AN ECONOMIC COMPARISON BETWEEN CONVENTION AND DEHUMIDIFICATION KILN DRYING TECHNIQUES FOR WESTERN RED CEDAR

Ronald G. Kent*
Fiji Forest Industries, Ltd.
Labasa, Fiji

W. Ramsay Smith
College of Forest Resources
University of Washington
Seattle, Washington

INTRODUCTION

Dehumidification drying is enjoying increasing popularity among eastern hardwood producers. Until recently, it was thought to be an infeasible process for many Pacific Northwest softwood species. In an effort to capture the softwood markets, however, manufacturers developed a higher temperature dehumidification kiln. The purpose of this paper is to economically compare this technique with a wood waste fired conventional kiln, both drying western red cedar.

The implementation of a kiln drying facility is a major capital cost investment in a lumber mill operation. Due to its large expense it should be carefully analyzed before initiation. There are many obvious costs and many seemingly insignificant costs that can turn a successful drying operation into a financial loss. It is necessary, therefore, to consider a number of variables when evaluating the technical and economic feasibility of installing a kiln. These include physical space, equipment, labor and product markets. The physical space requirements need to include added dry-sort areas, sheds to hold the stickered lumber for drying, and possibly increased storage capacity, in addition to the lumber handling, stacker and kiln areas. Consideration should also be given to whether the mill's layout is conducive to an efficient drying operation, and to possible layout alternatives.

If a mill intends to use waste wood as a fuel source, consideration must be given to whether there is an adequate, continual supply, and a determination of its heating value. If the residue exceeds 68% wet basis, for example, the hogfuel will not sustain burning. The fuel will then have to be supplemented, or a pre-drying operation will be needed which is an added expense.

If the mill does decide it is feasible to begin a drying operation, consideration must be given to the type of lumber that will be dried, and the quantity of material the market will bear. Because a dried material can be considered a "new" product line, thought must be given to the current production capacity and its ability to adequately supply the existing green and new dried markets. Forecasting future markets should also be examined with respect to demand and price fluctuations. Many of these decisions

* This paper is based on the results of Ronald Kent's Master Thesis. The authors would like to express their sincere appreciation for the support of the personnel at Loth Lumber. Without their assistance this study could not have been done.

and predictions are difficult to make and assess, but, through an understanding of the mill and a reasonable understanding of the lumber markets, management can choose the most appropriate drying technique, and avoid many pitfalls that turn drying operations from assets to liabilities.

OBJECTIVES

The overall objective of this paper is to compare the economic feasibility of installing a dehumidification kiln versus a conventional kiln to dry western red cedar. More specifically, it evaluates the lumber drying costs of each technique, compares major cost factors to determine their influences in the total cost, and analyzes how sensitive potential changes in the cost factors effect the total drying costs.

BACKGROUND

Total capital outlay for a dehumidification kiln varies widely depending on whether the kiln is constructed for higher temperatures (180°F) and/or increased horsepower to maintain a greater wet bulb depression. One estimate suggests that the capital outlay of a dehumidification system can be almost half of the cost of a conventional system (Milota and Wilson, 1984). A manufacturer suggests that the turn key cost for a dehumidification operation will run from 2.25 dollars to 2.50 dollars per board foot, which compares with the cost of a direct fired natural gas system (Compagna, 1983). Operating costs have been reported to range from a quarter to half the cost of a conventional kiln, depending on the type of fuel (Milota and Wilson, 1984).

Historically, warmup times of a dehumidification kiln were much longer than conventional kilns which tend to crease initial energy costs. However, with the introduction of auxiliary heaters, warmup times are decreasing and operating temperatures increasing, resulting in shorter drying periods--but a more costly operation. Air circulation fans, another energy consideration, has been reported to be only half the amount of a conventional hardwood kiln (Wooster, 1981).

It is believed by some that a wood waste boiler system is essentially free energy. Compagna (1983) has stated, however, that almost as much electrical energy is consumed for hoggers, conveyors, blowers, storage bins and screw feeds as a dehumidification system. The electrical consumption of both systems, therefore, should be carefully considered.

It has been suggested by a manufacturer that the interest saved on capital investment for a waste wood boiler system would pay for the dehumidification system's annual electrical consumption (Compagna, 1983). However, it should be noted that dehumidification requires the use of electrical compressors to condense and remove water, which consumes large amounts of electricity. In areas with high electrical costs this could be a deciding factor.

