COMPUTER SIMULATION OF KILN DRYING

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MOTIVATION - A DECISION MODEL

The simulation problem arose from the time honored activity of finding the "best" kiln schedule. Although it is hardly necessary in this company, let us first define what is meant by

1. A kiln schedule
2. The result of a schedule
3. What would constitute an answer to finding the "best" or optimum schedule

1. What is a kiln schedule?

For the purpose of this discussion a schedule will be defined as a series of temperatures each of which is associated with a time period. The temperatures consist of both wet and dry bulb readings with the difference being referred to as "depression." In some cases air speed may also be a part of the schedule.

Operating a schedule requires using valuable goods. Heat must be purchased in the form of fuel, and burned in heat generating equipment. Air is driven through the load with electricity and fans. All of these are costly to buy and maintain.

2. What is the result of a schedule?

In addition to operating a schedule, we also put into the kiln a load of "wet" wood. The result of the schedule is a load of wood which is no longer "wet," that is, its moisture content has changed. It may be drier overall, but equally important is the redistribution of moisture that has taken place. For our purposes we define the result of operating a schedule as a "moisture gradient." It is represented with a curve showing the moisture content distribution inside a piece of wood at a certain time.

3. What then, is an optimum schedule?

To define an optimum we must specify a desired result, that is, the moisture gradient curve we wish to achieve. An optimum schedule must then be one of all the possible schedules whose resulting moisture gradient curve will match the desired moisture gradient curve. The one of these that can be operated with the least possible cost is the optimum schedule.

A DYNAMIC PROBLEM

With these definitions in mind

1. A kiln schedule

2. The result of a schedule, and

3. The optimum schedule

I would like to briefly discuss how we combine our knowledge of schedules with the technical results of operating them in order to find the optimum schedule. As the problem deals with time and other costs, it can be classed as a dynamic problem. The result of one part of a drying schedule depends upon the previous history of drying.

Problems of this type (multistage decision processes) have been formulated in such a way that they can be solved with a technique called dynamic programing.[1]

The use of this technique, as well as others, requires certain information about alternative methods. You must know the technical result of each action as well as the monetary cost of taking the action. Restrictions can be made on the problem, and the costs and results compared. Iterative procedures are used to find the best solution. In order to use this approach to finding the optimum kiln schedule, we must know the result of a very large number of possible schedules. The number of possible schedules is large enough that we could not hope to find all the needed answers using conventional experimental techniques. Consequently I chose to simulate the drying process with a computer.

SIMULATION

The term simulation is used to cover many situations. It is most commonly used to describe an artificial construction whose behavior is similar to some real phenomenon. The miniature model of the Mississippi River basin simulates the real river basin, wind tunnels are used to simulate the conditions an aircraft must endure, chemists and physicists often use mathematical formulas to simulate real phenomena. Each of these forms of simulation uses an artificial construction to predict the outcome of a real event.

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[1] See Applied Dynamic Programming by Richard E. Bellman and Stuart E. Dreyfus. 1962.

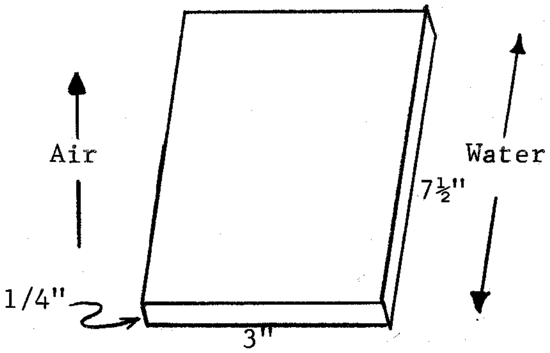
Computers can also be used as a basic tool for artificial constructions. Many times the mathematical formulation of a problem cannot be solved with mathematical manipulation alone. Even when analytical solutions are possible, they may be too expensive to obtain.

The present problem is a case in point. We could not solve the theoretical equation of moisture movement through wood without digital approximation. The great speed and flexibility of the computer has reduced the problem to a soluble size.

DRYING CEDAR PENCIL SLATS

Before proceeding further with the simulator, let's take a closer look at the phenomenon we wish to represent, drying cedar pencil slats. This problem was selected because of its relative simplicity. It is simple because the slats are stacked in such a way that the principal drying takes place on an end surface. The moisture movement is mainly longitudinal. In addition the wood is relatively easy to handle and measure.

Slats are bundled and stacked so that the warm air is forced between bundles across the slat ends.



The simulator is designed to predict the distribution of moisture along the length of a slat, from end to center after a specified drying period.

