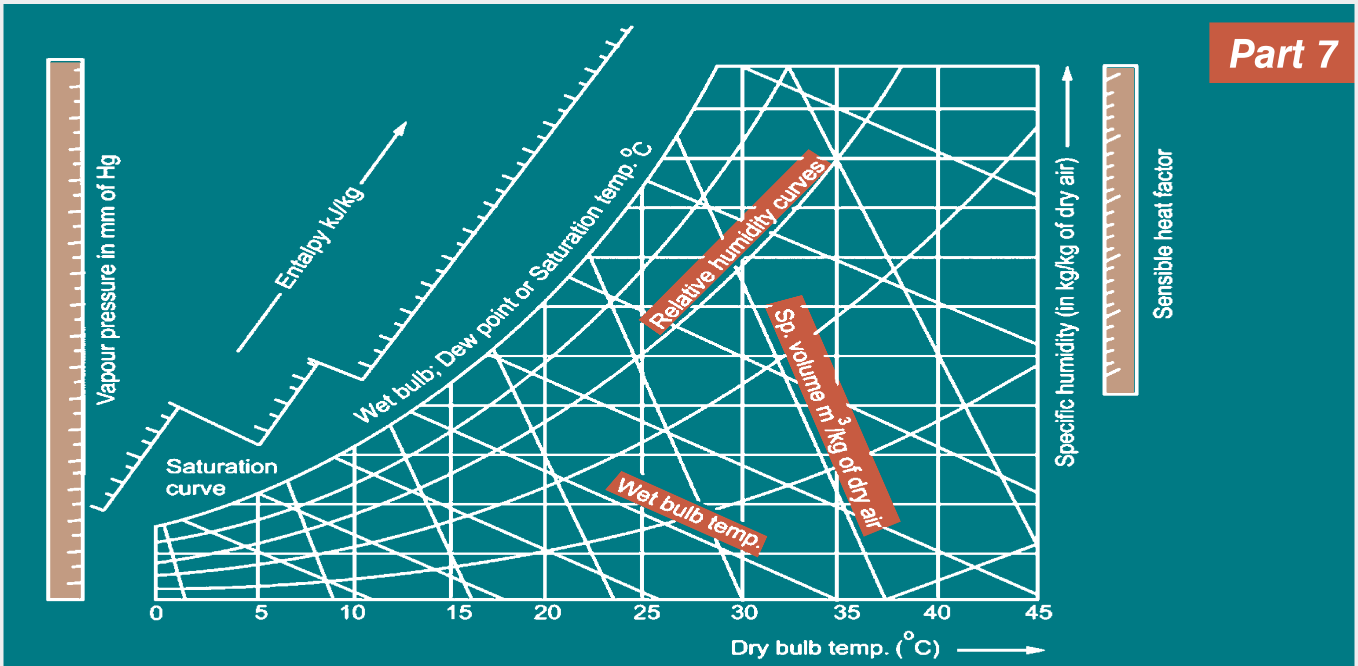

Understanding Psychrometrics

By Ramesh Paranjpey, *Distinguished 50-Year Member, ASHRAE*
Supported by *Mukund Ranade, AC Consultant*

Introduction

This is the last article in the series 'Understanding Psychrometrics'. Part VIII, the next article, will contain quiz questions. Part IX will contain answers to the quiz questions.

Psychrometrics in Cooling Tower Operation

We have gone into considerable details of cooling and dehumidification application for determining the quantity of air required to offset the various loads and one more area where the psychrometric process plays an important role that remains to be

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(This document is prepared by Ramesh Paranjpey assisted by Mukund Ranade, and Gayatri Adhikari of Aqua Chill systems india Pvt. Ltd.)