A study comparing lumber quality from conventional and low temperature dehumidification kilns was done by British Columbia Forest Products on spruce and fir (Cech and Pfaff, 1978). It showed that trimming was reduced 25 percent and degrade by crook was reduced 66 percent. This resulted in degrade costs to be reduced by nearly half. However, a study performed in New Zealand comparing low temperature dehumidification and conventional drying using Radiata Pine showed that there was no significant differences in shrinkage or warp. Stress conditions for the conventionally dried material, however, was greater than that for dehumidification material.

During the developmental stages of dehumidification drying, conditioning of dehumidified lumber was not routinely performed, resulting in some case hardening. Today, because of the increased dry bulb temperatures used, it is possible to condition lumber with the addition of a steam generator, powered by electricity.

DRYING TIME

Drying times for dehumidification kilns have been reported to be much closer to conventional kiln drying times because of increased horsepower and auxiliary heating. Test results, however, have not been conclusive and there is still a broad range of drying times associated with dehumidification drying. Table 1 presents times found in the literature.

It should also be noted that, in low temperature dehumidification drying operations (<120°F), sterilization of the wood cannot be done. This can be a serious consideration when a manufacturer is considering the export of their product. For example, the Australian quarantine regulations specify that material up to 50 mm thick must be exposed to a temperature of 74°C (164.5°F) for six hours to be heat sterilized (Kininmonth, 1980). A dehumidification kiln that is capable of operating at 180°F with the aid of an auxiliary heater is capable of sterilizing such material.

DRYING OPERATIONS

Figure 1 is a schematic representing the proposed drying operation to be used for costing purposes. This schematic is not intended to include all the possible equipment options that are available for any given operation, but is rather meant to show many of the considerations which may need to be made for a kiln installation.

All of the machine centers shown are used in the conventional kiln operation including the steam generation plant. The dehumidification drying operation excludes the steam generation equipment shown in the boxed area since its electrical supply is part of the drying unit.

KILN CAPACITIES

In order to effectively size the conventional kiln capacity, the following items were considered:

1) annual dried lumber production level,
2) species mix by percentage of each,
3) thickness ranges of each species by percentages,
4) product mix percentage by species and
5) final target moisture content for each product.

Species mix and annual drying quantities were established for each type of lumber that will enter the kiln and hence, drying times were obtained. These were used to determine an overall drying curve shown in Figure 2. This information was used as a basis for determining the total number of kiln charges made per year. Kiln capacity was then calculated. A computer model, that accounted for these factors and estimates the kiln size (Briggs & Dickens, 1984), was run using these data.

The resulting kiln capacity is estimated to be 120,000 board feet per charge for the conventional kiln. It was decided that flexibility was needed for the different lumber types (old growth and second growth) so two 60 MBF kilns were assumed. This flexibility, however, increases kiln costs 20 to 30 percent (Lumber Systems, 1985).

The dehumidification drying time shown in Figure 3 was based on a 9 percent moisture content loss per day for all products as estimated by the Nyle Corporation (Nyle Corp., 1985). Assuming an average initial moisture content of 100 percent and drying to an average final moisture content of 12 percent, to bring 95% of the material below the target of 16 percent the average drying time is 225 hours. With the addition of 12 hours for turn around time between charges, a total of 37 charges per year would result, requiring a 163 MBF kiln capacity.

BOILER CAPACITY

The energy that needed to dry 120 MBF of western red cedar was determined, using a computer program based on energy consumption in a dry kiln (Smith, 1984). The total energy required per charge was determined to be 380 million BTUs. The boiler size, however, is based on the warm-up time, which consumes the largest amount of energy. Two 60,000 board foot kilns started at the same time will require approximately 7 million BTUs per kiln or a 14 million BTU/hr boiler.

INPUT DATA

In order to perform all the calculations involved in obtaining a cost per unit volume of dried lumber, a drying economics model was used (Smith, 1979). This lumber drying model contains all of the steps involved in any actual drying operation, including the material handling steps from green chain through dry storage. From this model, one is not only able to determine the estimated costs of drying for each technique, but can also

1) determine individual cost factors such as labor, capital, fuel, maintenance, taxes, land, electricity, degrade, interest on lumber investment, and other miscellaneous costs; and
2) determine the sensitivity of potential changes in the input data on total drying costs.

