DEVELOPING A MODEL TO SIMULATE LUMBER DRY KILN

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INTRODUCTION

This presentation is a little different than most at the Western Dry Kiln Association Meetings. Not a lot will be said about lumber, drying, or defects. The objective of this presentation is to familiarize the group with models, their potential, their limitations, and how models might be used to improve drying operations. The information presented here will be a primer because in the future we will see a lot more applications for models in all parts of the lumber industry and indeed, in all parts of our lives.

SOME EXAMPLES OF MODELS

A model is a simulation, usually performed on a computer, which attempts to predict an outcome. Models touch our lives whether we realize it or not.

Meteorologists, for example, collect temperature, pressure, and relative humidity information from various surface stations and observations aloft, and put the information into a model. Using this real data, combined with mathematical representations of air properties such as those on the psychrometric chart, physical forces such as the Coriolis force, and terrain features such as mountains, these models predict our weather. If you came to the WDKA meeting by plane the amount of fuel in the tanks was probably based, at least in part, on wind predictions from a weather model.

Within our own industry we have used models for years. One example is the Best Opening Face (BOF) program. Knowing the diameter and taper in a log, this program uses target lumber sizes, saw thickness, sawing variation, and current lumber prices to predict how to saw the log for optimum value. There is also at least one simulation which can be used for training edge operators. In this case the computer generates a flitch with defects and the edgerman responds by setting the number of saws and their locations. The imaginary flitch is then sawn in the computer and the recovery and value of the resulting boards are compared to the optimum. The edgerman can resaw the board with various saw settings to learn how he is affecting the sawmill operation and profitability.

DEVELOPMENT OF A MODEL

A falling object is a phenomenon with which we are all familiar and will be used to illustrate the development of a model. This model will express the distance an object falls in a given time. The formula for this is Newton's Second Law,

$$F = m \times a \tag{1}$$

where F is the force, m is the mass, and a is the acceleration. Since a falling object is considered, F is equal to the gravitational acceleration times the mass, g x m, and the acceleration is the second derivative of position with respect to time, d^2p/dt^2. Making these substitutions, integrating twice, and rearranging gives

$$p = -(1/2) \times g \times t^2 \quad (2)$$

where p is the distance fallen and t is the time. Understanding the mathematics to get from Equation 1 to 2 is not critical to our objective.

Let's look at how well the model (Equation 2) fits in our real world. It predicts that if an object is dropped, after 0.5 seconds it will have fallen about 8 feet ($g = -32.17 \text{ ft/s}^2$). Notice that the size and mass of the object have no effect on the outcome. We know that a feather and a rock fall differently, yet out simple model doesn't reflect this. This illustrates the point that models must represent the physical phenomena. Our model applies in a vacuum. Since we live in air, its effects must be included if the model is to be useful. Similarly, the usefulness of a kiln model would depend on how well kiln phenomena are represented in the model.

If the drag due to air is put into the model, F is now equal to $g \times m + C_d \times v$, where C_d is a drag coefficient and v is the velocity. Substituting this into Equation 1 gives

$$p = g \times (mC_d) \times t - g \times (m/C_d)^2 \times [1 - \exp(-t \times C_d/m)] \quad (3)$$

Again, understanding the mathematics to get to this point is not important. Do note, however, that our new model (Equation 3) includes a new term, m/C_d, which enables the model to predict that a small, heavy object will fall further in a given time than a large, light object. Thus, we have complicated the model, but achieved more realistic results.

Our model applies in many situations, however, the drag coefficient is not a constant. Putting a variable drag coefficient into the model complicates the result even more but might be important, for example, if NASA was attempting to predict the reentry of a rocket. At our level of application, however, we could learn a lot about falling objects from the more simple relation in equation 3. This illustrates a second point. Models should be kept as simple as possible as long as the simplification results in acceptable accuracy.

In modeling something as complex as a dry kiln some simplifying assumptions must be made; however, we can still learn a lot about the way in which the kiln operates. For example, a simple model might not predict an exact drying time, but it might predict with considerable reliability the difference in drying time between two schedules.

APPROACHES TO MODELING

There are two general approaches to modeling, theoretical and empirical.

In a theoretical model we rely completely on the physical principles to make predictions. This is well established for certain things in the kiln such as the psychrometrics. The problem with this approach is evident when we consider something like how fast an individual board will dry at a certain location in the kiln. To predict this from theoretical principles is very difficult because we do not fully understand how moisture moves within the board, not to mention the board-to-board variation, both in initial properties and drying rates.

In an empirical model we take real-world data and make a model that predicts similar outcomes under similar conditions. Often statistical fitting is used for this. The empirical model is restricted to the range of conditions under which the data was generated in contrast to a theoretical model which is only restricted by the validity of the theory use in its generation.

In actual practice, most models utilize a combination of theoretical principles and empirical information. The rate of moisture loss (dMC/dt) as a function of the environment around the board,

$$dMC/dt = f(T_{db}, T_{wb}, v, MC) \tag{4}$$

is an example of empirical information which might be used in a kiln model. This relationship must be obtained from drying data generated in individual-board drying rate studies. Its shape and magnitude will depend on species and wood type, such as sap, heart, sinker, or possibly other factors. Obtaining this data is difficult, time-consuming, and represents perhaps the greatest obstacle to modeling the dry kiln.