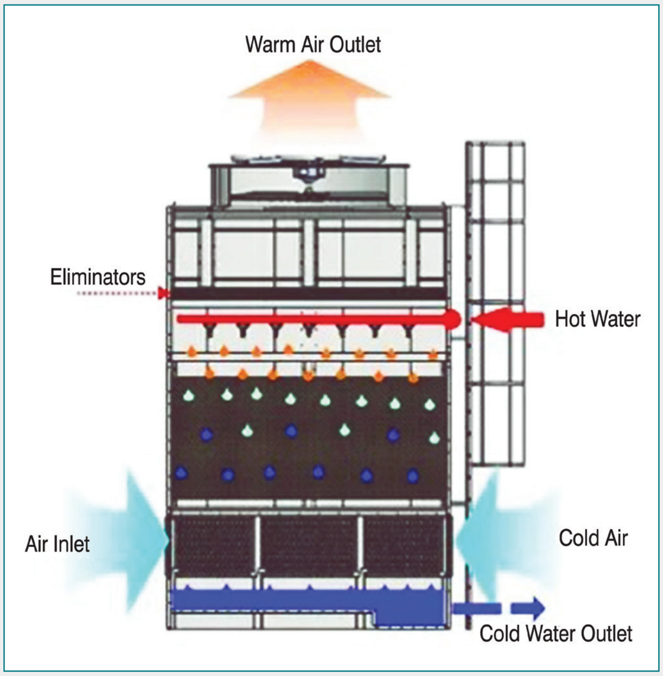

Figure 1: Psychrometrics in cooling tower operation

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looked at, is the cooling tower. Our discussions on Psychrometrics would not be completed unless we touch upon this apparatus as well.

If the question is asked whether water can be cooled from 30°C to 21°C when the ambient temperature is 26°C with 50% R.H., without knowing the psychrometric principles, one must think hard as to what the right answer would be. Now that we have learned the principles, the counter question that would immediately be raised is "what is the wet bulb temperature of ambient air?" Besides the use of evaporative cooling for coolers in dry climates, evaporation as a means of cooling water is utilized to its fullest extend in cooling towers. Now that we have learned Psychrometrics, we will immediately be able to find wet bulb temperature for above ambient condition.

When refrigeration equipment is not working, cooling tower acts as an evaporative cooler. Since no heat is added to the condenser water loop, the condenser water temperature will tend to approach the entering wet bulb temperature with a deviation to some extent due to the condenser pump heat addition. The tower will cool and saturate the air flowing through it like a desert or evaporative cooler. It is described in *Figure 2*.

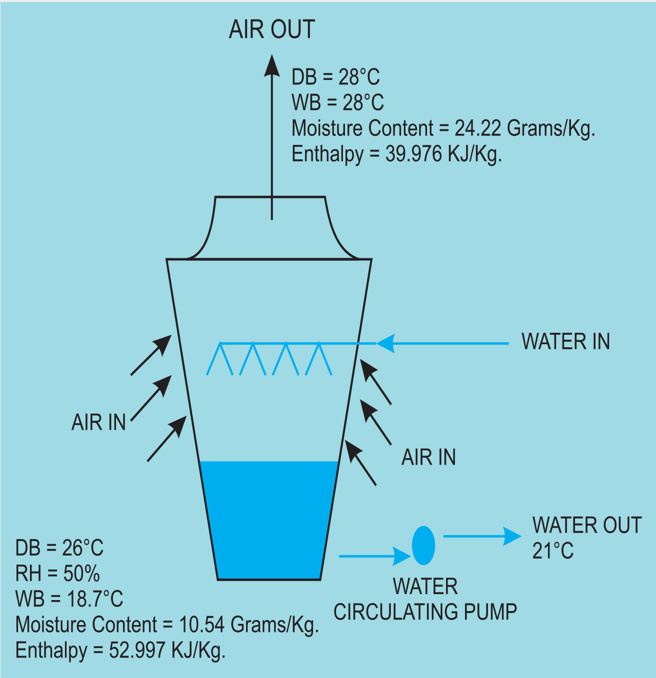

Figure 2: Heat and mass balance in cooling tower

We shall see how the heat exchange takes place in a cooling tower operation. When the compression starts, heat is rejected to the condenser water raising its temperature, say from 21°C to 30°C. The cooling tower working on the evaporation of water principle, will cool water to 21°C. This is possible even with dry bulb temperature higher at 26°C.

Since the incoming air temperature (26°C) is higher than the desired cold-water temperature (2l°C) sensible cooling of water by air is not possible. We must know the wet bulb temperature of outside air.

Assuming, wet bulb temperature to be 18.7°C corresponding to 50% R.H., it is possible now to cool water to 21°C by evaporation. We know very well that the large amount of latent heat required for evaporation, which plays a dominant role in transferring heat from water and thereby, cooling it, compared to sensible heat transfer.

As the moisture is evaporating, air will also get humidified, increasing its humidity ratio from 10.54 g/kg to 24.229g/kg. The enthalpy of air at 26°C DBT/18.7°C WBT is 52.997 kJ/kg and assuming air leaves in an almost saturated condition at 28°C DBT/28°C WBT, and the enthalpy is 89.976kJ/kg at this condition.

