ANALYZING KILN PROBLEMS WITH PSYCHROMETRIC CHARTS

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In previous presentations at these meetings I have referred to psychrometric charts to help explain a particular problem or solution to a problem in the dry kiln. These charts are an important tool to anyone dealing with air and vapor. These charts are often not used or misunderstood because many people do not work with them enough to feel comfortable with their use.

Today, we are going to spend a few minutes getting reacquainted with these charts and then work through a couple of real kiln problems using the chart as a tool to analyze the problem.

A psychrometric chart (Figure 1) is a graph which relates temperature, humidity, total heat, density, and other properties of moist air. To plot a psychrometric chart, first the dry bulb temperatures are located on the horizontal scale. Then the specific humidity scale is positioned on the vertical scale. All of the other data is located from the data on the horizontal and vertical scales.

1. Dry bulb scale across the bottom.
2. Specific humidity. Specific humidity is the actual moisture content of the air in pounds of water vapor per pound of dry air.
3. Relative humidity. With only slight error it can be said that the relative humidity equals the percent saturation, or the ratio of the actual specific humidity to the specific humidity at saturation.
4. Saturation line. The saturation line represents all the points representing a saturated air-water-vapor mixture.
5. Wet bulb scale. The wet bulb line meets the saturation line at the same dry bulb temperature. Another way of saying this is; if you add moisture to air of a given temperature until it becomes saturated, at the point it is saturated the dry bulb and wet bulb temperatures will be equal.
6. Dew point temperature. The dew point is the temperature that the air must be cooled to before condensing will begin.
7. Specific volume. Specific volume is the reciprocal of the density and is expressed in cubic feet of air-water-vapor mixture per pound of dry air.
8. Enthalpy. Enthalpy, or total heat content, is a quantity indicating the heat content of the air-water-vapor mixture above arbitrary zero points (0^{o}F for dry air and 32^{o}F of the water content). It is expressed in Btu per pound of dry air. (Enthalpy lines are parallel to wet bulb lines.)

Referring to Figure 1, if any two of the properties are known all the others can be easily found on the chart.

The psychrometric chart is shown in Figure 2. This particular chart is simplified and does not include all the data that a full chart contains. This simplified chart is easier to use and is very adequate for most kiln users. We will be using this chart for our purposes today.

Now let's take a look at what happens in a dry kiln with respect to the psychrometric chart. Figure 3 is a schematic representation of each change in the air on the psychrometric chart.

1. Starting as the air leaves the second overhead coil, assume the conditions of the air is 150 Dry bulb, 130 Wet bulb. For the sake of our example, assume a 15 degree drop as the air passes through the load. As the air passes through the courses of lumber, it absorbs moisture from the surface of the wood. This is an "Adiabatic Cooling Process." Such a process occurs along a constant wet bulb line. This is a constant enthalpy process, which means the drop in temperature can only occur if there is an increase in moisture. The dry bulb temperature is "used up" in evaporating moisture into the air.
2. As you can see, as the air passes through the lumber the wet bulb remains constant. Which is no doubt where the common "myth" that "the wet bulb temperature is constant everywhere in the kiln" originated. We will talk more about this in a minute.
3. As the air leaves the first load of lumber and passes through the center coil, the condition of the air moves horizontally toward the right. You will notice that now the wet bulb temperature moves above the 130 degrees that we started with. The actual wet bulb temperature at this point with the 15 degree temperature rise is actually over 131 degrees.
4. Now, the air enters the second load of lumber. The wet bulb temperature is higher than the set point. As the air continues through the load, it absorbs moisture and drops in temperature. On the chart, the condition of the air backs up the wet bulb line (upward toward the left).
5. The air leaves the second load and travels up the plenum area where it comes to the first bank of overhead coils. As the air passes through the coils, the air is heated with no change in moisture. Therefore, the condition of the air on the chart, moves horizontally toward the right. Again pulling further away from the original wet bulb set point.
6. Now the venting process occurs and enough dilution air is drawn into the kiln and enough moisture ladened air is exhausted to bring the specific humidity of the mixture back to equal the specific humidity of the set points of 150 dry bulb, 130 wet bulb.
7. Now the air is heated as it passes through the second overhead coil, the condition of the air moves horizontally toward the right until it reaches the original set points.