The equipment was chosen based on Figure 1. Unless otherwise noted, the following can be considered as constants; taxes, 1.72% of the capital cost; annual maintenance, 1.83% of capital costs; land value, $15,000 per acre; land tax, 2.51% of land value; and annual process thruput, 6 million board feet. Table 2 lists the equipment, costs and source of the information for all handling equipment used.

Degrade is an important cost that must also be considered. Five percent or more of the dried lumber value can be lost due to degrade; depending on the drying conditions, species, and target moisture content (Smith, 1980). Degrade versus average moisture content for this drying operation is assumed to be a linear function as seen in Figure 4. Since there is no conclusive evidence to support the assumption that either drying technique leads to less degrade, the same linear function was used for each drying process.

Tables 3 and 4 contain the costs associated with the dehumidification and conventional drying techniques, respectively. Other inputs for both techniques were calculated in the same manner to insure consistency between them. Table 5 contains the input data used for each.

The data in Table 5 represent the miscellaneous costs used in the program and the source of the information.

RESULTS AND DISCUSSION

Table 6 contains the costs of both drying techniques using the data as presented. Dehumidification is abbreviated (DH) and conventional kiln (CK).

Table 7 and Figure 5 provide cost breakdowns by major cost factor and reveals the greatest costs for each drying technique. As can be seen, over 80 percent of the total drying costs are made up of a combination of degrade costs, capital equipment costs, labor costs and electrical costs. The least cost areas are land and fuel costs.

Fuel costs may be somewhat misleading since they only include the fuel consumption of all forklifts used for drying and the residue boiler fuel used for the conventional kiln boiler. The waste residue boiler cost is included in the capital equipment for the conventional kiln. Electrical energy for the dehumidification kiln is included in the electrical costs.

The greatest cost is the loss of lumber value due to degrade ($31.18/MBF). These values are equal because there is no conclusive evidence that degrade is more or less for either technique, as discussed.

Capital equipment costs are the next most expensive, at $17.61/MBF for dehumidification and $21.17/MBF for the conventional kiln. This is the most significant factor in explaining the difference between the techniques, and consequentially causes dehumidification drying to be the less expensive drying method. The input data is a good indication since equipment for a conventional drying operation was over $250,000 more than the equipment for a dehumidification system. This is primarily due to the large cost of a wood waste boiler system costing $580,000 versus the energy and heating source for dehumidification being three 80 hp compressors. The disadvantage to the dehumidification system is that there is a 34 percent rise in electrical costs due to the demand from the electrical compressors.

Labor costs are equal for each technique at $14.73/MBF since no additional labor was assumed for either technique. Maintenance and tax costs are higher for the conventional system, reflecting the higher equipment costs. Because of the decrease in drying time for the conventional system, the cost of interest on lumber investment is slightly reduced.

The sensitivity of each of the cost factors needs to also be determined, since total drying cost and individual cost factors may change with time. This can be by changing the input data in a particular cost area by a known amount, and analyzing the change in the total drying cost. The significance of that change on total drying cost can then be determined. An analysis of this type will determine the:

1) cost factors which have the greatest effect on total cost,
2) effects of potential cost factor changes on the total cost of each technique, and
3) relative importance of each cost factor on total cost and thus, the significance that should be placed in obtaining the most accurate information pertinent to that cost factor.

One method of determining the significance of each of the cost factors is by calculating their slopes. This consists of taking the change in total cost and dividing it by the percentage change of the cost factor. Since only one variable is changed at a time, all slopes are linear. The greater the slope, the more significant that cost center is to the change of total drying cost. The slopes for each cost factor are shown in Table 8.

As can be seen in Table 8, the slope for dehumidification kiln's capital equipment cost is 23.08/100 or 0.2308. This means that for every one percent change in the total capital cost for equipment there is a change in total cost of $0.23. For example, if capital equipment cost is overestimated by 15 percent, the total cost to dry lumber would be reduced by (-15 x $0.2308) or -$3.46/MBF. Comparison of these slopes shows that the fuel and interest rate costs are relatively insignificant with respect to total drying costs when compared to the impact a change in capital equipment costs may have. Other significant cost centers that can have a profound effect on the drying economics are, in relative importance, degrade, labor and electrical costs.

