DEHUMIDIFICATION DRYING OF SPRUCE STUDS

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INTRODUCTION

Industry is becoming increasingly concerned about the rising cost of energy and possible future energy shortages. In the lumber industry this concern is primarily related to the cost of kiln drying. A new system currently receiving attention is drying by dehumidification.

In this process hot, moist air from the drying chamber is forced over the cold evaporator coils in the dehumidification unit. The moisture in the air condenses on the coils and the water is drained from the system. The sensible heat removed from the air and the latent heat of condensation causes the refrigerant fluid in the evaporator to vaporize. The heated refrigerant vapor is then cycled through the compressor where it absorbs some additional heat energy equivalent to the work input of the compressor. As a hot gas at high pressure the refrigerant passes through the condenser, at which point the acquired heat is transferred back to the "dry" kiln air coming from the evaporator, and the refrigerant reverts to the liquid state. In this manner heat is recycled, whereas in conventional kiln-drying systems considerable heat is exhausted to the atmosphere through venting.

In addition to the energy input of the compressor, the dehumidification system utilizes an electrical resistance heater for a few hours at the beginning of a run to bring the temperature up to approximately 25°C (77°F), the minimum temperature at which the heat recovery cycle is considered effective.

The dehumidification drying technique has advantages and disadvantages in comparison to conventional kiln-drying systems, and there are several economic uncertainties which must be considered.

Advantages

(1) In addition to the efficient utilization of available heat, the low operating temperature of dehumidifiers imposes fewer restrictions on materials and design of the drying chamber. The system can be adapted to any enclosure which is reasonably air-tight, moisture-resistant and insulated. Small driers can be built indoors using a simple, insulated, wood-frame construction with plywood, plastic or metal sheathing.

(2) Maintenance costs and peak energy requirements are comparatively low, and up to a certain kiln capacity, perhaps 45 to 70 cubic meters (20 to 30 Mbf) the initial capital investment in heating equipment would be less than that for conventional kilns.

(3) The system operates at relatively low temperatures, up to about 49°C (120°F), and as drying rates are unavoidably slower than

for conventional kiln drying, a number of similar hardwood or softwood species can be dried at the same time.

Disadvantages

(1) The low operating temperatures result in a substantial increase in drying time. To maintain annual production rates comparable to conventional systems, dehumidifier kilns of greater capacity would be required. This is particularly true for softwood operations where normal drying times are relatively short. Thicker lumber will require longer drying time, especially for species which are normally kiln dried rapidly at higher temperatures.

(2) The system provides no means of conditioning lumber for stress relief. To properly complete the drying process, the chamber should be fitted with some type of humidification system, either steam spray from a small generator or an atomized hot water spray.

(3) Kiln temperatures and drying rates are comparatively low and therefore kilns must be well insulated to prevent heat loss during winter months, as any reduction in temperature will result in a substantial increase in drying time. In some installations it may be necessary to use a supplementary source of heat to maintain effective drying temperature.

General

From the available information, it appears that dehumidification drying may present a technically viable alternative to conventional kiln-drying.

This preliminary study was designed to provide some comparative data on energy consumption and to test instrumentation for the development of drying schedules to optimize the efficiency of the process. Additional work is being undertaken to further assess the relative economics of the technique and its application in relation to conventional kiln-drying.

DEHUMIDIFICATION EQUIPMENT

The dehumidification unit, designed by Ontario Hydro, was fitted to one of the Laboratory's 1.4 m^3 (600 fbm) experimental kilns (Figure 1). Insulated air ducts and a 0.85 m^3/s (1800 cfm) fan in the dehumidification unit are used to circulate air to and from the kiln, and the normal kiln fans are used to circulate the air through the lumber which is stacked in the conventional manner. A small electrical heater (4 Kw) in the dehumidifier exit air duct is used to bring the kiln charge up to effective operating temperature.

The only humidity available during drying is that produced by the evaporation of moisture from the wood. By controlling the rate at which this humidity is removed, a schedule can be established whereby the drying rate is adjusted to suit the particular species and thickness of lumber being dried.

