4 =$ value of $h_w - h_a$ at $T_1 - 0.1(T_1 - T_2)$

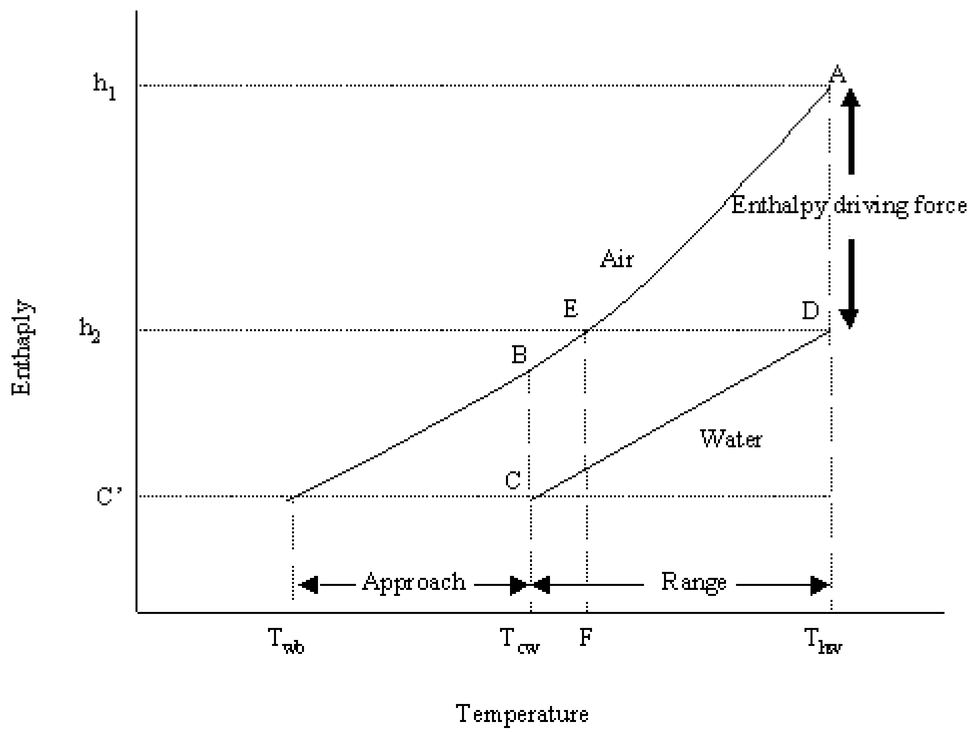

Figure 5: Graphical Representation of Tower Characteristic

The following represents a key to Figure 5:

C' = Entering air enthalpy at wet-bulb temperature, T_{wb}
BC = Initial enthalpy driving force
CD = Air operating line with slope L/G
DEF = Projecting the exiting air point onto the water operating line and then onto the temperature axis shows the outlet air web-bulb temperature

As shown by Equation 1, by finding the area between ABCD in Figure 5, one can find the tower characteristic. An increase in heat load would have the following effects on the diagram in Figure 5:

1. Increase in the length of line CD, and a CD line shift to the right
2. Increases in hot and cold water temperatures
3. Increases in range and approach areas

The increased heat load causes the hot water temperature to increase considerably faster than does the cold water temperature. Although the area ABCD should remain constant, it actually decreases about 2% for every 10 ^{0}F increase in hot water temperature above 100 ^{0}F. To account for this decrease, an "adjusted hot water temperature" is used in cooling tower design.