THE MOISTURE TRANSPORT SIMULATOR

The basic theory for the simulator was taken from the work of previous investigators. They made an analogy between heat movement and moisture movement, then made the theory specific for wood. Two basic equations are used:

1. One represents the way moisture moves inside wood

$$\frac{\delta U}{\delta t} = \frac{\delta}{\delta x} D(U,T,) \quad \frac{\delta U}{\delta x}$$

where U is the moisture content

t is time

x is distance from the center of the slat

T is Temperature

$\frac{\delta U}{\delta t}$ = the rate of moisture movement over time

$\frac{\delta U}{\delta x}$ is the slope of the moisture gradient curve with respect to distance from the center of the slat

$D(U,T)$ a function that determines the permeability of wood

2. The other equation represents the evaporation of water from the drying surface.

$$F = k(P_v - P_a)$$

where F = rate of evaporation at the surface

k = depends on air velocity

P_v = vapor pressure of moisture at the wood surface

P_a = partial pressure of moisture in air

From these basic equations and a given initial condition, we were able to derive an expression for the rate of moisture movement over time and distance. The expressions were then converted into a computer program using digital approximation techniques. With a small amount of experimental data the coefficients specific to incense-cedar were calculated. Computer results are displayed graphically as a time series of moisture gradient curves.

Figure 1 is the result of one simulation. The moisture content on the vertical scale is in percent of dry weight, and the distance in inches from the center of the slat is on the horizontal scale. There is one curve showing the moisture gradient at each of three times.

Figure 2 is a graph of measurements taken from a load of slats. This load was dried with the same schedule as the computer simulator followed.

USE OF THE SIMULATOR

If our results remain as consistent as the one you are looking at, we will use the simulator as the basic device for predicting the results of following specific schedules. These predictions will then be used by a dynamic programing model to find the optimum schedule. In essence, the simulator is being used to replace conventional experimental techniques.