Wet-bulb temperature

Control of the drying rate is based on maintaining a suitable wet-bulb depression. Wet and dry-bulb thermocouples, located in the return air duct (Figure 2) are connected to a differential-reading thermocouple thermometer. The temperature differential or depression is translated into a voltage signal which operates an adjustable voltage-sensitive relay. When the depression falls below the set level the relay opens a liquid line solenoid valve, refrigerant flows through the evaporator coils, pressure in the coils increases and, at 379 kPa (55 psi), a pressure switch engages the compressor. This starts the dehumidification process and as water is removed from the air the wet-bulb temperature drops, causing the depression to increase. At a depression slightly greater than the set level the voltage signal closes the solenoid valve, pressure in the evaporator drops, and at 103 kPa (15 psi) the compressor shuts off. Moisture continues to evaporate from the lumber, causing the wet-bulb temperature to increase until the depression once again falls below the set level. In this manner the cycle is repeated, maintaining the wet-bulb depression within ± 0.7°C (1.3°F) of the set level.

Dry-bulb temperature

Initially the auxiliary electrical heater is used to raise the temperature to a thermostat setting of 24°C (75°F), at which point the heater automatically shuts off. This provides the heat energy necessary to raise the kiln temperature to an effective level for efficient heat recovery, and through the additional heat supplied by the dehumidification process the kiln temperature slowly increases through an operating range of about 27 to 49°C (80 to 120°F) depending on the wet-bulb depression and MC of the lumber.

The dry-bulb temperature in dehumidification drying systems is limited by the operating pressure in the condenser. The study unit, using "refrigerant 22", is designed for a maximum condensing pressure of about 1862 kPa (270 psi), at which point the kiln temperature is approximately 49°C (120°F). To prevent overheating of the system during the initial warm-up period, the electrical heater circuit has a high-temperature limit switch which, in the event of thermostat failure, shuts off the heater if the temperature in the heater housing exceeds 57°C (135°F). Similarly, the compressor will shut off if the temperature causes the pressure in the condenser to exceed a safety limit of 2068 kPa (300 psi). The safety limit switch must be reset manually and therefore, to avoid the possibility of a shut-down, the kiln vents were set to open at 46°C (115°F), so as to exhaust heat if necessary. This situation was not encountered, although the uncontrolled dry-bulb temperature was allowed to establish its own level in accordance with the set wet-bulb depression.

MATERIAL AND PROCEDURES

Approximately 7 m^3 (3 Mbf) of mill-run eastern spruce studs (no jack pine or balsam fir) were obtained as study material. Four kiln charges were prepared, each containing 150 studs with similar distributions of grades, ranging from Select Structural to No. 3 (National Lumber Grades Authority, Standard grading rules for Canadian lumber). The average initial MC of charge 3 was high, (89 percent) due to a high proportion of sapwood, whereas other charges had average initial MC's ranging from 52 to 64 percent (Table 1).

The width and thickness of 25 percent of the studs in each charge were measured for shrinkage determination. Average green dimensions were 1-9/16-inch by 3-9/16 inches (39.7 by 90.5 mm). Studs were piled on 11/16-inch (17.5 mm) stickers placed on 24-inch (61 cm) centers and a dead weight of approximately 20 lb/sq. ft. (98 kg/m^2) was placed on top of each load. One charge was dried as a control, with a conventional kiln schedule (Table 2), using steam heating and humidification. The remaining charges were dried by the dehumidification process, one under mild conditions (Schedule B) and two under slightly more severe conditions (Schedule A, Table 3). Eight sample boards in each charge were used to establish drying curves. The conditioning period was omitted from the conventional schedule so as to be comparable with dehumidification drying in terms of the final quality of the lumber.

For comparison of energy consumption, kilowatt hour (kwh) readings were taken at regular intervals during the dehumidification process; and both kilograms of steam (flow meter) and kilowatt hours for the kiln fans were measured during conventional kiln drying.

Operating procedure for the dehumidification process:

(i) Kiln fans were set to produce an average air velocity of 0.51 m/s (100 fpm).
(ii) Dehumidifier circulation fan was turned on and thermocouples and electrical heater were energized.
(iii) Desired wet-bulb depression was set.

