

Cooling Tower Basics and Common Misconceptions

Introduction

In comparison with most other industrial equipments, the water cooling tower is a simple device, based on the direct contact of two of the earth's most common substances: air and water; yet a surprising number of misconceptions on its design, operation and behavior prevail.

Cooling basics and important misconceptions are discussed herein, with the goal of helping to achieve the most economical and beneficial application, design, and operation of this important heat transfer device.

Cooling Tower Fundamentals

Heat Transfer: The basic principle of the cooling tower operation is that of evaporative condensation and exchange of sensible heat. The air and water mixture releases latent heat of vaporization which has a cooling effect on water by turning a certain amount of liquid into its gaseous state thereby releasing the latent heat of vaporization.

This is more effectively demonstrated by wetting the back of your hand with water and blowing on it. This effect is what happens inside the cooling tower. The air stream releases latent heat of vaporization thereby dropping the temperature of the water on your skin. The liquid changing to its vaporous state consumes heat which is taken from the water remaining, thus lowering its temperature.

There is a penalty involved, and that is loss of water which goes up to the cooling tower and is discharged into the atmosphere as hot moist vapor. Under normal operating conditions, this amounts to approximately 1.2% for each 10 °F cooling range.

Sensible heat that changes temperature is also responsible for part of the cooling tower's operation. When water is warmer than the air, there is a tendency for the air to cool the water. The air then gets hotter as it gains the sensible heat of the water and the water is cooled as its sensible heat is transferred to the air.

Approximately 25% of the sensible heat transfer occurs in the tower while the balance of the 75% cooling is due to the evaporative effect of latent heat of vaporization.

Dry-Bulb Temperature [DBT], Wet-Bulb Temperature [WBT] and Relative Humidity [RH]:

The temperature of air as read on the ordinary thermometer is called DBT. WBT is the reading when the bulb of a thermometer is covered with a wet cloth, and the instrument is whirled around in a sling. RH is the ratio of the quantity of water vapor present in a cubic feet of air to the greatest amount of vapor which that air could hold at a given temperature.

When the relative humidity is 100%, the air cannot hold any more water and therefore, water will not evaporate in 100% humid air. When the RH is 100% the WBT is the same as the DBT, because the water cannot evaporate any more. But when the RH is less than 100%, the WBT will be less than the DBT and water will evaporate.

The capability of the cooling tower is a measure of how close the tower can bring the water temperature to the WBT of the entering air. A larger cooling tower [i.e., more air and/or more fill] will produce a closer approach [colder leaving water] for a given heat load, flow rate and entering air condition. The lower the WBT, which indicates either cool air, low humidity or a combination of the two, the lower can the cooling tower cool the water. The thermal performance of the cooling tower is thus affected by the entering WBT; the entering air DBT has an insignificant effect on thermal performance.

In actual practice, the final cold water temperature will always be at least a few degrees above WBT, depending on design conditions. It is not customary in the cooling tower industry to guarantee any approach less than 5 °F.

Cooling Tower [Counter-Flow] Theory –Merkel Equation

Figure 1 illustrates a drop of water falling through an upstream of unsaturated air at a wet-bulb temperature of WBT with enthalpy h_A , in a counter flow cooling tower. The drop of water is assumed to be surrounded by a film of saturated air at the water temperature WT with saturation enthalpy h_w . As the drop travels downward, heat and mass transfer takes place from the interface air film to the upstream air, thereby cooling the water from HWT to CWT.

This cooling process can best be explained on a

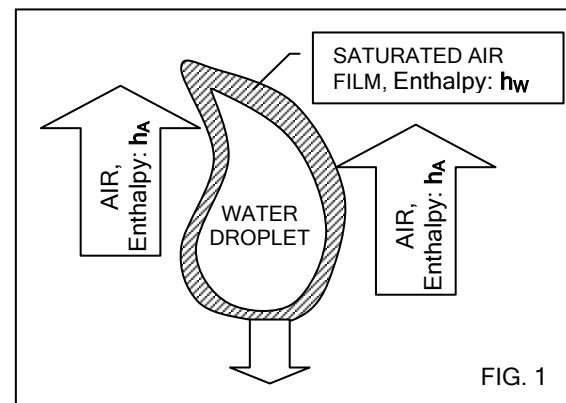


FIG. 1

Psychometric Chart. The process is shown in figure 2 – known as the Driving Force Diagram. The air film is represented by the Water Operating Line on the Saturation Curve. The main air is represented by the Air Operating Line, the slope of which is the Water/Air [L/G] ratio. The cooling characteristic, a “degree of difficulty” to cooling is represented by the Merkel Equation:

$$KaV / L = \int_{CWT}^{HWT} \frac{dt}{h_w - h_A}$$

The Merkel Equation primarily says that at any point in the tower, heat and water vapor are transferred into the air due [approximately] to the difference in the enthalpy of the air at the surface of the water and the main stream of the air. Thus, the driving force at any point is the vertical distance between the two operating lines. And therefore, the performance demanded from the cooling

tower is the inverse of this difference. The solution of the Merkel Equation can be represented by the Performance Demand Diagram shown in figure 3. The KaV/L value is equal to the area under the curve.