MOISTURE-TRANSPORT SIMULATOR

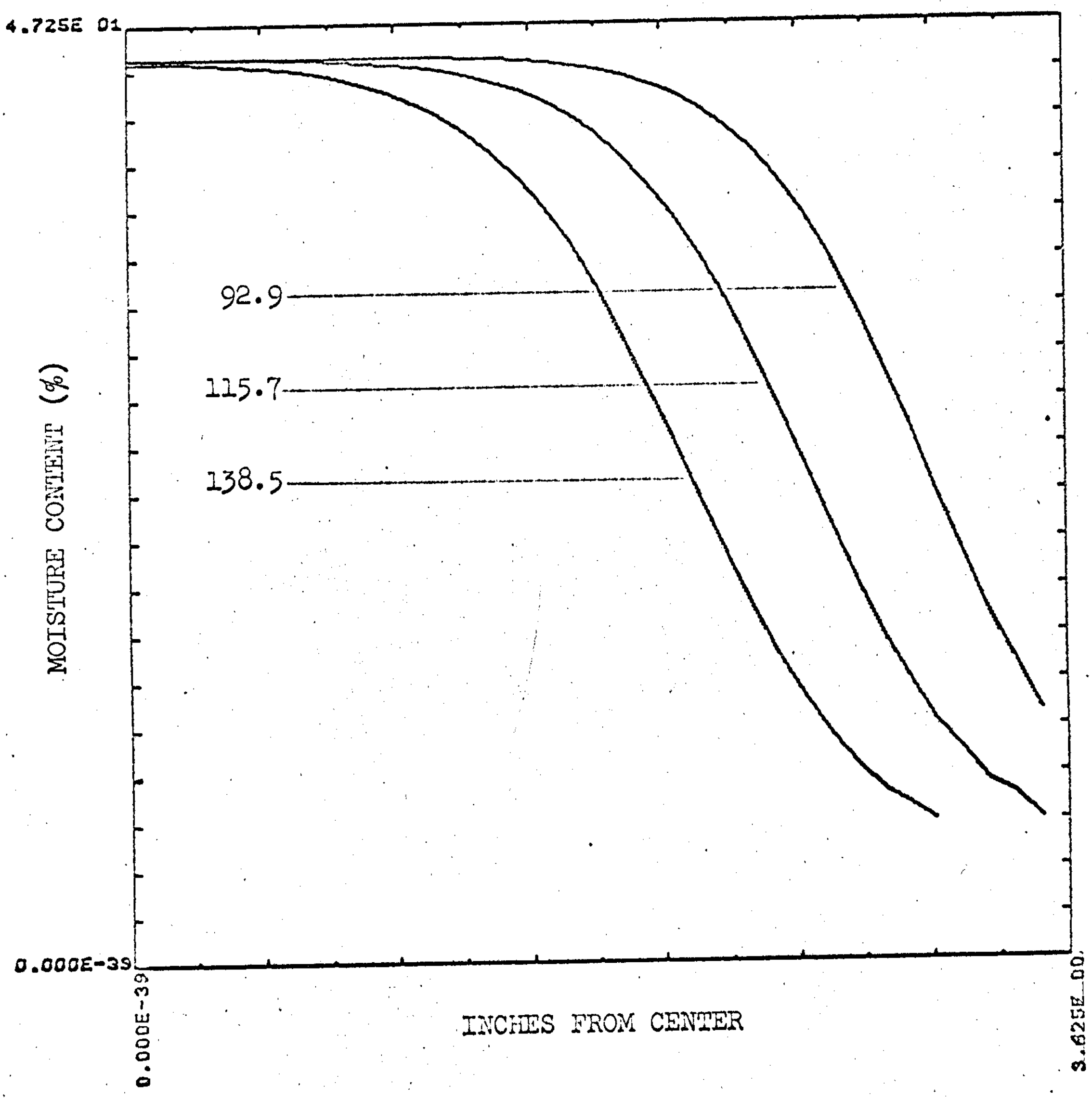


FIGURE 1

DATA CURVES

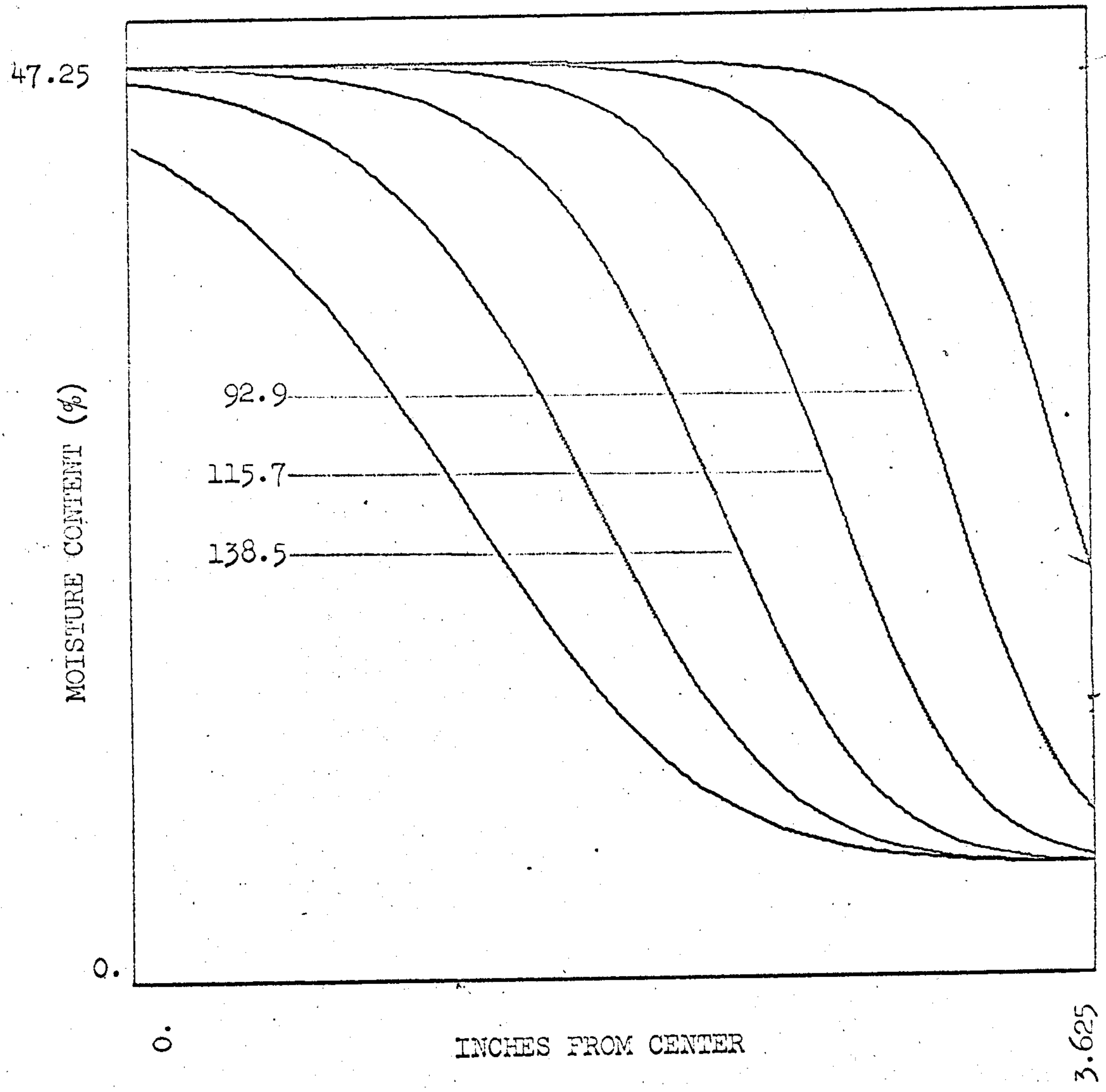


FIGURE 2