STEAM DRYING LUMBER ABOVE ATMOSPHERIC PRESSURE

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The high cost of fossil fuel and soaring interest rates have encouraged people in the wood industry to look for faster and more energy-efficient methods to dry lumber. At our laboratories in Carbondale, Illinois, we have been looking at a new approach to dry lumber called pressure steam drying. In this method lumber is dried at a pressure above one atmosphere and a temperature above 212°F. In this paper we discuss the principles of steam drying lumber, present data from a prototype dryer, and compare the cost of conventional kiln with that of pressure steam drying.

Background

The idea of drying lumber with steam goes back to the middle 1800's, but little research was done in this area until the early 1900's. Steam drying has been attempted (1) at atmospheric pressure (superheated steam drying), (2) below atmospheric pressure (vacuum drying), and (3) above atmospheric pressure (pressure steam drying). Tiemann (13) pointed out that the quickest method to remove free water from wood was to heat the wood and water to the boiling point. He suggested using superheated steam in lumber drying but warned that careful control was required because the steam rapidly became saturated and lost its moisture-carrying capacity, often causing nonuniform drying across a lumber pile.

Steam drying at atmospheric pressure has been explored by many researchers. Several superheated steam dryers have been operated effectively at commercial installations in Germany (7). Eisenmann (1) discussed the theory of high temperature drying in superheated steam and showed that steam drying was cheaper and faster than conventional drying and that steam driers took up less space than conventional kilns. Keylwerth, Gaiser, and Meichsner (6) showed that several green softwoods and air-dried hardwoods could be dried in a 1,700 bf capacity commercial steam dryer. Drying defects included resin exudation, surface discoloration, and loosened knots.

Lumber has been dried in an airtight chamber at pressures below one atmosphere. Malmquist and Noack (9) concluded from their investigation of drying refractory hardwoods (beech and oak) in superheated steam at pressures less than one atmosphere that drying in pure superheated steam was faster than in air-steam mixtures at the same temperature. They also suggested drying those species sensitive to temperature in superheated steam at pressures below atmospheric and those species insensitive to temperature and easily dried in superheated steam at pressures above one atmosphere. Because of difficulties in rate of heating (largely by convection) and rate of moisture diffusion through the wood, vacuum drying of lumber had not been commercially successful until recently. Vacuum drying has been improved by better air circulation (10) and by combined dielectric heat-vacuum drying (8).

Little work has been reported on drying wood in steam at pressures above atmospheric. In a theoretical study, Hann (3) dried yellow-poplar at pressures to 65 psi and temperatures to 350°F. Yellow-poplar lumber was dried to 7 percent moisture content (MC) in 30 hours in a prototype pressure steam dryer by Rosen (12).

Principles Involved

Assume water is contained in an airtight chamber from which all air has been evacuated. At equilibrium conditions the pressure in the chamber will equal the vapor pressure of water and will depend on the temperature in the chamber. For example, at 70°F the pressure in the chamber will be 0.4 psi. The change in pressure, p^*, with temperature, T, in the chamber will follow an integrated form of the Clausius-Clapeyron Equation (4):

$$\log(p^*) = \frac{-3793}{T + 459} + 6.820 \tag{1}$$

where p^* is in psi and T is in °F. Equation (1) is most accurate in the range of 210 to 350°F.

If heat is added to the chamber until the pressure is above atmospheric pressure and the pressure controlled at a set value by bleeding water vapor from the chamber, at steady state and with no temperature gradients in the chamber, the temperature in the chamber can be determined from Equation (1).

The equilibrium vapor pressure of water as a function of temperature, called the saturation curve, defines the border for describing the commonly used ranges of temperature and pressure for superheated steam, vacuum, and pressure steam drying (Figure 1). No drying occurs if conditions are those along the saturation curve: conditions must exist such that temperature is above its saturation value for a given pressure. The difference between the temperature in a drying chamber and the saturation value is defined as the amount of superheat temperature.