All charges were dried to an average MC of 16 percent based on the calculated MC of the sample boards. Dry studs were dual graded (with and without drying defects considered) according to NLGA rules for structural light framing, and measurements were made for warp, shrinkage and final MC. To locate any pieces exceeding 19 percent MC, each stud was tested at room temperature using a resistance-type moisture meter. The electrodes (2-pin insulated were driven to mid-thickness at one-foot intervals along the stud length. When the meter test indicated a MC in excess of 19 percent, an oven dry determination was conducted on a specimen cut from the joist at that point.

RESULTS

Drying time

Drying times from green to an average MC of 25 and 16 percent are shown in Table 1. The time to 16 percent MC was about 4 days for each dehumidification charge to 2.3 days for the conventional charge. Differences in initial green MC had little effect on the total drying time to 16 percent for the dehumidification process. Even with a difference in average green MC of 30 percent (charges 2 and 3), there was essentially no difference in average dry MC. Furthermore, the high variation in green MC for charge 3 standard deviation (SD) of 29.2 was effectively reduced and variation in the final MC was similar to that of the other charges. As expected, variation in dry MC for the faster-drying conventional system was somewhat greater, with a SD of 3.1 compared to 1.8 to 2.3 for the charges dried by the dehumidification process.

Drying times to 25 percent average MC are given primarily to illustrate the pronounced change in the drying rate for the dehumidification process at moisture contents below the fiber saturation point (FSP) i. e., 25 to 30 percent MC. For charges of similar green MC (charges 2 and 4), the drying time to 16 percent MC was 39 hours longer (70 percent) for dehumidification drying, whereas at an average of 25 percent MC the difference was only 9 hours. The drying rate for charge 3 was relatively fast, due to the high proportion of sapwood. Drying curves for all charges are shown in Figure 3.

Lumber quality

In overall appearance the quality of the studs dried by the dehumidification process was not appreciably different from that obtained by conventional kiln drying although an evaluation of degrade showed that a higher portion of studs maintained their grade when dried by the dehumidification process (Table 4). This trend is also evident in the average warp measurements shown for the four charges. It is expected that the omission of the conditioning period contributed somewhat to the larger grade drop in conventionally-dried studs.

Shrinkage in width and thickness was slightly less for the studs dried by dehumidification. Prong tests made on several studs showed noticeable case-hardening but, considering the end use of the material, this was not a significant factor.

Energy consumption

Drying by dehumidification resulted in substantially less in energy consumption compared to conventional drying (Table 5 and Figure 4). For the two charges of similar initial MC, dehumidification required approximately 67 percent less energy in reducing the MC to 25 percent; however, with the subsequent decrease in drying rate, the saving in energy at the final MC of 16 percent was only 56 percent.

Naturally the initial MC of the lumber is an important factor in total energy consumption. For each pound of water evaporated a certain quantity of heat energy is required; however, as MC decreases a higher temperature is required to achieve or maintain an acceptable drying rate. In dehumidification drying the capacity to increase temperature is minimal and therefore drying times are much longer, resulting in greater net loss through leakage and transmission. Since the drying rate below FSP is slow, the energy required to reduce the MC from 25 to 16 percent may be as much as or more than that required in drying from green to 25 percent MC. Dehumidification charge 1 (Schedule A), at an average green MC of 51.6 percent, required 125 kwh in drying from green to 25 percent MC, whereas a further reduction of only 9 percent MC required an additional 138 kwh.

Energy consumption for dehumidification drying is also affected by the drying schedule used. Schedule A, charge 1 (96 hours) required a total of 263 kwh, whereas Schedule B, charge 2 (95 hours), required 336 kwh (Table 5). A higher energy consumption was expected for charge 1 since its average green MC was somewhat higher; however, the increase of 73 kwh cannot be attributed entirely to a difference of

7 percent in initial MC. Variation in the set wet-bulb depression affects the running time of the compressor and this in turn has an effect on total energy consumption.

SUMMARY

1. This study shows that dehumidification drying has potential as an energy-saving system. Compared to conventional kiln drying, energy consumption can easily be reduced by more than 50 percent when drying spruce studs to a final MC of 16 to 19 percent. Furthermore, the dehumidifier used in the study was designed to handle larger volumes of lumber and consequently was not used to maximum efficiency. The portability of the unit also restricted design efficiency to some degree. Since the unit was used outside the kiln, all heat transmitted from the unit was lost whereas units used inside the kiln would add their transmission losses to the heating of the drying chamber.

