INDUSTRIAL DEHUMIDIFICATION DRYING OF SOFTWOODS

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The drying of wood is the most energy intensive operation in forest products manufacturing. Therefore, any changes made in drying practices that would reduce drying costs would have a significant impact on the cost of production as a whole. To examine ways of reducing drying costs, we decided to conduct a study of new drying technologies that could be used commercially for drying lumber or veneer by the forest products industry in the Pacific Northwest (Milota and Wilson, 1984). As a result of this study, two drying technologies were identified as being commercially viable; they are the dehumidification drying of lumber and the radio-frequency drying of veneer. We recommended that a demonstration project be conducted for each technology in order to determine their commercial feasibility. This follow-up study examines the dehumidification drying of lumber to determine its commercial feasibility. The Cornett Lumber Company of Central Point, Oregon, having recently installed a dehumidification kiln with 230 thousand board feet (MBF) of capacity for drying western pine and hem-fir studs, volunteered the use of their facilities for this demonstration study.

The basic concept of dehumidification drying is that a heat pump system (which is similar to a refrigeration system) is used to recover the heat of vaporization by condensing the water vapor removed from the kiln. Although heat pumps are electrically driven, their cost advantage comes from an "energy multiplier effect" which translates into less consumed energy than occurs during conventional drying practices. We found that a dehumidification dry kiln uses about 750 Btu per pound of water evaporated, whereas a conventional dry kiln, fired by either hogged-wood fuel, natural gas, or oil, uses about 2,000 Btu per pound of water evaporated.

Dehumidification dry kilns operate at lower drying temperatures (typically below 150°F) than do conventional kilns, which results in longer drying schedules. Although dehumidification kilns are slower than conventional kilns for drying, the lower drying temperature has the reported advantage of less degrade and less shrinkage. Temperatures higher than 150°F can be obtained in a dehumidification kiln if needed for such operations as killing bugs or setting pitch.

Another feature of dehumidification kilns that must be considered in any decision to select this type of drying equipment is the disposal of condensed water. A permit must be obtained from the appropriate agency. In conventional kilns, most of the water evaporated from the lumber exits the kiln as water vapor whereas, in a dehumidification kiln, over half of the water exits the kiln as condensate.

COMMERCIAL FEASIBILITY

Although there are a large number of small-sized dehumidification units used for drying mostly hardwood lumber in the East, little is known about the practice and cost of commercially drying lumber in dehumidification kilns for the large-scaled operations and species typical of the Pacific Northwest. Thus, in July of 1985 we studied two kiln charges of western pine and hem-fir that were dried in Cornett's dehumidification kiln. The study's intent was to fully document the performance of the kiln in terms of cost, energy consumption, kiln operation, and lumber quality.

The following cost analyses were conducted for the commercial dehumidification drying of western pine and hem-fir studs: 1) the drying cost for Cornett's retrofitted kiln, 2) the drying cost for a "typical" new dehumidification kiln and a sensitivity analysis of pertinent parameters affecting this cost, and 3) a drying cost comparison between a dehumidification and conventional kiln.

Cornett's Drying Cost for Their Retrofitted Kiln

Table 1 contains the drying cost data for Cornett Lumber Company based on their actual costs as determined by the study of their drying operation. It is important to note that their drying cost of $14.21 per MBF is relatively low. This cost ignores both the income tax and the drying degrade loss, which is consistent with the way most drying costs are calculated. If degrade and income tax had been considered, the drying cost was $26.78 per MBF.

Drying Cost for a New Dehumidification Kiln

The drying cost analysis for Cornett's kiln may not be typical of those for other manufacturers. Table 2 presents a cost analysis of a new 230 MBF capacity kiln having those cost factors that reflect typical costs for most mills. The drying cost for this typical dehumidification kiln is $16.81 per MBF, which compares to $14.21 per MBF found for Cornett's drying cost. The lower drying cost for Cornett are primarily due to lower costs for a retrofitted kiln and cheaper labor.

A sensitivity analysis of the various factors affecting the drying cost for this "typical" kiln is given in Figure 1. As with the cost analysis for Cornett, electricity consumption is the most significant factor affecting drying cost.

Cost Comparison for Dehumidification and Conventional Drying

Table 3 presents a cost comparison for two new kilns with the same annual capacity. Because the drying schedule is longer for a dehumidification kiln, a larger kiln is needed to achieve the same annual capacity as for a conventional kiln. Thus, a 180 MBF conventional kiln is compared to a 206 MBF dehumidification kiln.

