DETECTION OF WATERLOGGING IN KILN COILS AND ITS EFFECT ON MOISTURE CONTENT

Steve Carroll
Watercare Industrial Services
Washougal, Washington
and
Marty Brint
Hampton Lumber Co.
Willamina, Oregon

Introduction

In order to operate at peak efficiency, every steam heating coil in a dry kiln must fully purge the condensate that forms within it. Failure to do so results in a condition known as waterlogging, where a portion of the coil becomes flooded with condensate. Waterlogging is recognized as an undesirable condition that leads to uneven heat distribution and increases the corrosivity of condensate. This paper reviews a unique method to detect waterlogging, and assesses its impact on the lumber's moisture content.

The Thermal Properties of Steam

Steam is a remarkable material for transferring energy from one place to another, and it's useful to understand steam's basic thermal properties to evaluate its behavior in a heating coil.

The first important concept concerns ***sensible heat*** and ***latent heat***. As water is being heated in a boiler, its temperature rises toward the boiling point. For each pound of water, it takes one BTU (British Thermal Unit) of energy to raise the water's temperature by one degree Fahrenheit. We refer to this energy as sensible heat. When we reach the boiling temperature of the water, we have to provide about ***one thousand times*** as much energy to convert that same pound of liquid water to gaseous steam. In effect, we have ***supercharged*** the steam with this extra energy, known as latent heat. So, latent heat is the energy associated with a material's conversion between a liquid and a gas.

Once we've produced the steam, we can pipe it wherever we need for heat. We then ***release*** the steam's latent heat energy by allowing it to ***condense back into liquid form***.

Another important characteristic of steam is that its temperature and pressure are closely related and very predictable. If we know the pressure of dry, saturated steam, we can accurately predict its temperature, and vice versa.

Steam in the Heating Coil, and Detection of Waterlogging

From our discussion above, we can see that in order to transfer the maximum amount of energy to the heating coil, the steam has to condense ***within the coil***. Furthermore, you want the steam to condense ***throughout the entire coil***, to transfer latent heat across the coil's entire surface. And, finally, because the steam pressure is considered to be equal throughout the coil at any given time, we should expect the ***temperature throughout the coil to be uniform***.

These conditions form the basis for our waterlogging detection method: In any region of the coil where condensate has accumulated, steam is excluded. Therefore, no active condensation is taking place in that region of the coil, and no latent heat is being released there. One should expect, then, that the coil's surface temperature in the flooded region of the coil will be lower than the region that contains steam. Our study shows that measuring the temperature differences between several locations on a coil confirms the presence and relative position of the waterlogged area.

Typical Causes of Waterlogging

In a coil that's operating properly, any condensate that forms is quickly pushed through the steam trap at the bottom of the coil, leaving the entire coil available for steam. Basically, waterlogging occurs because condensate is unable to leave the heating coil. We've identified a few reasons for this:

1) Back Pressure on the Coil

If the condensate has to overcome excessive pressure downstream of the steam trap, the coil can waterlog. Condensate piping that runs uphill is the most common example. Another example involves a condensate header pipe that is shared by several kilns, where the piping isn't adequately sized to handle the discharge from all kilns without pressure buildup. This condition is exacerbated by leaking steam traps which allow higher steam pressures to enter the condensate header, creating more back pressure on other traps.

2) Undersized and/or Plugged Steam Traps

If the volume of condensate produced cannot pass through a restriction in the opening of the steam trap, the coil will waterlog. The selection of the correct trap, as well as routine testing of traps to detect failures, is crucial to their successful performance.

3) Insufficient Steam Pressure

The condensate relies on the pressure of the steam to push it through the trap. Low steam pressures can, therefore, cause waterlogging. Almost all kilns are vulnerable to this condition during idle periods, where a "closed" steam valve allows a small volume of steam to leak by. Condensate will form in the coil, but there's insufficient steam pressure to push it out. Insufficient steam pressure is particularly troublesome if combined with conditions of back pressure and/or trap restrictions.

