A COMPARISON OF ENERGY REQUIREMENTS FOR KILN-DRYING SOUTHERN PINE AT DIFFERENT DRYING TEMPERATURES

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ABSTRACT

The energy consumption used to dry green pine dimension lumber in a 1,200-board-foot-capacity experimental kiln was studied at various operating conditions. Energy consumed by the steam-heated kiln was measured with the aid of a system of condensers and holding tanks that separated and collected the steam condensate.

Results show that charges dried at high temperature (240 F) required 12% less energy than similar charges dried in a similar way at 190 F, and 15% less energy than charges dried at temperatures between 165 and 175 F. Data are presented to illustrate that differences in energy for drying at different temperatures are the result of increased heat lost by radiation during the longer kiln residence required when drying at lower temperatures.

Keywords: Drying energy, kiln drying, steam consumption, high-temperature drying, southern pine drying.

INTRODUCTION AND OBJECTIVE

Southern pine has traditionally been dried, immediately after sawing, in forced-circulation kilns heated to approximately 180 F. More recently, pine kilns have been heated to higher temperatures (nominally 245 F) to decrease drying time and supposedly reduce energy consumption. However, the actual energy savings that accrue from high-temperature drying are not clearly documented.

The difficulty in obtaining useful energy data arises from inability to measure the work done (water removed) accurately, to control kiln conditions over a range of temperatures, and to control the uniformity of lumber among kiln charges used for comparison. These difficulties have, in fact, discouraged the collection of data on drying energy required in any kiln at any temperature.

The energy required to dry fir and hemlock was reported to be approximately 2,500 Btu's per pound of water removed (Davis 1954). Energy required to dry spruce pine at a maximum dry-bulb temperature of 240 F was reported to be 1,800 Btu's per pound of water removed (Bramhall and McIntyre 1977), and energy to dry southern pine at the same temperature was reported to be 1,850 Btu's (Rosen 1979). Values ranging from 2,000 to 2,400 Btu's per pound of water removed have been reported by kiln manufacturers and consultants (Bramhall and McIntyre 1977).

In a previous study by the author (Taylor 1979), entire kiln charges of southern pine were weighed both before and after drying to determine the weight of water removed. The energy used during drying was also determined. Two conventional-temperature and two high-temperature kilns were studied. The results were inconclusive in regard to energy differences associated with drying temperature. Differences in kiln capacity, heating characteristics, and air circulation resulted

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in greater energy variation among high-temperature kilns than between high-temperature and conventional-temperature kilns. Also, the energy measurement technique did not measure flash-off steam emitted when the pressure on condensate water was released.

To supplement the energy data collected at these commercial kilns, another study was initiated to determine energy consumption of a laboratory kiln over a series of operating conditions. The objective of the study was to determine variations in energy consumption related to drying temperature. The intent was to show relative differences, not to indicate the optimum that can be achieved in commercial kilns.

EXPERIMENTAL KILN

The laboratory kiln used for the study was a masonry kiln with a brick exterior and cement block interior separated by insulation. The kiln (designed to hold 3,000 board feet) was 12 × 12 × 6 feet. Air was circulated by variable speed fans that can provide air velocities of over 2,000 feet per minute. Steam coils, originally designed for conventional temperatures, were supplemented by additional coils to permit the kiln to be operated at high temperatures. Steam at 100 to 125 psi was supplied by a 15-horsepower boiler. The kiln doors and vents fit snugly, but there were some air leaks in the structure and around openings.

The drying conditions and energy requirements of this kiln should be similar to those of commercial kilns. However, more heat would probably be used or lost by radiation from this kiln because the ratio of kiln surface to lumber volume in the charge is considerably higher in this small kiln than in larger commercial kilns.

