

PSYCHROMETRICS CAN WORK FOR YOU - OR AGAINST YOU!

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In several previous presentations I have referred to psychrometric charts to help explain a particular problem or solution to a problem in the dry kiln. "Psychrometrics" refers to the interdependent relationship of the properties of an air-water-vapor mixture. These interdependent properties (D.B. TEMPERATURE, W.B. TEMPERATURE, SPECIFIC HUMIDITY, RELATIVE HUMIDITY, SPECIFIC VOLUME, DEW POINT ENTHALPY) are well suited for graphical representation, and the graph or chart of these properties is called a psychrometric chart.

Everything that happens in the dry kiln relating to air and water vapor can be found, tracked, and analyzed on the psychrometric chart. The psychrometric chart is an important tool to anyone dealing with air and water-vapor. The more a person understands about the psychrometric chart, the more he will understand the drying process he is using, and the more he will be able to avoid problems relating to drying uniformity, quality, energy conservation, and corrosion of the kiln.

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.

THE PSYCHROMETRIC CHART

A psychrometric chart is a graph which relates temperature, humidity, total heat, density, and other properties of moist air. The major elements of a psychrometric chart are shown in Figure 1. 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° F for dry air and 32° F of the water content). It is expressed in Btu per pound of dry air. (Enthalpy lines are parallel to the wet bulb lines.) Enthalpy is the sum of the heat in the dry air, and the heat to raise the temperature of the water, and the heat to evaporate the water.

Referring to Figure 1, if any 2 of the properties are known all the others can be easily found on the chart.

Figure 2 is a simplified psychrometric chart. This chart only shows dry bulb, wet bulb, specific humidity, relative humidity and specific volume. This will be adequate for most of what we will discuss today.

APPLYING THE PSYCHROMETRIC CHART

Now for some practical application of the psychrometric chart. To help understand what happens to the air in the dry kiln let's look at Figure 3, a schematic representation of the kiln and a portion of the chart which shows the conditions of the air at the key points.

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. This is the temperature drop across the load.

As you can see, as the air passes through the lumber the wet bulb remains constant.

2. 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 dry-bulb temperature rise is actually over 131 degrees.
3. 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).
4. 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.
5. Now the venting process occurs and enough dilution air is drawn into the kiln and enough moisture laden 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.
6. 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.

Last year at about this point we talked about how the wet bulb changes temperature as it passes through the heating coils. Now before any one tries to "shout me down," or throw anything, be advised we are going to talk about several different subjects. Possibly equally offensive to some of you, but different!

HOW MUCH AIR VELOCITY IS ENOUGH?

The first subject I'd like to explore with the help of the psychrometric chart is how much air velocity is enough? To do this we will use Figure 4. This question may seem unrelated to psychrometrics, however in the normal range of air velocities it is very related. This question is often asked of us, and the way I prefer to address it is like this.

1. As we can see from the Figure 3 the air cools and absorbs moisture as it passes through the lumber. The condition of the air backs up the wet bulb line, as it loses D.B. temperature, this is the "Drop Across the Load" people talk about.
2. The more the air is cooled, the more moisture the air is absorbing, and the closer to saturation the air is getting.
3. If the air becomes saturated or even near saturated before leaving the course of lumber, there is no more W.B. depression and without W.B. depression drying would be slowed or stopped. You could have adequate depression for drying as the air enters the course, and become saturated midway through the course. If you compare your leaving temperature with your W.B. temperature you will find how close to saturation you are really getting.
4. There are two ways to attain more depression leaving the load:
 - A. Increase the depression entering the load,
 - B. Increase the velocity through the load.

If due to the sensitive nature of the product, a wider entering depression would cause loss of uniformity or quality, then increasing the air velocity should help.

Over the years there has been a lot of talk about "Drop Across the Load" and controlling the kiln based on some magic number of degrees of temperature drop. I have never heard anyone relate temperature drop to wet bulb, wet bulb depression, or E.M.C. Unless these points are also considered, you could very well have psychrometrics working against you.

THE TEMPERATURE DROP ACROSS THE LOAD CAN NOT EXCEED THE AVAILABLE DEPRESSION

There has also been a lot of discussion about controlling the kiln on the leaving side of the load. As you see here you lose depression as the air goes through the load. If your kiln is now controlling on the leaving side with the same depression that you previously had on the entering side, you could be causing problems due to the excessive depression on the entering side. Since E.M.C. is directly related to depression, the greater the depression, the lower the E.M.C. If you have been drying successfully on a schedule controlling on entering air, then change to controlling on leaving air, the same drying schedule will be much more severe!