An increase in the entering WBT moves the Air Operating Line towards the right and upward to establish equilibrium. Both the CWT and HWT increases, while the approach decreases. The curvature of the saturation line is such that the approach decreases at a progressively slower rate as the WBT increases.

An increase in the heat load increases the cooling ranges and increases the length of the Air Operating Line. To maintain equilibrium, the line shifts to the right increasing the HWT, CWT, and

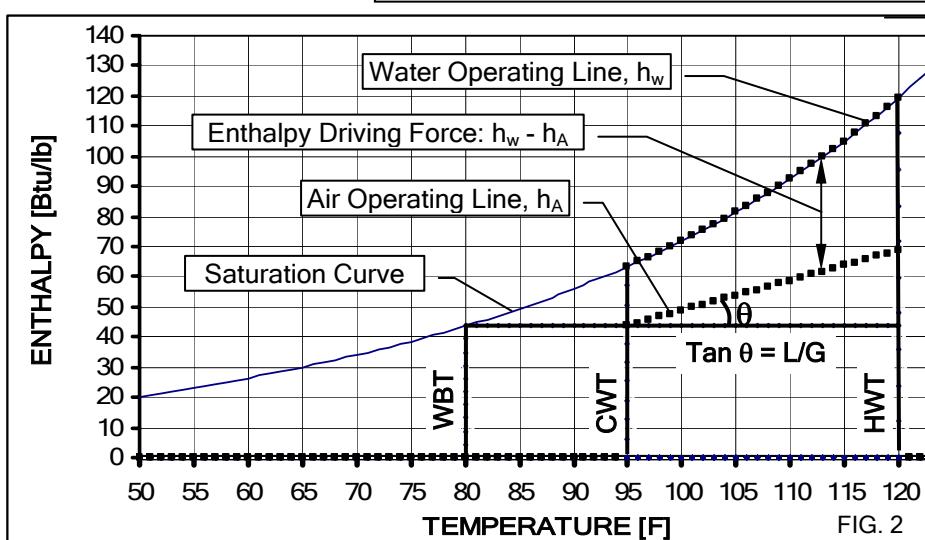


FIG. 2

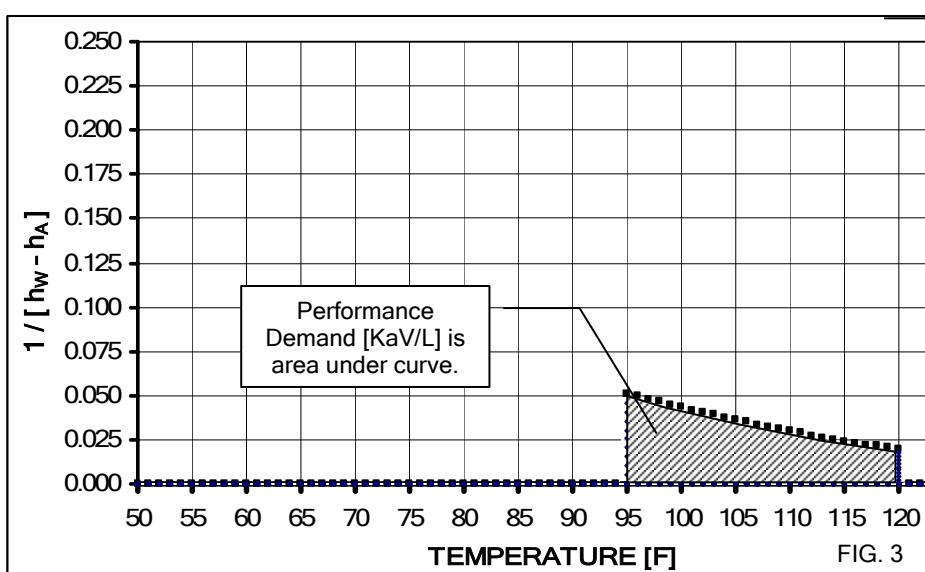


FIG. 3

approach. The increase causes the hot water temperature to increase considerably faster than does the cold-water temperature.