Examination of the labor and degrade values shows that their slopes practically are the same for both the dehumidification and conventional kiln techniques. This illustrates the initial assumption that these costs are similar and that changes in cost of labor or degrade affects either process equally.

Also shown in Table 8 are slope differences between the drying techniques and percentage changes required in cost input for the processes to have the same total cost per MBF. For example, for every 10 percent change in equipment cost there is a total drying cost change of $2.31 per MBF for dehumidification and $3.24 per MBF for conventional kilns. Therefore, a 62 percent reduction in equipment costs for both processes would cause both drying operations to become equal, given all other costs were kept constant. In this case, the cost of the conventional process is $92.28-$20.06 or $72.22, and the dehumidification is $86.52-$14.30 or $72.21.

Each drying possibility can also be changed independently. For example, if the equipment cost for the conventional process was reduced 17.8 percent and the dehumidification costs were held constant, the cost of the two drying techniques would be equal.

Therefore, if any cost factor is not what was assumed, the percentage difference and the appropriate sensitivity slope can be used to evaluate the change in total drying cost for an individual technique.

The only major cost factor which affects dehumidification adversely is electrical costs. If electrical costs were to increase 137% or from .035/kwh to 0.083/kwh and all other costs remained constant, the cost of both drying techniques would again be equal. Any increase above this would favor the conventional kiln system.

SUMMARY AND CONCLUSIONS

Total drying costs for each technique examined were determined to be $92.28 per thousand board feet for a conventional system, and $86.52 per thousand board feet for a dehumidification system. Annual drying costs were $519,106 per 6 MMBF for dehumidification and $553,656 per 6 MMBF for conventional with a residue boiler. The dehumidification system requires a longer drying time, resulting in an increase in kiln capacity.

The primary reason that the dehumidification was a less expensive system is that its total capital cost is directly proportional to the kiln capacity. In contrast, the conventional system requires a waste fired boiler system with a high fixed cost of $580,000, and the kiln building costs are proportional to the kiln capacity. This results in capital costs being over 25 percent more for the conventional system.

In addition, maintenance and taxes are 20 to 30 percent higher for the conventional system, since these were assumed to be proportional to the capital cost of the system. The other significant cost difference is the amount of electrical consumption. Dehumidification requires approximately 30 percent more electricity than a conventional operation, resulting in a 30 percent increase in electrical costs.

It has therefore been found that it is economically advantageous to install a dehumidification operation based on the established assumptions. If a conventional system could reduce its capital costs by 17.8 percent or if electrical costs were increased 137 percent, this system would be economically as favorable. If this occurs, it is up to the mill personnel to select a system that is the most comfortable for them to manage.

LITERATURE CITED

Briggs, D. and Dickens, N. (1984). Kiln capacity estimation (Computer Program). Seattle, WA: University of Washington, College of Forest Resources.

Cech, M.Y., and Pfaff, F. (1978). Dehumidification drying of spruce studs. Forest Products Journal, 28(3), 22-24.

Compagna, P. (1983). Future of dehumidification drying on the west coast. Proceedings of the 34th Annual Meeting of the Western Dry Kiln Clubs, 78-79.

Kininmonth, J.A. (1980). Dehumidifiers for timber drying. What's New in Forest Research, 84, 1-4.

Lumber System Inc. (1985). Personal Communication.

Milota, M.R., and Wilson, J.B. (1984). Review of innovative drying methods. Proceedings of the 35th Annual Meeting of the Western Dry Kiln Clubs, 92-111.

Nyle Corp. (1985). Personal Contact.

Rasmussen, E.F. (1961). Dry Kiln Operators Handbook (USDA No. 188). Washington, DC: U.S. Government Printing Office.

Smith, W.R. (1979). An economic model of the lumber drying system. Proceedings of the 30th Annual Meeting of the Western Dry Kiln Clubs, 84-101.

Smith, W.R. (1984). Boiler energy usage (Computer Program). Seattle, WA: University of Washington, College of Forest Resources.

Wooster, R. (1981). Kruger installs new generation dehumidifiers. Australian Forest Industries Journal, 47(10), 29-31.

