Full-time Or Part-time Kiln-drying?

Comparison Of The Energy, Drying Time And Costs

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Summary

Kiln-drying data were obtained on green 4/4 Northern red oak under three methods of kiln operation: (1) Heat, spray, and air circulating systems in continuous operation; (2) part-time operation of heat and spray systems with full-time circulation of air; and (3) part-time operation of heat, spray, and air circulating systems. Two kiln charges were dried under each of the three procedures. The same drying schedules were used for all runs.

The drying data indicated that:

1. Method 1 required less total energy to evaporate a pound of water from a kiln charge. Method 2 required the greatest amount of energy to evaporate a pound of water from the actual kiln charges; however, Method 3 required the most energy to evaporate a pound of water when all three methods were calculated on the basis of a full charge of 1,723 board feet of lumber.
2. A high percentage of the energy supplied was lost by heat transmission through the kiln structure, leakage, and venting.
3. The shortest drying time was under Method 1, and the longest drying time was under Method 3.
4. The cost of evaporating a pound of water was least under Method 1 and greatest under Method 3.
5. Surface checks occurred and began to close at a lower average moisture content under part-time drying procedures than under continuous operation.
6. The amount of surface checking that developed was about the same in all three methods.
7. There was no significant difference in the total shrinkage of the boards between the three methods of operation.
8. The quality of the kiln-dried material appeared to be the same under all three methods.
9. The total on-time under part-time operation is only about 20 to 25 per cent of the total time required for drying. Therefore, while the drying schedule during part-time operation can probably be more severe than that used for full-time operation, it will have little effect on total time in the kiln.

Introduction

Part-time kiln operation has been used by many plants, particularly those drying hardwoods, for many years. Studies made and reports received on this type of operation have been conflicting.[2,3,4] It has been fairly well established that part-time kiln operation will increase the over-all time in the kiln. There are differences of opinion, however, on the over-all energy requirements and drying costs, and the quality of drying obtained from part-time drying as compared with full-time drying.

So far as is known, there have been no studies made to determine the energy required for part-time drying as compared with that for full-time drying. This report covers such a study. In addition, the report contains information on drying time and quality.

Material and Equipment Used

The study was made on six charges of Grade 1 and Better green 4/4 Northern red oak. The charges ranged in footage from about 1,500 to 1,700 board feet.

Kiln No. 5 at the Forest Products Laboratory was used for the study. The inside dimensions of this kiln, located within the main building, are 8 feet wide, 18 feet long, and 12 feet high. The walls are constructed of hard-burned brick and are 12 inches thick. Roof and floor are of concrete, with the roof 6 inches thick and the floor 4 inches. Both side walls of the kiln are common, with kilns located on either side. The adjacent kilns were maintained at a temperature of about 80° F. during each charge dried in kiln No. 5 to reduce the effect of varying ambient temperatures on heat losses through the kiln structure.

Air is circulated by four 24-inch-diameter propeller-type fans, each directly connected to a % horsepower motor. Air circulation could be reversed automatically by a reversing switch. During the study, circulation was reversed every 6 hours. The air velocities through the loads of lumber averaged about 270 feet per minute.

Measurements of energy used during the study were made with meters. Steam used for heat was measured by a condensate meter; steam spray used for humidification, by a steam-flow meter; and power supplied to the fans, by a kilowatt-hour meter.

Dry- and wet-bulb temperatures were automatically controlled by an air-operated recording-controlling instrument.

Procedure

Drying *Methods*

Two kiln charges were dried under each of three methods. Under Method 1 the dry kiln was operated continuously; the desired drying conditions at the various stages of drying were constantly maintained from start to finish of drying.

Under Method 2 the fans were operated continuously, but the steam

[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2]Campbell, G. S. "A Comparison of the Effect of Three-Shift and One-Shift Kiln Operation on the Drying Time of 1-Inch Mixed Sawn Mountain Ash. Project S. 6-5/12. Division of Forest Products, Commonwealth Scientific and Industrial Research Organization, Australia. 1952.

[3]Devine, John. "Production Kiln Drying." 149 pp., illus. 1959.

Wolfe, C. "Part Time Drying," Journal of the Forest Products Research Society, June 1952.

used for heat and spray was on for only 8 hours for 5 days each week. This meant that the drying conditions were under control only for 40 hours of each week during the drying cycle.

