THERMODYNAMICS OF ENERGY USE IN DRY KILNS

John M. Vranizan
Carroll, Hatch & Associates, Inc.
Portland, Oregon

OVERVIEW

An opportunity to reduce manufacturing costs exists at most sawmills using dry kilns. The expense reduction comes about through adoption of a practice that conserves electrical energy at the kilns.

Two types of energy are used at dry kilns, thermal and electrical. Thermal energy provides heat necessary to evaporate water out of wood. Electrical energy is used to power motors which turn fans that provide air movement for bringing heat to and carrying water vapor away from the wood.

For at least the last 50 years, dry kilns have been designed with the ability to vary the input of heat to meet demand. Steam valves or fuel values (in the case of direct fired kilns) open and close as directed by a temperature controller.

Conversely, air circulating systems in kilns have been designed to operate at a single "fixed" speed. Even though it has been recognized that the magnitude of air flow volume is less important as the lumber becomes drier, it has not been economic to provide equipment in the kiln to slow down air flow. Until recently, the cost of electrical energy saved, would not pay for the additional equipment in a reasonable period of time.

Electrical energy costs have increased rapidly over the past 10 years. The increase has caused economics to change. Now depending upon a number of factors, i.e., electrical energy costs, drying schedules and kiln design, it may be advisable to equip kilns with the ability to change air flow to more closely match actual requirements.

This process will result in reducing electrical energy which saves "kilowatthours" thereby directly reducing manufacturing costs. Some simple calculations are required to determine how good a "return on investment" the process provides. Each sawmill's situation is different and must be judged on its own equipment design, operating practices and economic factors.

Some experimental work is currently taking place at the Frank Lumber Company in Mill City, Oregon. The goal of the work is to demonstrate the theory presented herein. Specifically, tests are being conducted to determine: 1) "when" the fan speed can safely be reduced and 2) the extent to which the speed can be slowed.

This "overview" and the balance of the presentation is being written as part of a booklet to be published by the Department of Energy, Bonneville Power Administration, for the purpose of guiding the users through the process of analyzing potential for energy and expense reduction for dry kilns at his mill.

BACKGROUND

Water exists in trees to perform important functions such as transporting nutrients from the soil to living cells in the tree to promote growth. However, when timber is harvested and sawn into lumber it is desirable to remove most of the water from the wood. Dry wood is lighter, dimensionally more stable, and more resistant to decay.

At a sawmill, lumber is dried in the kilns. Typically, packages of lumber are loaded onto truck devices that roll on rails into and out of the kilns. Some kilns are loaded via lift truck through side doors. Lumber is dried in "batches," that is to say, the kiln is loaded with packages of lumber, then closed and not reopened again until the lumber is dried to the desired moisture content. A full load of lumber in a kiln is referred to as a "kiln charge."

THE DRYING PROCESS

When the kiln is started and the air system is turned "on," heat is required for: heating the building, heating the lumber (fiber and water) and drying the surface moisture. The kiln heating system is taxed to its limit.

In the drying process water must be changed from liquid to vapor (phase change) at the surface of the wet lumber. Limitations on the rate at which water is removed are the ability of the kiln to:

1) deliver heat to and
2) provide air movement from the surface of the lumber

Large amounts of heat are required to accomplish phase change. Once the phase change occurs the moisture laden air must be moved to make way for continuing drying. During these times in the process the drying rate could be referred to as being "heat transfer" limited.

During this period of drying the kiln instrument controller will be calling for "full" heating capability. The vents on the kiln will be opening frequently to discharge vapor. Temperature difference between the air stream entering the charge and leaving the charge, ΔT, is large because heat is being absorbed out of the stream and the loss of heat causes the air stream temperature to drop.

Drying continues in this fashion for some time. However, as wood loses moisture the rate at which water moves within wood and to the surface of the lumber (diffusion rate) slows. While the drying rate was "heat transfer" limited initially, the drying rate begins to change to the limitation of the "diffusion" rate or a balanced condition between the two limiting rates. Eventually the kiln will deliver more heat and air flow than the drying rate (now controlled by the diffusion rate) requires. The result is a reduction in temperature drop, ΔT, of the air stream as it passes across the load.

Drying progresses through the "fiber saturation point" (FSP). Free water is no longer available in the wood and the airstream contains "unused" thermal capacity.

When the kiln control instrument senses a reduction in heating load, the instrument signals the heat control valve to "throttle back" thus reducing heat input to the kiln. The heat release has been reduced but surplus air still circulates.

At this point in time air flow is much more than adequate to deliver heat and remove airborne moisture. A reduction in air flow should not effect the drying rate since that rate is now controlled by other influences. A reduction in air flow will, however, significantly reduce the electric power demand at the kiln.