A well-designed commercial system could conceivably reduce energy consumption by 60 to 70 percent. This, however, does not necessarily apply to lumber dried to 6 to 8 percent MC. The drying rates decrease rapidly below 25 percent MC and any energy saving may be minimized or lost in the time required to reduce the MC to 8 percent.

2. The quality of the lumber dried by the dehumidification process is comparable to, or slightly better than, that normally obtained by conventional kiln-drying. This is a normal consequence of slower drying. However, without provision for final conditioning of the lumber, severe case-hardening will result and therefore some type of supplementary humidification system must be included to complete the drying process properly. This is particularly critical for shop lumber which is to be machined or resawn.

3. Dehumidification drying results in a considerable increase in drying time. Compared to conventional kiln drying, spruce studs required 70 percent more time when dried to 16 percent MC by the dehumidification process.

4. A substantial saving in energy does not necessarily reduce total drying costs. The comparative economics of dehumidification and conventional drying methods will depend on differences in drying time (species, lumber thickness and final MC), size of kiln and equipment, and the cost of alternative energy sources.

FUTURE CONSIDERATIONS

1. Future studies should examine the potential of a combination dehumidification-electrical heating system whereby electrical heating is used at moisture contents below 25 percent, to increase temperature and drying rate when low moisture contents are required.

2. An evaluation of the overall economics of dehumidification drying is required to fully assess the commercial implications of the system.

ACKNOWLEDGMENT

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Tables to supplement, *Dehumidification Drying of Spruce Studs* by M.Y. Cech and F. Pfaff, in the Proceedings of the 28th annual meeting of Western Dry Kiln Clubs

Table 1. Average Moisture Content and Drying Time for Spruce Studs.

Drying Method	Moisture Content (%)		Pieces Exceeding 19% MC Limit (%)	Drying Time (h)	
	Green	Dry		to 25% MC	to 16% MC
Dehumidification					
Schedule A					
Charge 1	51.6(7.6)[1]	16.3(1.8)	3.3	38	96
Schedule B					
Charge 2	58.7(9.4)	15.9(2.2)	5.0	44	95
Charge 3	89.1(29.2)	15.8(2.3)	4.0	64	98
Conventional kiln-drying					
Charge 4	64.2(11.0)	15.9(3.1)	6.0	35	56

[1] Figures in parentheses are standard deviations.

Table 2. Conventional Kiln-Drying Schedule[1] (Spruce Studs).

Time (h)	Temperature Dry-bulb °C	Dry-bulb °F	Wet-bulb °C	Wet-bulb °F	Relative Humidity (%)	EMC[2] (%)
17	65.6	150	57.2	135	66	9.8
24	71.1	160	54.4	130	43	5.3
15	82.2	180	54.4	130	26	3.0
56						

[1] Air velocity of 1.8 m/s (350 fpm) throughout.

[2] Equilibrium MC.

Table 3. Drying Schedules for the Dehumidification Process (Spruce Studs).

Schedule[1]			Approximate Drying Conditions[2]			
Time (h)	Set depression (kiln exit air) C°	F°	Dry-bulb temperature °C	°F	Relative humidity (%)	EMC (%)
			Schedule A			
5[3]	5.6	10	--	--	--	--
42	5.6	10	28.9	84	63	11.5
30	10.6	19	32.2	90	39	7.1
18	13.3	24	32.8	91	27	5.0
95						
			Schedule B			
5[3]	5.6	10	--	--	--	--
15	5.6	10	27.2	81	61	11.3
24	8.3	15	27.8	82	45	8.3
25	11.1	20	30.0	86	33	6.1
26	13.9	25	33.9	93	26	4.9
95						

[1] Wet-bulb depression varies slightly in response to $\pm$ 0.7°C (1.3°F) on-off compressor activating range.

[2] Values are approximate as there is no direct control of dry-bulb temperature.

[3] Time to reach set conditions - includes 1 1/2 to 2 h auxiliary electric heating.

Table 4. Shrinkage, Warp, and Grade Drop of Spruce Studs.