Table 1. Published Drying Times of Various Species

Author	Species	Thickness	Conventional	Dehumidification	M.C.%
Rea	Pine	4/4in	90 hours*	144 hours	10%
Cech	Spruce	8/4in	56 hours	96 hours	16%
Erickson	Red Oak	4/4in	378 hours @ 3.8%MC	535 hours	7.8%
Kininmonth	Pine	8/4in	144 hours	504 hours	--
Nyle Corp.	Cedar (proposed)	4/4in	50-203 hours*	240 hours	6%
Cornett Inc.	Hem/Fir	8/4in	75 hours*	96 hours	19%

*Estimates were taken from the Dry Kiln Operators Manual (Rasmussen, 1961).

Table 2. Handling equipment for conventional and dehumidification operations

Equipment	Cost	Source
Forklift		
Capital cost	$21,580	Hyster, 1985
Annual labor/benefits/%time	$36,480 @ 100%	Loth Lumber, 1985
Expected life	4 years	Hyster, 1985
Annual maint/supply	$1,748 8.1% of cptl.	Smith, 1981
Annual taxes/insurance	$371 ($1.72/$100)	Loth, 1985
Annual operating hrs.	3120 hrs (12hrs/day for 260 days)	Loth, 1985
Annual fuel consumption	12,090 liters/yr. (3.875 l/hr.)	Hyster, 1985
Stacking process (transfers, stacker, sticker placer)		
Capital cost	$81,734	Irvington Moore, 1985
Annual labor/benefits/%time	$29,760 @ 100%	Loth, 1985
Expected life	20 years	Smith, 1980
Annual taxes/insurance	$1,405	Loth, 1985
Land value	$413 (1500 sq.ft.)	
Annual kwh	15,904kwh (20.5hp, 5hr/day for 208 days)	
Sticker handling		
Capital cost	$500	Smith, 1980
Annual labor/%time	$29,760 @ 5%	Loth, 1985
Expected life	20	Smith, 1980
Annual taxes/insurance	$8	
Land value	$172 (500 sq.ft.)	
Unstacking prior to drysort (tilt hoist, infeed chain)		
Capital cost	$37,192	Irvington Moore, 1985
Annual labor/benefits/%time	$29,760 @ 45%	Loth, 1985
Expected life	20 years	Smith, 1980
Land value	$413 (1200 sq.ft.)	
Annual kwh	11,799kwh (32.5hp, @ 8hrs/day for 61 days)	
Redry sort (production line moisture meter)		
Capital cost	$5,722	Wagner Electronics, 1985
Annual labor/benefits/%time	$29,760 @ 70%	
Expected life	10 years	Smith, 1980
Annual kwh	243kwh (.5kwh @ 8/hrs/ day for 60 days)	
Dry storage		
Capital cost	$38,740 (897 sq.ft. @ $4/sq.ft.)	Loth, 1985
Annual labor/benefits/%time	$29,760 @ 5%	Smith, 1980
Annual maintenance	$387 (1% of capital)	
Land value	$666 (897 sq.ft.)	
Annual process thruput	5.1 MMBF 85% of annual production	
Annual kwh	3482kwh (9.5 kwh/day)	

Table 3. Dehumidification kiln costs

Equipment	Cost	Source
Dehumidification 0% redry		173,000 bf total capacity (#3, 58,000 bf kilns), each kiln having an 80hp compressor
Capital costs	$612,565	3 complete kiln systems plus one 12hp steam generator. Nyle Corp. 1985
Expected life	20 years	
Annual maint.	$11,210	1.83% of capital costs. Smith, 1980
Annual tax	$10,536	1.72% of capital costs. Loth, 1985
Land value	$1,350	3920 sq. ft. @ $15,000 per acre
Annual kwh	2,066,996 kwh	345 kwh per mbf. Nyle Corp., 1985
Avg. #hrs/charge	240 hours	

Table 4. Data inputs for a conventional kiln operation

Equipment	Cost	Source
Conventional kiln		126,000 bf total capacity (#2, 63,000 bf kilns; 14,000,000 BTUs/hr. (low press. boiler)
Capital costs	$937,340	kilns=$357,340 (installed) Lumber Systems, 1985; boiler=$580,000 (installed) Wellons, Inc., 1985
Expected life	20 years	
Annual maint.	$17,153	1.83% of capital. Smith, 1980
Annual taxes	$16,122	1.72% of capital. Loth, 1985
Land value	$1.033	3,000 sq. ft.
Annual kwh	1,353,813 kwh	657,000 kwh, boiler; 696,813 kwh, kilns
Avg. #hrs/charge	174 hours	