Let's stop here for a minute and talk about the "myth" that "the wet bulb temperature is constant everywhere in the kiln." This is no doubt the reason why nearly all kilns only have one wet bulb. As you see the wet bulb temperature has to change every time the air passes through a heating coil. In the previous example we assumed the air passed over the wet bulb before passing through the loads and center coil.

Now try to visualize what happens when the air reverses direction and passes through the loads and center coils before contacting the wet bulb. In the previous example we found that the second load was exposed to a one degree higher wet bulb temperature than the first because of the rise in wet bulb temperature as it passed through the center coil. When the air flow reverses, the wet bulb temperature is increased before it gets to the control bulb. Since the controller is going to control to the same set point, the air entering the far load now will be experiencing a wet bulb temperature of one degree below the set point. This means the wet bulb temperature changes over two degrees in the right load when the fans reverse.

This difference of two degrees in wet bulb temperature could cause some of the control problems we sometimes see on kiln charts and are unable to do anything about.

1. A wet bulb line that seems to oscillate more in one fan direction than the other.
2. A dry bulb line that drops a few degrees in one fan direction.
3. A dry bulb line that seems to oscillate more in one direction than the other.

Under some conditions this difference can cause some other interesting problems, for example:

We were asked to look at the corrosion on the center coils of a double-track kiln drying treated material. The fins were rusting away on one side of the pipe but not nearly so bad on the other.

After much thought we related the problem to the single wet bulb in the kiln. Our reasons were as follows:

The kiln was drying treated material. The treatment evaporated from the wood and was very corrosive if allowed to condense. In one direction of the fans (where the air passed over the wet bulb before entering the lumber) the wet bulb set point could be maintained very easily and the valves were throttled back. No doubt the valves were adjusted to that the valves controlling the overhead coils opened first. The moisture evaporated from the first load and quickly condensed on the center coils, which were throttled back. The vapor which condensed on the coils caused the corrosion.

When the fans reversed the wet bulb was on the leaving side of the second load. This caused the kiln to vent more to get the wet bulb temperature to the set point on the leaving side (due to the W.B. rise going through the center coil). Because the kiln was having to vent more, the evaporation rate was higher and thus caused a greater load on the heating coils. This caused the steam valves to come open further and the coils to be hotter. When the coils are hot, no condensing occurs.

Our solution to this problem was to install a second wet bulb. Since this kiln had an electronic controller the second wet bulb was easy to install. We set it up so that the wet bulb control was always from the air leaving side of the kiln, causing the kiln to work harder in both directions of the fan.

It has been over 1-1/2 years now since the wet bulb was added, and there is little sign of additional corrosion of the center coils.

All your kiln problems cannot be blamed on a "single wet bulb," however, I believe that the problem of the single wet bulb plays a larger part than you realize in many uniformity problems.

In conjunction with psychrometric charts, I often use schematic temperature profiles to analyze the drying operation.

Figure 4 shows a cross section of the kiln we just analyzed. Below the drawing is a series of lines representing:

A. Dry Bulb Temperature
B. Wet Bulb Temperature
C. Depression
D. E.M.C.
E. The same data is shown when the fans reverse

1. Using the same temperatures, drops and rises, we find that the air enters the first load at 150/130. This provides a depression of 20 degrees, and an E.M.C. of 8.0%.
2. When the air leaves the first load the temperature has dropped to 135 degrees, the wet bulb is still 130 degrees. Now the depression is 5 degrees and the E.M.C. is 15.9%.
3. As the air passes through the center coils the temperature raises back to 150 degrees, and the wet bulb raises to 131 degrees. This provides a depression of 19 degrees and an E.M.C. of 8.3%.
4. Now when the air leaves the second load, the temperature has dropped to 135, the wet bulb is still at 131. The depression is 4 degrees and the E.M.C. is 17%.
5. When the fans reverse, the air enters from the point it just exited. Now the temperature is 150 degrees with a wet bulb of 129. (The W.B. is being controlled to 130 from the other side of the kiln which would require a 129 wet bulb temperature on the entering side.) This provides a depression of 21 degrees and an E.M.C. of 7.8%.
6. As the air leaves the first load, the temperature has dropped to 135 and the wet bulb is 129. The depression is 6 and the E.M.C. is 14.9%.
7. When the air passes through the center coils the temperature is increased to 150 degrees and the wet bulb is increased to the 130 degree set point. This provides a depression of 20 degrees and an E.M.C. of 8%.
8. Now as the air leaves the second load the temperature has dropped to 135 degrees and the wet bulb is at the set point of 130. This provides a depression of 5 degrees and an E.M.C. of 15.9%.