Energy consumption by the kiln was determined by weighing condensate in a system of condensers and holding tanks that separate and collect the condensate (Fig. 1). The trap discharge, containing condensate and untrapped steam, was collected in the condensate collector. Water in the collector was maintained at a little less than one-half the collector tank capacity by placing the discharge to

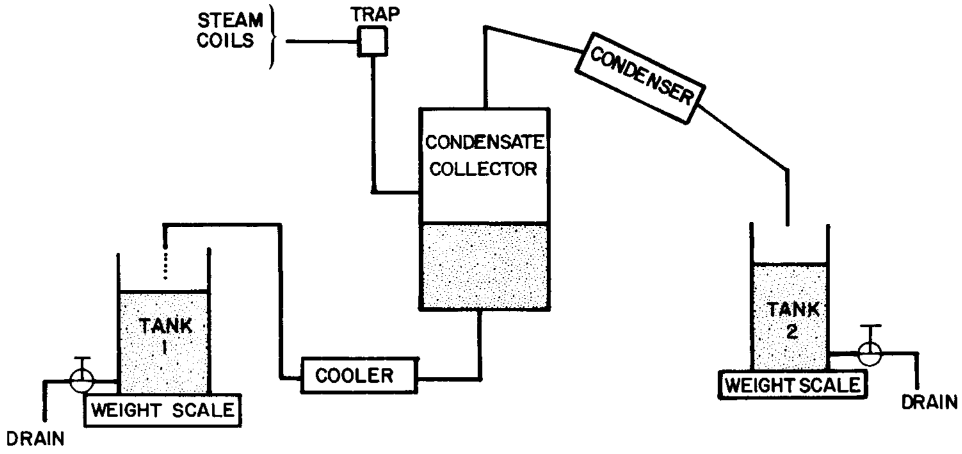

Fig. 1. Apparatus for measuring steam condensate.

tank Number 1 at that elevation. Flash steam and steam that escaped through the trap either condensed and collected in tank Number 2 or condensed in the condensate collector and added to the condensate in tank Number 1.

A collection system such as that illustrated in Fig. 1, with individual weight data for the two discharge fractions, permits very accurate energy calculation. The Btu's released when steam condenses are precisely known for any given steam pressure. The amount of vapor that escapes from hot water leaving the traps at any pressure can also be calculated. If the amount of water collected in tank Number 2 was higher than the calculated amount, it would indicate that the trap was allowing steam to pass through. Such calculations, made during the conduct of this research, revealed that less than the calculated amount of flash steam water was being collected in tank Number 2. Hence, it was concluded that the traps were very efficient in discharging condensate without permitting steam to escape.

PROCEDURE

Green pine lumber (nominal dimensions of 12 feet × 2 inches × 6 inches) was obtained from a local sawmill for each kiln charge. The lumber was transported to the experimental kiln and stacked for drying. In each kiln charge, 100 pieces (1,200 board feet) were stacked in 13 layers. Each of the first 12 layers was 8 pieces wide. Four pieces were placed on the top layer. Layers were separated by dry 1½-inch-wide by 1⅛-inch-high laminated wooden stacking sticks supplied by Simpson Timber Company. As stacking progressed, each course of lumber was weighed.

Pins for measuring electrical resistance were driven into sample boards near the center of courses 2, 4, 6, 8, 10, and 12. Leads were attached to the pins and extended outside the kiln for estimating moisture content with a resistance-type meter as the charges dropped below fiber saturation point.

Variable-speed fans were adjusted to provide an average air velocity of 1,000 feet per minute through the load. The kiln was started and energy consumption was calculated periodically to determine the rate of energy consumption during various stages of drying.

Three different drying temperatures (dry bulb) were evaluated. They were: (1) 240 F, (2) 190 F, and (3) a schedule starting at 165 F for 24 h, followed by 24 h at 170 F, followed by 175 F until drying was complete. For each temperature, the kiln was operated with closed vents and no live steam injection. Drying was continued until the charge was dried to an estimated average moisture content of 12%.

The 240 F schedule is similar to the operating procedure for high-temperature pine kilns. The 190 F schedule is representative of common practice in many conventional kilns. However, in most cases, kilns would be vented during part of the drying period. The schedule with temperature increases from 165 F to 175 F represents a conservative time schedule.