Drying Method	Average Shrinkage (%)		Average Warp (in)[1]			Grade Drop (%)		
	Width	Thickness	Twist	Bow	Crook	Number of grades dropped		
						1	2	3
Dehumidification								
Schedule A								
Charge 1	2.1	2.5	0.21	0.15	0.16	9.2	12.7	3.5
Schedule B								
Charge 2	2.4	1.9	0.15	0.16	0.17	5.4	13.0	4.3
Charge 3	2.5	2.3	0.23	0.20	0.17	10.8	12.9	5.8
Conventional kiln-drying								
Charge 4	2.8	3.1	0.20	0.19	0.21	15.5	11.3	6.3

[1] Based on 8-foot studs.

Table 5. Energy Consumption: Dehumidification and Conventional Kiln-Drying (Spruce Studs Dried to 16% MC)[1].

Drying Method	Green MC (%)	Electrical Energy (kwh)	Steam[2] (kg)	Total Energy[3] (GJ)
Dehumidification				
Schedule A				
Charge 1	51.6	210 (53)[4]		0.947
		104 (21)		0.450
Schedule B				
Charge 2	58.7	283 (53)		1.210
		150 (24)		0.627
Charge 3	89.1	375 (54)		1.545
		240 (35)		0.990
Conventional kiln-drying				
Charge 4	64.2	(51)	1182	2.786
		(32)	798	1.872

[1] Underlined values are for energy consumption at 25% MC.

[2] Average guage pressure of 95 kPa (13.8 psi).
(Heat from steam taken as latent heat only: 1 kg = 2.201 x 10^{-3} GJ).

[3] 1 Gigajoule (GJ) = 948, 406.68 BTU = 277.72 kwh.

[4] Figures in parentheses represent the additional electrical energy consumed by the kiln circulation fans.

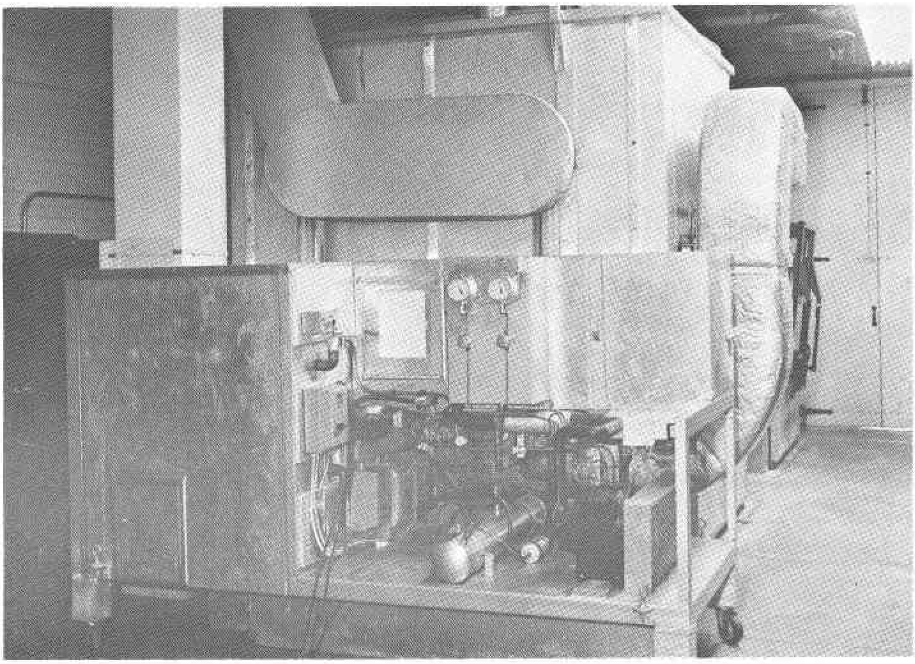

Figure 1. Dehudifier unit.