The comparative drying costs are $16.81 and $21.83 per MBF for the dehumidification and conventional kiln, respectively. The cost advantage for the dehumidification kiln would be greater if the drying degrade for the dehumidification kiln was less than that of the conventional kiln and the cost of degrade considered in drying cost calculations. Because no significant difference in degrade could be documented between a conventional and dehumidification kiln, the degrade rate was considered to be the same for both kilns. If the degrade loss and income tax shield were considered, the comparative drying costs would be $28.26 and $34.34 for the dehumidification and conventional kiln, respectively.

The drying cost comparison in Table 3 considers the cost of steam to be $6.20 per 1,000 lbs. of steam, which would be the case for a new hog fuel fired boiler where all operating costs were considered. Figure 2 shows the conventional and the dehumidification kilns had the same drying cost when the cost for steam was about $3.50 per 1,000 lbs. At any higher steam cost, the dehumidification kiln would have lower drying costs.

DRYING OF LUMBER STUDY

Equipment Description

The dehumidification kiln studied was a retrofitted, double-track, baffled kiln that was originally direct-fired with natural gas. The kiln was constructed of cinder block with external dimensions of 104-feet long by 40-feet wide by 22-feet high. The inside walls were insulated with approximately 12 inches of urethane foam. The kiln has a capacity of approximately 230,000 board feet (230 MBF). Air circulation in the kiln was provided by twenty 3/4 hp overhead fans. The fans reversed rotation every three hours during the drying schedule. The exhaust system used eight 3/4 hp 13-11/16 inch squirrel cage fans which operated at 1,725 rpm. The heating equipment consisted of four Nyle Corporation dehumidification dryers. Three of the units were equipped with six 24 Kw resistance heaters, three 30 hp compressors, and one 20 hp circulation fan. The fourth unit was similar but lacked resistance heaters.

The operation of the dehumidification kiln is summarized as follows. The operation began with the resistance heaters and the 20 circulating fans. When the kiln temperature reached 80^{o}F half of the resistance heaters were shut off. At this point the compressor motors began operation and remained on throughout the balance of the drying schedule, thus providing the thermal energy required for drying. At a kiln temperature of 100^{o}F the remaining resistance heaters shut down. The exhaust fans operated as needed to maintain the internal kiln temperature below 140^{o}F. Moisture in the kiln was removed by the following two mechanisms: 1) water vapor was condensed out of the air by the dehumidification units and drained from the kiln via a sump system, which accounted for approximately 60% of all moisture removed, and 2) the remaining 40% of the moisture was removed by the exhaust fans.

Power Consumption

The electrical power consumed during the test is shown in Table 4. Charge 1 consumed 40,880 KwH during a 125.25 hour kiln run for an average demand of 326.4 Kw. Charge 2 consumed 58,240 KwH during a 155.5 hour kiln charge for an average demand of 374.5

Kw. The lower demand observed for Charge 1 was the result of several compressors being off-line during much of the kiln run. All compressors operated during Charge 2.

The dehumidification kilns used an impressively low average of 756 Btu per pound of water evaporated compared to a conventional kiln which uses about 2,000 Btu per pound of water evaporated.

Power Costs

Table 5 gives the power costs for drying the lumber in Charges 1 and 2. The costs are based on PP&L's summer rate schedule and the power consumption for the kiln during the entire length of the drying schedule of 5.25 and 6.50 days for Charges 1 and 2, respectively.

The higher total rate for Charge 2 can be explained by noting that there were a greater number of compressors operating during the drying cycle.

Moisture Distribution

The moisture content distribution of the lumber in each charge was measured to determine overall drying rates and to provide an indication of the ability of this particular kiln to dry to a desired final moisture content.

Figure 3 provides the moisture content distribution for the dried lumber from Charge 1. In total, 1,128 pieces of lumber were measured, yielding an average moisture content of 12.9%. The load consisted of approximately 25% hem-fir and 75% western pine. The moisture content distribution for the dried lumber from Charge 2 is also given in Figure 3. The average moisture content of the lumber out of the kiln was 10.6% for the 794 pieces of lumber that were measured throughout the charge. The charge consisted of approximately 15% hem-fir and 85% western pine.

The final low moisture content for Charge 2 indicated significant overdrying, which adversely impacted the cost of drying and the amount of shrinkage and degrade.