Method 3 consisted of part-time operation of the heat, spray, and air circulating systems operating for 8 hours 5 days per week.

Under part-time operation the systems involved were turned on at 8 a.m. and cut off at 4 p.m. Monday through Friday of each week. Holidays falling within these periods were considered as working days. Also under part-time operation, the reversing switch that controlled direction of air flow across the loads was set to reverse at 6 a.m., noon, 6 p.m., and midnight. This meant that, during the on-time period of 8 a.m. to 4 p.m., air was circulating through the loads for 4 hours in each direction.

Drying *Schedule*

The same drying schedule was used to dry the six kiln charges. This was schedule T4-D2, the schedule recommended in Chapter 8 of the "Dry Kiln Operator's Manual"[5]

[5] Rasmussen, Edmund F. "Dry Kiln Operator's Manual." U. S. Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, Agriculture Handbook No. 188. 197 pp., illus. 1961.

Table 1.--Comparative drying results on drying green 4/4 northern red oak under three methods of kiln operation[1] (based on the actual board footage dried)

Item		Method 1 (Average of runs 1 and 5)	Method 2 (Average of runs 2 and 4)	Method 3 (Average of runs 3 and 6)
Size of kiln charge	bd. ft.	1,495	1,545	1,723
Initial moisture content	percent	77	71.3	69.4
Moisture content at end of drying	percent	6.5	6.2	7.8
Total time in kiln	days	19.1	35.5	49.5
Total "on" time	days	19.1	8.5	11.3
Total "off" time	days	0	27.0	38.2
Total weight of water evaporated	lb.	3,562	3,475	3,877
Average loss of water per day	lb.	186.5	97.9	78.3
Total steam used for heating	lb.	16,450	17,770	20,785
Total steam used for humidification	lb.	113	297	186
Total steam used per pound of water evaporated	lb.	4.65	5.20	5.41
Total power used by fans	kw.-hr.	484.1	958.6	295.3
Power used per pound of water evaporated	kw.-hr.	0.136	0.276	0.076
Total energy supplied	1,000 B.t.u.	17,923	20,851	21,567
Energy required to evaporate 1 pound of water	1,000 B.t.u.	5.03	6.00	5.56
Energy used for:				
Air circulation	percent of total	9.22	15.69	4.67
Evaporating water	percent of total	21.15	18.30	19.47
Humidification	percent of total	0.01	0.02	0.01
Miscellaneous losses (includes transmission, venting, leakage)	percent of total	69.62	65.99	75.85

[1] Does not include equalizing and conditioning treatments.

Table 2,--Comparative drying results on drying 1,723 board feet of green 4/4 northern red oak under three methods of kiln operation[1]

Item		Method 1 (Average of runs 1 and 5)	Method 2 (Average of runs 2 and 4)	Method 3 (Average of runs 3 and 6)
Size of kiln charge	bd. ft.	1,723	1,723	1,723
Initial moisture content	percent	77	71.3	69.4
Moisture content at end of drying	percent	6.5	6.2	7.8
Total time in kiln	days	19.1	35.5	49.5
Total "on" time	days	19.1	8.5	11.3
Total "off" time	days	0	27.0	38.2
Total weight of water evaporated	lb.	4,105	3,875	3,877
Average loss of water per day	lb.	214.9	109.1	78.3
Total steam used for heating	lb.	17,035	18,214	20,785
Total steam used for humidification	lb.	113	297	186
Total steam used per pound of water evaporated	lb.	4.18	4.78	5.41
Total power used by fans	kw.-hr.	484.1	958.6	295.3
Power used per pound of water evaporated	kw.-hr.	0.118	0.247	0.076
Total energy supplied	1,000 B.t.u.	18,502	21,290	21,567
Energy required to evaporate 1 pound of water	1,000 B.t.u.	4.51	5.49	5.56
Energy used for:				
Air circulation	percent of total	8.93	15.36	4.67
Evaporating water	percent of total	23.62	19.98	19.47
Humidification	percent of total	0.01	0.02	0.01
Miscellaneous losses (includes transmission, venting, leakage)	percent of total	67.44	64.64	75.85

[1] Does not include equalizing and conditioning treatments.

for the drying of 4/4 Northern red oak.

Changes in drying conditions were governed by the average moisture content of the five wettest samples in the kiln charge. These changes were made when called for by the schedule, regardless of the time of the day.