In both these cases, the KaV/L should remain constant. However, a change in L/G will change the KaV/L value.

Cooling Tower Designing

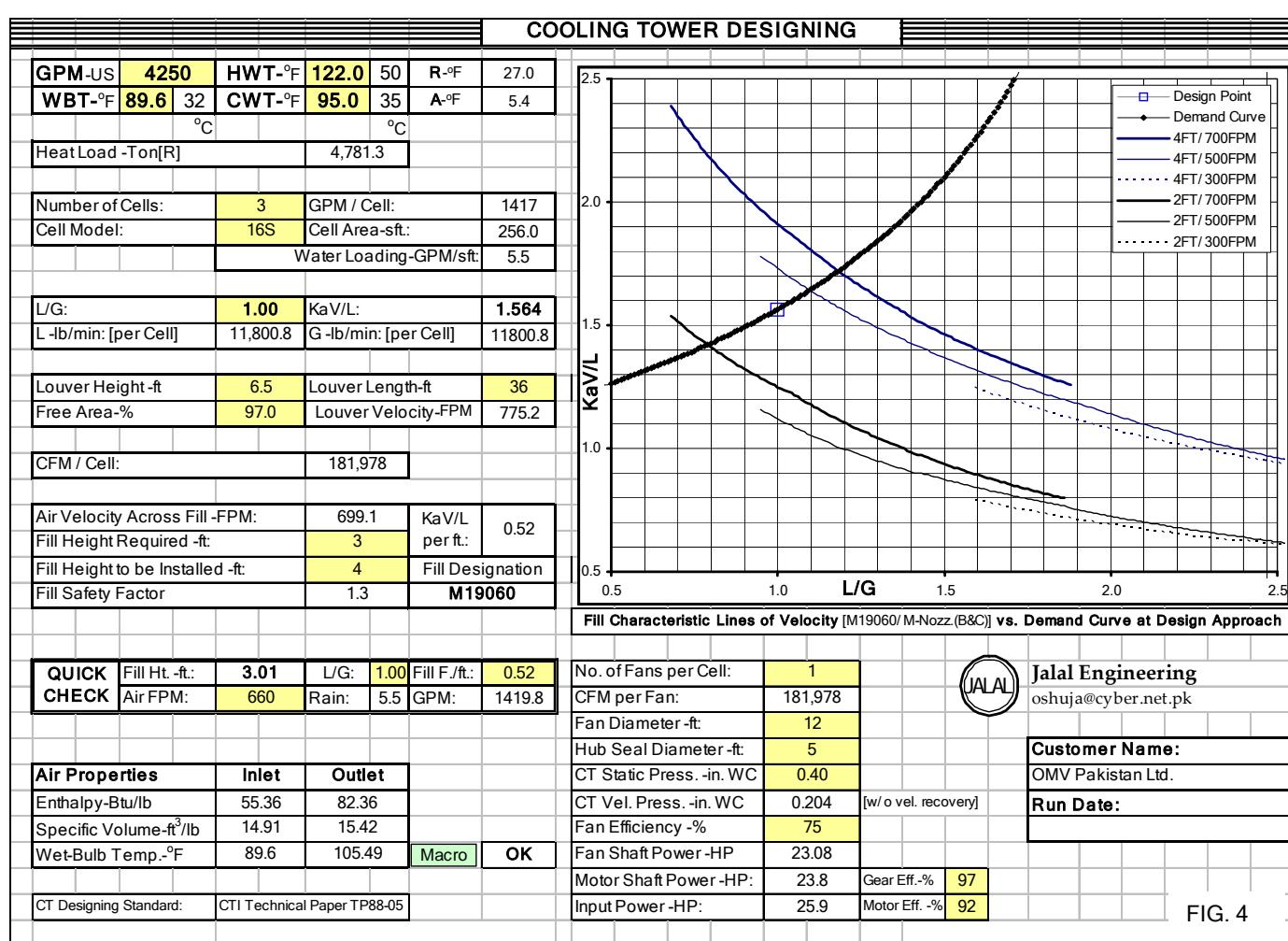
On the basis of the above discussion, it is clear that there are five parameters that in combination dictate and define the performance of a cooling tower: **1. Hot Water Temperature –HWT, 2. Cold Water Temperature –CWT, 3. Wet Bulb Temperature –WBT, 4. Water Flow Rate –L, 5. Air Flow Rate –G.**

The first four data are the ones, which are given by the user. The fifth one [G], is selected by the cooling tower designer. Once these five data are available, the tower characteristic [KaV/L], can be calculated through the Merkel Equation.