Table 5. Miscellaneous cost factors and sources

1) Sticker cost	$0.12 each	Loth, 1985
2) Bolster cost	$1.35 each	Loth, 1985
3) Number of stickers/m3	26	estimate
4) Number of bolsters/m3	0.6	estimate
5) Quantity of m3 serviced over sticker life	6	Smith, 1980
6) Quantity of m3 serviced over bolster life	1000	Smith, 1980
7) % time forklifts are attributed to drying	100%	Loth, 1985
8) Annual forklift oil consumption	12 liters	Hyster, 1985
9) Oil cost per liter	$1.00	estimate
10) Specific gravity of species	0.33	Fahhey, 1981
11) Kiln efficiency factor	10%	Smith, 1980
12) Cost per kwh	$0.035/kwh	Loth, 1985
13) Annual thruput for drying operation	6 MMBF	Loth, 1985
14) Interest rate	12%	estimate
15) % overhead for drying only	4%	Smith, 1980
16) Price of green lumber per MBF	$.400	Loth, 1985
17) Price of dried lumber per MBF	$.600	Loth, 1985
18) Forklift fuel price	$0.40/liter	estimate
19) Boiler fuel price	$8.00/cunit	Loth, 1985
20) Number of interest compounds/yr.	4	estimate
21) Volume of residue needed for boiler	800 cunits	estimate

Table 6. Total costs of each drying technique

Technique	Total Cost/MBF
DH	$86.52
CK	$92.28

Table 7. Costs within each major cost center in dollars/cubic meter

	Labor	Capital	Fuel	Maint.	Tax & Insurance	Land	Elec.	Degrade	Interest on Lumbr.	Other
DH	$14.73	$17.61	$0.50	$2.41	$2.19	$0.14	$11.89	$31.18	$2.60	$3.30
CK	14.73	24.17	1.53	3.37	3.09	0.12	7.86	31.18	2.24	3.54

Table 8. Slopes for cost sensitivity and breakeven percentages

Cost Area	DH	CK	Slope Difference	Breakeven
	($/% change per MBF x 10^{-2})			(%change)
Labor cost	15.29	15.32	-0.03	
Cap. equip. cost	23.08	32.36	-9.28	-62
Fuel costs	0.52	1.60	-1.08	-533
Elec. costs	12.37	8.17	+4.20	+137
Degrade costs	32.38	32.43	-0.05	
Interest rates	1.70	2.26	-0.56	-1029