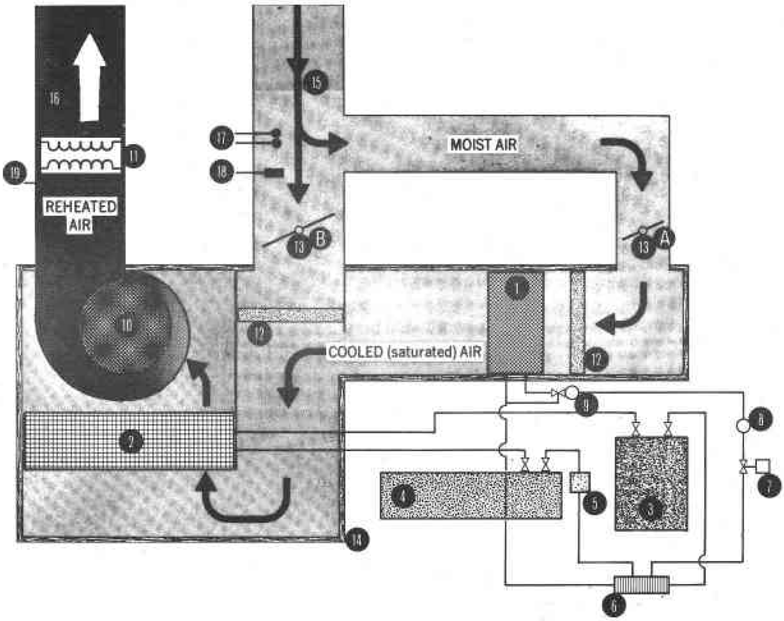

Figure 2. Design of a dehumdification system.

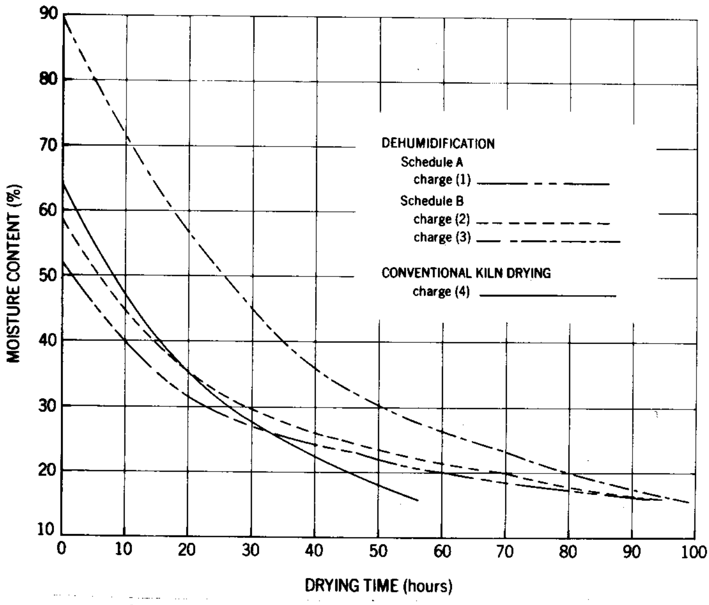

Figure 3. Drying curves for spruce studs.

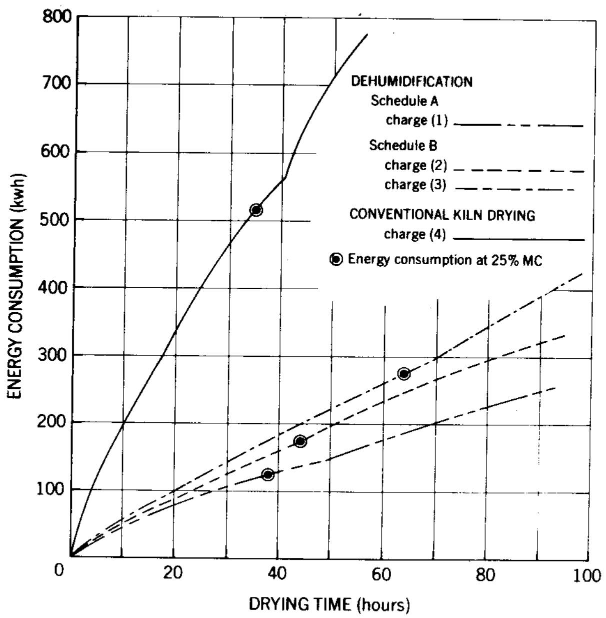

Figure 4. Energy consumption (includes energy for circulation fans).