Conducting a Trial

For purposes of this study, we selected a kiln with certain features that could be suspected to cause waterlogging. Specifically, we chose a 104' packaged, double-track kiln with center booster coils having horizontal fin pipe. These booster coils were of the two-zone variety, with upper and lower positions. A lower coil was used for this test. Circulation fans were cross-shaft, moving approximately 1000cfm. The kiln uses Armstrong #214 bucket traps. The condensate piping involved an overall vertical lift of 13' 6" relative to the coil's lowest piece of fin pipe. The resulting net static head (back pressure) at the bottom of the tested coil was calculated to be approximately 5.6psi. Steam pressure to the heating valves was approximately 90psig.

Four thermocouple probes were secured to the coil at positions shown in Figure 1. Specifically, the probes were mounted on the top of the selected fin pipes, at the inlet (steam) side of those pipes. It is felt that this positioning avoids the normal temperature depression expected on the bottom of the fin pipes as condensate runs along their length. In other words, if any of the probes detected significant temperature depression, it could be legitimately regarded as due to waterlogging.

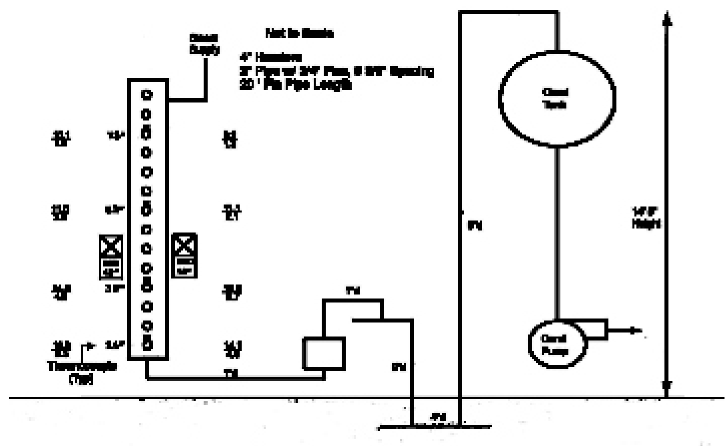

FIGURE 1. Location of probes on coils shown with black squares.

Temperatures were recorded throughout the lumber drying schedule (about 33 hours, 30 minutes overall) at one minute intervals. The results were very revealing. Below is a brief summary of our observations and interpretations. Pertinent graphs follow the text.

There was relatively little error between the individual thermocouples. That allowed us to confidently regard significant temperature differences as evidence of waterlogging.

At the beginning of the schedule (Figure 2), at least 38" of coil height started out as being waterlogged (following an extended idle period). It took almost ***thirty minutes*** for the coil to completely purge its condensate. During that time, the bottom fin pipe was approximately ***130˚F cooler*** than the rest of the coil.

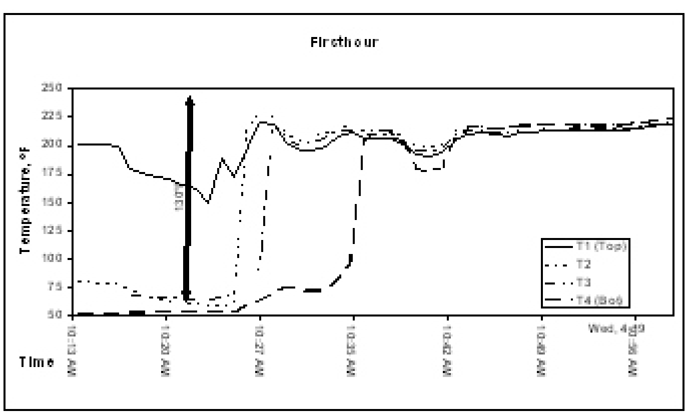

FIGURE 2. Temperature on coil during first hour of operation. Waterlogging is evident for about 30 minutes.

As the dry bulb temperature (measured independently) in the kiln increased, the surface temperatures of the coil decreased. This is consistent with normal observations of a heating valve, which throttles steam flow as the drying schedule progresses. The lower steam pressures associated with the reduced coil temperatures became a factor in the subsequent waterlogging that was observed.

