SOLAR-DEHUMIDIFICATION LUMBER DRYING

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Because of the high cost and limited supply of oil and natural gas, many industries are seeking ways to conserve energy and are also exploring alternative energy sources. This is particularly true for those industries such as the lumber industry that must dry their product before marketing. Lumber drying consumed 60 to 70 percent of the energy used in lumber processing, or approximately 7.5 x 10^{13} Btu in 1972. This was about 0.1 percent of all the energy used in the United States in that year (7).

Although solar lumber drying kilns have been designed and tested for more than 20 years, few commercial dryers are in operation (4). Drying lumber with solar energy takes longer than conventional kiln drying because of limited kiln temperatures (generally less than 120°F), lack of heat supply at night or during cloudy weather, and unpredictable drying conditions due to changes in the weather. Dehumidification-type wood dry kilns, in which moist air from the lumber is drawn over refrigerator coils to condense out the water, have been in operation commercially in Europe for more than a decade but are just gaining acceptance in North America. Dehumidification kilns dry lumber slower (especially below 20 percent moisture content) and at lower temperatures but require less energy than conventional kilns (3).

The combination of solar-dehumidification drying offers advantages not found when each of these methods is applied separately: initial heat-up of the kiln and wet lumber charge is faster and more economical, drying times are shorter, and drying conditions are less dependent on the weather. Also, the efficiency of the solar collector is increased because of the lowered temperature of air entering the collector. If a nonconventional refrigerant such as R-114 is used, the performance of the dehumidifier is improved by allowing higher operating temperatures.

This paper describes the design of a solar-dehumidifier kiln, and presents the preliminary results on drying rate, power consumption, collector efficiency, and wood quality of 4/4 yellow-poplar (*Liriodendron tulipifera*) lumber.

Solar-Dehumidifier Kiln Construction

Drying Chamber

The kiln has a wooden frame and inside dimensions of 8 feet by 8 feet by 6.5 feet high. The walls, ceiling, and floor are insulated with 6 inches of Fiberglas[1] wool and 2 inches of styrene foam. The interior of the kiln is covered with an exterior plywood that is coated with a sealer. Aluminum siding covers the outside walls. The air inside the kiln is circulated by a 27-inch fan attached to a 1-hp motor (2).

Solar Collectors

Surface area of the solar collectors is 122 square feet. The absorber plates are made from aluminum beer cans cut in half and painted black. Double layer Fiberglas sheets form the cover plates. Blowers circulate the kiln air through the collectors when the collector outlet temperature exceeds the kiln temperature (2).

Dehumidifier

The dehumidifier consists of a 1-1/2-hp open compressor driven by an 1,800 Rpm, 2-hp, 220-volt motor. The compressor and motor are housed outside of the kiln so that they are not exposed to the high temperatures in the kiln (Figure 1). A check valve in the discharge line prevents liquid from backing up into the compressor during off cycle operation.

The condenser has 2.5 square feet of face area and 193 square feet of surface area and is mounted so that the kiln fan will continually draw kiln air through it. The liquid refrigerant leaving the condenser goes through a thermo expansion valve that produces 10°F superheat at the compressor inlet. The evaporator is four rows deep and has a surface area of 78 square feet and a face area of 1 square foot. Moist air from the kiln is drawn through the evaporator, which cools and removes the moisture from it. Then the cool, dry air is divided into two flow streams--one to each of the two solar collectors. The refrigerant leaving the evaporator returns to the compressors through 1/2-inch copper tubing. All refrigeration tubes are insulated to reduce heat losses. A suction line accumulator is upstream of the compressor to reduce slugging during start-up.

System Control

Two control devices are used in the solar-dehumidifier kiln: (1) the solar collector blowers activate whenever the outlet temperature of the collector exceeds the kiln temperature and (2) the dehumidifier activates whenever the relative humidity (RH) in the kiln exceeds a preset value on the humidistat (e.g., 80 percent). However, when there is no sunshine but the RH in the kiln exceeds a preset value, the blowers will be on but the air flowing through the evaporator will return to the kiln without going through the solar collectors (Figure 1). Thus, the control of the solar collectors and the dehumidifier are independent of each other. A thermocouple on the compressor discharge line shuts off the compressor motor when the refrigerant temperature exceeds a preset value (about 225°F) to avoid damage to the compressor discharge valve.