To determine the energy required to circulate air in the kiln, measurements of electrical energy consumption were made for various fan speeds.

To determine the energy required to bring the kiln to operating temperature and balance heat loss due to radiation and air leaks, the procedure was: (1) dry a charge of lumber at high temperature (240 F) until moisture loss ceased, (2)

TABLE 1. *A summary of energy use and drying conditions of individual kiln charges.*

Charge no.	Maximum drying temp. (°F)	Drying time (h)	Weight before drying (#)	Weight after drying (#)	Weight of water removed (#)	Final average MC (%)	Total heat energy million (Btu's)	Heat energy per pound of water removed (Btu's)	Electrical energy (Btu's)	Total energy (Btu's)
1	175	80	5,860	2,995	2,865	11	6.76	2,358	0.32	2,471
2	175	84	5,812	2,994	2,818	12	6.96	2,483	0.34	2,590
3	175	80	5,860	2,857	2,823	10	6.53	2,313	0.32	2,426
4	190	64	5,939	2,847	3,092	12	6.89	2,229	0.26	2,312
5	190	69	5,901	3,074	2,827	16	6.63	2,346	0.28	2,444
6	190	78	5,820	2,866	2,954	12	6.92	2,342	0.32	2,451
7	240	29.5	5,218	2,991	2,227	13	4.91	2,205	0.12	2,259
8	240	31.5	5,953	2,902	3,051	16	5.93	1,949	0.13	1,986
9	240	30.0	5,825	2,912	2,913	10	5.99	2,055	0.12	2,097

allow the kiln and lumber to cool to ambient temperature, and (3) re-start the cooled kiln and measure the energy required to bring it to operating temperature and maintain that temperature.

RESULTS

The amount of energy used and a summary of other pertinent data about individual lumber charges are presented in Table 1. The data show that the charges dried at high temperature required 12% less energy than similar charges dried at 190 F and 15% less energy than charges dried at temperatures between 165 and 175 F. These energy differences are statistically significant, but it should be noted that there are some rather large differences in heat energy requirements among charges dried at the same temperature. For high-temperature-dried charges, the 2,205 Btu's of heat energy required to remove each pound of water from charge 7 is 7% more than the 2,055 Btu's required to remove a pound of water from charge 9.

An obvious explanation for this difference is that charge 7, which had a weight before drying of 5,218 pounds, was considerably drier than charge 9, which weighed 5,825 pounds. The drier charge (charge 7) used only 4.91 million Btu's to dry compared to 5.99 million Btu's to dry charge 9. Although the total heat energy use was less for drying lumber with a lower initial moisture content, the energy use per pound of water removed was more. This substantiates the finding for commercial kilns (Taylor 1979).

Lumber used for this study was obtained from a sawmill producing lumber with a circular headsaw and a sash-gang resaw. With this headsaw equipment and the rather large log size processed by this mill, most 2 × 6 dimension was produced by the edger from headsaw pieces or the sideboards of cants larger than 6 inches. Hence, most of the material dried was flat-sawn from the mature wood portion of trees and would presumably have quite similar rates of drying. Drying rates were, however, quite different, as evidenced by charges 4 and 6. The weight after drying and the final moisture content of these charges were almost identical. This indicates that they were similar in average specific gravity. Nevertheless, charge 4, with a higher initial moisture content, dried in 14 h less time than charge 6. In some charges there were minor fluctuations in kiln temperature due to steam