Thus, the heat added in the air stream is (89.976-52.997) = 36.979kJ/kg. The wet-bulb temperature rise is approximately 9°C (28°C - 18.7°C). We can, thus, see that an exactly equivalent temperature drop takes place in water from 30°C to 21°C.

The heat added for the evaporation of water can also be established with the help of the chart. The moisture content of air at inlet is 10.54 g/kg, whereas at the outlet it is 24.229 g/kg. The increase in moisture content of air is (24.229 - l0.54) =13.689 g/kg. The latent heat of evaporation at this temperature is 2434.85kJ/kg and multiplying these, we get the total heat used in evaporating water as 33.3kJ/kg, which gets reflected in enthalpy increase of air as calculated earlier at 36.979kJ/kg. Out of 36.979 kJ/kg, 33.3 kJ/kg is the latent heat due to moisture added in air from evaporation and the remaining 3.679 kJ/kg is reflected in dry-bulb temperature increase from 26°C to 28°C.

While selecting the cooling tower, the temperature drops in water from 30°C to 21°C is called range whereas the difference between water outlet temperature of 21°C to wet-bulb temperature of 18.7°C is termed as 'approach.'

The size of tower increases as the 'approach' is reduced.

We should, therefore, select a cooling tower for monsoon conditions when the wet-bulb temperature is higher and the load on cooling tower may be higher than in summer.

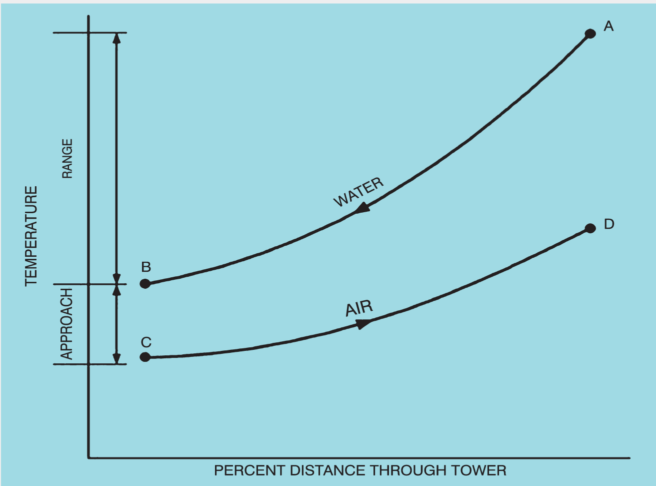

Figure 3: Temperature relationship between air and water in counterflow cooling tower

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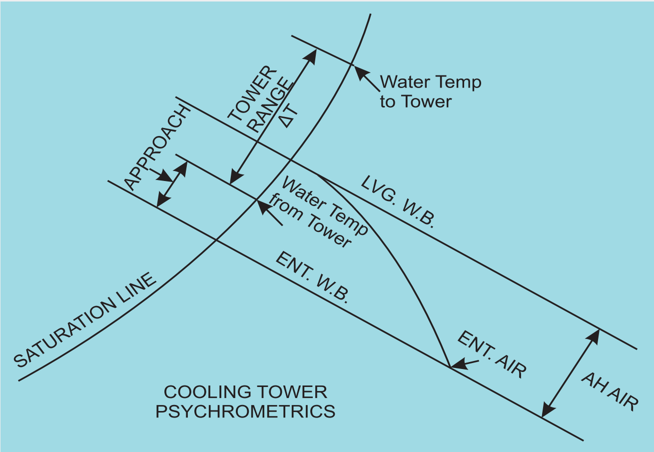

Figure 4: Cooling tower Psychrometrics

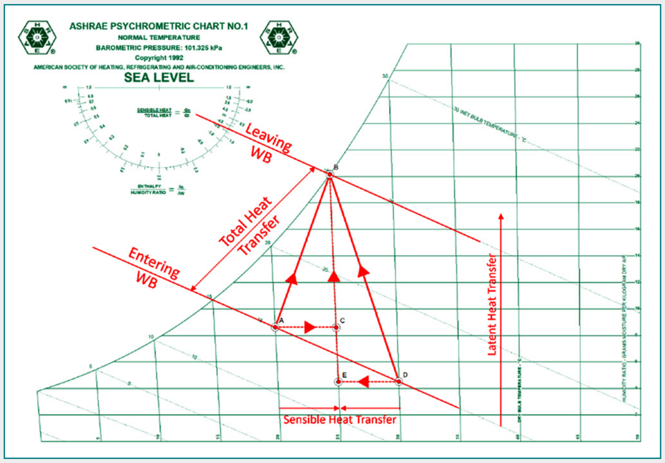

Figure 6: Latent heat and mass transfer – Psychrometric analysis

In summer, although the dry-bulb temperature is more, the air is drier, and the wet-bulb temperature is much lower providing a greater 'approach'. Cooling towers may, therefore, perform better in summer with drier climate than in monsoon with humid air.