Board Data

All boards of each kiln charge were weighed before and after drying to the nearest 0.01 pound. The difference in weight gave the total moisture lost during drying.

All boards were graded green and dry to obtain the degrade during drying. Also, all boards were measured green and dry, in thickness and width, to determine if the three different methods of operation had any significant effect on shrinkage.

Kiln Samples

Ten kiln samples were used in each kiln charge, five on each side of the load. These were selected, prepared, and their moisture content and ovendry weight calculated in accordance with the procedures recommended in Chapter 6 of the "Dry Kiln Operator's Manual."

All kiln samples were weighed and their moisture content calculated at least once daily under full-time operation and at least twice daily under part-time operation. The regular weighings under part-time operation were made at 8 a.m. and 4 p.m. Monday through Friday of each week during the drying cycle. From these two daily weights the moisture lost during the on- and off-time periods was obtained.

To eliminate errors in moisture calculations associated with the presence of water pockets in the kiln samples at time of preparation and possible errors in initial weighings and calculations, intermediate moisture content determinations were made on all of the samples. This determination was made when they reached an average moisture content of about 15 per cent, based on the initial determinations.

The final kiln sample weights and moisture content values were used, together with the final total weight of the kiln charge, to calculate the weight and moisture loss of the kiln charge at each sample weighing.

Steam and Power Used

The amount of steam used for heating was measured with a condensate meter. This meter was read at least once daily under full-time operation and at least twice daily Monday through Friday each week at 8 a.m. and 4 p.m. under part-time

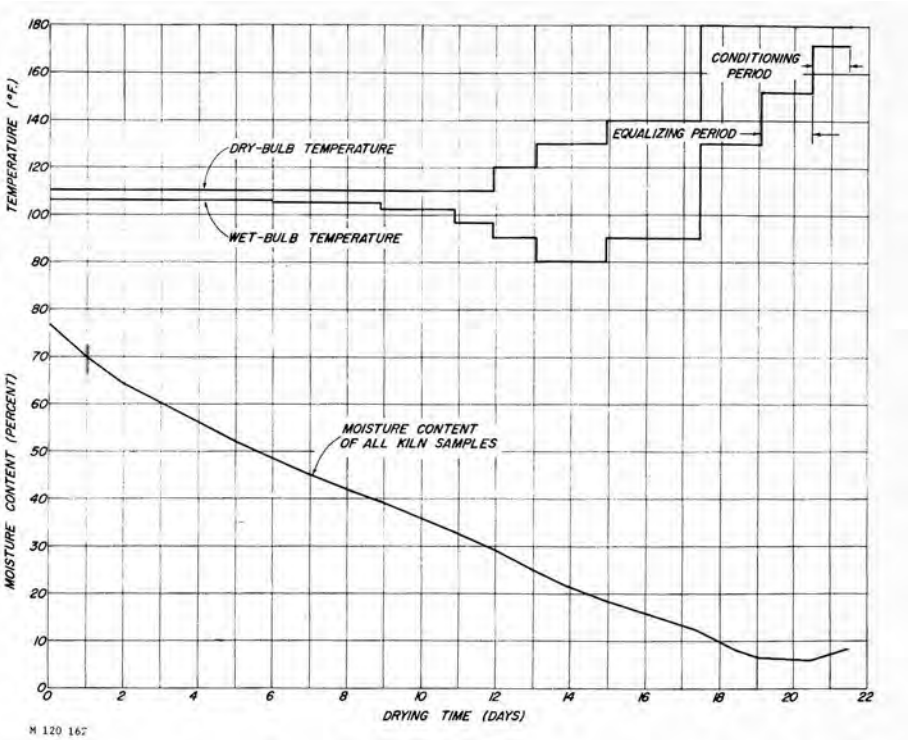

FIGURE 1.—*Kiln conditions and drying* curve *for operational Method 1 (average of runs 1 and 5).*