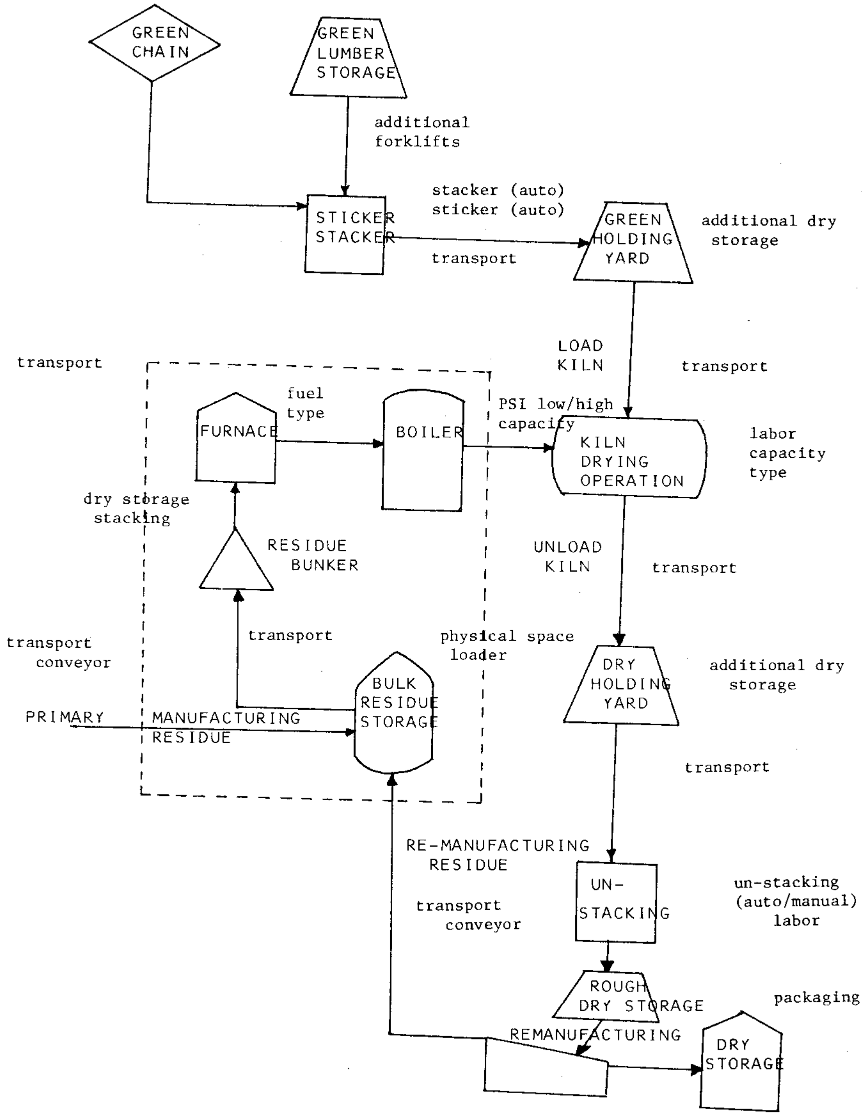

Figure 1. Proposed lumber drying operation

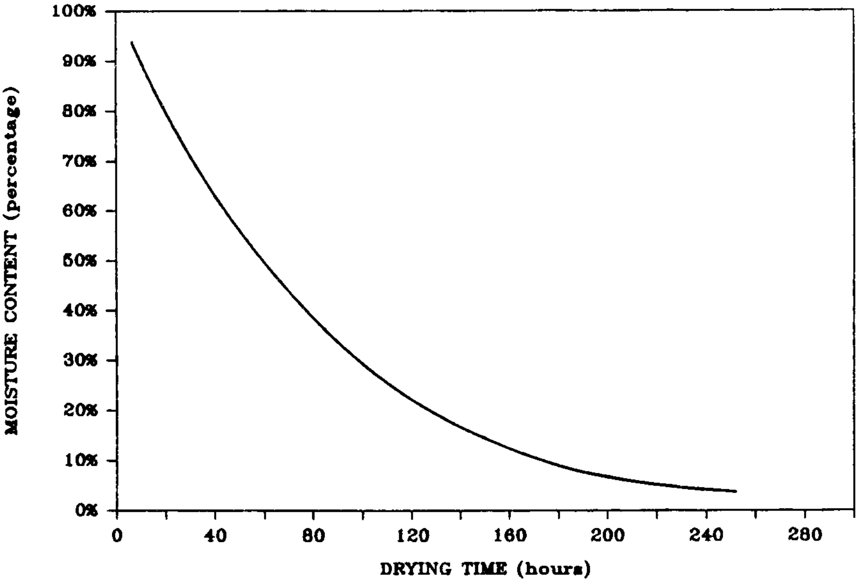

Figure 2. Conventional drying curve

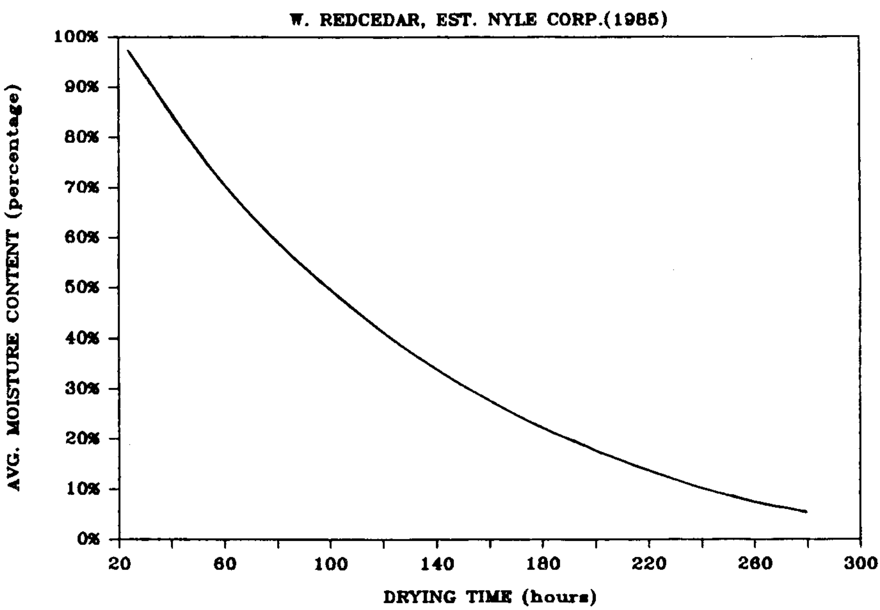