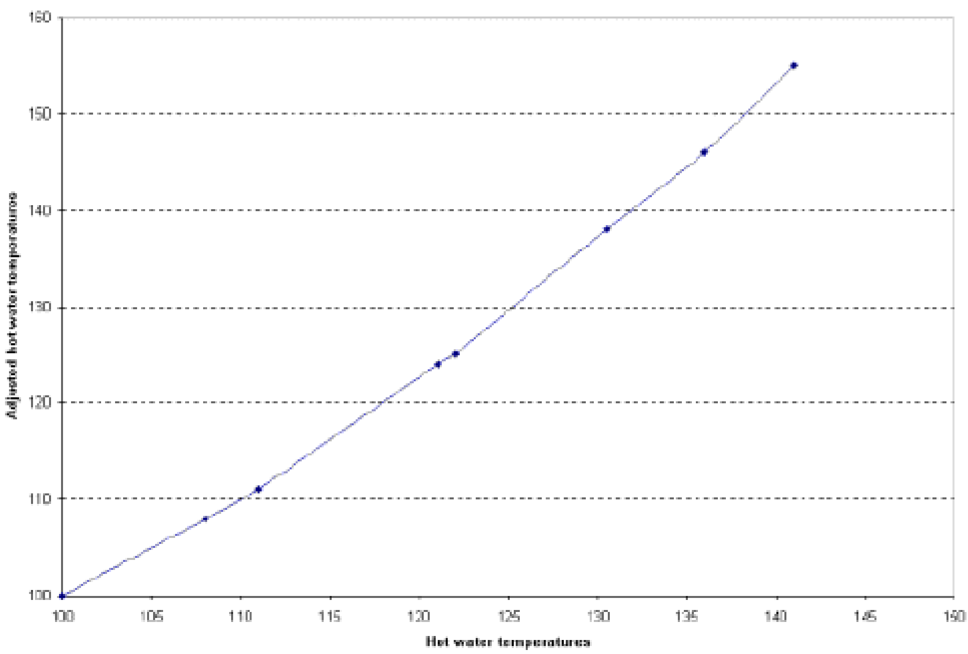

Figure 6: Graph of Adjusted Hot Water Temperatures

The area ABCD is expected to change with a change in L/G, this is very key in the design of cooling towers.

Cooling Tower Design

Although KaV/L can be calculated, designers typically use charts found in the <u>*Cooling Tower Institute Blue Book*</u> *to estimate KaV/L for given design conditions. It is important to recall three key points in cooling tower design:*

1. A change in wet bulb temperature (due to atmospheric conditions) <u>will not</u> change the tower characteristic (KaV/L)