If air at T_{db} = 180° F and T_{wb} = 140° F entered a sticker slot (point A in Figure 1), Equation 4 might be used to predict the rate of moisture loss from the boards directly above and below the sticker slot. Once this moisture loss is known, theoretical considerations (the psychrometric chart) can be used to estimate new dry-bulb and wet-bulb temperatures for the air at point B in Figure 1. We then do a similar analysis on the next two boards. Since the air has cooled slightly and picked up some moisture, equation 4 should predict a slightly slower rate of moisture change for the next two boards (between points B and C in Figure 1). This might give a 0.5° F drop in air temperature between the first set of boards and a 0.4° F drop between the second.

For a preset time interval we could proceed like this across the stack and predict a new moisture content for each board. TDAL could also be calculated. For succeeding time intervals we could repeat this set of calculations until the lumber is dry. Schedule changes could be made as needed. This set of calculations would be a very simple model for a dry kiln which combines the theoretical and empirical approaches. The repetitive nature of the calculations and the considerable bookkeeping makes the use of a computer mandatory.

In this discussion only the stack of lumber has been considered. No mention has been made of trying to model the heating coils, vents, or other kiln components. This is a valid approach because the way in which the lumber dries is independent of how the entering air was supplied. In other words, the lumber doesn't know if it is in a dehumidification, steam, or direct-fired kiln. It only knows that the entering air is a certain T_{db}, T_{wb}, and v.

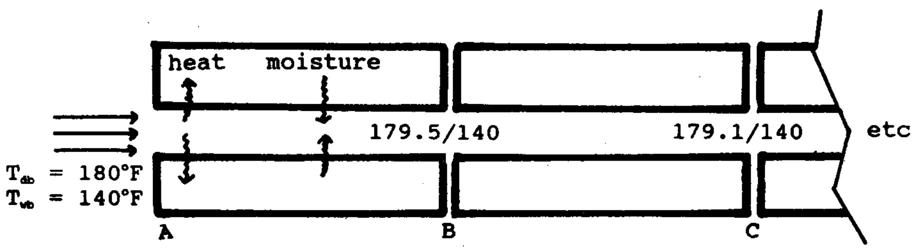

Figure 1. Air movement, temperature drop, and humidity increase through a sticker slot.

COMPLICATIONS IN THE KILN

What has been presented is a very simplified version of a dry kiln model. In actual practice there are many complications. The fans reverse. Air can become saturated so that the wood does not dry. Water can condense on the lumber, particularly during start-up, and either be absorbed into the wood or run onto the floor of the kiln. A certain amount of energy is used to heat the boards and the temperature drop across the load and condensation are very dependent on the rate of heating early in the schedule. Geometrically, the sticker thickness, board dimensions, and stack size can vary.

All of these and many other complications reflect back on our first important point about modeling. The model must accurately represent the physical phenomena. While doing so the second point must be observed, that is, the model must be kept as simple as possible.

POTENTIAL USES FOR A KILN MODEL

At first consideration one might think that the potential for a kiln model would be to predict drying times; however, a good model should be able to do a lot more than that. In fact, even if a model was only approximate in calculating total drying time, there are many possible uses.

Redry has been discussed as a way to possibly increase kiln throughput while increasing lumber quality. A model predicting drying time and board-to-board moisture distribution at different target moisture contents could predict kiln throughput at different redry rates. Then by estimating the equipment and handling costs for the lumber to be redried, one could estimate if redry was a profitable option.

One objective of kiln drying is to minimize both the final board-to-board moisture distribution and the drying time. How these are affected by small schedule changes is difficult to measure in the mill environment and scale-up problems may cause lab data to not reflect distributions in a larger kiln. The distribution changes may be small enough that they are masked by the variation due to other sources and a model may be the only way to ever determine them. Also, a model could be used to determine the effect of green-end sorting on the final board-to-board moisture distribution and overall kiln throughput.

Velocity and temperature vary in different parts of the kiln. There is usually some variation from top-to-bottom and maybe from end-to-end. The effect of this on the final moisture distribution could be predicted with a model. After knowing the effects, decisions can be made about if and how to correct the problems and what costs the mill is willing to incur to do so.

What is the effect of reducing fan speed on the drying rate and final board-to-board moisture distribution? We have a fundamental understanding of this; however, a model would enable the optimum fan speed reduction times to be determined.

Control in the dry kiln can be based on many things such as time, moisture content, temperature drop across the load, steam use, or weight to name a few. Models will allow novel control options to be tested without the risk of building a kiln.

There are countless uses for a kiln model. These will become more apparent as more models are generated and we begin to realize their potential and limitations. Besides models for drying rate, in the next ten years we will see models for wood quality and the kiln hardware. The careful use of models will help keep science and engineering as the basis for kiln design and help keep our industry competitive as we move into the 21st century.