As shown in *Figure 4*, the temperature drop of water in passing through the tower is known as the 'cooling range ΔT'. The 'approach' is the difference between the tower leaving water temperature and the wet-bulb temperature of the entering air.

The rate of heat transfer from the water to the air depends primarily on the enthalpy of the air and is dependent only on the wet-bulb temperature of the air.

This explains that the cooling tower performance is independent of the entering dry-bulb temperature of the air. *Figure 5* will explain this in more detailed manner.

In *Figure 5*, air leaving the cooling tower is shown as saturated air.

The ambient air at 'A' enters the tower. It absorbs heat and moisture and exits the tower at point 'B'. The amount of heat transferred from the water to the air is proportional to enthalpy difference (Hb-HA). Since the wet bulb lines define constant enthalpy lines with only minor variation, the change in the enthalpy of the air may be considered for all practical purposes to be determined only by the change in wet-bulb temperature.

The total enthalpy difference, line AB, is made up of summation of the sensible heat component, line AC and CB which represents the latent heating of the air (latent water cooling). If the entering condition is changed to 'D' at the same wet bulb temperature, the total heat transfer remains same but the ratio of sensible and latent heat components have changed.

Case AB represents cooling of the water by sensible and latent heating of the air. Case BD again represents cooling of the water by evaporation, but the air is sensibly cooled and latent heating of the air increases to compensate for the sensible cooling of the air. Therefore, for the same cooling load, the amount of evaporation of water in the tower depended on the amount of sensible heating or cooling of the air.

Eliminating Fog or Mist and Condensation in Cooling Towers

On many occasions, we notice that there is fog or mist formation at the air outlet of cooling towers. When the outside ambient temperature is lower and warm air mixes with this stream, on some

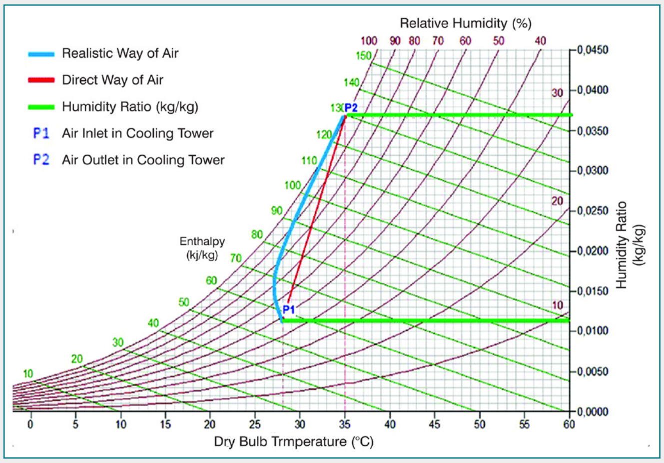

Figure 5: Path of air travel

Figure 7: Mist formation in cooling tower outlet air

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occasions the mixture joining line will be going through the region, which is to the left of the saturation line on the psychrometric chart, indicating that there is free moisture present in the air, after the air is fully saturated and is unable to hold any additional moisture. This moisture then appears in the form of fog/mist.

On some installations, we also notice that if our air conditioning equipment is working, there is water dripping or condensation forming on carpets, walls developing wet patches, curtains appearing to be foggy etc.