When wet wood instead of water is placed in the chamber, similar principles apply. The wood can be heated in the absence of air until the pressure in the chamber is above one atmosphere and consequently the temperature above 212°F. As heat is transferred to the wood, the wood dries and the steam generated is removed through a pressure control valve.

In practice, however, the wood-steam drying system never reaches steady state or equilibrium conditions because of the significant internal resistance of the wood to water removal. Water must first be transferred from the interior to the surface of the wood before being transported by circulating steam and removed from the chamber through a bleed valve. In pure superheated steam drying, diffusion does not occur. Heat and mass flows are countercurrent to each other; heat moves by conductivity and evaporated water by pressure drops from the inner regions to the surface via cell cavities and connecting pits. Once the water moves to the wood surface, the removal of the water depends on the degree of superheat in the circulating steam. The driving force of the amount of superheat in the steam is balanced by the resistance of the wood to water removal, a resistance that increases as the wood dries. To dry lumber as quickly as possible with acceptable degrade in a steam dryer requires controlling the temperature by varying pressure and heating rate.

A major advantage of pressure drying is the ability of the process to maintain high levels of EMC at high temperatures. Thus, wood can dry rapidly without overdrying the surface. Also, conditioning of the lumber to relieve stress can be done at higher temperatures and therefore faster than with conventional methods.

Previous researchers have observed greater defects such as collapse, honeycomb, and checking in high temperature-dried lumber than in lumber dried at lower temperatures (15). These defects were probably due in part to the steep moisture gradients from the surface to the center of the wood. High temperature drying has generally been done at atmospheric pressure above 220°C and with an air-steam mixture. At these conditions, the maximum value of the equilibrium moisture content, EMC, of the wood is 11 percent (that in pure superheated steam represented by the 14.7 psi curve in Figure 2), but in commercial kilns considerable air is mixed with the steam so that EMC is usually below 4 percent.

In pressure steam drying, rapid drying occurs because of high temperatures, but the wood surface is not overdried because high levels of EMC can be maintained at elevated pressures (Figure 2). Equalizing and conditioning can also be done at high EMC's and at temperatures above 212°F--thus rapidly providing a narrow MC distribution among the boards as well as relieving stress.

Results of Drying With a Prototype Pressure Steam Dryer

We dried several lumber types in a prototype pressure dryer (Table 1). The dryer has a capacity of 100 bf, circulates steam at a rate of 250 fpm across the boards, and can operate at a maximum pressure of 35 psi and temperature of 320°F (12) (Figure 3). Nonrefractory species such as yellow-poplar and silver maple were dried from the green condition to 6 percent MC with good quality. Shrinkage was less than conventionally dried lumber, end checking was slight, and no honeycomb was observed. The wood was darker throughout than conventionally dried lumber but was structurally sound. Green refractory woods were dried with excessive degrade, although air-dried refractory lumber such as red oak dried very well in the pressure steam dryer.

Although most wood types had minimal internal stress after drying (shell MC differed from core MC by less than 1 percent), conditioning for a short time relieved these stresses (11). For example, 4/4 red oak was conditioned for 4 hours at 215°F and 15 psi (EMC of 14 percent) to achieve a shell to core MC difference of only 0.4 percent. Conditioning of red oak in a conventional kiln takes approximately 1 day (14).

An economic comparison of conventional kiln and pressure steam drying of 4/4 red oak shows a $5.70/Mbf savings by pressure steam drying (Table 2). Although the cost of pressure steam dryers is greater, maintenance and labor is less. Energy costs are comparable--pressure drying uses less steam energy but more electrical energy.

Future Work

Pressure steam drying is a promising method to dry lumber. We will test this method with thicker material and other species and evaluate new schedules to determine the range of application of this process. Also, the vent steam from the pressure dryer is a high-quality heat source from which energy can be recovered for use elsewhere in the processing plant. We will explore ways to recover this energy.