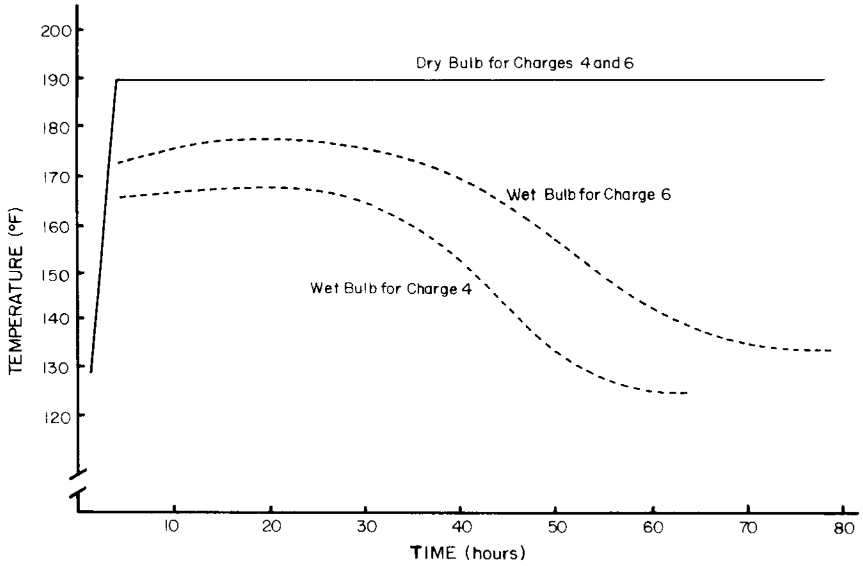

FIG. 2. Graph of wet-bulb and dry-bulb temperature during the drying of charges 4 and 6.

pressure variation or fan reversals at critical times, but in these charges the dry-bulb temperature was quite constant throughout the drying period (Fig. 2). A possible explanation for the reduced wet-bulb depression in charge 4 could be an undetected major air leak around the kiln door or vent or some other uncontrolled venting. Whatever the explanation for such variation, it is noteworthy that at every temperature there were differences in energy used to dry similar charges in similar manners even under closely controlled conditions.

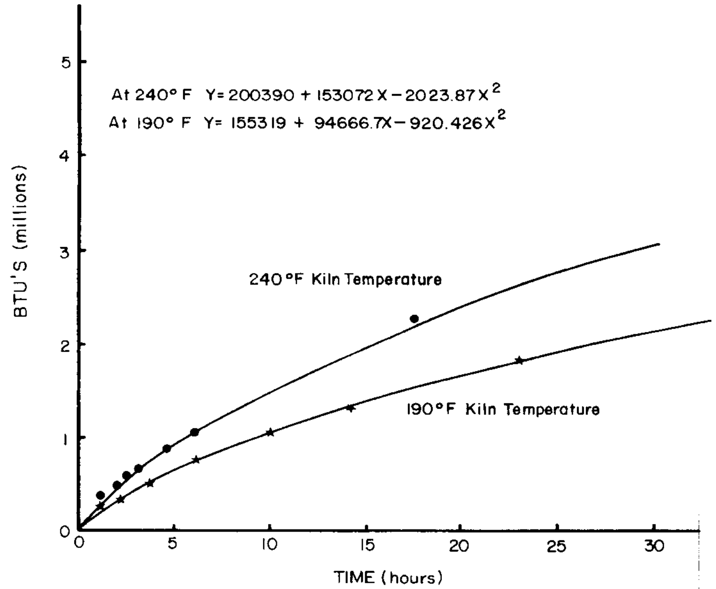

FIG. 3. Energy required to heat and maintain the kiln and wood at temperature of 240 and 190 F.

