MODELING THE HEMLOCK DRYING PROCESS

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Simulation of a process can reduce the need for experiments or trials. Simulations can also test things that are very difficult to measure. For example, an operator could try to determine when to reduce fan speed by changing the fan speed at times during the drying cycle and observing the results. However, it is likely that during these tests the weather would change, the log supply would change, and other factors associated with kiln operation would cause difficulty in interpreting the results. In a simulation, the fan speed could be changed while all other variables are held constant. The operator would have the results in a few hours instead of weeks.

Description of the Simulation

A kiln simulation consists of two parts. The first part is a drying rate function that describes how fast an individual board dries. This rate depends on its moisture content and the air temperature, humidity, and velocity. This part of the simulation is species-dependent. The second part of the simulation is the kiln model. This part simulates the moisture change for every board in the kiln. It is independent of the species and handles the material end energy balance so that the air temperature decreases across the stack of lumber and the boards on the entering-air side of the pile dry faster. The kiln model applies the drying rate function to each board using the board's moisture content and the air temperature humidity and air velocity above and below the board.

Drying Rate Function

A drying rate function was developed for hemlock from approximately 500, 4-foot-long, 2-inch nominal, pieces of dimension lumber dried in 23 kiln charges. Each charge was dried using commercial schedules. Each piece was weighed before and after drying, then oven-dried to determine the initial and final moisture content. The moisture content at any time was determined from the dry-bulb, wet-bulb, and vent rate of the kiln. For each hour of drying we then had a drying rate, a wood moisture content, a dry-bulb temperature, and a wet-bulb temperature. All the data from all charges was grouped so that we could correlate drying rate to the other variables.

The data was divided into two parts – above 80% moisture content and below. At high moisture content, the drying rate was found to be a function of wet-bulb depression (Figure 1) in accordance with drying theory. At low moisture contents, the drying rate was found to be a function of moisture content minus equilibrium moisture content and the dry-bulb temperature, also in accordance with drying theory (Figure 2).

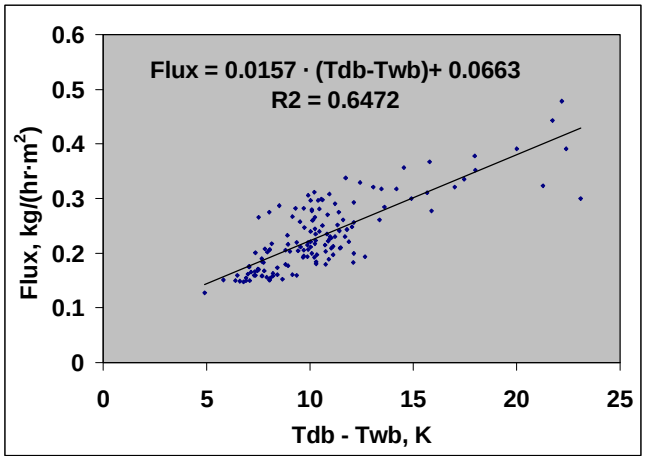

FIGURE 1. Flux of moisture from a board as a function of the wet-bulb depression. Data is for all boards when greater than 80% moisture content.

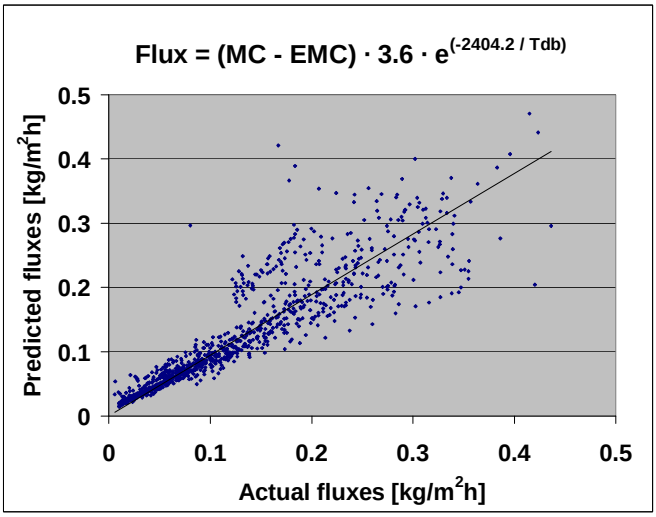

FIGURE 2. Flux of moisture from a board as a function of temperature and the difference between the board's moisture content and the EMC. Data is for all boards when less than 80% moisture content.

$$Rate = Area \bullet \{[(3.6033 \bullet e^{-2404.2/T_{db}}) \bullet (MC - EMC)]^{-16.64} + (0.0157 \bullet \sqrt{\frac{V}{3.81}}(T_{db} - T_{wb}) + 0.0663)^{-16.64}\}^{-1/16.64}$$

Rate	Drying rate, %/hr
Area	Board surface area, m^2
V	Air velocity, m/s
T_{db}	Dry-bulb temperature, °C
T_{wb}	Wet-bulb temperature, °C
MC	Moisture content of the board, %/100
EMC	Equilibrium moisture content of the air, %/100

This equation describes how a hemlock board will dry in a kiln at the conditions input to the equation.

Kiln Model

The kiln model inputs include the initial moisture content, specific gravity, and thickness of each board. Thus, the user can put in a distribution of board properties. All boards must be of the same the same width. The kiln schedule is input including the dry-bulb temperature, wet-bulb temperature, air velocity, and fan reversal times. The schedule is restricted to the valid range of the drying rate function. Other inputs include the sticker thickness and number of boards wide and high for a package.