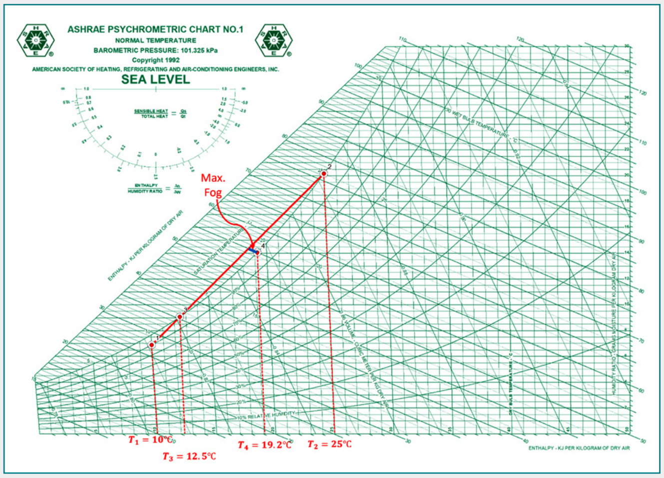

Figure 8: Fog and mist zone

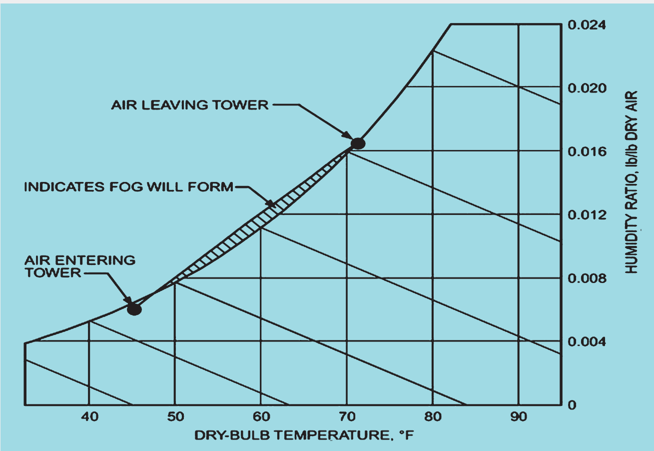

Figure 9: Fog and mist zone

The most common observations are window glasses getting fogged either from inside or outside, depending upon outside weather conditions or inside conditions in an air-conditioned space. In rainy season, many people would have observed that with door opened for passenger coming in air from aircraft nozzles falling on passenger has a fog. This is because the point 3 lies as shown in *Figure 8* the fog region.

The most irritating experience is while driving the car during monsoon when visibility gets obscured due to misting of glass. If the inside conditions in the air-conditioned space have higher specific humidity than outside ambient air, one would notice window glasses getting fogged as additional moisture beyond the dew point will condense on surfaces that are at lower temperature than dew point like inside wall, curtains, uninsulated ducts etc. It is now easy to address all these problems, having learned Psychrometrics.

Psychrometrics in Evaporative Condensers

The evaporative condenser utilizes the principles of evaporative cooling to lower the refrigerant condensing temperature.

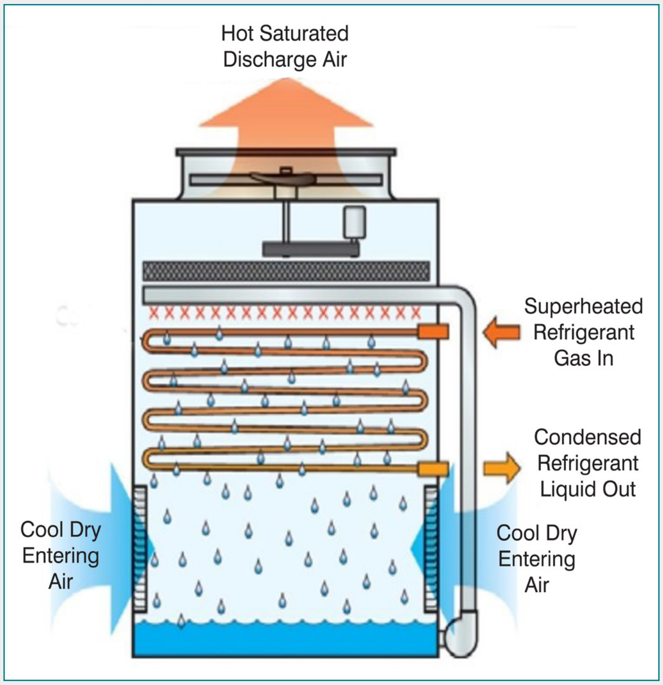

Figure 10: Evaporative condenser

Evaporative condenser is a combination of cooling tower and shell and tube condenser. The tubes are inside the evaporative condenser and carry refrigerant instead water.