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Table 1.--Drying times for pressure steam dried lumber[1/]

Lumber type	Drying time (hrs)
Air-dried	
Black walnut	24
Red oak	24
Green	
River birch	32
Silver maple	25
Southern pine	15
Southern pine (7/4)[2/]	20
White ash	32
Yellow-poplar	24

[1/] All lumber is 4/4 and dried to 6 to 8 percent MC. Drying time includes 4 hours of steam conditioning unless otherwise specified.

[2/] Structural lumber, dried to 12 percent MC, but not conditioned.

Table 2.--Cost of drying 4/4 red oak for an 8 MMbf/year plant: Conventional kiln compared to pressure steam drying[1]

(In dollars)

Costs	Conventional kiln	Pressure steam
Capital		
Dryers	$280,000	$490,000
Fork lifts	75,000	75,000
Stacker	150,000	150,000
Stickers	6,000	23,000
Boiler	100,000	100,000
Total	611,000	838,000
Annual		
Energy[2] - steam	65,000	33,500
- electricity	45,500	87,800
Maintenance	116,000	35,000
Inventory interest[3]	108,000	108,000
Sticker replacement	2,000	5,000
Depreciation on capital	61,100	83,800
Miscellaneous (supplies, office, etc.)	12,000	12,000
Total	409,600	365,100
($)/Mbf	51.30	45.60

[1] Material is air-dried to 25 percent MC.

[2] Assume steam cost $4/10^6$ Btu and electricity 4¢/Kwh.

[3] Assume 3 months supply at 18 percent interest.

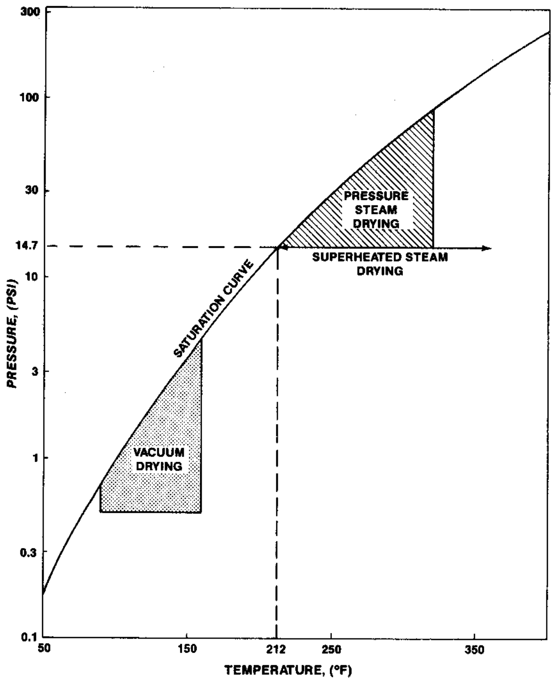

Figure 1. Pressure-temperature diagram for steam showing saturation curve and operating regions for vacuum, superheated steam, and pressure steam drying.