DEW POINT

The next subject I'd like to address is the dew point. Figures 1 and 2 will be referred to. As shown previously, Dew Point is the temperature that air must be cooled to cause condensing. Condensing of the kiln atmosphere inside the dry kiln is your **enemy!** It nearly always means wasted energy and corrosion.

The purpose of the dry kiln is to evaporate water, not condense it. However, there are several situations which often occur that allow water from the kiln atmosphere to condense inside the dry kiln.

1. Hot humid kiln air condenses on the inside of the vent lids. Approximately 1,000 BTU's of heat is lost for each pound of water that is condensed and drips back inside the kiln.
2. When the vents open and draws cooled outside air into the kiln, and chills the nearly saturated air inside the kiln, often moisture is condensed which falls to the floor, load or kiln structure.
3. Examples of these conditions can be seen in most kilns as an increase in corrosion around and under the vents.
4. We believe it also follows that the larger the vent opening the greater the tendency for the localized chilling of the kiln atmosphere and structure and the greater the energy loss and corrosion.

In a kiln we inspected recently, you could determine where the vents were located by looking at the kiln floor. Falling drops of water had eroded the concrete away exposing the aggregate. These areas were directly under the vents which were located above the plenums.

5. Another good example of the problems associated with dew point is the corrosion often seen on fin pipe which has not been drained properly. Recently a good question was raised regarding corroded fin pipe. While I was explaining that the corrosion on the lower lines of fin pipe was caused by moisture condensing from the kiln atmosphere on the cooler pipe (filled with water), someone asked how can the pipe be cooler than the kiln atmosphere? This puzzled me for a bit, as the kiln air had to be warmer than the pipe to condense, but how could the air be warmer than the pipe if the pipe is the device that is heating the air.

There are a couple of good explanations for this:

- A. Undersized traps usually become apparent at the beginning of the drying schedule when the kiln is coldest and the condensing load on the coils is greatest, and the steam pressure within the coil is the lowest. The problem first appears in the center coils.
 - B. If the trap fails to pass the amount of condensate being condensed, the condensate begins to back up in the coil and remove radiating surface from the coil. This **does not** mean that steam flow stops, or that the whole coil is filled with water. The water backs up until enough radiating surface is removed from the system until it reaches a point of equilibrium.
 - C. During this time the upper portion of the center coils, and possibly the overhead coils continues to condense steam and transfer heat into the kiln air.
 - D. the coils affected may not cool below the kiln air, the kiln air continues to be heated above the water logged coil temperature. The affect on the coil is the same.
6. Another example of where condensing occurs is at the base of the columns. The ground is colder and carries heat away from the kiln, and often brings the base of the column below the dew point. Here on a new kiln being installed, plastic insulating pads are used to insulate the column from the concrete.
 7. The kiln rail also conducts heat out under the door. Since heat is conducted out of the kiln by the rail, the rail at the door front is at or below the dew point and is very prone to corrosion. This slide shows the common practice of adding steel to the rail by welding.

A good solution to this problem is to interrupt the conductivity of the rail at the door front. A lift out rail section is shown here.

By analyzing conditions on the Psychrometric Chart, you can get a good idea of the problem and what can be done to correct it.

IMPLOSION

The word implosion should cast fear in the hearts of all of us. An implosion is a rapid contraction of the volume of air in the kiln. Often the implosion causes physical damage to the kiln. Over the years I've talked to people who have experience implosion first hand. Having spent many years with "Moore Dry Kiln", I often discussed implosion with these people when they called us to replace their kiln doors, wall or roof panels. There were photos on file at "Moore Dry Kiln" showing concrete block walls damaged due to the effects of implosion. These slides show damage to kiln doors.

In order to better understand what happens in an implosion, let's take a look at the Psychrometric chart. To the first chart we now have added the lines indicating specific volume. These lines show how many cubic feet air-water-vapor -mixture are required to contain one pound of dry air.

Dry air is like a sponge and can contain various amounts of water. As this sponge absorbs more and more water it becomes saturated. As the temperature is increased the ability of the air to absorb water is increased. The chart shows that air at a given temperature expands as the amount of moisture is increased.

Now armed with this bit of knowledge let's look more closely at the conditions which produce an implosion.