As shown in *Figure 10*, water is pumped from the basin section and is distributed over the exterior of the condensing coil by a series of distribution troughs or spray nozzles. The flow rate of water need only be enough to thoroughly wet the condensing coil to provide uniform water distribution and prevent accumulation of scale. Therefore, minimum pumping horsepower is required. A fan system forces air through the falling water and over the coil surface. A small portion of the water is evaporated, removing heat from the refrigerant, and condensing it inside the coil.

It eliminates the sensible heat transfer step of the condenser water, which is required in the cooling tower/refrigerant condenser system. This permits a condensing temperature substantially closer to design wet-bulb temperature, and consequently, minimum compressor energy input. These conditions result in an economical evaporative condenser selection.

Evaporative cooling can be visualized using a psychrometric chart by locating the initial condition of air and moving along the line of constant enthalpy towards a state of higher humidity.

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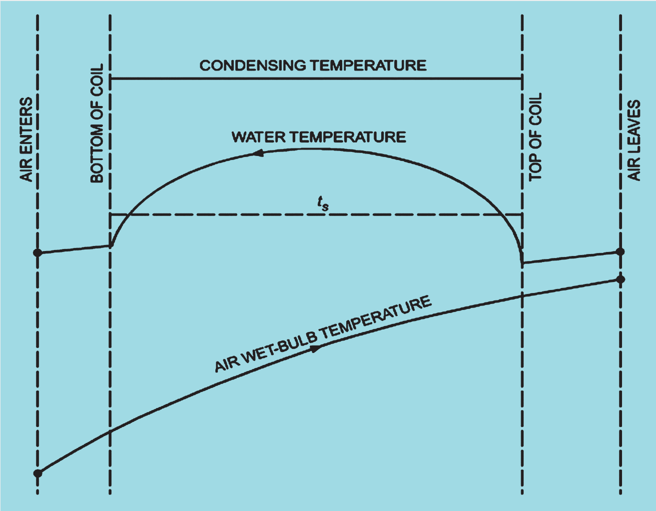

Figure 11: Heat Transfer Diagram for evaporative condenser

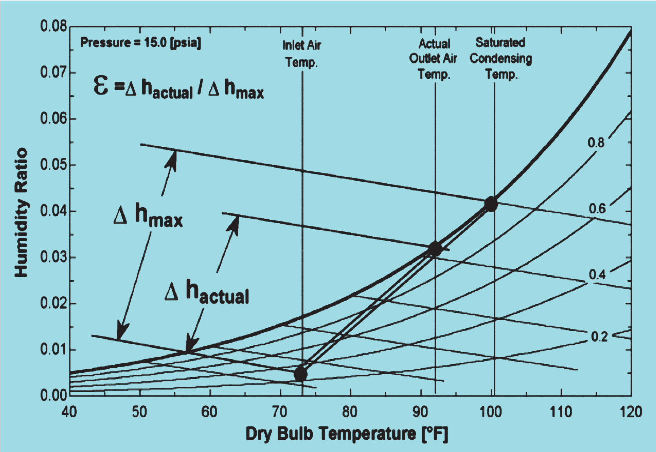

Figure 12: Evaporative condenser Psychrometrics

This is a psychrometric representation of cooling tower effectiveness based on air-side enthalpy change.

- $\varepsilon = \dfrac{(\Delta h_{actual})}{(\Delta h_{max})}$
- Inlet air ⟶ outlet air ⟶ saturated exit condition
- Humidity ratio vs dry-bulb temperature
- Constant pressure (15 psia)

This formulation is typical for cooling towers, where

- Air gains both sensible + latent heat
- Performance is measured via enthalpy rise of air

Evaporative condenser function depends on wet-bulb temperature, not dry-bulb as explained below.

Cooling tower heat transfer depends on:

$Q \propto (h_{(air,sat)} - h_{(air,in)})$

Where,

- $h_{(air,sat)}$ ⟶ enthalpy of saturated air at water temperature
- $h_{(air,in)}$ ⟶ enthalpy of entering air

This enthalpy difference is governed primarily by wet-bulb, not dry-bulb alone.