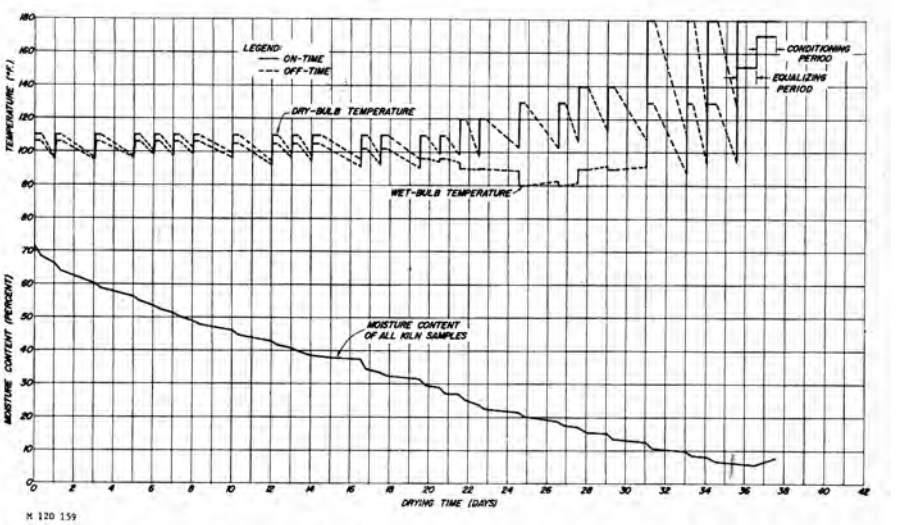

FIGURE 2.—*Kiln conditions and drying curve for operational Method 2 (average of runs 2 and 4).*

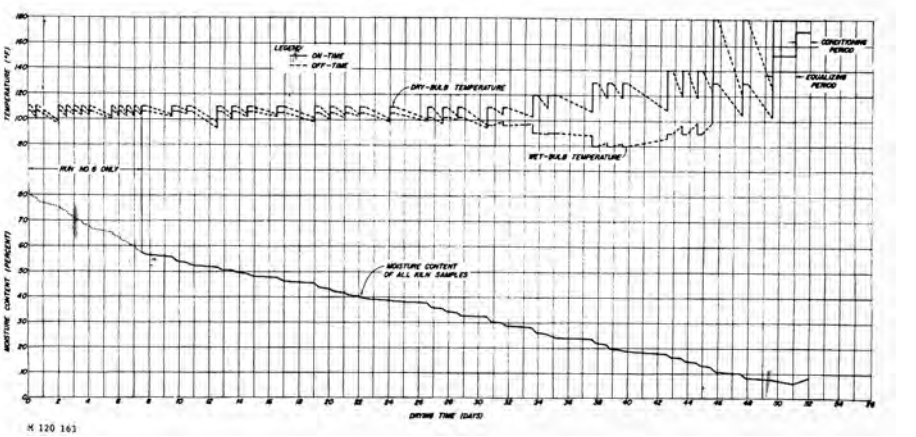

FIGURE 3.—*Kiln conditions and drying curve* for *operational Method 3 (average of runs 3 and 6).*

Table 3.--Comparative drying costs[1]

Item	Operational method 1	2	3
BASED ON ACTUAL BOARD FOOTAGE DRIED			
Fixed charges on dry kiln ($0.75 per day)	14.33	26.63	37.13
Steam costs ($1.50 per 1,000 lb.)	24.84	27.10	31.46
Power ($0.01 per kw.-hr.)	4.84	9.59	2.95
Total cost	44.01	63.32	71.54
Cost of evaporating 1 lb. of water	0.0124	0.0182	0.0185
Cost per board foot	.0294	.0410	.0415
BASED ON FULL KILN CHARGES OF 1,723 BOARD FEET			
Fixed charges on dry kiln ($0.75 per day)	14.33	26.63	37.13
Steam costs ($1.50 per 1,000 lb.)	25.72	27.77	31.46
Power ($0.01 per kw.-hr.)	4.84	9.59	2.95
Total cost	44.89	63.99	71.54
Cost of evaporating 1 lb. of water	0.0109	0.0165	0.0185
Cost per board foot	.0261	.0371	.0413

[1]Based on Laboratory costa.

operation. At these same times a steam-flow meter was read to measure the amount of steam used for humidification, and a kilowatt-hour meter reading was taken to measure the power used by the fan motors for air circulation.

Averaging of Drying Data

To eliminate as much as possible the effects of variables between the lumber in the kiln charges, the data collected on each of the two charges dried under the same method were averaged. Therefore, the results shown for Method 1 are the average of runs 1 and 5; for Method 2, the average of runs 2 and 4; and for Method 3, the average of runs 3 and 6.