Figure 3. Dehumidification drying curve

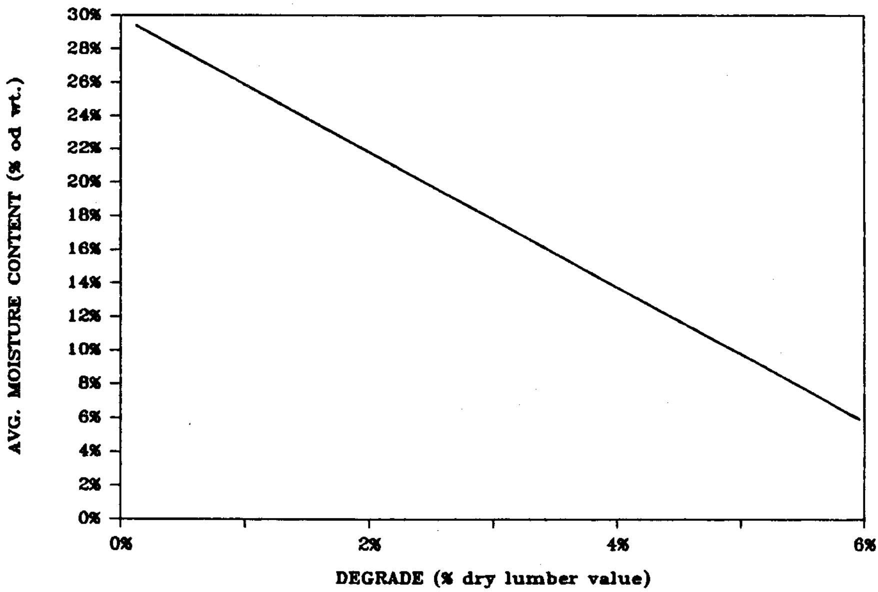

Figure 4. Degrade for western red cedar

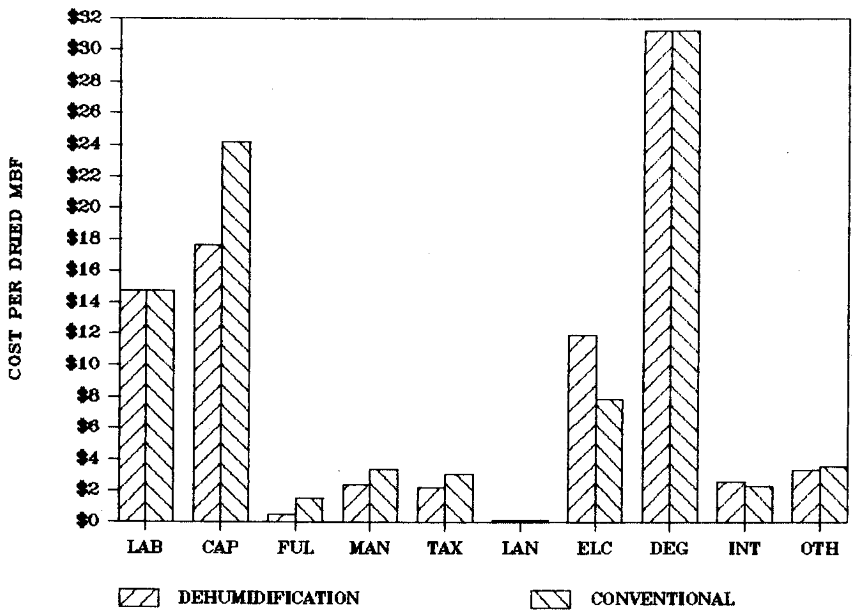

Figure 5. Cost factor breakdown