1. Implosions happen at the beginning of a kiln charge or at a fan reversal, when the kiln fans are restarted.
2. Generally speaking the conditions for an implosion are more severe during the winter when lumber may be frozen when it enters the kiln. I have heard of, and seen the results of implosions which happened in the spring and summer when the air and lumber were in the 60 degree range.
3. If a dry charge of lumber is rolled out and a green frozen charge of lumber is rolled in, and the kiln doors are open only for a short period of time, the kiln air tends to stratify. The hot moist air raises to the fan chamber. Remember that moist air is lighter than drier air, it only follows that the hotter and more humid air will find its way to the top of the kiln.
4. To gain some idea of the dynamic forces of an implosion lets make some assumptions which seem reasonable and then walk through the mathematics to see what happens. Assume:
 - A. A double track, 104' kiln, which is filled with hot humid air from the top of the doors to the peak of the roof. This volume would be approximately 27,300 cubic feet.
 - B. If this air had a dry bulb temperature of 170 degrees and a wet bulb temperature of 150 degrees, the specific volume at these conditions would be 21 cubic feet per pound. Dividing 27,300 cubic feet by the 21 cubic feet per pound gives 1,300 pounds of dry air in the space above the tops of the kiln doors. This air contains 273 pounds of water.
 - C. Now, if a frozen charge of lumber is rolled into the kiln and the fans are started, all the air in the dry kiln will be cooled very

rapidly. However, if we only assume that the hot air above the doors is cooled to 40 degrees, the new specific volume is 12.7 cubic feet per pound. Since there are 1,300 pounds of air in question, and the change in volume is $21 - 12.7 = 8.3$, the change in volume is 10,790 cubic feet.

- D. If this kiln has an average air velocity of 500 feet per minute during the critical implosion period, and there is 5 feet of sticker opening, the following can be determined:

As soon as the fans start hot air is supplied to the upper courses of frozen lumber, and the volume starts to shrink.

Within about 2 seconds the hot air has been driven down the side of the load and is entering all the sticker openings.

Within 2 additional seconds the leading edge of the hot air has started to exit all the sticker openings.

During the next 2 seconds the remaining portion of the hot air enters the lumber. During this period the contraction of the air would be at its greatest.

In the following 2 seconds the trailing edge of the hot air travels through the load and exists.

With these conditions the potential for implosion lasts approximately 8 seconds. Reaching the maximum contraction rate in about 4 seconds, and continuing for about 2 seconds. Then tapering off over a 2 second period.

If we assume that 65% of the contraction takes place in the middle 2 second period, the contraction rate for this period would be--

$$10,790 \times .65 / 2 \text{ seconds} = 3,567 \text{ cubic feet per second}$$

$$\text{By applying the formula } T_1 / T_2 = P_1 / P_2$$

we can get an idea what causes the real damage during an implosion, - the difference in pressure.

To use this formula the temperatures must be converted to absolute. The absolute temperature scale starts at -460 degrees.

Time Step	Total	% of Total Contraction	Volume Per Period	Drop in Pres. This Step	Total Drop in Pressure
2	2	5	540ft ³	.15 psi	.15 psi
2	4	15	1,618ft ³	.45 psi	.06 psi
2	6	65	7,134ft ³	1.95 psi	2.55 psi
2	8	15	1,618ft ³	.45 psi	3.00 psi

This drop in pressure on the inside of the kiln produces a load on the housing, doors and even the structural system of the kiln. The 3.0 PSI drop in pressure is a load of 432 pounds per square foot. This means a kiln door which is 12' wide by 15' high would see a force of 77,760 pounds. This explains why the doors in the last slide showed some visible damage. No one can design a kiln housing to resist that kind of load. You are much better off to be sure your implosion protection sequence is adequate and is operating properly. These calculations do not account for any inward leakage. As kiln housings become tighter and tighter, implosion becomes more critical.

The volumes and masses of air and water being processed by the dry kiln is tremendous. Subtle changes in the psychrometrics of the kiln can have a major influence on production, quality, corrosion, and maintenance. I hope that these thoughts and comments have brought a little more understanding to the psychrometric chart and the dry kiln. We are actually dealing with the forces of nature here, and it is much better to have them working for you, than against you.