Evaporative Condenser Salient Points

- Most widely used and popular in ammonia refrigeration installations.
- Low condensing temperatures compared to shell and tube condensers-saving in power.
- Low pump power
- Low fan power
- Can be kept anywhere, preferably near the machine room

Psychrometrics in Cooling Coil Selection

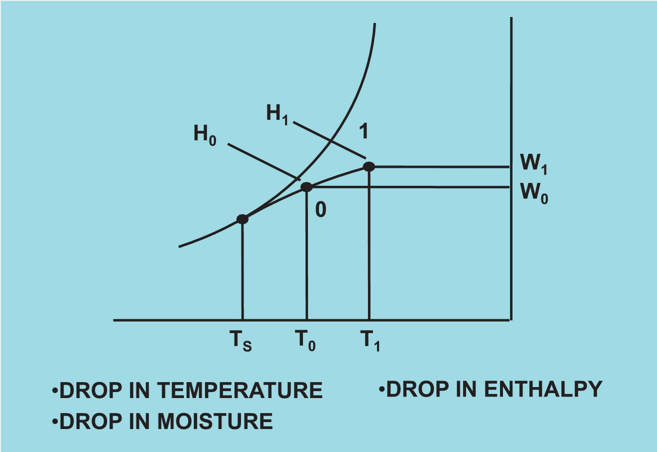

Figure 13: Cooling and dehumidification

Figure 13 shows the situation prevailing in cooling and dehumidification coil. Air flowing across the coil surface changes condition from I to 0 and, during that process, the enthalpy and the moisture content both drops. A reduction in enthalpy from H_1 to H_2, indicates that the air gives up heat, which is absorbed by the coil and carried away by the refrigerant. The drop in moisture content, from W_1 to W_2 shows up as condensation on the coil in the form of water or frost. The drop in temperature is indicated by T_1 to T_2 with the coil wetted surface. The driving force for these reactions is indicated by T_s (Apparatus Dew Point Temperature).

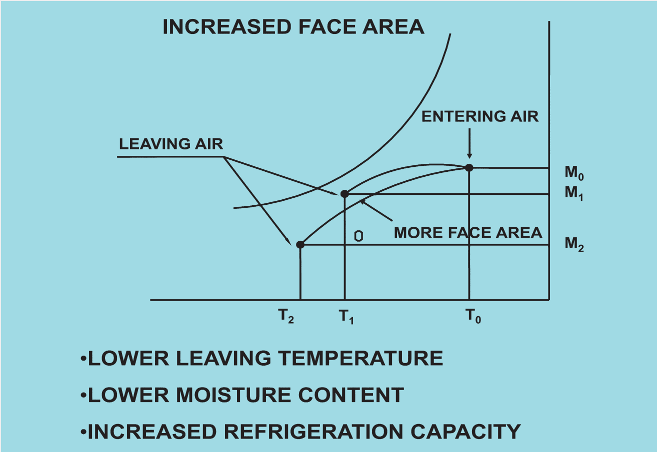

Figure 14: Coil with increased face area

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While selecting the cooling coil and quantity of air circulated, the total heat removed as well as drop in required temperature is important consideration. It is also important as to how much moisture should be removed. In some cases, such as vegetable storages as little moisture should be removed as possible. On the other hand, the coils at the loading dock of frozen food warehouse must remove as much moisture as possible so that minimum moist air is carried inside the low temperature space by infiltrating air.

Figure 14 shows that coil with increased face area assumes a lower position on the psychrometric chart. This indicates that the leaving air temperatureT2 and moisture content M2 drop further than the T1 and M1 achieved by the coil with smaller face area. The cooling capacity, thus, increases with increased face area.

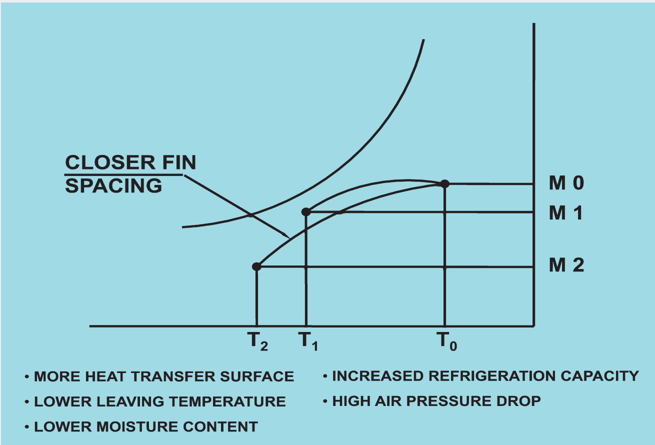

Figure 15: Closer fin spacing

Figure 15 shows that closer fin spacing, lowers the coil condition curve, similar to what is observed when face area is increased. Closer fin spacing leads to lower air outlet temperature and reduced moisture content. The refrigeration capacity also increases.