2. A change in the cooling range <u>will not</u> change KaV/L

3. Only a change in the L/G ratio <u>will</u> change KaV/L

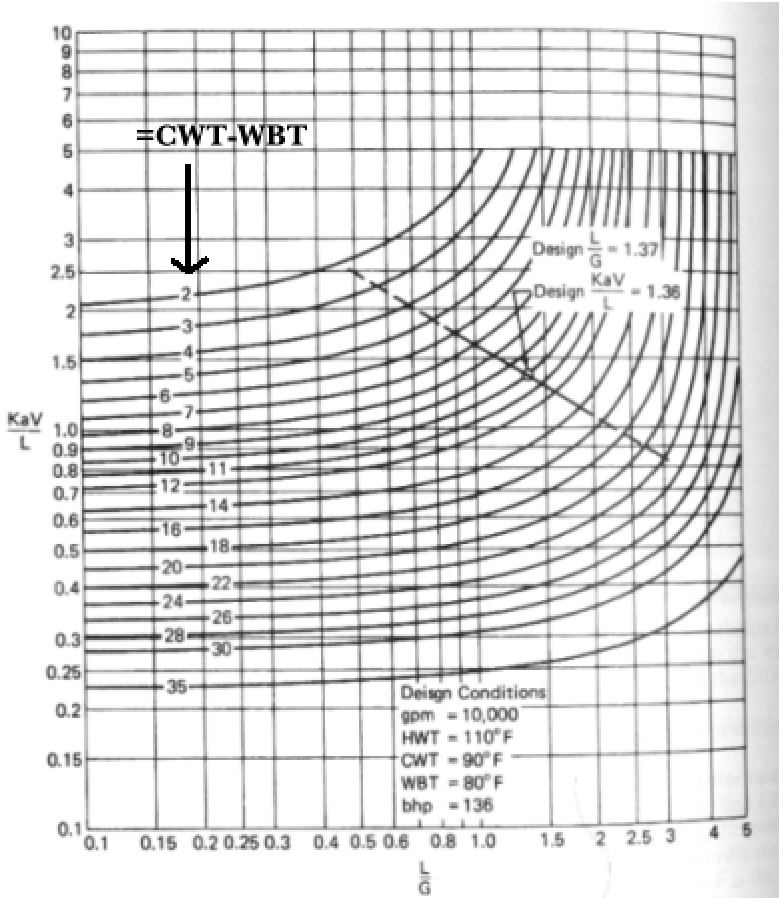

Figure 7: A Typical Set of Tower Characteristic Curves

The straight line shown in Figure 7 is a plot of L/G vs KaV/L at a constant airflow. The slope of this line is dependent on the tower packing, but can often be assumed to be -0.60. Figure 7 represents a typical graph supplied by a manufacturer to the purchasing company. From this graph, the plant engineer can see that the proposed tower will be capable of cooling the water to a temperature that is 10 ^{0}F above the wet-bulb temperature. This is another key point in cooling tower design.

Cooling towers are designed according to the highest geographic wet bulb temperatures. This temperature will dictate the minimum performance available by the tower. As the wet bulb temperature decreases, so will the available cooling water temperature. For example, in the cooling tower represented by Figure 7, if the wet bulb temperature dropped to 75 ^{0}F, the cooling water would still be exiting 10 ^{0}F above this temperature (85 ^{0}F) due to the tower design.

Below is the summary of steps in the cooling tower design process in industry. More detail on these steps will be given later.

1. Plant engineer defines the cooling water flow rate, and the inlet and outlet water temperatures for the tower.

2. Manufacturer designs the tower to be able to meet this criteria on a "worst case scenario" (ie. during the hottest months). The tower characteristic curves and the estimate are given to the plant engineer.

3. Plant engineer reviews bids and makes a selection

Design Considerations

Once a tower characteristic has been established between the plant engineer and the manufacturer, the manufacturer must design a tower that matches this value. The required tower size will be a function of:

1. Cooling range
2. Approach to wet bulb temperature
3. Mass flow rate of water
4. Web bulb temperature
5. Air velocity through tower or individual tower cell
6. Tower height

In short, nomographs such as the one shown on page 12-15 of Perry's Chemical Engineers' Handbook 6th Ed. utilize the cold water temperature, wet bulb temperature, and hot water temperature to find the water concentration in gal/min ft^2. The tower area can then be calculated by dividing the water circulated by the water concentration. General rules are usually used to determine tower height depending on the necessary time of contact:

Approach to Wet Bulb (^{0}F)	Cooling Range (^{0}F)	Tower Height (ft)
15-20	25-35	15-20
10-15	25-35	25-30
5-10	25-35	35-40

Other design characteristics to consider are fan horsepower, pump horsepower, make-up water source, fogging abatement, and drift eliminators.

Operation Considerations

Water Make-up

Water losses include evaporation, drift (water entrained in discharge vapor), and blowdown (water released to discard solids). Drift losses are estimated to be between 0.1 and 0.2% of water supply.

Evaporation Loss = 0.00085 * water flow rate (T_1-T_2) (5)

Blowdown Loss = Evaporation Loss/(cycles-1) (6)
where cycles is the ratio of solids in the circulating water to the solids in the make-up water

Total Losses = Drift Losses + Evaporation Losses + Blowdown Losses (7)

Cold Weather Operation

Even during cold weather months, the plant engineer should maintain the design water flow rate and heat load in each cell of the cooling tower. If less water is needed due to temperature changes (ie. the water is colder), one or more cells should be turned off to maintain the design flow in the other cells. The water in the base of the tower should be maintained between 60 and 70 ^{0}F by adjusting air volume if necessary. Usual practice is to run the fans at half speed or turn them off during colder months to maintain this temperature range.

References:

1. The Standard Handbook of Plant Engineering, 2nd Edition, Rosaler, Robert C., McGraw-Hill, New York, 1995

2. Perry's Chemical Engineers' Handbook, 6th Edition, Green, Don W. et al, McGraw-Hill, New York, 1984