Materials and Methods

A 500-board-foot charge of green 4/4 yellow-poplar boards were dried from 121 percent moisture content (MC) to 8 percent MC in a solar-dehumidifier kiln in December 1979. The boards were 8 feet long, 4 or 6 inches wide, and 1 inch thick.

Kiln air velocity was set at 250 feet per minute (fpm), and the solar collector air velocity was set at 520 fpm. The humidistat was set from 25 to 80 percent RH depending on the MC of the wood (Table 1). An attempt was made to relieve drying stresses in the wood by resetting the humidistat back to 80 percent RH for 14 hours when the three wettest sample boards reached 15 percent MC.

Boards were weighed before and after drying to calculate the total weight of water removed. Weights of six sample boards were checked twice a day until the three wettest boards reached 8 percent MC. Twenty percent of the boards were measured for thickness and width at three different points before and after drying to calculate shrinkage due to drying. All boards were graded before and after drying to determine grade drop due to drying. After kiln drying, those 20 percent randomly selected boards were measured for crook, bow, and twist, and all boards were inspected for surface checking, end checking, and collapse. Two stress pins were cut from each of the six moisture sample boards and from each of six randomly selected boards to examine the degree of drying stresses.

The electric energy consumed by the compressor motor for the dehumidifier was recorded by a watt-hour meter. The power consumption rates of the collector blowers and the circulation fan were measured by an ampere meter. The hours of operation of the fan and blowers were automatically recorded.

The ambient temperatures (both dry and wet bulb), the kiln temperatures (both dry and wet bulb), and the inlet and the outlet temperatures of solar collectors were recorded at 10-minute intervals. Also, solar radiation was recorded throughout the run by a pyranometer mounted on the solar collectors.

Results and Discussion

The time required to dry green 4/4 yellow-poplar lumber from 121 percent MC to 8 percent MC in the solar-dehumidifier kiln was 18 days during December 1979. This was approximately twice as fast as drying in a solar kiln during the winter months of the year (6) but was only half as fast as drying in a conventional steam- or gas-heated kiln (5). Drying from green to 20 percent MC took 12 days, during which the drying rate was constant at about 8 percent MC/day (Figure 2). Then the drying rate slowed down considerably from 20 percent MC to 8 percent MC. Two apparent causes contributed to the decrease in drying rate during this period. First, the humidistat was set back to 80 percent RH for 14 hours between days 13 and 14 to equalize and thereby relieve drying stresses in the wood (Table 1). Second, the dehumidifier was shut down due to a refrigerant leak for 21 hours between days 15 and 16, which greatly reduced the drying rate during that period. The average kiln temperature during the run was only 94°F because two-thirds of the days were cloudy. This low kiln temperature reduced the dehumidifier's capacity to remove water from the wood and, thus, slowed down the drying rate during the entire run. The dehumidifier only removed 4.0 lb of water/hr during the run but it is capable of removing 20 lb/hr at 180°F.

The efficiency of the solar collector during sunny days was about 43 percent, which was expected because the air velocity through the collectors was reduced to decrease power consumption and to increase the outlet temperature.

The quality of solar-dehumidifier dried wood was excellent and the light color of the lumber was aesthetically pleasing. No collapse, surface checking, or end checking was noted and volumetric shrinkage was similar to solar kiln-dried but 20 percent less than conventional kiln-dried yellow-poplar (Table 2). The dry warpage was slightly less than solar and slightly more than conventional kiln-dried yellow-poplar. Drying degradation was less than solar drying. The 14-hour reversal of RH in the kiln to 80 percent did not remove the moderate drying stresses that occurred in the solar-dehumidifier dried wood (Figure 3).

Although the run consumed approximately three-fourths of the power compared to a conventional kiln (1), it consumed the same amount of power as a solar kiln (6). High air velocity across the condenser and continuous running of the kiln circulation fan accounted for about 40 percent of the total power consumption.

Future Plans

We plan to test at least one run per season for 1 year to examine the affect of season on the drying time and rate of 4/4 yellow-poplar. We expect a better performance of the dehumidifier in spring through fall. Operating at a higher kiln temperature will increase the capacity of the dehumidifier to remove water as well as increase the drying rate of the lumber.

