Cooling Towers

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WATER is an important industrial raw material and not only its quality but temperature and quantity of the available supply are also factors to be considered, particularly for cooling requirements in a plant. Temperature of the available cooling water has a critical bearing on design and operation of distillation columns, power plants and electric furnaces. The water used for cooling job in an equipment gets heated. Either it must be replaced continuously by a fresh supply of water or the hot water should be cooled down to the initial temperature and recirculated. The first alternative is economical only if good quality water supply is available continuously and the effluent hot water can be profitably utilised somewhere else in the plant. Otherwise water must be cooled and thus the cooling tower becomes indispensable.

Cooling tower is nothing but a tower wherein the hot water and the cold air are contacted with the ultimate aim of obtaining cool water. In order to accelerate cooling by better contact, the tower is provided with filling material and with parts to aid the relative movements of two fluid streams. The water is conserved quantitatively except for some make-up water which has to be added to provide for the loss due to evaporation (necessary for cooling of the rest of water) and drifting of water sprays from time to time. Roughly for each 10° of cooling effected, 1% of water is lost by evaporation. Spray loss can be taken around 0.25%.

Theoretical considerations:

Primarily the process of cooling involves the exposure of water surface to air with varying degrees of efficiency. The heat transfer process involves a latent heat transfer due to change of state of a small portion of the water from liquid to vapour and a sensible heat transfer due to the difference in temperature of water and air, the former transfer playing the predominant part. It requires about 1000 Btu to evaporate 1 lb. of water and this evaporation can cool 100 lb. of water through 10°F. The latent heat transfer is proportional to mass transfer which is the result of difference in vapour pressure between the water at its temperature and the water if it were at the wet-bulb temperature of the air.

The wet-bulb temperature or the adiabatic saturation temperature represents the minimum temperature that the water would reach with infinite time of contact with air in a cooling tower. This is the temperature obtained when air is blown over a thermometer whose bulb is encased in a muslin covering saturated with water. This temperature will vary with the time of day, the weather and the season of the year. On commercial towers it is not possible for the wet-bulb temperature of the exhaust air to equal that of the hot water. Furthermore, it is not possible for the cold water to be reduced to the wet-bulb temperature of the incoming air.

There are two schools of thought in the development of the fundamental equations of cooling tower performance. One considers the cooling tower a heat exchanger and the other considers it a fractionation column. In a heat exchanger, the driving force producing cooling is the temperature potential between two fluids but in a cooling tower,

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it is the difference in total heat or enthalpy between the air at its wet-bulb temperature and the air if its wet-bulb temperature were raised to that of the water. For the same temperature differential, the enthalpy potential will be greater than the temperature potential. This means significantly that the mere presence of the water on the air side increases the transfer rate. The problem in cooling tower is more complicated by the fact that the fluids—water and air—are intimately mixed instead of being separated by a metal partition and one of them partially changes phase.

In treatment of a cooling tower as a fractionating column, one determines the number of times equilibrium is required to obtain a given performance. A theoretical plate is the height equivalent of filling, in which the temperature of the air leaving the section is equal to the temperature of the water leaving and it varies between 5 to 15 ft., depending upon water concentration. In this approach, the water concentration is fixed at about $2\frac{1}{2}$ gallons per square foot of ground area and the air velocity at 350 ft. per minute and then the height of the tower is varied to accomplish the given performance. In the latter treatment, therefore, the chance of obtaining the most economical selection is greater.

Design concepts:

Direct-contact heat transfer which forms the basic concept for the operation of a cooling tower is becoming increasingly important except where the mutual contamination of fluid streams should be avoided. Elimination of a metal partition between fluid streams increases intimacy of contact and removes all fouling resistance, thus leading to a substantially greater heat transfer rate.

Diffusional process of mass transfer coupled with heat transfer is the fundamental unit operation in the cooling tower. In diffusion, the principal resistances are the interfacial films of the two fluids flowing past each other in the contact apparatus, and the major driving forces are the difference in heat content or enthalpy potential and the temperature differential. Owing to this inter-play of these potentials and resistances, the rate of transfer of material as well as of heat is a function of variables like viscosity, density, conductivity and thickness of the fluid films and also enthalpies, humidities and temperature of the fluid streams. In design practice, some overall coefficients have been developed to take care of these variables. The coefficients have been related to a concept of a transfer unit, in this case called a diffusion unit, by combination with rates of flow of water and air streams and with variation of enthalpy of air stream with temperature of water stream. Thus a design equation is written :—

$$N_d = \int \frac{dT}{H^1 - H} = K_x a \frac{V}{L}$$

where :—

N_d = Number of diffusion units,

H^1 and H = Saturated enthalpy of air and enthalpy of air respectively, Btu/lb. dry air,

K_x = Overall coefficient of mass transfer, lb./(hr.) (ft.^{2}) (lb./lb.),

a = Surface of packing or fill, ft.^{2}/ft.^{3},

V = Tower volume, ft.^{3},

L = Water concentration, lb./(hr.) (sq. ft. ground area) and

T = Temperature of water (hot fluid), °F.

N_d is determined by graphical integration on an enthalpy-temperature diagram. The curve for saturation enthalpies vs. water temperature is plotted and an operating line with slope equal to ratio of water concentration to air concentration is placed between actual enthalpies of entering and leaving air at temperatures of leaving and entering water respectively, the lower extremity of the line being the bottom of the tower. Area between these two lines is a measure of potential available for performance and the greater the area, greater is the potential, and faster the rate and therefore, the fewer the number of diffusion units required. A correction is made for liquid film resistance which reduces the potential in practice. Having thus obtained N_d from graphical integration and multiplying it with HDU or height of diffusion unit (which is an experimental value of performance of the particular packing or fill under specified rates of fluid streams) one obtains the height of the cooling tower required to perform the given cooling job.