My purpose in stepping through this analysis is to try to describe how dynamic the air in the kiln really is. We often make the set point adjustments and assume that whatever the set point shows is exactly what the conditions of the air is anywhere in the dry kiln. In the few seconds it takes for air to circulate completely around the kiln, it gets heated 3 times, absorbs moisture 2 times, diluted with dry air 1 time, and the excess moisture is exhausted. In reality the actual temperature is "anything but" the set point. In the typical kiln, the air temperature coincides with the set point only at the point it passes over the sensing bulb. As we have seen here, even the wet bulb temperature is not constant, and can induce unequal venting loads on the kiln.

A few additional thoughts on the subject.:

1. As kiln suppliers and kiln users push for more efficient and rapid drying times, the temperature drops through the load are higher and higher, the center coils must reheat the air back to the original set point. The actual wet bulb temperature will be changed by an amount proportional to the rise in dry bulb temperature through the center coils. Do not forget about this change in wet bulb.
2. As kiln controllers become computerized and more sophisticated with multiple control zones, and new control methods, do not forget about the change in actual wet bulb temperature.

I hope you have found something of interest in this information, and maybe the next time you are pondering a kiln chart trying to figure out what is causing a particular problem, something from this discussion will give you a clue.

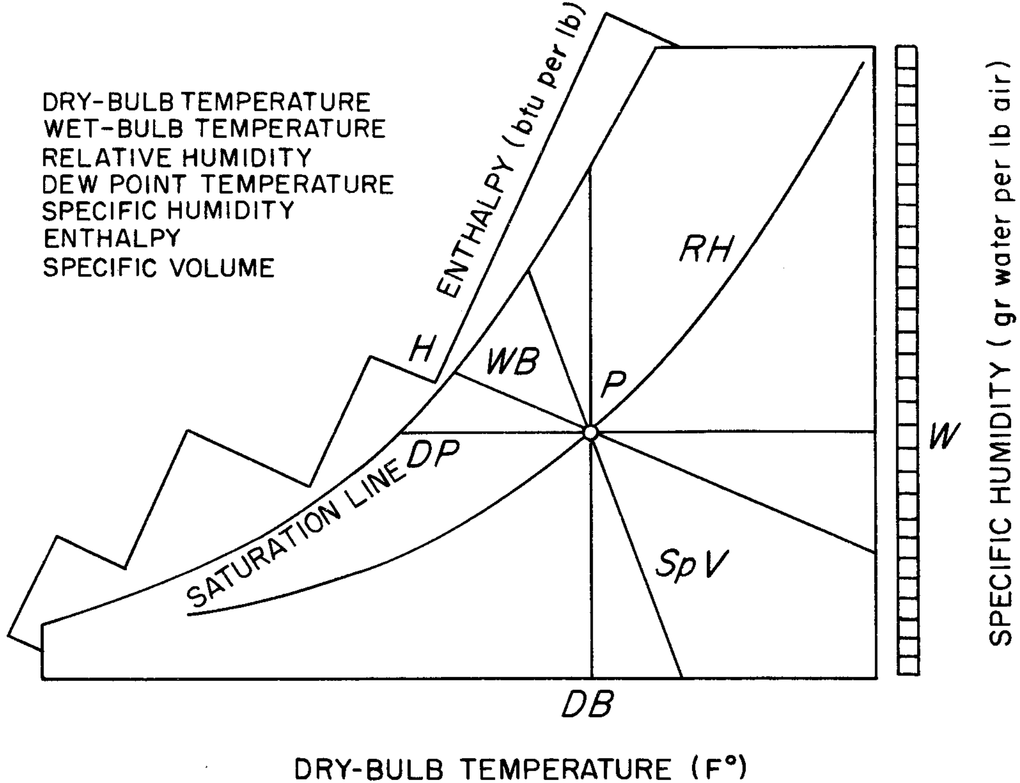
DRY-BULB TEMPERATURE
WET-BULB TEMPERATURE
RELATIVE HUMIDITY
DEW POINT TEMPERATURE
SPECIFIC HUMIDITY
ENTHALPY
SPECIFIC VOLUME
ENTHALPY (btu per lb)
H
WB
P
RH
DP
SATURATION LINE
SpV
W
DB
SPECIFIC HUMIDITY (gr water per lb air)
DRY-BULB TEMPERATURE (F°)