The first step in cooling tower designing is the generation of a Demand Curve. In this curve, the KaV/L values are plotted against varying the L/G ratios. The next step is to superimpose fill characteristics curves and demand curves.[Cooling Technology Institute has tested a variety of fill configurations and generated fill characteristic curves for each type; CTI's Technical Paper TP88-05 can be referred to in this regard.]

Cooling Tower designing is basically an iterative process. The factors that effect the selection of design L/G and consequently the fill height are: cell dimensions, water loading, air velocities across various cooling tower sections and pressure drops, and fan selection.

Please refer to figure 5 below, which is a screen print of Jalal Engineering's cooling tower designing program.



Common Misconceptions

"My Tower is Cooling the Water 20°" Many people have been guilty at one time or another of defining what a cooling tower is doing in terms of range (HWT-CWT). Often, this is accepted as a level of performance of the cooling tower. Nothing could be further from the truth. The equation for heat load is as follows:

$$\text{Heat Load [Btu/hr]} = 500 \times \text{Water Flow Rate [GPM]} \times \text{Range [°F]}$$

Now, heat load, of course, is supplied by the unit being served by the cooling tower. The tower itself is neither a heat source nor a heat sink. In the usual circulating system the heat -load is independent of the cooling tower. The number 500 is a constant, therefore is independent of the cooling tower. The circulating water flow is determined by the number of pumps running and the pressure drop in the overall circulating water system. Therefore, it likewise is independent of the cooling tower.

If heat load, the constant, and the circulating water flow are all independent of the cooling tower, then by mathematical deduction the range is likewise completely independent of the cooling tower. Therefore, the range is the same whether there is a two-cell tower or a four-cell tower. The range would be the same if the fans were on full-speed, half-speed, or turned off. Consequently, such a statement as "My tower is not performing because I bought it to cool 20°, and it is only cooling the water 10°" has no validity whatsoever. Likewise, the converse is true. Someone who has a cooling tower which is "cooling the water 30°" whereas it was only designed to cool 20°, may not be in such a fortunate position as he might think.

Both these cases show no indication whatsoever of actual thermal capability of the cooling tower. What then is a measure of the thermal capability of the cooling tower? It is not the amount of heat being rejected, rather it is the *level* at which this heat is rejected. *The measure of performance of the cooling tower is the resultant cold water temperature or even more specifically, the approach (CWT-WBT) under given conditions.* Cold water temperature is the primary dependent variable, and vividly indicates cooling tower capability.

Approach

Approach is CWT minus WBT. Another misconception that constantly crops up in cooling tower work is concerning approach. One will say, "I bought a tower to make a 10° approach, yet I have a 15° approach today. Therefore, the cooling tower is not working in accordance with its design."

As the WBT goes down, the CWT also goes down. However, this is not a one-to-one relationship. It is more nearly a two-to-one relationship. That is, for each 2°F drop in WBT, the CWT will drop approximately 1°F. Therefore, if the WBT is 10° below design WBT, then by definition the approach will be increased 5° above that specified as design. Of course, the converse is also true: as wet bulb increases above design, then the cold water temperature will increase roughly one degree for each two degree increase in wet bulb. These are rough approximations and can be changed somewhat by different L/G ratios.

Therefore, when attempting to determine whether or not performance appears to be satisfactory at other than design conditions, it is wiser to utilize the cooling tower performance curves or the *CTI Blue Book* [with cooling tower characteristic curves] rather than to just compare the actual approach to the design.

Drift Loss

Today, we see more and more interest in low drift loss cooling towers. This increased interest has been brought about by several factors. The major factor is continual insistence by the regulatory bodies that drift loss be minimized to reduce ecological effects.

A second factor is an attempt to reduce water costs and treating costs by reducing water

consumption. However, let us now look at the basic concept "reducing drift loss reduces water consumption." Water is lost out of a cooling tower in the following ways: drift, evaporation, blowdown and windage.

Drift loss is a loss of water due to physical entrainment of liquid droplets in the air stream. This places water, with its attendant dissolved solids, in liquid form in the atmosphere. Windage is of a similar nature but usually much smaller in quantity. Windage is the sometimes loss of water through the louvered area of the tower due to wind blowing through the tower. This occurs more often with operation of the fans at half-speed or off. For the purposes of this discussion, we will consider windage a portion of drift loss. The fact that drift leaves the cooling tower as liquid water, thereby containing its proportionate share of dissolved solids, is the important factor to remember.