The air stream is slowed by reducing kiln fan speed. Since the kiln fans are driven by electric motors, a reduction in fan speed means a reduction in the amount of electricity required to drive the motors.

Analytically, the phenomena can be represented as follows:

$H_e \equiv$ entering enthalpy of the air stream

$H_l \equiv$ leaving enthalpy of the air stream

The energy in the entering and leaving air streams must balance, $H_e = H_l$;

$H_e \infty$ (gas volume)(gas density)(specific heat)(Tentering)

$H_l \infty$ (gas volume)(gas density)(specific heat)(Tleaving)

$T_e - TL = \Delta T$

The amount of gas (water vapor) added to the air stream is a constant, the gas density is a function of absolute temperature so it, too is a constant, the specific heat is a constant in this sawmill temperature range, therefore when the air volume is changed (by changing the fan speed), the leaving temperature, T_l, must change to compensate.

When gas volume (air stream) is reduced or increased, and density and specific heat remain constant, then "ΔT" must change in inverse proportion to the change in gas volume. All of this is required to take place within the constraints of a "constant" drying situation.

RESULTS OF TESTING

At the test kiln many charges of lumber have been dried with close temperature monitoring. Charges were dried while fans operated at full speed and other charges were dried while the fans operated at reduced speeds. All results have produced lumber that is acceptably dried and the length of drying schedules has not changed appreciably.

Temperature drops across the load for the duration of two charges are presented in Figures 1 and 2. These are examples where fan speed was held constant for the entire charge. A most significant item to be noted is the absence of a discernible fiber saturation point.

Figures 3 and 4 show temperature drops across the load for the duration of the drying cycle, but in these cases the fan speeds were reduced. Both of these graphs show the phenomena referred to earlier, i.e., a slow down in fan speed is met with an increase in delta "T".

FAN SPEED--POWER RELATIONSHIP

There is an interesting relationship between fan speed and electrical power. Fan operation is governed by well known physical laws. The relationship between power and fan speed is "exponential," that is, for a change in speed, the change in electric power demand is to the third power (cubed) (Figure 5).

For example:
Speed (S_1) is 300 rpm (normal kiln fan speed)
Power (P_1) required to drive fans at S_1 is 50 kw

Speed (S_2) is 200 rpm (one third speed reduction)
Power (P_2) required to drive fans at S_2 is:
$P_2 = P_1 (S_2/S_1)^3 = (50)(200/300)^3 = 14.8$ kw
P_2 is 29.6% of P_1

The example illustrates that a 33% reduction in fan speed yields a 70.4% reduction in power.

The economic value of this energy reduction can be calculated when the amount of time is determined during which the fan can be operated at a reduced level. If, for instance, the above dry kiln fan operates 6,000 hours per year and it is decided that the fan can be operated at a lower speed for half that time, 3,000 hours per year, the energy savings available is:

(50 - 14.8) kw x 3,000 hr/yr = 105,600 kwh/yr

at a cost of $0.04/kwh, the value of that energy savings is:

105,600 kwh/yr x $0.04/kwh = <u>$ 4,224/yr</u>

Where there are a number of kilns at a mill and they are all subject to this decrease in electrical energy consumption then the savings available can be quite attractive.

Initially, the intent was to use the fiber saturation point (FSP) as the indicator for slowing down the fan. Investigation of the two specie dried at Frank Lumber showed that the "FSP" was neither easily recognized or surely determined.

It was necessary to find some other indicator from which to "key" the fan slowdown. After a great deal of alternative investigation, delta "T" itself was chosen as the "indicator." It was decided to control the fan speed as a function of delta "T".

In order to carry out the control scheme it was necessary to equip the kiln with an intelligent controller. This controller now senses delta "T" and depending upon the value of delta "T" compared to an arbitrary selected reference value, the controller slows down or speeds up the fans.

This is where the project is at the present time. Final results will be determined through the summer.

POTENTIAL CAPITAL COST

Nothing worthwhile is free. A capital investment is required of any mill desiring to take advantage of potential energy savings. The amount of capital cost is dependent upon the style of the air system in the kiln and the size of the kiln fan drive(s).

Line shaft kilns can be equipped with a second motor that drives the line shaft through a different pulley system to achieve the second (and lower) speed. This will be a relatively low cost capital improvement.

Cross shaft design kilns present a more difficult problem. Since there are a number of fans, each with an individual drive, the speed control problem is more complex. The solution to controlling multiple motors in unison is to use a variable frequency controller of adequate size to control <u>all</u> load at the kiln. The capital cost is higher than going to a single second drive motor, but the savings should be greater!

In each case the cost of the capital improvement should be compared to the value of energy cost savings in order to develop proper justification for the investment.