Shrinkage

The thickness and width at four locations on each stud were measured before and after kiln drying for 500 studs in Charge 1 and 250 studs in Charge 2. In general, the observed shrinkage was less than the expected values derived from the WWPA "Technical Guide to Dimensional Stability" (1971). The thickness shrinkage was 16% less than expected, and the width shrinkage was 10% less. As this reference is somewhat dated (1937), there may be reason to expect more shrinkage in lumber cut primarily from small logs, such as those tested in this study, due to the greater percentage of juvenile wood.

Drying Degrade

Defects due to drying were determined by Cornett plant personnel at the grading line after planing. Charge 1 consisted of 16 graded test bundles for a total of 7,033 pieces of lumber and had 613 pieces identified as having drying defects for a total degrade rate of 8.7%. Charge 2 consisted of 14 graded test bundles for a total of 6,044 pieces of lumber and had 478 identified as having drying defects, for a total degrade rate of 7.9%.

Hem-fir, which is approximately 20% of the total graded lumber, had an average occurrence of drying defects of 7.1% compared to an overall occurrence of drying defects of 8.3%.

Previous studies have shown drying degrade to range from 10% to 50% for lumber in conventional dry kilns. Because the temperature of the kilns in these studies commonly exceeds 150°F, it is expected that dehumidification drying would yield less degrade than conventional drying.

CONCLUSIONS AND COMMENTS

The dehumidification drying of lumber appears to be an attractive alternative to present drying practices in the Pacific Northwest. The drying cost of a retrofitted dehumidification kiln having a single-charge capacity of 230 MBF was found to be $14.21 per MBF. Had the entire kiln been new, the drying cost would have been $16.81 per MBF assuming typical labor costs. This compares to $21.83 per MBF for a new conventional kiln with the same annual capacity. In our comparison we considered the drying cost for the conventional kiln to include the cost of a new boiler of sufficient size to meet the steam demand of the kiln.

This study identified several other favorable features of dehumidification drying. The dehumidification kiln used approximately 750 Btu per lb. of water evaporated, which compares to 2,000 Btu for a conventional kiln. Observed values of shrinkage (1.8% in thickness and 3.5% in width, when dried from 75% to 14% moisture content) were less than expected. The amount of degrade due to drying defects was determined to be approximately 8%; it has been reported that degrade is usually less for dehumidification drying than for conventional drying.

Because the dehumidification kiln studied was used for drying studs, there was no control of the wet-bulb temperature depression used to control the equilibrium moisture content conditions in the kiln. Dry-bulb temperature was controlled via exhaust fans. If dimension lumber was to be dried, control of the wet-bulb temperature depression would be required to maintain the drying schedule, and to avoid too-rapid drying. In this event, a small boiler could be used to generate the needed steam.

Overall, the dehumidification kiln appears to be cost competitive when all factors are considered and deserves consideration as a candidate when new drying capacity is needed. Those possible situations where dehumidification drying should be considered are any cases where: 1) a substantial investment is needed to maintain or increase boiler capacity for steam heated kilns, such as when there is no existing boiler, the boiler needs major repairs or replacing, additional steam is needed for increased kiln demands, or there is limited or no wood waste available for fuel, 2) new kilns are being considered, 3) there is a high value loss of lumber during conventional drying, or 4) there is a strong need to reduce or eliminate boiler emissions.

Table 1. Drying cost estimates for Cornett Lumber Company's retrofitted-dehumidification kiln.

Kiln capacity (MBF)	230	
Operating days per year	340	
Kiln residence time (days)[1]	4	
Annual kiln throughput (MBF)	19,550	
	Drying Cost	Drying Cost (Includes income tax and drying degrade)
Capital cost	$450,000	450,000
less: Federal investment tax credit (10%)	45,000	45,000
Adjusted capital cost	405,000	405,000
Annual costs and expenses		
Electrical power	145,000	145,000
Depreciation[2]	56,000	56,000
Interest[3]	29,720	29,720
Sticker replacement	14,663	14,663
Maintenance, supplies, office overhead	14,500	14,500
Labor	18,000	18,000
Degrade @ 8%[4]	0	273,700
Total annual cost and expenses	277,883	551,583
less: Income tax shield[5]	0	28,000
Adjusted annual cost	277,883	523,583
Drying cost per MBF	$ 14.21	$ 26.78

Notes:

1. Although the actual duration of the kiln schedules for the study was 5.25 and 6.5 days for the two charges, recent modifications to the equipment and changes in drying practices have reduced the schedule to 4 days.
2. The depreciation was provided by Cornett Lumber Company.
3. Calculated by assuming the project was financed with borrowed funds at an interest rate of 11.5% (prime plus 2 points). Although Cornett paid cash for their kiln, interest was considered an opportunity cost because they could have invested this money.
4. Degrade value was calculated by assuming a transfer price for green lumber of $175 per MBF.
5. Income tax shield is equal to the product of tax rate (50%) and the annual depreciation charge. There wasn't a tax shield for interest because Cornett paid cash for their kiln.