Let us now consider the factors which affect the area between the saturation curve and the operating line and thus also the performance of the tower. If inlet air is less saturated than is assumed in design on the basis of wet-bulb, operating line goes lower, area (potential) increases and therefore, the tower does a better cooling job than designed for. If wet-bulb temperature is higher, potential decreases and less cooling is effected. If water concentration is increased, the slope of the operating line increases thus decreasing the potential and requiring a higher tower. Sometimes owing to the closeness of the cooling range, the two lines intersect and to do any further cooling, staging or cooling with two towers in series is called for. Altitude of the place raises the saturation curve owing to the reduced atmospheric pressure and thus potential is increased and dimensions of the water tower are reduced.

Performance of cooling towers :

There are two types of cooling towers in general use today : the atmospheric and the mechanical draft. Both these types are capable of cooling water to the same minimum temperature.

In mechanical-draft towers the fan is mounted at the base and air is forced in the bottom and discharged through the top at low velocity. These are forced-draft type and are losing favour owing to possibility of recirculation of the hot humid exhaust air. The other type is the induced-draft where the fan is mounted on the roof of the structure and air is pulled upward and discharged at a high velocity. The flow is truly counter-current, the coldest water contacting the driest air and the warmest water contacting the most humid air.

Theoretically, a cooling tower cannot cool water to a temperature lower than the prevailing wet-bulb temperature. Air has a greater capacity for absorbing heat at the higher wet-bulb temperatures. At the lower wet-bulb, air in passing through the tower, must have a greater temperature rise to accomplish the same cooling.

In design, the value of the temperature should be chosen which is high enough to include 95% of the maximum wet-bulb temperature during the summer months. Allowance for recycling of hot humid exhaust air must be made by adding 2 to 4 degrees as influenced by height of the tower and area around its location. In induced-draft towers the recycling increases with the height.

Approach :

By ' approach ' is meant how close the cold water temperature is to the wet-bulb. The closer the approach, the greater will be the size and cost of the tower. The lower the design wet-bulb temperature chosen, the more difficult it is to obtain a close approach. Normally, for an approach of 15-20°F the height is about 15-20 ft. while water travel of 25-30 ft. is required if 8-15°F is the approach. It is not economical to design a tower with an approach of less than 4°F.

Cooling range:

It is the difference between the hot water temperature and the cold water temperature and is normally between 20-35°F. The lower the wet-bulb temperature for the same cooling range and approach, the larger the area of the tower required and therefore, the more difficult the cooling job. It is more economical to purchase a cooling tower having a greater cooling range and using a reduced quantity of water rather than one with a smaller cooling range and a greater quantity of water.

Water concentration:

The product of the water quantity per unit time and the cooling range represents the heat load to be handled by the cooling tower. The performance is governed by the ratio of the weights of air to water and the time of contact between water and air.

In commercial practice, the variation in the ratio of air to water is first obtained by keeping the air velocity constant at about 350 ft. per minute per square foot of active ground area and varying the water concentration (expressed as gallons per minute per square foot of tower ground area). The maximum contact and performance is obtained with a tower having a water concentration of 2 to 3 g.p.m. per sq. ft. ground area. The cooling capacity of any tower with a given wet-bulb temperature and wind velocity, varies with the water concentration.

Wind velocity and Fan horse power:

Wind velocity has an important rôle to play in atmospheric cooling towers. The higher the wind velocity, the greater the amount of air going through the tower, and greater is the cooling. Average wind velocity can be taken as 3 miles per hour and a still better design practice is to calculate for zero wind velocity, thus whatever actual wind present serving for additional cooling.

In mechanical—draft towers, horsepower of the fan is another consideration. Within reasonable limits, the shortage of actual area can be compensated for by an increase in air velocity through the tower which, in turn, requires a higher fan horsepower. To illustrate how sensitive the fan horsepower is to small changes in tower area, let us suppose we wish to obtain the cooling equivalent of 1000 sq. ft. standard design tower area out of a tower of smaller area of 910 sq. ft. and out of a tower of a larger area of 1110 sq. ft. The fan horsepower required is 41 for the 1000 sq. ft. tower, 51.9 for 910 sq. ft. tower, requiring increased air velocity to accomplish the same cooling and 34.5 for the 1110 sq. ft. tower, requiring less air velocity. This shows the importance of designing just the right ground area of the tower.

Maintenance:

For preventive maintenance the tower must be installed in an accessible location and periodic blow-downs and shutdowns must be made in order to remove excess salt concentration caused by evaporation and to clean off the dust, dirt etc. carried over to the tower by the prevalent winds. Water treatment is essential to control algae growth—harmful to wood construction of the tower, to control scale formation and to control pH. The higher the pH of the water, the greater the tendency for a scale to deposit. If pH is below 7, little scale deposits but corrosion becomes significant. pH may be kept between 6.5 and 7 and a corrosion inhibitor may be added. If pH is 9.0 or so for alkaline waters, the wood is badly affected by delignification and for such waters pH increases when concentration of salts increases by evaporation. pH of such waters must, therefore, be kept below 8.5. Fillings must not get oily; otherwise surface would not be wetted by water. Distribution system, drift eliminators, basin, gears and fans must be periodically checked and cleaned.

Conclusion:

Thus it is seen that the cooling tower has versatile flexibility only if it is properly designed and the effects of variables are understood. Its investment is amply justified by the constant supply of water of the required quality and temperature it offers thereby assuring the uniformity and continuity of the plant operation.

Direct-contact heat transfer as a unit operation has been successfully applied in cooling tower but its full potentialities as to the wide application in industry yet remain to be explored.