Figure 1

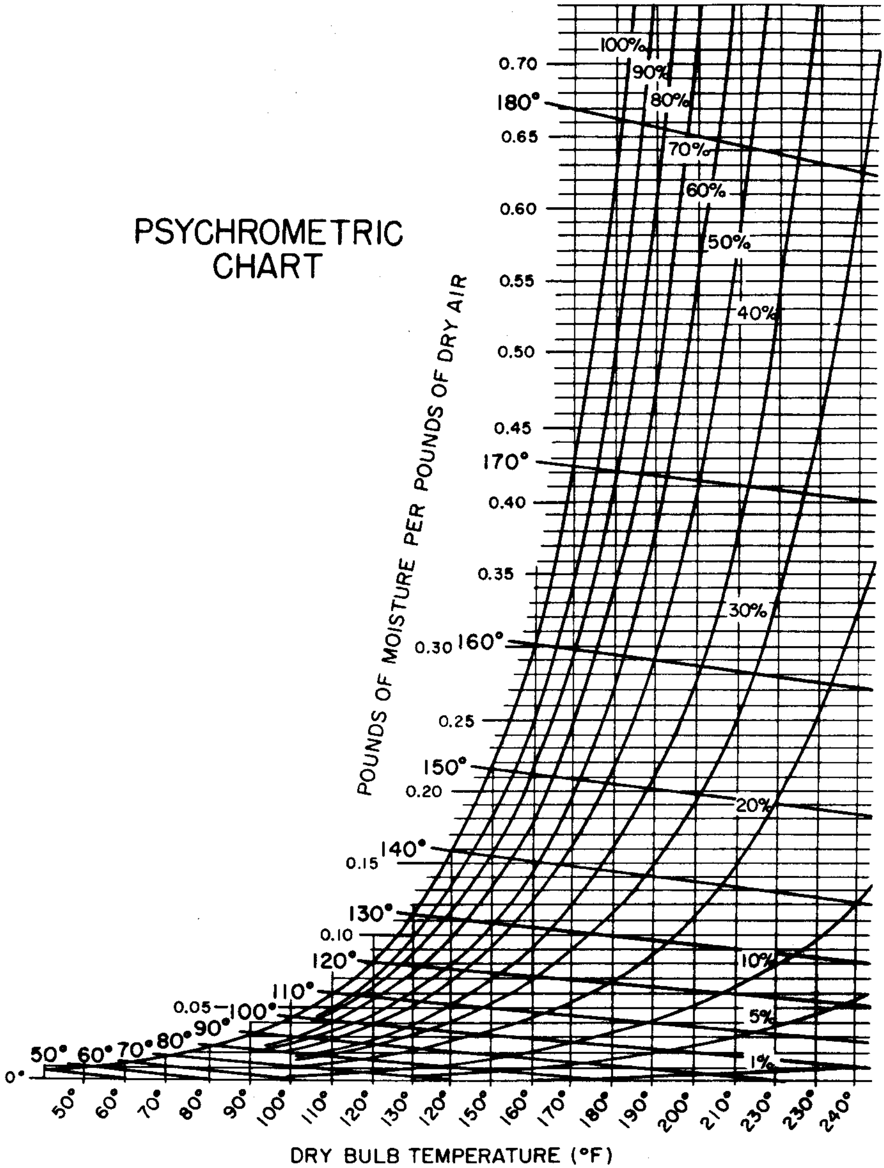
PSYCHROMETRIC CHART
POUNDS OF MOISTURE PER POUNDS OF DRY AIR
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
5%
1%
50° 60° 70° 80° 90° 100° 110° 120° 130° 120° 150° 160° 170° 180° 190° 200° 210° 230° 230° 240°
DRY BULB TEMPERATURE (°F)