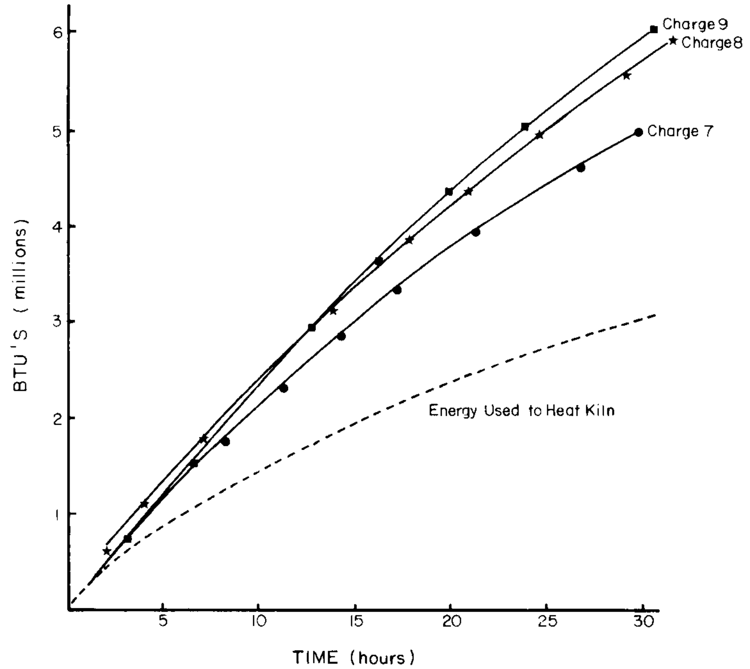

FIG. 4. Graphs of energy used during the drying of charges 7, 8 and 9; and the energy required to heat and maintain the kiln at a temperature of 240 F.

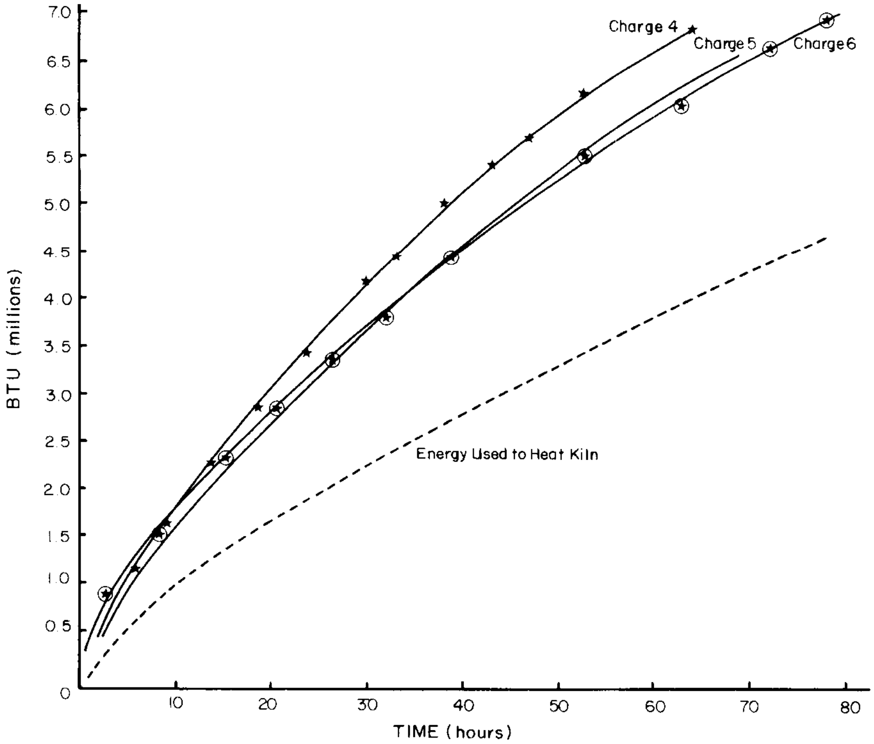

FIG. 5. Graphs of energy used during the drying of charges 4, 5 and 6; and the energy required to heat and maintain the kiln at a temperature of 190 F.