At any time during drying the simulation will predict the average moisture content of the charge and the variability in moisture content. It also produces graphical displays of the boards' moisture contents versus location in the kiln, the boards' temperatures versus location in the kiln, the air temperature versus position, and the air relative humidity versus position. The calculations are done using standard engineering equations for mass balances, energy balances, and the rates of mass and energy transfer. Details can be found in Berberović, 2007.

Simulation Results and Validation

Three packages, each containing 168 pieces of 16-foot 2x6 hemlock, were dried to validate the model. The weight of each board was recorded before and after drying. The moisture content of each board was measured in two places with a Wagner L612 hand-held moisture meter. A third measurement was made if the first two differed by more than five percent. The charge was continually weighed during drying using in-kiln load cells and the moisture content as a function of time was calculated. The specific gravity for each board was estimated from the board dimensions, weight, and moisture content. The dry- and wet-bulb temperatures as measured during drying were input to the model. The air velocity was measured and introduced to the model. The internal temperature of a board was measured.

The predicted moisture content versus time is compared to the actual in Figure 3. A good agreement can be seen. The model dries a little too slowly later in the cycle. When conditioning occurs at about 85 hours, the predicted moisture content does not increase because the EMC is not high enough. The actual moisture content is below the EMC, so the wood gains moisture.

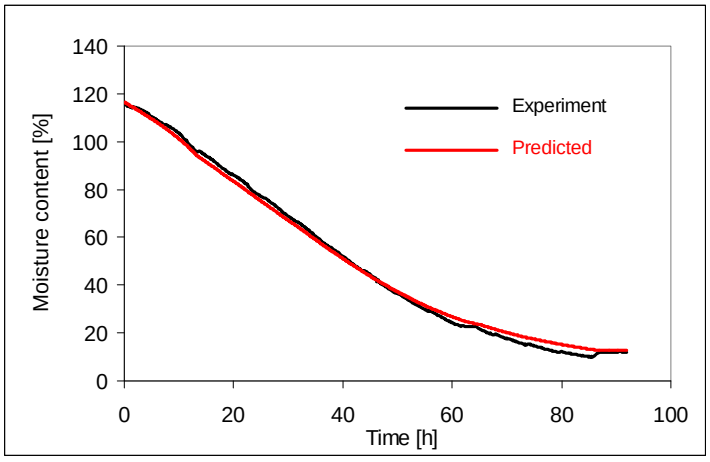

FIGURE 3. Moisture content versus time predicted by the model and measured during drying.

Figure 4 shows the temperature drop through the package as measured by thermocouples placed on the package and as predicted by the model. Again, the agreement is good. The predicted temperature drop is slightly less than the actual. This is because the drying was slightly slower in the model. The temperature drop will be lower when less water is removed.

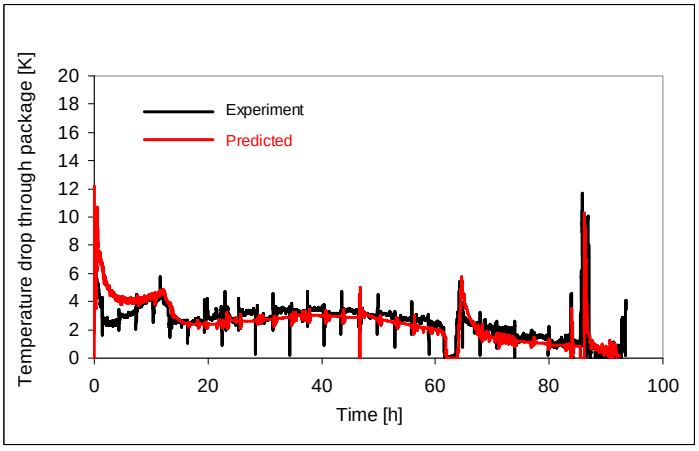

FIGURE 4. Temperature drop through the package versus time for the model and the experiment.

Figure 5 shows the temperature inside of a board. Again, the agreement is good between the predicted and the experimental.

The model was tested on a full-sized package of lumber using the actual temperature, humidity, and air velocity experienced by the package. A full size-package in a large kiln and a small kiln will behave similarly; therefore there is no reason why the model should not work on a larger kiln. The model will be useful for answering what-if questions. For example, what would be the effect on drying time and moisture uniformity if the package was made one board wider? Or, what would be the effect of reducing the fan speed earlier in the cycle?

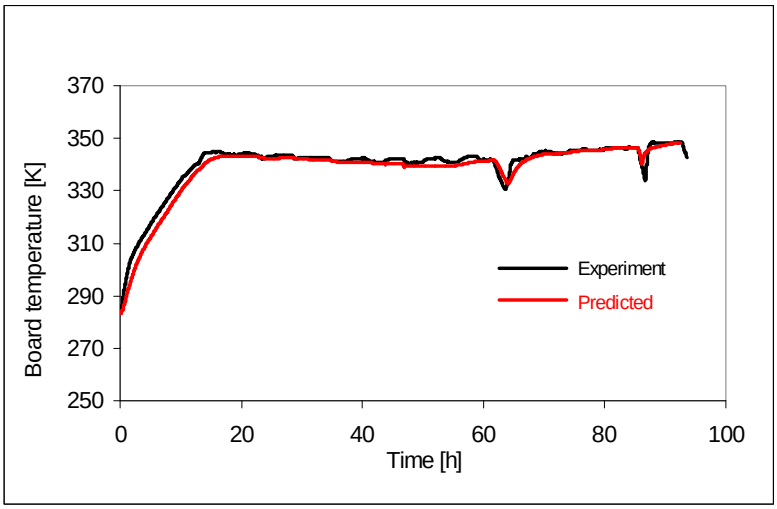

FIGURE 5. Measured and predicted temperature inside a board versus time.