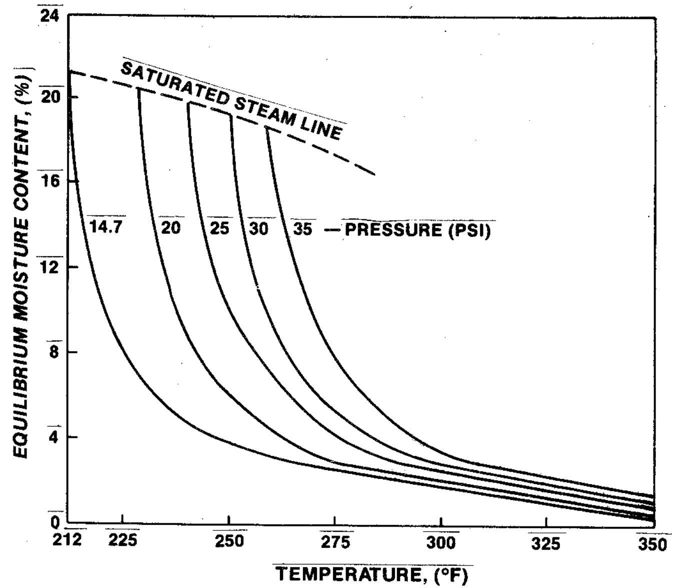

Figure 2. Equilibrium moisture content of wood versus temperature at various pressures. Curves are derived from data by Keylwerth (5) at atmospheric pressure (14.7 psi) and by Engelhardt (2) above atmospheric pressure.

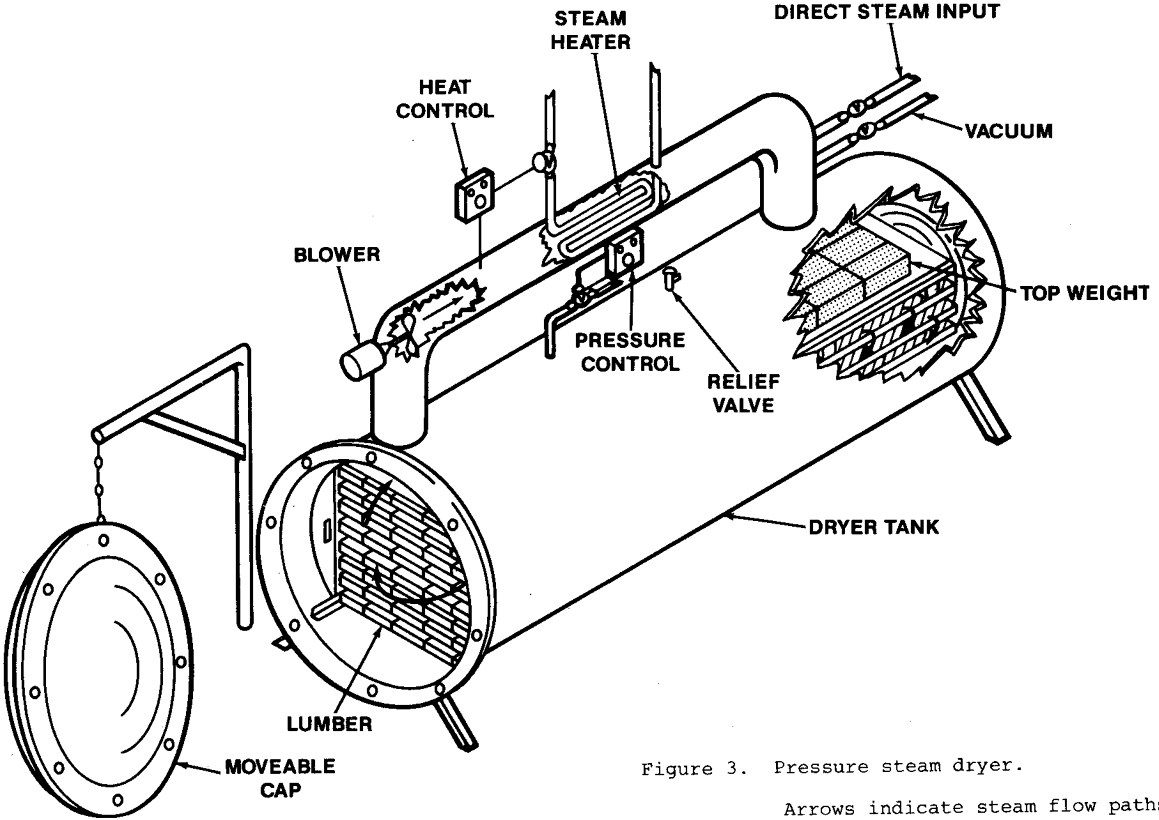

Figure 3. Pressure steam dryer.

Arrows indicate steam flow paths.