Table 2. Drying cost estimates for a typical, new dehumidification dry kiln.

Kiln capacity	230	
Operating days per year	340	
Kiln schedule residence time (days)	4	
Annual kiln throughout (MBF)	19,550	
	Drying Cost	Drying Cost (Includes income tax and drying degrade)
Capital cost	$517,500	$517,500
Less: Federal investment tax credit (10%)[1]	51,750	51,750
Adjusted capital cost	465,750	465,750
Annual costs and expenses		
Electrical power	145,000	145,000
Depreciation (10-year straight-line)	51,750	51,750
Interest[2]	34,175	34,175
Sticker replacement	14,663	14,663
Maintenance, supplies, office overhead	24,438	24,438
Labor	58,650	58,650
Degrade @ 8%[3]	0	273,700
Total annual costs and expenses	328,675	602,375
less: Income tax shield[4]	0	42,963
Adjusted annual cost	328,675	559,413
Drying cost per MBF	$ 16.81	$ 28.61

Notes:

1. Hopefully, the Federal investment tax credit will be available in 1986 and subsequent years.
2. Calculated by assuming the project was financed with borrowed funds at an interest rate of 11.5% (prime plus 2 points).
3. Degrade value was calculated by assuming a transfer price for green lumber of $175 per MBF.
4. Tax shield is equal to the product of tax rate (50%) and sum of the annual depreciation and interest charges.

Table 3. Cost comparison of a conventional and a dehumidification kiln.

	Conventional Kiln	Dehumidification Kiln
Kiln capacity (MBF)	180	206
Operating days per year	340	340
Kiln residence time (days)	3.5	4
Annual kiln throughput (MBF)	17,486	17,486
Capital cost	$315,000	$462,857
less: Federal investment tax credit	31,500	46,286
Adjusted capital cost	283,500	416,571
Annual costs and expenses:		
Electrical power	32,490	129,689
Steam (from wood-fired boiler)[1]	212,040	0
Depreciation (10-year straight-line)	31,500	46,286
Interest[2]	20,800	30,570
Sticker replacement	13,110	13,110
Maintenance, supplies, office o/h	19,350	21,860
Labor (includes all payroll expenses)	52,460	52,460
Total annual operating cost	$381,750	$293,975
Drying cost per MBF	$21.83	$16.81

Notes:

1. The steam cost was determined based on a cost of $6.20 per 1,000 pounds, which reflects the true cost for operating a new boiler. If a fully depreciated, older boiler is used to supply steam, the steam cost would be significantly less at $1.50 to $4.00 per 1,000 pounds of steam.
2. Calculated by assuming the project was financed with borrowed funds at an interest rate of 11.5% (prime plus 2 points).

Table 4. Amount of energy used to evaporate the moisture from lumber during dehumidification drying.

Charge number	Total KwH	Total water evaporated, lb	Btu per lb. water evap.	Btu per BF dried*
1	40,880	180,556	773	608
2	58,240	269,016	739	867

* dried from 60 to 12.9% for Charge 1 and from 82 to 10.6% for Charge 2.

Table 5. Electricity costs for Charges 1 and 2.

Charge number	Total power cost	Power cost per MBF	Power cost per hour
1	$ 2,053	$ 8.96	$ 16.39
2	$ 2,924	$ 12.64	$ 17.31