Figure 2

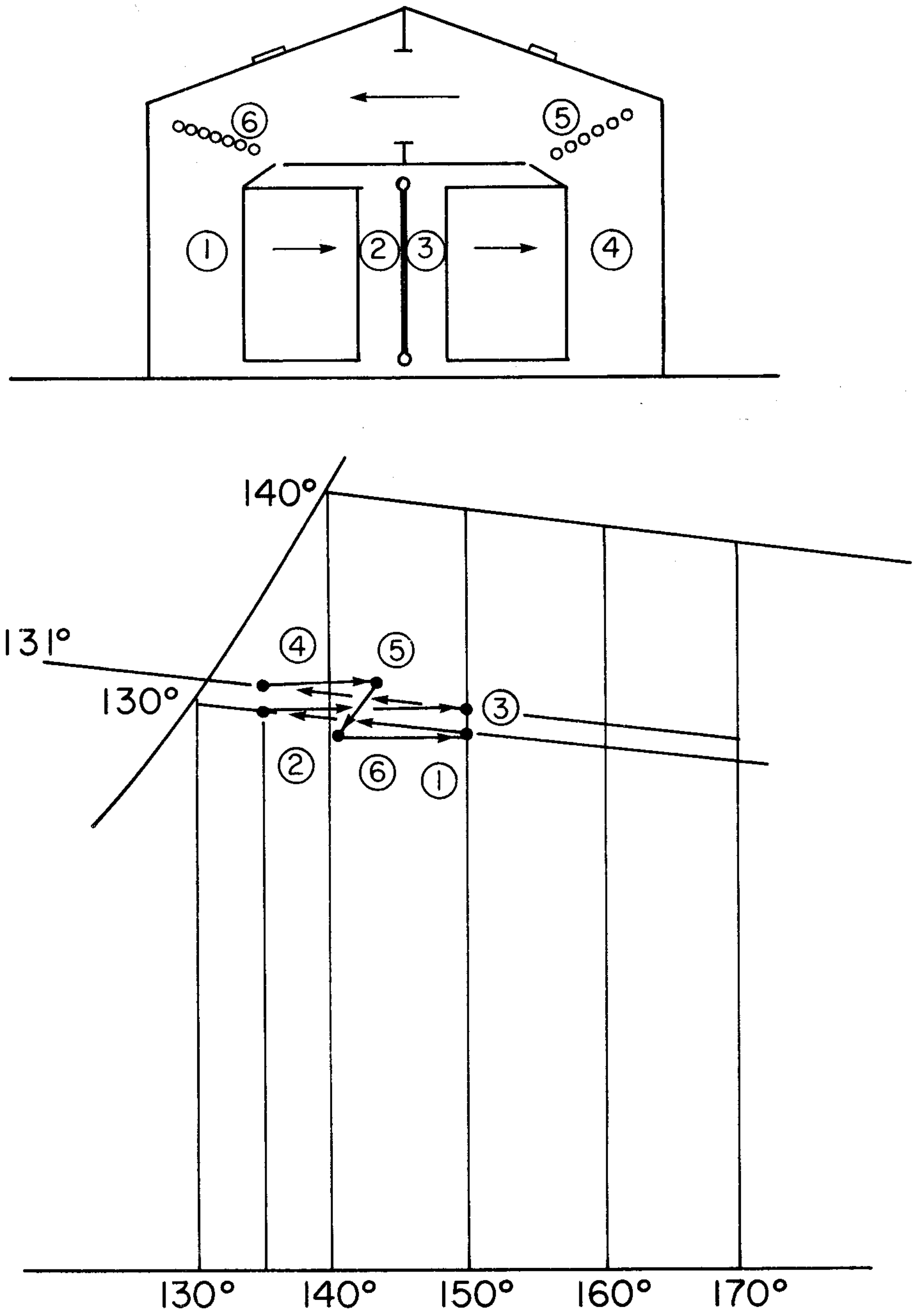

Figure 3

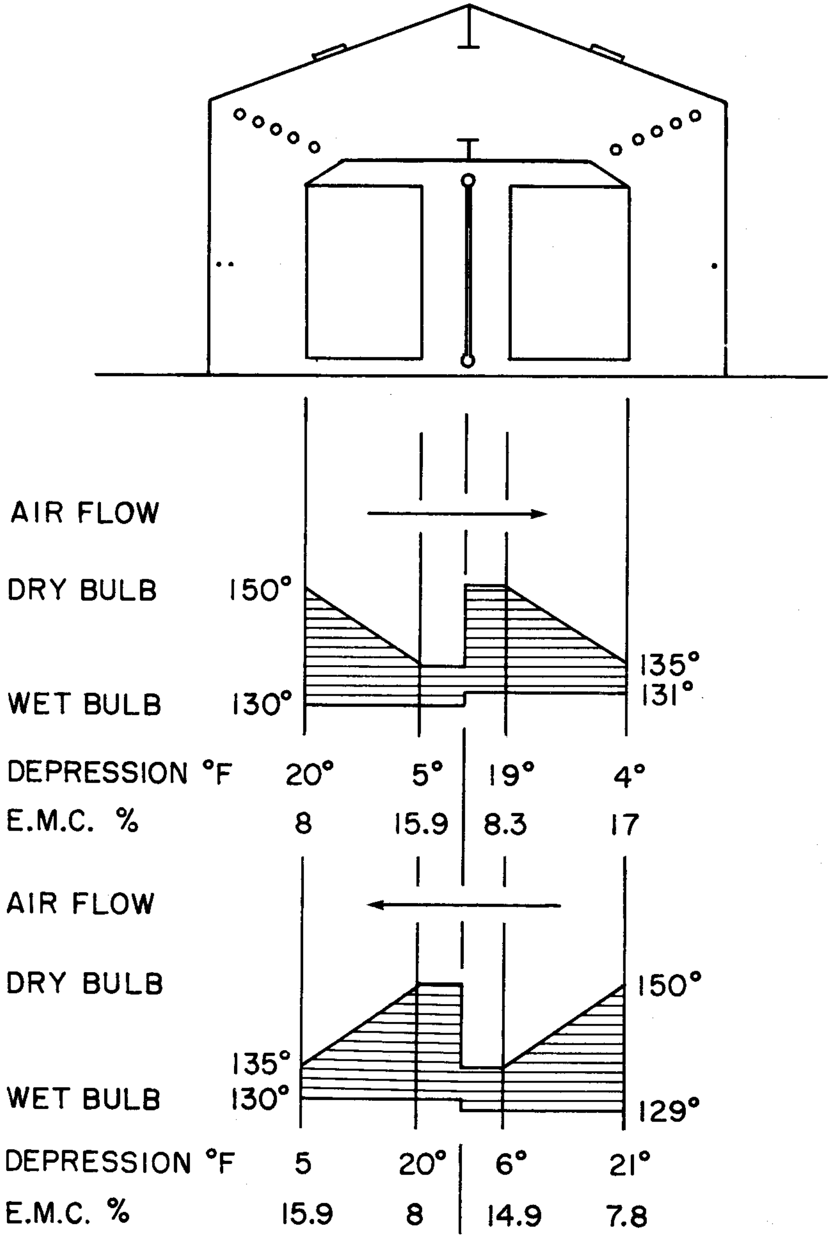
AIR FLOW
DRY BULB
150°
135°
WET BULB
130°
131°
DEPRESSION °F
20°
5°
19°
4°
E.M.C. %
8
15.9
8.3
17
AIR FLOW
DRY BULB
150°
135°
WET BULB
130°
129°
DEPRESSION °F
5
20°
6°
21°
E.M.C. %
15.9
8
14.9
7.8

Figure 4