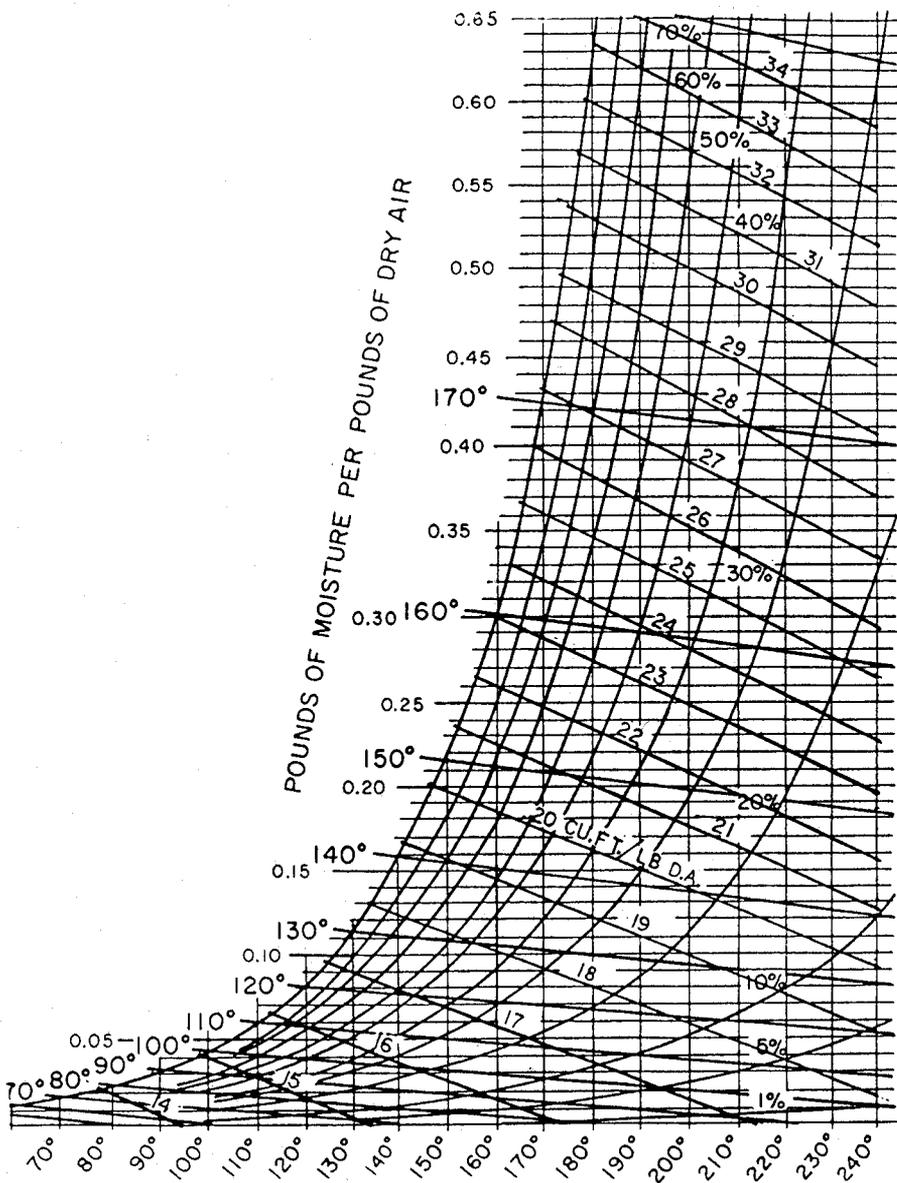


Figure 2. Psychrometric chart.