Waterlogging of the coil again became evident less than 14 hours into the schedule (Figure 3), affecting at least the bottom fin pipe. By the 17-hour mark, the bottom pipe remained waterlogged for the remainder of the schedule, with the exception of steam spikes when fans were reversed.

Waterlogging affected at least the bottom four fin pipes (16” of coil height) in less than 21 hours; they remained largely waterlogged for the remainder of the schedule with the exception of the brief spikes of fan reversal (Figures 4 and 5).

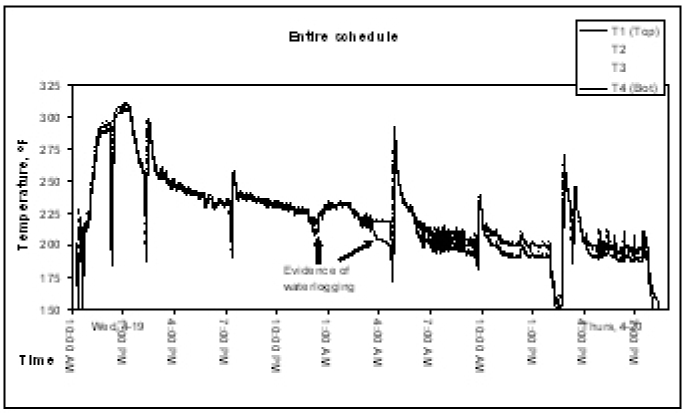

FIGURE 3. Temperature on coil during entire schedule. Waterlogging becomes evident after about 12 hours when the pressure in the coil decreases.

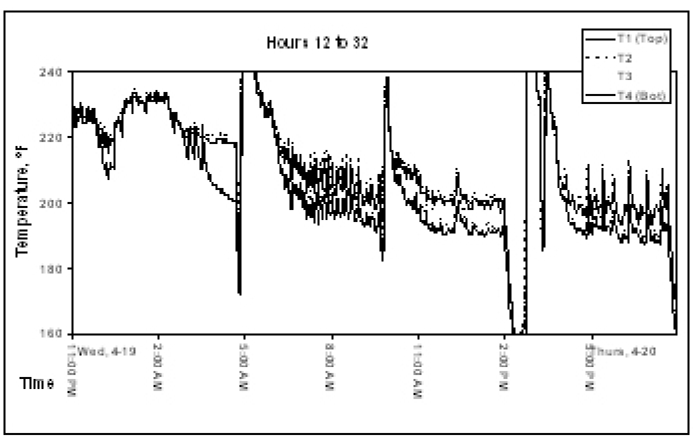

FIGURE 4. Temperatures on coil magnified. At each fan reversal all four temperatures become equal indicating that the coil drains when the valve opens and the pressure in the coil increases.

During the final three hours of the schedule, at least 38” of coil height was affected by waterlogging. Since the “T2” thermocouple was intentionally placed at the approximate height of the coil’s RTD temperature sensor, the RTD’s throttling of the steam valve could be readily seen in the graph.

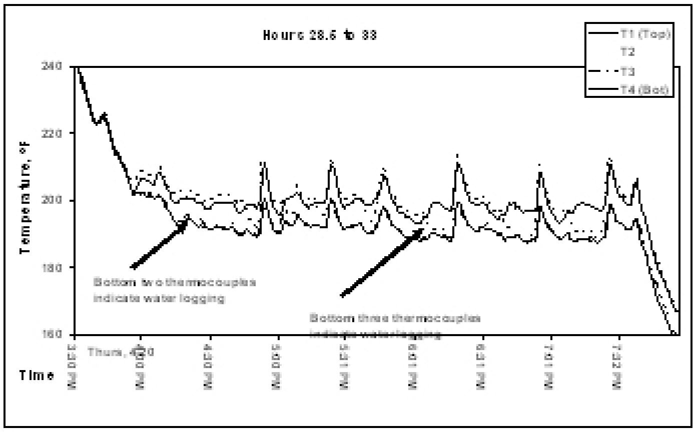

FIGURE 5. Coil temperatures at end of schedule. The water level reaches the third thermocouple from the bottom as the coil pressure reduces.

