AN ECONOMIC MODEL OF THE LUMBER DRYING SYSTEM

Ramsay Smith
College of Natural Resources
University of Washington
Seattle, Washington

The drying of lumber is an energy intensive and costly operation, energy wise reported to consume 60% to 70% of that in the sawmill operation and cost wise -- a good question. Literature values range from $5.45/MBF (Englalichev and Eddy, 1970) to $66.73/MBF (Cuppett, 1977), depending on drying technique, processes considered and assumptions made.

The true overall or total costs involved in drying for a specific operation are very difficult to obtain because of the complexities and interdependence of steps involved. Even if the true cost is known for one operation, it would not necessarily be applicable to any other operation since each has unique costs involved. They may be as dissimilar as a difference in drying techniques, such as air drying versus high temperature drying or simply obscured costs found in material handling, stickers, or fringe benefits.

Knowing the true costs involved in a drying operation, however, can be extremely beneficial to that operation. The most obvious is being able to justify the drying operation itself or at least knowing the opportunity available for drying lumber, whether it is concerned with higher market value or lower transportation costs. Also, if only a dry market is available, knowing these costs may show an advantage or disadvantage for custom drying by another firm.

Other reasons may not be quite as clear. If, for a given operation, all costs were known for each step in that operation, a large quantity of useful information would be available. It could be used as an inhouse research tool to locate those areas within that operation which had the highest costs and those with the greatest economic potential for improvement. That is, those areas which would yield the greatest monetary return for some given amount of input.

Also, if one knew all costs and physical parameters involved, the addition of any given drying technique could be evaluated. The importance of various drying factors such as degrade, percentage redry, drying time, etc., could also be examined.

When evaluating changes in a drying operation however, one must also consider the interdependence of one process on another. A change made in one stage of the operation usually has a definite effect on other stages. For example, an increase in the amount of redry could decrease overall drying time, however, increase handling, sticking, and sorting costs. A change from kiln drying to air drying would decrease fuel costs, however, the entire material flow, forklift requirements, space requirements, etc. would be affected. The entire drying operation, therefore, must be examined before a thorough analysis of additions or changes can be performed.

A guide or tool is needed, therefore, to aid in the analysis of the drying operation because of the complexities involved. It is the purpose of this paper to describe such a tool; a computerized model of the lumber drying system. The model was derived from the lumber drying system concept, Figure 1, which incorporates all steps affecting the drying of lumber from tree growth to sales or dry storage prior to use, as described previously (Smith, 1975). Since it would be impractical to include this entire system, a better defined drying cost system shown in Figure 2 is used, consisting of those steps which feasibly may contribute to and/or influence the cost of drying. The steps involved begin with the green chain and end with shipping of dried lumber. In addition, to allow various combinations of drying techniques to be evaluated for a given operation, the model has the capability to evaluate up to any combination of three specific drying techniques desired. For example, air drying, predrying, and high temperature drying, or air drying, dehumidification drying, and conventional kiln drying, etc.

A redry option is also incorporated so various percentages of redry can also be examined. Obviously, not all of these steps shown in Figure 2 will be found in every drying operation, however, any steps present in any specific drying operation can be located therein.

In practice, a lumber drying operation can use the model by supplying costs and drying data which pertain to their given situation. If various drying techniques would like to be compared, each of their costs are supplied. Once this data has been placed in the program, cost values for each step on a unit volume basis, such as \$/MBF or \$/M^3, as desired, are computed. Also, values for total labor, capital expenditures for equipment, fuel, electricity, maintenance, degrade, land, interest on lumber investment, taxes and insurance, extra supplies, stickers, bolsters, and overhead are computed. Percentages of the total cost for each are also calculated to aid in sensitivity analysis.

The model and its usefulness may better be illustrated through an example. It is beyond the scope of this paper to discuss all of its capabilities, therefore only a portion will be discussed, using input cost values obtained either in the literature or direct contact with manufacturers.

Drying Operation

Let's assume a softwood dimension mill having ample space for expansion desires to begin drying and surfacing 30 million board feet (70,800 m^3) of lumber annually. It is known that the lumber has an average initial moisture content of 100% and will be dried to 19% moisture content, producing 0% or no redry. The mill has heard much about greenhouse type solar drying and would like to include it in its analysis of drying techniques with air drying and conventional kiln drying. The proposed drying extension will also need to include additional processes along with the drying techniques, as shown in Figure 3.

Data Input

Input data for the analysis is broadly contained in the following five categories:

1. Cost data for the various processes and equipment used.
2. Cost data, drying times, and degrade for each drying technique used.
3. Energy type and quantities required during drying.
4. Forklift transportation times and energy consumption.
5. Other miscellaneous price and factual data, such as sticker prices, appropriate interest rates, fuel prices, etc.

Cost data obtained from the literature and personal contacts for the various processes other than the three drying techniques are summarized in Table 1. In column 6, the land value and tax figures may be confusing. They are composed of the value of the land required by the process plus its appropriate annual tax. In the program, the land costs attributable to drying consist only of the interest which could have accrued on the value of the land value plus the annual land tax. The value of the land cannot be considered directly as a cost since it is assumed recoverable when sold. Miscellaneous equipment costs consist of equipment such as moisture meters, scales, drying ovens, etc.