Drying Conditions, Drying Time, And Moisture Content

The drying conditions, drying time, and moisture content for each of the three methods of kiln operation are shown in Figures 1, 2, and 3.

The total on- and off-time and total time in the kiln under the three methods of operation are shown in Figures 4 and 5 and Tables 1 and 2. Under the two methods of part-time operation the total on-time was about one-fourth of the total time in the kiln.

The plotted data for the two part-time methods of operation (Figs. 2 and 3) may appear confusing, since the on and off periods do not in all cases tie in with the operational methods as described previously. One reason for this inconsistency is due to the averaging of two runs under each method of operation that involved variations in moisture content throughout the drying cycle. Another reason is that drying times under each drying condition varied between the two runs under each operational method.

Moisture Loss

The total moisture loss in pounds for each method of operation is shown in tables 1 and 2.

Tables 1 and 2 and Figures 4 and 5 also show the average moisture loss per 24-hour period under each method of kiln operation.

Steam And Power Consumption

Data obtained are shown in Tables 1 and 2 and Figures 4 and 5; Table 1 and Figure 4 for the a1Averageln charges, and Table 2 and Figure 5 for full kiln charges of 1,723 board feet.

The break-down of the energy supplied is shown in Tables 1 and 2. The energy in British thermal units was obtained from steam and power tables.

The total energy in 1,000 British thermal units to evaporate 1 pound of water under each method of kiln operation is shown in Tables 1 and 2 and Figures 4 and 5.

A large percentage of the total energy supplied was used to compensate for heat transmission losses through the kiln structure, heat lost by venting, and heat lost through cracks and openings in the kiln structure.

Table 4.--Comparative shrinkage values of northern red oak dried under three methods of kiln Operation

Operational method No.	Shrinkage[1] Width	Thickness
	Percent	Percent
1	6.650	4.548
2	6.801	5.032
3	6.871	3.685

[1]Average of 2 kiln charges for each operational method.

Kiln-Drying Costs

Drying costs for the actual kiln charges and also for kiln charges of 1,723 board feet for each method of operation are given in Table 3. These are based on the drying time, steam and power consumption, and moisture loss values given in Tables 1 and 2.

These costs are based on laboratory cost figures and therefore cannot be applied to commercial operations. Not included in Table 3 are the stacking and unstacking costs and the man hours used to operate the kiln.

Table 3 shows that the fixed costs involved with the kiln itself have a large effect on the total drying cost. It is believed that this will be generally the case at most plants if the dry kilns have not been fully depreciated.

These cost tables bring out one important point. The closer a kiln is loaded to its rated holding capacity, in this case about 1,700 board feet, the lower the drying costs will be regardless of the method of kiln operation.

Other Data Obtained

While the primary purpose of this study was to obtain a comparison of the energy required to dry the same species and thickness of lumber under three different methods of kiln operation, other data were obtained. These included the effect of the different methods of operation on degrade, shrinkage, and occurrence and degree of surface checking.

Also obtained was the steam and power consumption during the equalizing and conditioning treatments. These treatments, on all six runs, were given under full-time operation.