We also plan to try to reduce power consumption through better control of blowers and the circulation fan.

Footnote

[1]Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.

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Table 1.--Drying conditions and moisture content (MC) of solar-dehumidifier dried 4/4 yellow-poplar lumber

Elapsed time	RH setting	MC of lumber	Drying chamber: Maximum daily temperature	Drying chamber: Minimum daily RH	Insolation
Days	Percent	Percent	°F	Percent	Btu/ft^2-day
0	80	121	85	66	1,681
1	80	113	103	56	1,013
2	80	102	88	70	100
3	80	96	71	72	459
4	80	91	101	65	1,932
5	80	79	95	60	1,848
6	80	69	77	66	491
7	80	63	92	58	1,498
8	80	55	98	68	1,884
9	75	47	108	65	1,794
10	65	37	110	57	1,763
11	35	27	89	52	93
12	25	20	91	44	80
13	80[1/]	15	100	41	95
14	25	13	98	41	77
15[2/]	25	11	86	38	80
16[2/]	25	10	105	46	1,228
17	25	9	94	37	152
18	25	8	95	37	486

1/ Humidistat was set back to 80 percent RH for 14 hours.

2/ Dehumidifier inoperational for 21 hours.

Table 2.--Comparison of properties of solar-dehumidifier, solar (6), and conventional kiln-dried (5) 4/4 yellow-poplar

Property	Solar-dehumidifier	Solar kiln	Conventional kiln
Moisture content, %			
Green	121	99	102
Dry	8	14	8
Dry warpage, inches			
Twist	0.08	0.17	0.09
Bow	0.11	0.13	0.05
Crook	0.19	0.19	0.03
Volumetric shrinkage, %	9.6	9.2[1/]	12.1
Grade drop, %	3.0	5.0	-

1/ Corrected to 8 percent moisture content.

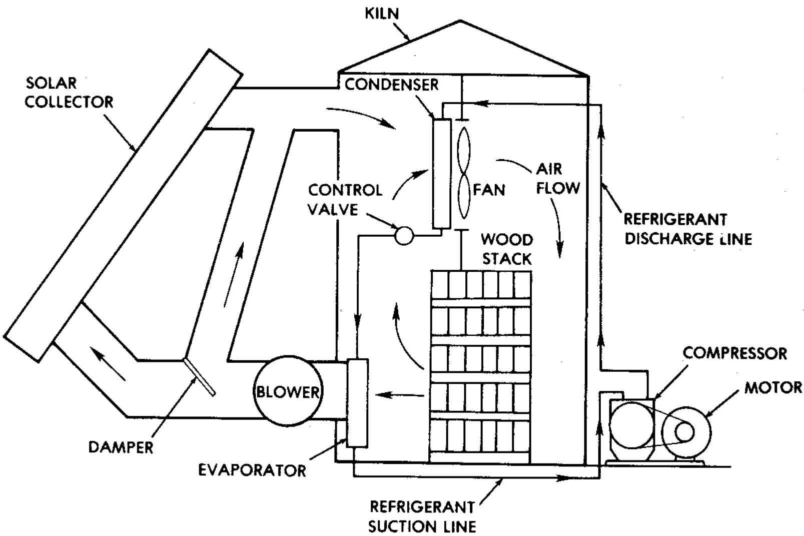

Figure 1.--Solar-dehumidification lumber drying kiln.