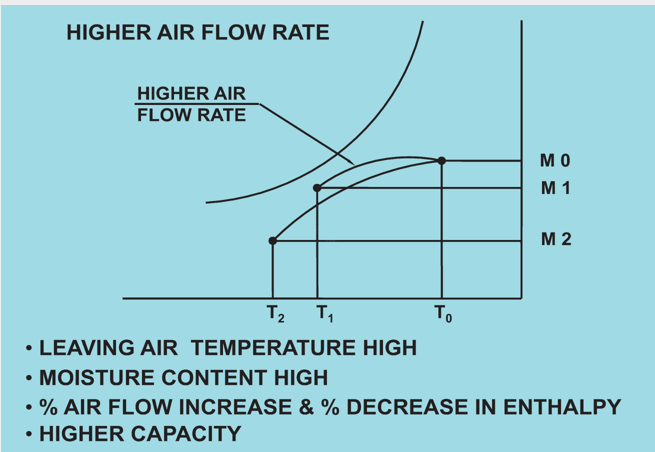

Figure 16: Higher air flow rate raises the coil condition curve

Figure 16 shows that higher air flow rate raises the coil condition curve. The leaving air temperature and moisture content are not reduced as much as with lower airflow rate. However, because of increased air flow rate by a greater percentage than decrease in enthalpy, the cooling capacity actually increases.

$Q = CMH \times \rho \times \Delta H$

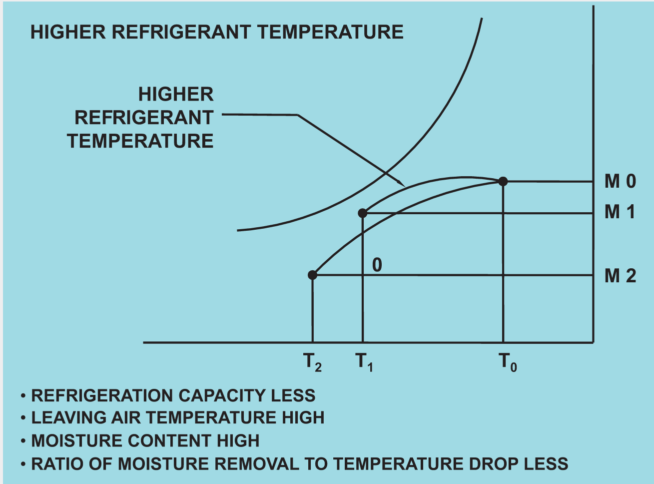

Figure 17: Higher refrigerant temperature raises the coil condition curve

Figure 17 shows higher refrigerant temperature raises the coil condition curve by raising the coil surface temperature. Neither the air leaving temperature nor the moisture content are reduced as much as with a lower coil temperature. The cooling capacity decreases.

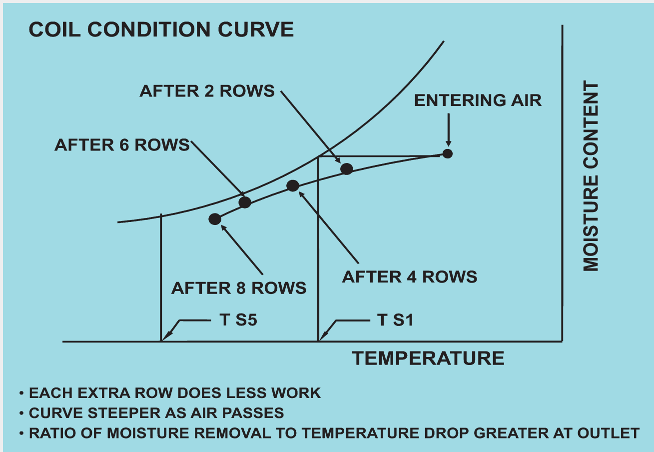

Figure 18: Coil condition curve

Looking at the coil condition curve and condition of air as it passes through the coil that is eight rows deep, it is observed that each succeeding row of the tubes does less work in sense of dropping the temperature and removing, moisture from the air, the greatest rate of heat transfer where the air enters the coil. Because it is here that the air temperature and the moisture content are highest. Another observation is the curve becomes steeper as air passes through the coil, which indicates that the ratio of moisture removal to temperature drop is greatest at the outlet of the coil.

In the next part, we shall cover some examples and skill checks, which one should be able to tackle if he has studied the chapters so far published.