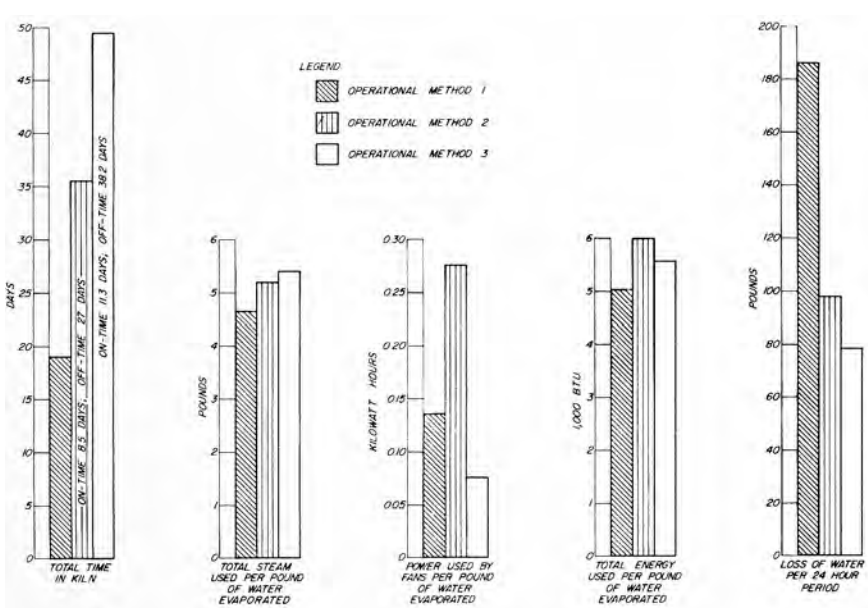

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FIGURE *4.-Comparative results on drying green 4/4* Northern *red oak under three methods of kiln operation based on actual board* footage *in kiln charges. Do* not *include equalizing and conditioning treatments.*

Kiln Degrade and *Footage* Reduction

All boards in each kiln charge were graded and scaled green and rough dry. No significant difference in degrade was found between the three methods of kiln operation.

Loss in footage during drying ranged from 3.07 to 6.51 per cent of the green scale. The average loss of footage for the two kiln charges dried under each method was 3.65 per cent for Method 1, 4.32 per cent for Method 2, and 4.37 per cent for Method 3.

Most of the loss in footage was associated with shrinkage. Some loss, however, resulted from end trim because of the extension of end splits that were present in the green boards.

Shrinkage

All boards in each kiln charge were measured green and dry for width and thickness at two or three points. From these measurements the percentage of shrinkage was calculated. Shrinkage in width under the three methods of operation ranged from about 6.4 to 7.2 per cent and in thickness from about 2.7 to 7.2 per cent. The average shrinkage values for the two charges dried under each of the three methods of operation are shown in Table 4.

The values indicate that full-time operation (Method 1) results in the least shrinkage and that part-time operation under Method 3 results in the greatest shrinkage.

Energy Required *During Equalizing and Conditioning*

The equalizing and conditioning treatments were given under full-time kiln operation. The energy used for heating, humidification, and air circulation is given in Table 5.

Discussion

The data that were obtained during the study and calculations that were made using these data show that total time in the kiln and the cost of drying under both methods of part-time drying are greater than drying time and cost under full-time operation. Full-time operation, based on a full kiln charge, required only about 54 per cent of the drying time obtained under part-time operational Method 2. Full-time operation required only about 39 per cent of the time required under part-time Method 3. The cost of drying under full-time operation was about 70 per cent of the cost for Method 2, and about 63 per cent of the cost for Method 3.

Tables 1 and 2 show that the total on-time under operational Methods 2 and 3 was only about 25 per cent of the total time required for drying. Therefore, while a more severe drying schedule would perhaps reduce over-all drying time under part-time operation to some extent without increasing kiln degrade, this reduction in time would be small.

Tables 1 and 2 also show that only a small amount of steam was used up to the point of the equalizing treatment. This was due to the fact that the steam spray was not turned on at the start of drying or after off-time periods until the desired dry-bulb temperature was reached. Actually, throughout the entire study it was found that the moisture being evaporated from the lumber was sufficiently great to obtain and maintain the desired wet-bulb temperature without the use of steam spray.

One of the greatest demands on steam occurs during the warming-up period of a kiln charge of lumber. If two or more kilns are operated on a part-time basis, all kilns will be turned on simultaneously after their "off" period. The steam required during this warm-up period may exceed the output of the boiler. If this occurs, the warm-up time will be extended, thereby extending the over-all drying time.

The peak load of condensate from the heating coils also generally occurs during the warm-up period.

Table 5.--Energy used during equalizing and conditioning

Step	Steam used for-- Heating: Lb.	Heating: 1,000 B.t.u.	Humidification: Lb.	Humidification: 1,000 B.t.u.	Power used by fans: Kw.-hr.	Power used by fans: 1,000 B.t.u.	Total energy used: 1,000 B.t.u.	Total time: Hr.	Total energy used per hour: 1,000 B.t.u.
METHOD 1[2]									
Equalizing	1,785	1,767	307	5	32.9	112	1,884	32.5	58
Conditioning	1,045	1,034	850	15	23.4	80	1,129	24.0	46
Total	2,830	2,801	1,157	20	56.3	192	3,013	56.5	53
METHOD 2[2]									
Equalizing	941	931	128	2	24.2	83	1,016	24.0	42
Conditioning	1,123	1,110	781	13	23.9	82	1,205	24.0	50
Total	2,064	2,041	909	15	48.1	165	2,221	48.0	46
METHOD 3[2]									
Equalizing	2,430	2,403	257	3	37.6	128	2,534	36.0	70
Conditioning	900	890	1,069	18	23.0	78	986	24.0	41
Total	3,330	3,293	1,326	21	60.6	206	3,520	60.0	59

[1]Full-time operation.