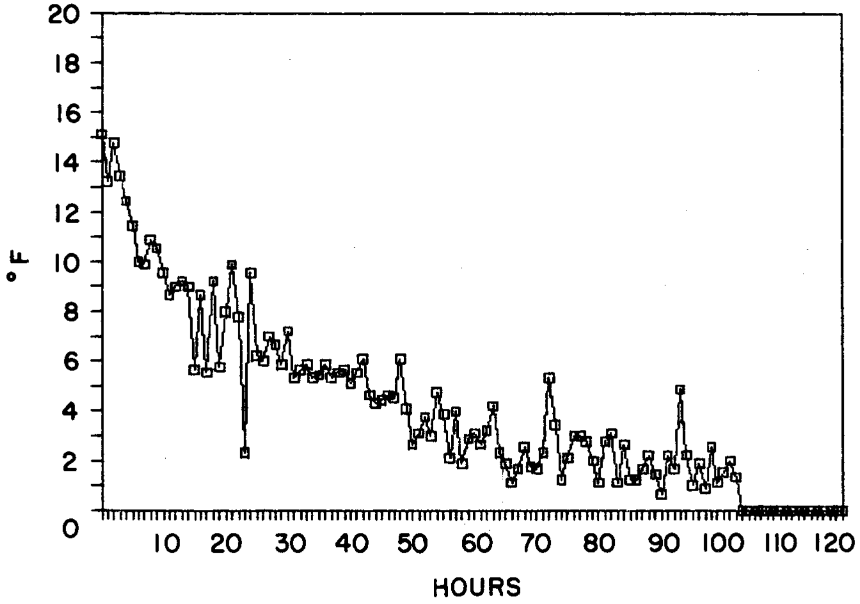

Figure 1. Duration of kiln charge 4-507 (fir lumber)

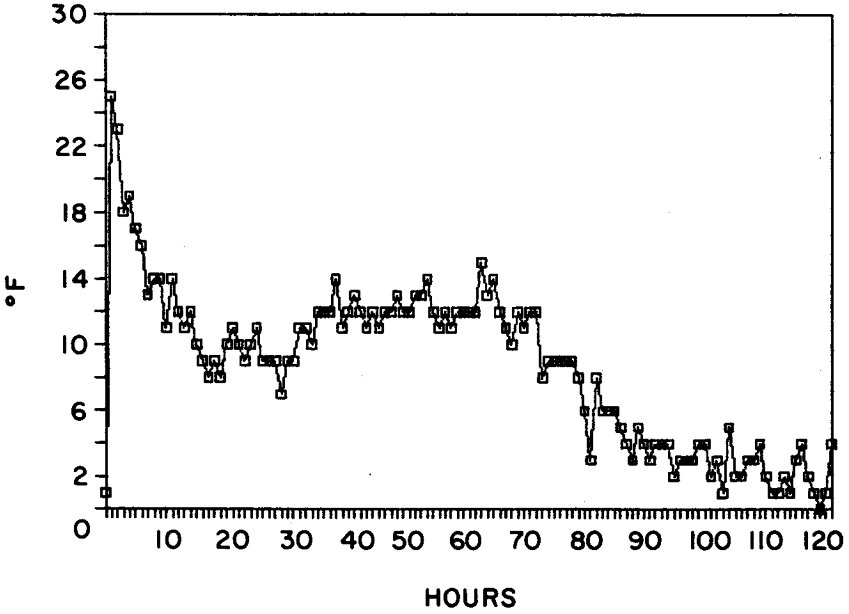

Figure 2. Duration of kiln charge 590 (hemlock lumber)

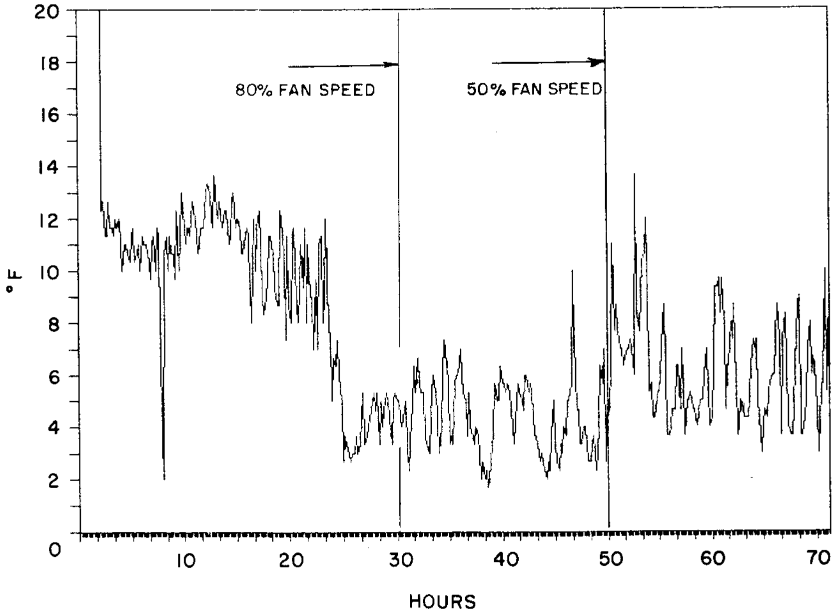

Figure 3. Duration of charge 62 in kiln (fir lumber)