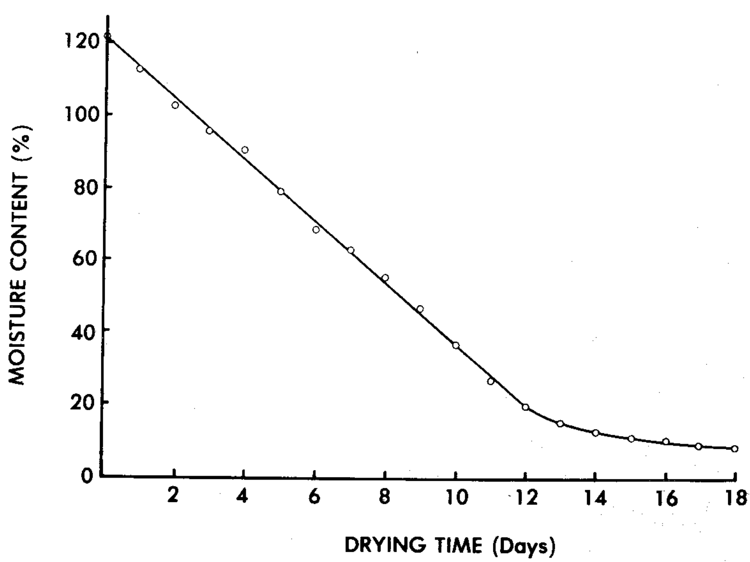

Figure 2.--Drying curve for solar-dehumidification drying of 4/4 yellow-poplar during December 1979 in southern Illinois.

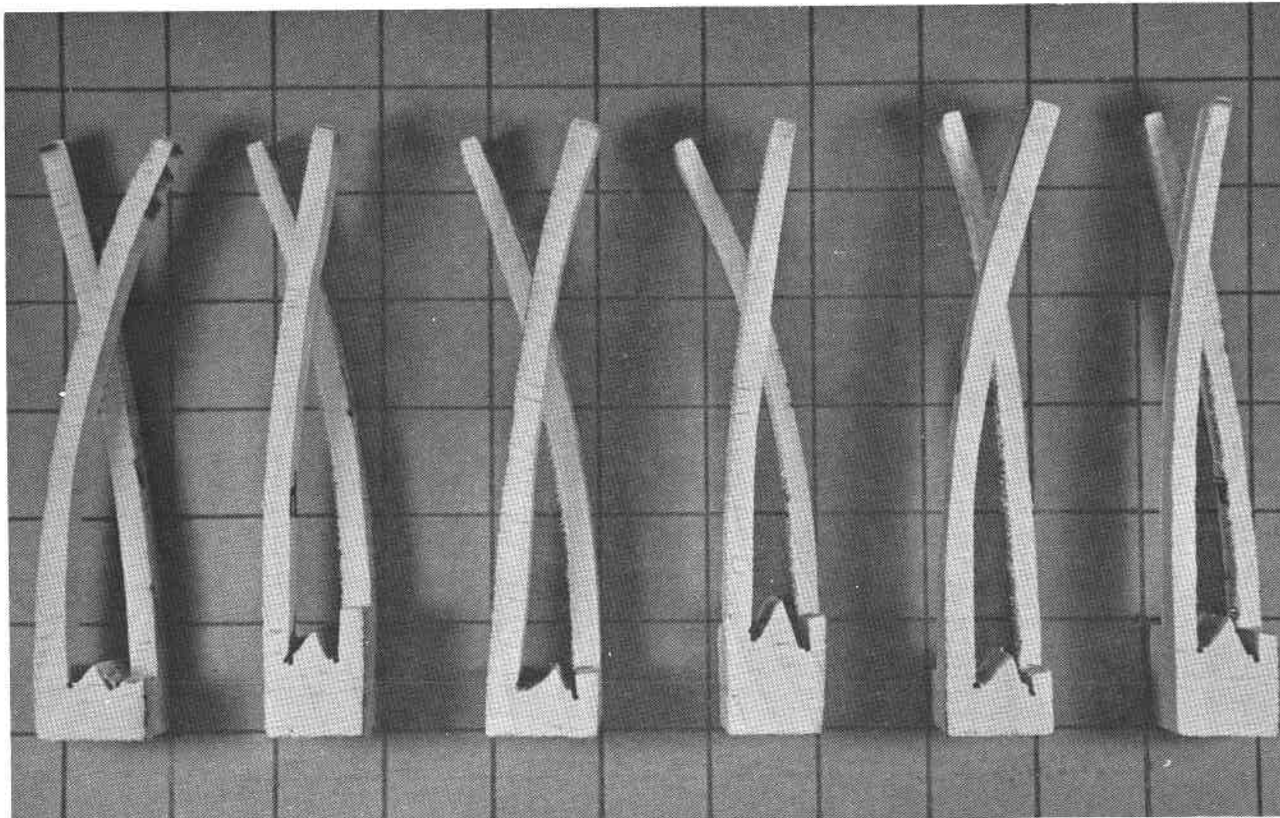

Figure 3.--Demonstration of internal stresses remaining in solar-dehumidifier dried lumber.