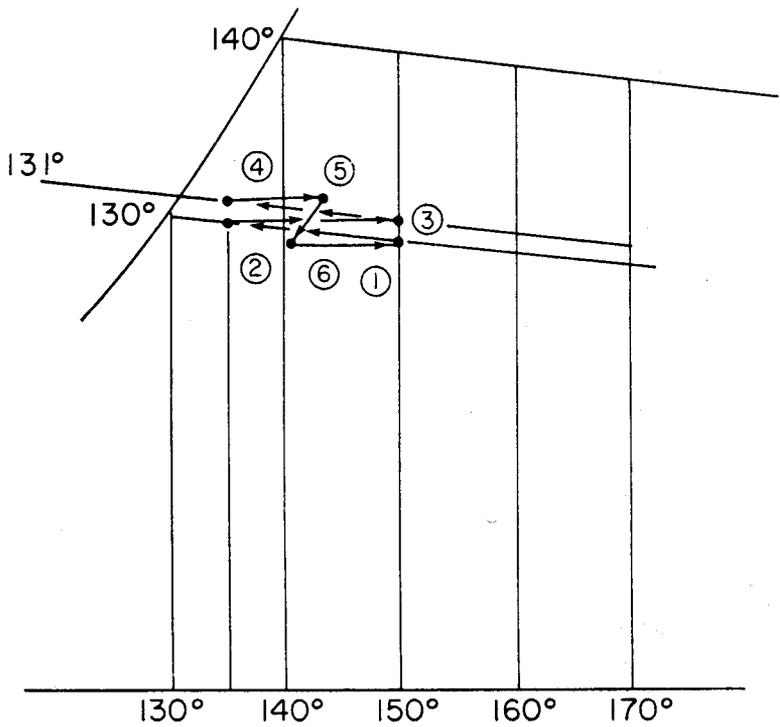
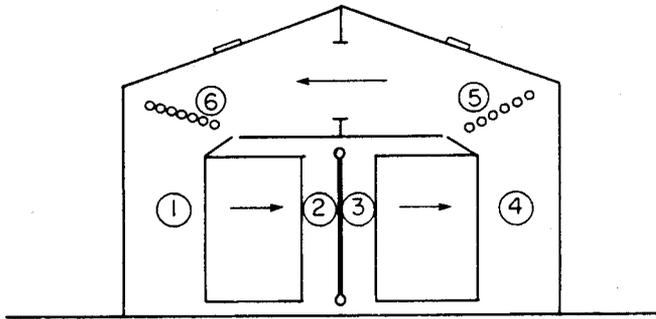


Figure 3. Diagram relating air properties in kiln to corresponding points on psychrometric chart.

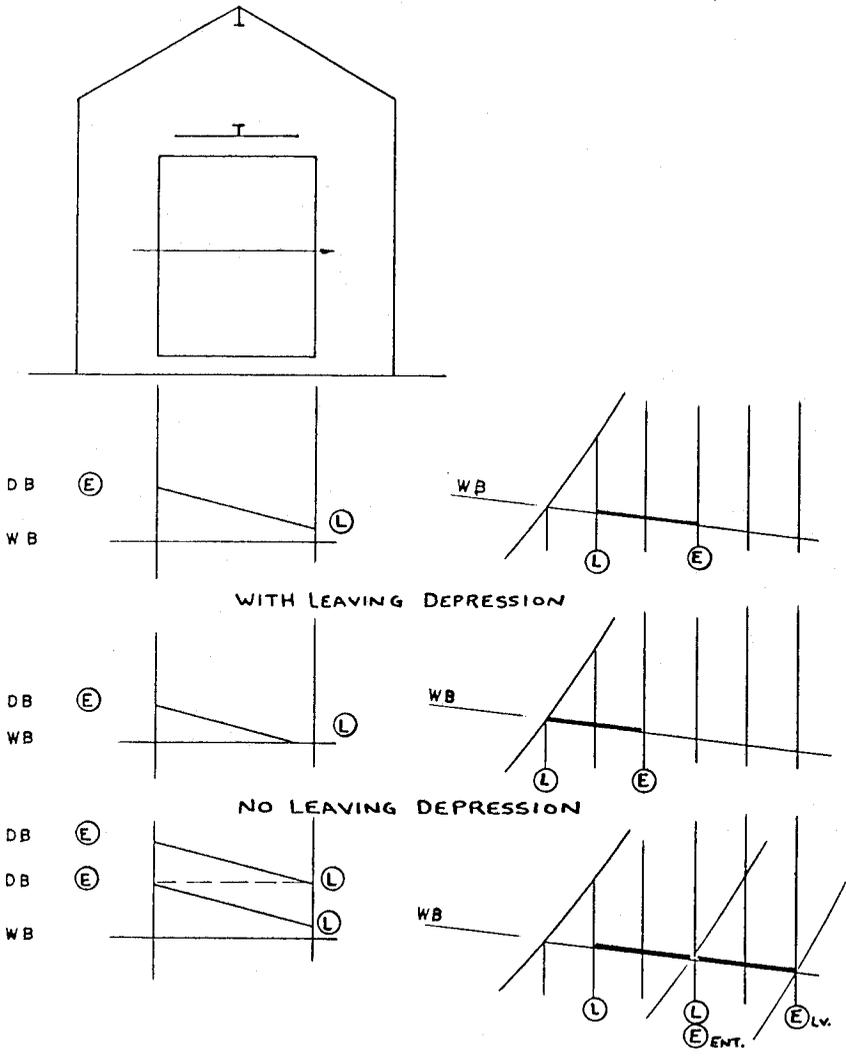


Figure 4. Temperature and wet-bulb depression for exiting air not saturated, exiting air saturated, and exiting air temperature control.