In order to maintain a proper total dissolved solids content level in a cooling tower, it is necessary to continuously blow down or throwaway a portion of circulating water. This is done to prevent the tower from accumulating excessive amounts of total dissolved solids which would cause severe scale and/or corrosion problems. This loss of water from the system is absolutely essential and cannot be avoided for the successful operation of the cooling tower. Therefore, drift is more properly defined as "involuntary blowdown." It now becomes readily apparent that any decrease in the drift loss from the cooling tower will result in an equivalent increase necessary in the blowdown in order to prevent excessive solids buildup. When viewed in this manner, it is evident that lowering drift loss does not reduce water consumption and consequently does not save anything in basic water cost or chemical treating costs.

Another common misconception occurs when large clouds of "fog" emanate from cooling towers under certain atmospheric conditions. Many people assume that drift is a major contributing factor. However, this "fog" is quite different from drift as this water leaves the system in the vapor state and recondenses to small liquid droplets after encountering the relatively colder ambient air. The fog itself does not carry with it the dissolved solids and consequently does not fit into the category of involuntary blow down. Furthermore, it cannot be stopped by reducing drift loss. Therefore, one should not specify more stringent drift loss requirements to reduce fogging. Energy and money would be expended for absolutely no benefit.

The only real justification for reduction of drift loss is based on the nature of the area where the drift falls and its affects on the mechanical equipment of the cooling tower. If the dissolved solids in the drift are being deposited on sensitive areas then it is important to keep drift loss as low as practicable. If a cooling tower is of induced draft design, excessive drift will certainly erode the mechanical equipment. Therefore, one should be certain as to the desired effect to be accomplished prior to making very restrictive and costly requirements in reduction of drift loss.

Evaporation

The most common misconception concerning evaporation is that competing tower manufacturers and designs can accomplish widespread differences in the amount of water being evaporated in a cooling tower.

The truth of the matter is that the large majority of heat exchange in a cooling tower is accomplished by the evaporation of a portion of the circulating water. This removes heat from the remainder of the circulating water by removing the latent heat of vaporization necessary to accomplish this phase change. Inasmuch as evaporating water is the basic function of the cooling tower, one is misled to believe that a cooling tower can operate successfully without the proper evaporation.

There are a few design features that can have a minor effect on the evaporation rate. For example, cooling towers with identical duties, but operating at different L/G ratios, will have slightly different evaporation rates. The normal "rule of thumb" for determination of evaporation is 0.1 % 1°F the circulating water flow for every 1.0 °F range.

The "More Water" Syndrome

The "more water" fallacy is important and worthy of inclusion here. This situation commonly occurs in an operating cooling tower when, in the heat of summer, the temperature begins to rise on, say, a shell-and-tube exchanger in a refinery unit. Operation calls for more water in order to hold the temperature of the cooled process stream. Additional water is pumped over the tower, and this results in a decrease in the tower's performance capabilities, thereby raising the CWT. The raising of the CWT going to the exchanger in some cases more than offsets the effect of increased heat transfer coefficient in the exchanger due to increased water flow. Therefore, the situation becomes worse and again "more water" is demanded. It takes a well-trained operator to recognize the fact that, when trouble is occurring temperature-wise, less water rather than "more water" is often necessary to bring the temperatures down.

Of course, situations can exist where the increase in velocity through an exchanger occasions a better overall heat transfer, even though the temperature of the water through the unit is rising. This trade-off must be looked at very carefully rather than just assuming that more water is the cure-all to summertime operating cooling problems.

Power Considerations

Often the effect of fan power on cooling tower thermal capability is misunderstood. For instance, it is quite often thought that a 10% increase in power by increasing fan pitch will accomplish a 10% increase in the capacity of the cooling tower. A quick check of the fan laws will reveal that this is far from the truth.

If we are near design fan power and are operating at an essentially constant fan efficiency, air flow rate (and hence, cooling tower capability), will increase in proportion to the cube root of the power increase. For example, if the horsepower were increased to 110% of its original value, the air flow and thermal performance capability of the tower would only be increased approximately 3.2%.

Conclusion

This article demonstrates rather pointedly that cooling tower performance and operation are not so straightforward as they many times are thought to be. These misconceptions and inadequate knowledge of cooling tower design can cost you money in all phases of dealing with cooling towers.

Purchase of a new tower will cost more in the long run if plant operations do not run efficiently due to an ill-designed cooling tower. Tower operation, in terms of energy cost, will be more expensive if utilization of fan power is misunderstood. Upgrading an existing tower may turn out to be futile because tower performance was viewed in terms of range.

It is necessary to have a working knowledge of the performance of cooling towers, without misconception, in order to purchase and operate them to the best advantage for maximum production at minimum cost.