[2]Average of 2 kiln charges.

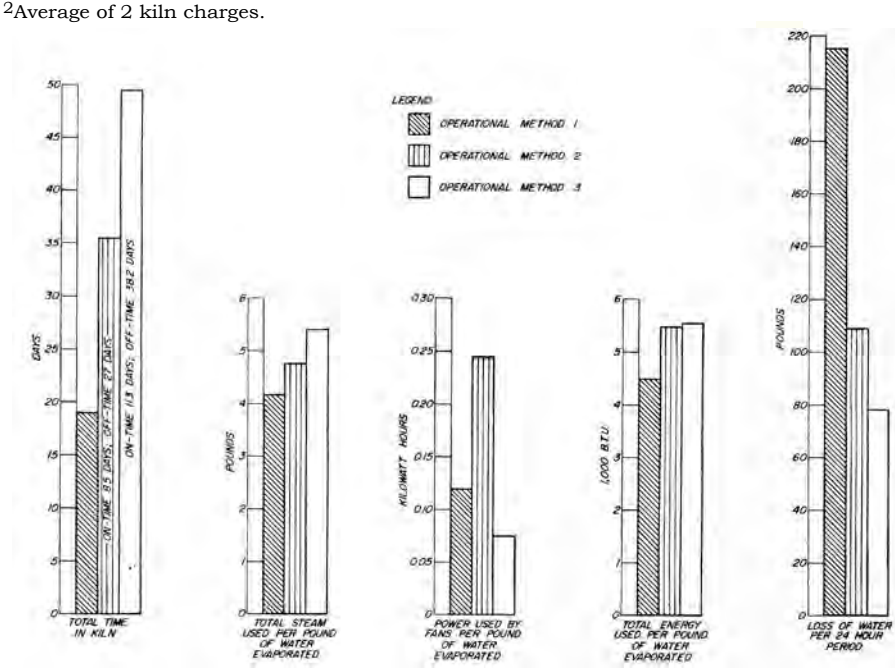

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FIGURE *5.-Comparative results on drying green 4/4 Northern red oak under three methods of kiln* operation *based on full kiln charges of 1,723* board *feet. Do not include equalizing and conditioning treatments.*

Therefore, the steam traps and return lines to the boiler must be sufficiently large to carry the condensate discharged from all the kilns being warmed up simultaneously after an off period under part-time operation. If they are not, warm-up time will be extended.

The total energy in British thermal units required to evaporate 1 pound of water from a full charge of lumber is about the same for both part-time methods of operation. The total energy requirements for full-time operation, however, are about 82 per cent of that required for part-time operation.

The calculated miscellaneous losses of energy are of interest in all the methods of operation ranging from about 65 per cent for Method 2 to 76 per cent for Method 3. The greatest calculated loss under miscellaneous losses is associated with heat losses through the kiln structure. This indicates strongly the need for better constructed and insulated kiln structures.

Shrinkage appeared to be normal under all methods of operation. Also the degree of stress present in stress sections cut prior to equalizing appeared on visual examination to be the same in all six kiln charges.

Recommendations

As a result of this study a few recommendations can be made. These are:

1. Plants short of kiln capacity should not consider part-time kiln drying, because of the increase in drying time.
2. If part-time drying is considered necessary, full-time operation of the fans, Method 2, may be desirable unless power costs are quite high.
3. A more severe drying schedule can probably be used for part-time drying, thereby reducing over-all drying time. Such a schedule will not, however, reduce the time too much, particularly in the drying of green or partially air-dried stock.
4. Regardless of the method of kiln operation, the use of steam spray during warm-up periods should be avoided as much as possible.
5. The high percentage of energy lost through the kiln structure emphasizes strongly the need for better designed, constructed, and insulated dry kilns.
6. Kilns should be loaded to their rated holding capacity regardless of the method of kiln operation. This will help to reduce drying costs.

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