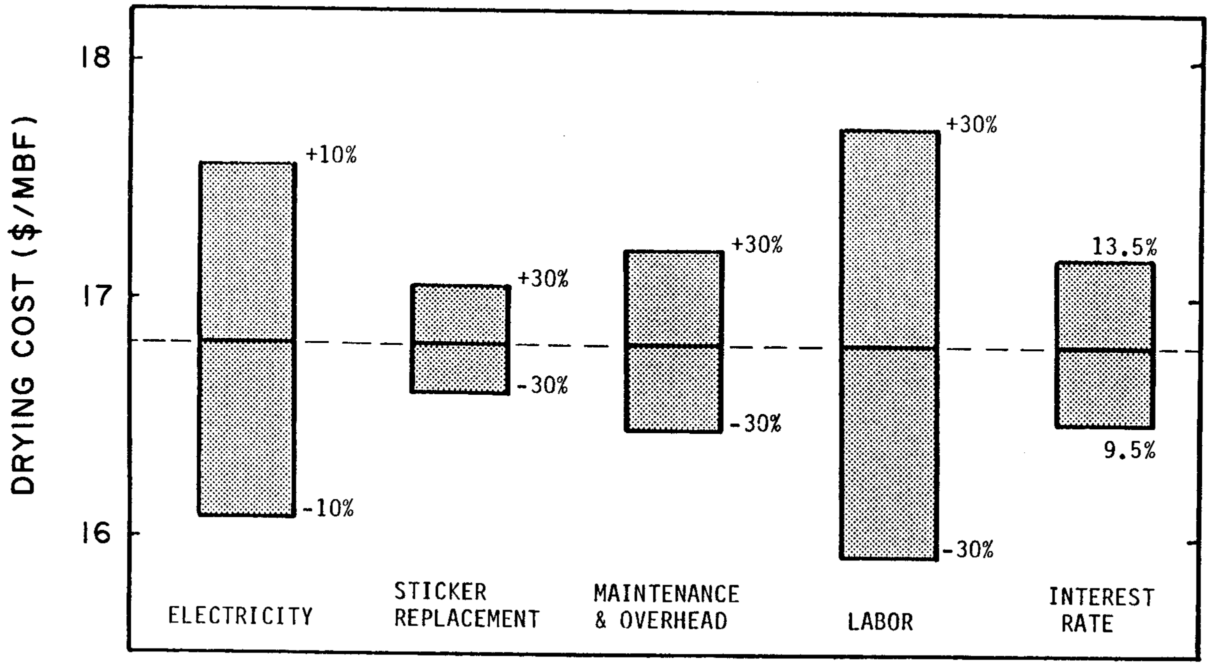

Figure 1. Cost of dehumidification kiln drying as affected by the variability of the principle operating costs for a new kiln