Cost data, drying times and degrade for each drying technique were based on the following assumptions. Air drying is seasonally dependent, therefore, average drying times need to be obtained from more than one drying curve. To better approximate lumber being placed on the yard at different times of the year, five drying curves were used to determine drying time and yard capacities. These curves: 2, 2.5, 3, 3.5, and 4 months each are shown in Figure 4. Yard capacities were based on that needed to provide a uniform quantity output of 2500 MBF per month.

Solar drying is also seasonally dependent and must be based on multiple drying curves as well. Four curves are used, Figure 5, derived from air drying-solar drying ratios. These ratios were obtained from comparisons in the literature between air drying and solar kiln drying in a greenhouse type dryer, to provide a reasonable base on which to make their comparisons. Also, to calculate required capacities, insulation values of 2666, 1975, 1200 and 1020 Btu/ft^2/day for summer, spring, fall, and winter, respectively, were assumed requiring an overall 64.47 ft^2/MBF collector surface area for a 50% efficient kiln.

A typical five-day drying curve is assumed for the conventional dry kiln, Figure 6. Energy requirements are based also on 50% kiln efficiency, i.e., only 50% of the energy consumed is directly used to evaporate the water from the lumber; the remainder is lost through vents and walls, warming up lumber, incoming air, etc.

Cost inputs for each drying technique need to be categorized into moisture content groups so they may be used in various drying combinations. For example, to determine the costs involved for combining air drying and solar drying, the costs for air drying from 100% MC to 30% moisture content must be determined and added to those derived for solar drying from 30% moisture content to the desired 19% moisture content. These ranges are given in Table 2, with drying costs for each drying technique.

The degrade function is one of the most difficult pieces of information to obtain. Therefore, for this example, a conservative straight line function based on loss in lumber price will be used equally for each drying technique, shown in Figure 7.

Drying Operation Analysis

Using these input data, the drying operation described can now be economically analyzed. This consists of looking at seven possible drying methods, consisting of each drying technique as an entity and various combinations of each. They are given in Table 3 with their computed total drying cost including costs of all processes preceding and following the drying techniques as shown in Figure 3.

As can be seen, drying completely on the air yard or drying to 30% moisture content (fiber saturation point) on the air yard then completing drying in a conventional kiln to 19% moisture content have equal total costs $39.84/MBF. These are followed by drying in a conventional kiln (100% MC to 19% MC) $43.24/MBF; air yard (100% - 30%) - solar kiln (30% - 19%) combination, $43.35/MBF; air yard (100% - 50%) - solar kiln (50% - 30%) - conventional kiln (30% - 19%) combination, $46.49/MBF; solar kiln (100% - 30%) - conventional kiln (30% - 19%) combination, $50.20 and finally solar kiln only (100% - 19%) $54.11/MBF.

Table 4, the cost breakdown of each possible drying technique by major cost areas, provides an insight into why the total costs vary. Initially, one can see that the greatest cost in all possibilities is attributable to degrade. As was mentioned previously, the degrade function used was conservative and applied equally to each drying possibility, amounting to a total of 3% of the dry lumber price. The real importance of this factor can now be recognized. As in reality, it does vary between drying techniques and more notably between operations, this can greatly affect final drying costs. It is a very important function to know when actually comparing drying techniques and should be obtained with as much certainty as possible.

Land costs are the other extreme and do not have much influence on total drying costs. This is a factor not near as much detail need to be given. Other than these two extreme factors, costs vary widely within a given factor depending on the specific drying technique used.

A closer examination of the two lowest cost drying possibilities, air yard only and air yard-conventional kiln drying will help explain the logic behind their costs. In the air drying possibility, the greatest cost other than degrade is interest accrued on the money invested in the lumber during the long drying times, $12.25/MBF. This cost is based on green lumber price since it is the amount being invested. The air yard-conventional kiln drying possibility also has as its second highest cost interest on lumber investment, $8.00/MBF which is lower because of shorter time spent in the system. However, it also has higher capital and fuel costs because of the addition of the conventional kiln which offsets this gain. Comparing these two drying possibilities to the other five possibilities, their overall advantage stems from lower capital expenditures and lower electricity costs per MBF.

Examination of the solar drying only possibility will show why the type of solar kiln used in this example is not economically feasible. Its highest costs other than degrade are capital expenditures for equipment, $10.54/MBF, cost of electricity, $9.89/MBF, and interest on lumber investment, $6.44/MBF. Even though the initial equipment costs per board foot capacity were lower than for the conventional kiln, $.70/BF vs. $2.00/BF respectively, the overall or total cost was greater because of the much longer drying times required, tying up a greater amount of capital per MBF. The longer drying times than conventional kiln drying greatly increased electricity costs for fan operation even though the same number of fans were used per MBF. Even if fan usage was cut in half, assuming only day usage, the overall cost would still be much higher. Therefore, for solar kilns to be more economically feasible under the above assumptions, drying time must be shortened. This might be done through external collection and heat storage facilities.