Somewhat surprising was the unexpectedly low temperature drop associated with a waterlogged condition in later stages of the schedule. We initially expected a drop several times greater than the ~10˚F observed, but in retrospect we realized that circulation of heated air (from the overhead coils) over the waterlogged coils would prevent a large temperature drop. Nevertheless, we recognized that even a small temperature drop would have dire consequences on drying rate, as explained further below.

Moisture Content Evaluation

The temperature measurements were made while drying 2” x 6” Douglas-fir, with dry bulb setpoints of 170˚F to 180˚F and depressions from 10˚F to 25˚F. The targeted moisture content during the hot check was 15-16%.

After the lumber was pulled from the kiln and allowed to cool, moisture measurements were taken of boards that had been adjacent to each of the thermocouples. For each thermocouple location, 24 boards were checked from each side of the booster coil. The results of those tests are shown on Diagram 1, represented by eight pairs of numbers to coincide with thermocouple height and side of the coil. The top number of each pair is the average moisture content of the 24 boards, while the bottom number is standard deviation of that set.

The range of measured moisture contents is significant, and the sequential increase in moisture content of lower boards certainly implicates the observed waterlogging of the coil.

The waterlogging is further implicated by reviewing a table that compares dry bulb temperatures and wet bulb depressions to determine EMC (equilibrium moisture content). For example, a dry bulb setpoint of 180˚F with a depression of 15˚F produces an emc of 9.0%. If part of the steam coil is producing an air temperature only 10˚F lower than dry bulb setpoint, the depression associated with that air becomes only 5˚F, producing an

EMC of 14.8%. This confirms that a relatively small drop in coil surface temperature can significantly impair drying performance, exactly as represented by the collected data.

Additional Observations and Comments

The authors believe that the waterlogging identified in this study is primarily due to elevated condensate piping downstream of the coil, and its associated back pressure. Some additional speculation can be made about quantifying the effect of this back pressure.

As stated earlier, the calculated static head above the coil is about 5.6psi. Therefore, at least 5.6psig within the coil must be present to purge the condensate. When you relate that pressure to steam temperature, you can conclude that the ***steam temperature inside the coil*** must be at least 229˚F in order to purge the coil of condensate. Our test measured coil ***surface*** temperature, which is expected to be slightly lower than the coil's ***internal*** temperature. Nevertheless, it is reasonable to state that the last half of this drying schedule didn't continuously require an internal coil temperature of 229˚F in order to reach its 180˚F dry bulb setpoint. Otherwise, the coil wouldn't have waterlogged as observed.

Therefore, we predict that, in this kiln, if you attempted to eliminate waterlogging by moving the coil's RTD to near the bottom of the booster coil, you would produce excessively high air temperatures above the RTD, resulting in overdried lumber. For kiln schedules that permit higher dry bulb setpoints, however, it ***may*** be possible to reduce waterlogging by lowering the booster coil's RTD. Each kiln and schedule must be evaluated separately for such a determination.

Hopefully, this study will help eliminate the myth that a high steam supply pressure to the heating valves will prevent waterlogging. Modern kiln controls will modulate those valves to produce ***very low coil steam pressures***, which are frequently insufficient to purge the condensate.

Although not directly related to its effect on the lumber's moisture content, we're compelled to stress that waterlogging of a coil will frequently increase the corrosivity of the condensate, resulting in irreversible coil damage. The severity of this corrosion is influenced by a number of factors such as water chemistry and pretreatment equipment. Any suspicion of waterlogging should be given serious consideration by a treatment consultant.

The authors feel that this study produced remarkable and credible information. Even so, we realize that this topic will benefit from additional testing, which could include measurement of the coil's internal temperature and pressure, as well as pressure measurement on the outlet side of the steam trap. Comparison tests that involve changes to condensate piping and steam traps will certainly be useful. Ultimately, we hope that the reader will become alert to the causes of waterlogging, and take steps to avoid them.