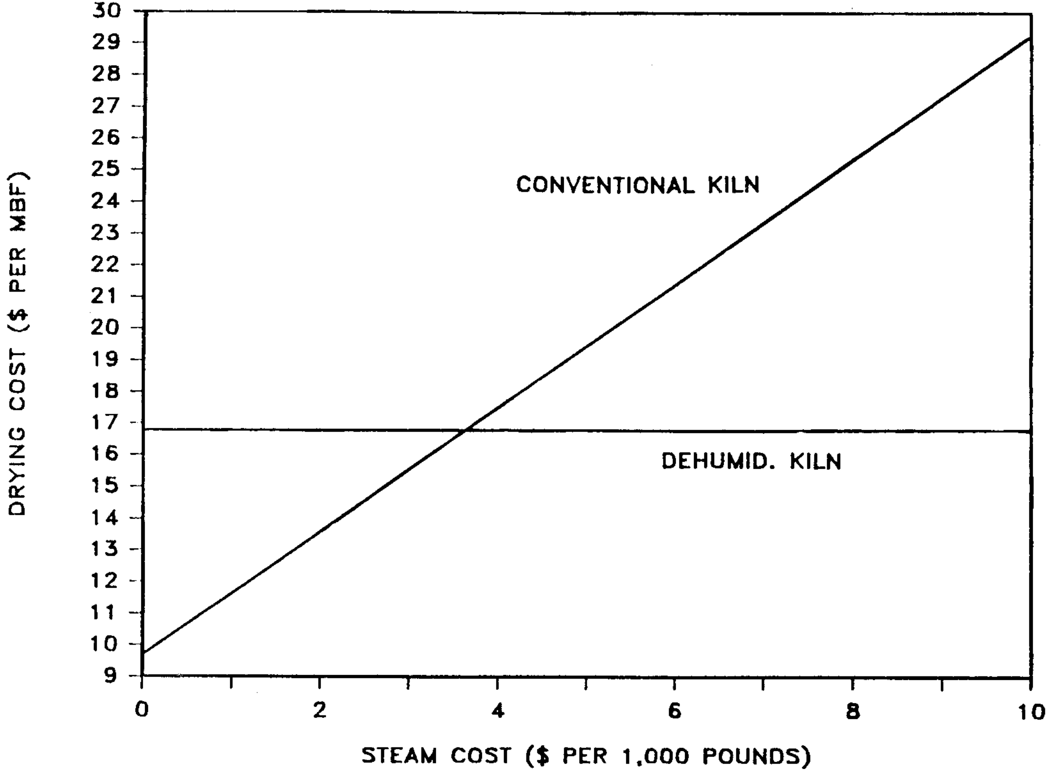

Figure 2. The cost of conventional drying as affected by steam cost

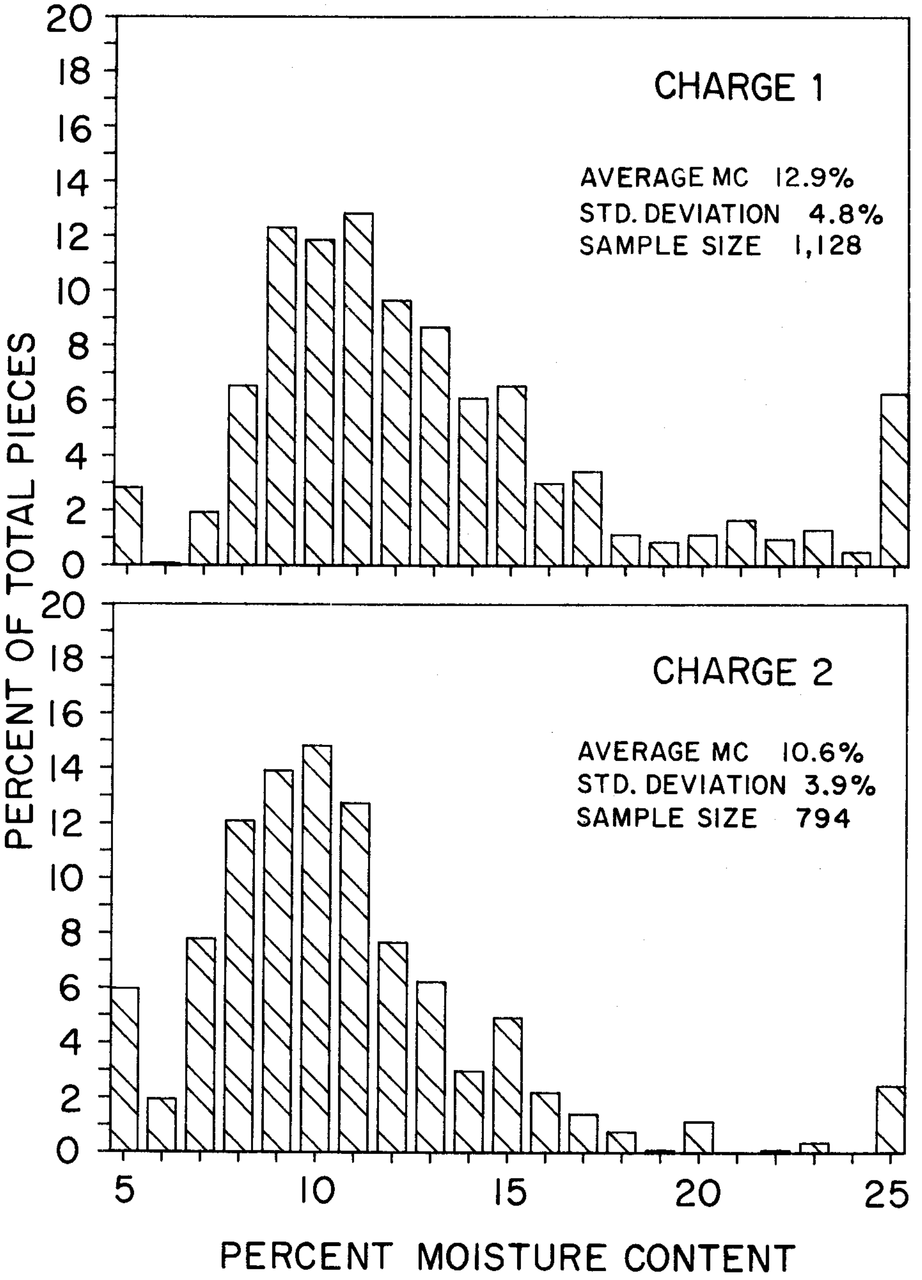

Figure 3. Histogram of moisture content distribution for lumber dried in a dehumidification kiln