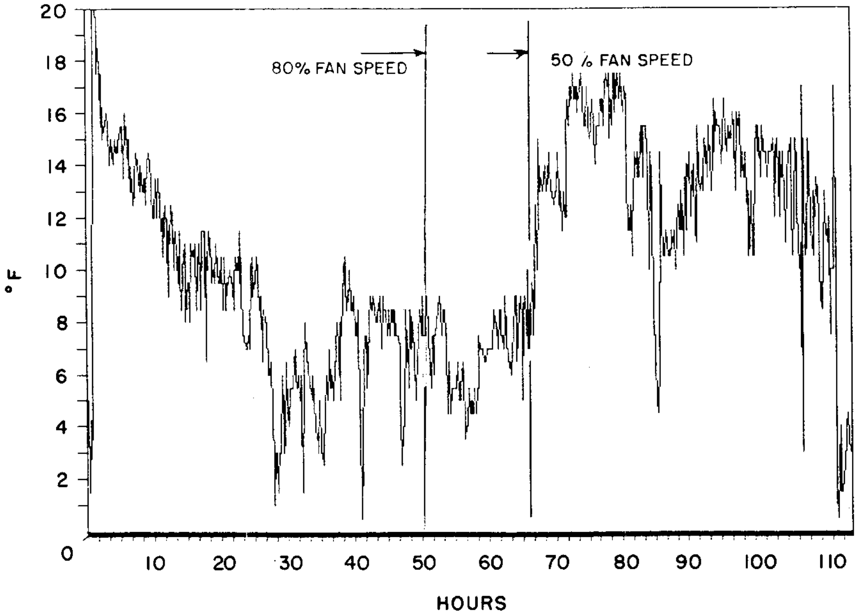

Figure 4. Duration of charge 157 (hemlock lumber)

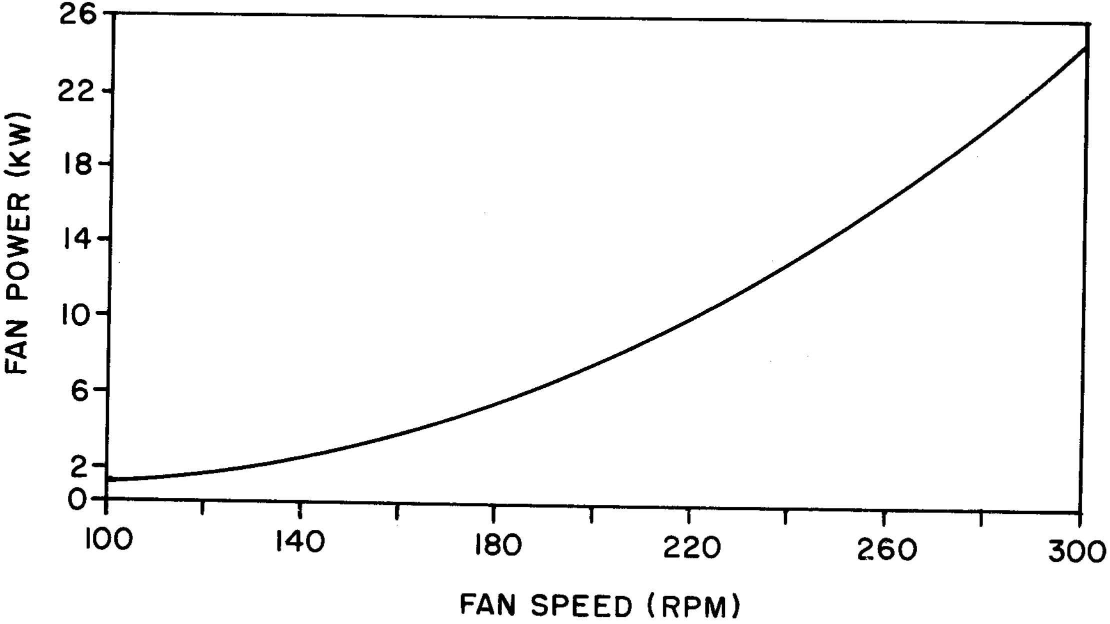

Figure 5. Kiln fan speed vs. fan drive power