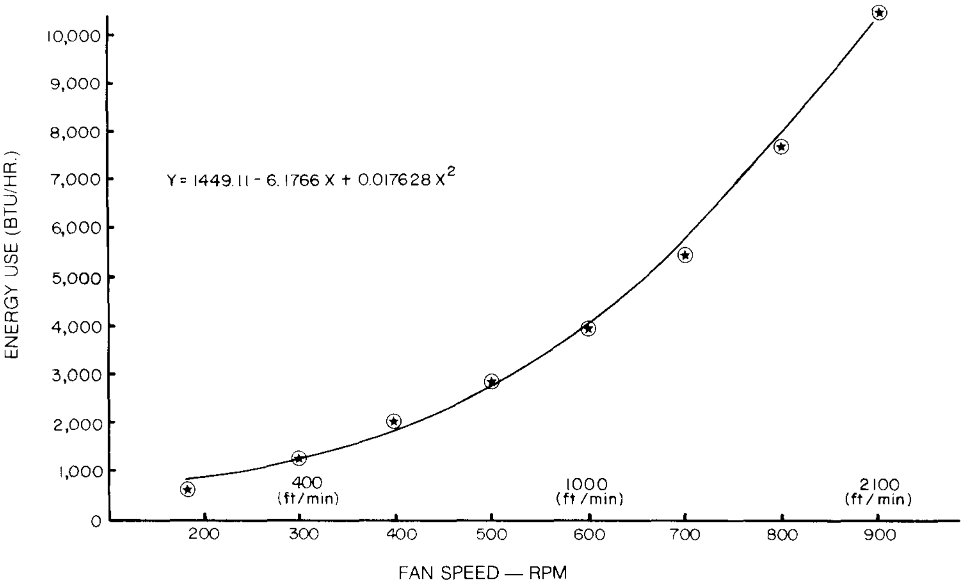

FIG. 6. Relationship of energy consumption (Btu's per hour) to fan speed (RPM). Numbers in parentheses are air velocities in feet per minute associated with specific fan speeds.

The average differences between energy consumed at high temperatures and conventional temperatures in the study kiln can be adequately explained by the energy lost by radiation and air leaks. Data collected from operating the kiln with a charge of completely dry wood permitted calculation of equations that very accurately predicted energy consumption during the early stages of drying (Fig. 3). The rate of energy consumption was high during warmup and the early stages of operation. Energy was being used at a nearly constant rate after 30 h of consumption. Beyond 30 h, it was used at a constant rate of 67,161 Btu's per hour to maintain the kiln at a temperature of 240 F and 52,140 Btu's per hour to maintain it at 190 F.

A plot of energy use over time for the three high-temperature charges (charges 7, 8, and 9) superimposed on the graph for energy use over time shows that an average of 955 Btu's per pound of water removed was used to heat and evaporate the water in the wood (Fig. 4). A similar plot for the 190 F charges (charges 4, 5, and 6) shows that an average of 930 Btu's was used to heat and evaporate each pound of water from these charges (Fig. 5). The similarity of these energy values for heating and evaporating water at each temperature illustrates that differences in total energy related to drying temperature result from more or less heat loss from the kiln during the drying cycle.

Another factor contributing to higher energy use for schedules that require longer drying time is increased energy consumption for air circulation. Measurement of electrical energy required to move the fans at different rates showed that energy use increases curvilinearly as fan speed increases (Fig. 6). An air velocity of 1,000 feet per minute is recommended for high-temperature drying. The energy required to move air at this velocity through lumber in the experimental kiln was 4,089 Btu's per hour. Although the cost of energy to move air (electrical energy) is quite large, it is only a very small portion of the total energy requirement for drying and would be only a minor contributor to the differences in energy required to dry lumber at different temperatures.

In high-temperature commercial drying, the procedure of drying without venting may be used. It is seldom employed at conventional temperatures and may not represent a valid comparison for energy consumption at different dry-bulb temperatures. Venting at conventional temperatures would decrease the relative humidity of the kiln air and increase drying rate. This would effect a saving in energy used for air circulation. However, venting would increase the heat energy requirement by creating the need to heat air drawn into the kiln. The energy required to heat air introduced into the kiln would probably be greater than the energy saved by reduced kiln residence time.

A test charge of lumber (5,943 pounds original weight and 2,993 pounds dry weight) was dried to 12% average moisture content with constant venting. The relative humidity in the kiln was quite low and the lumber dried in 46 h, compared to approximately 70 h in the closed-vent kiln. Although drying was much faster, energy use was much greater. A total of 9.39 million Btu's was used. This was 3,122 Btu's per pound of water removed, a much higher figure than the average 2,307 Btu's used for drying similar charges at the same temperature with closed vents.

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