Conventional kiln drying only in this example places second due primarily to higher fuel costs and capital expenditures. Other types of kilns using wood or other fuels, may have some cost advantages over the kiln used in this example. This, however, is difficult to ascertain until examined thoroughly because of other influencing factors such as higher boiler construction and maintenance costs, fuel handling, etc.

The results discussed so far pertain only to existing conditions. What happens if the values used are wrong or change in the future? Will the air yard or air yard-conventional kiln possibilities remain equal and less expensive than the other possibilities? These questions can be entertained through sensitivity analysis, that is, looking at changes in total costs when specific values change.

Since the most variable cost factors in the given example are interest rates used on lumber investment and fuel costs, disregarding degrade, an examination will be made to determine what happens when these costs change. Degrade in this example cannot be used. Since it is applied equally to all drying techniques in the input data, a change would only be seen as an upward or downward shift in total costs without any given drying possibility gaining an advantage over another.

Figure 8 shows how total drying costs change with changes in interest rates used to calculate costs of lumber investment. It contains only air yard, air yard-conventional kiln, solar kiln, and conventional kiln possibilities to simplify the discussion. If the interest rate remains at 10%, the rate used in this example, then either air yard or air yard-conventional kiln possibilities remain the lowest cost. If, however, the interest rate drops below 10%, the air yard drying possibility becomes increasingly less expensive. As the interest rate increases above 10%, the air yard becomes less favorable and the air yard-conventional kiln possibility becomes the least expensive up to a 66% increase in interest rates, or 16.6% where costs become equal with conventional kiln drying at $45.17/MBF. Any increases above this will widen the gap between conventional kiln drying and other possibilities. This says that in the long run if interest rates are likely to stay the same or get lower, air drying is the most likely choice under the assumed conditions; if they increase but stay below 16%, air yard-conventional kiln drying is the most logical choice, and if they are expected to increase above 16%, conventional kiln drying is the most logical.

Fuel price changes, on the other hand, adversely affect the cost of conventional kiln drying and air yard-conventional kiln possibilities, as might be expected, Figure 9. Therefore, any increase above $.30/gallon used in this analysis, would favor air drying only and below, air yard-conventional kiln. Fuel prices have only a very slight effect on air yard and solar kiln costs since the only fuel used is in the forklifts transporting the material.

Examining these costs in this manner, then, provides a more firm basis on which to make decisions. It points out the most important cost factors, such as degrade, interest on lumber investment, capital expenditures, etc. which demand more precision as input costs, and more importantly indicates those areas which may have the greatest economic potential for improvement. It also provides a method to carefully examine uncertain input data by using a range of values in the sensitivity analysis. Without these, a true economic analysis cannot be properly performed.

Conclusions

The analysis of the assumed softwood dimension mill shows that either air drying or air drying combined with conventional kiln drying is less expensive than other possible drying combinations including solar drying. It indicates the importance of various cost factors, their influence on overall drying costs, and the magnitude of costs involved in drying lumber when additional processes are included. The final outcome as to exact prices and least expensive drying techniques determined here however, cannot be construed to always be the same since results are directly dependent on operational conditions such as species, drying techniques, geographical location, and regional costs. Exact drying costs have to be determined for a given operation using their specific values.

The example used here helped only to describe a portion of the model's capabilities for one particular type of drying economic analysis, a new drying operation. It can also be used to evaluate an existing drying operation by supplying cost values pertinent to its existing processes. This type of analysis could best be used to help determine:

1. drying cost opportunities,
2. effects of changes or additions on the operation prior to their being made, and/or
3. effects of a redry program.

A complete analysis of a drying operation can be extremely beneficial to any company presently drying or considering drying lumber. Costly mistakes can be avoided for either new operations or existing operations considering changes or additions and help all drying operations maintain a highly efficient operation.

References

Englalichev, N. and W. E. Eddy. 1970. Economic Analysis of Low Temperature Kilns in Processing Softwood Lumber for Markets. Extension Bulletin No. 178, Coop. Ext. Serv., Univ. of N. H., Durham, N. H.

Smith, W. R. 1975. Lumber Drying as a System as Exemplified Through An Analysis of a Redwood Operation. Master's Thesis, Univ. of Calf., Berkeley.

Cuppet, D. G. 1977. Personal communication, letter. N.E. For. Exp. Sta., For. Prod. Mkt. Lab., P.O. Box 152, Princeton, W. Virginia.

TABLE 1. Cost Input Data For Processes Other Than Drying Techniques.

	Labor $/Yr.	Capital Total Invest. $	Life Yrs.	Maint. $/Yr.	Tax & Ins. $/Yr.	Land Value and Tax $/Yr.	KWH's Used KWH/Yr.
Greensort	20,000	135,000	15	5,400	4,374	331	74,570
Stacking	10,000	42,480	15	850	1,376	120	53,690
Unstacking	1,100	17,510	20	320	567	8	74,646
Surfacing	10,000	260,000	15	22,500	13,624	144	105,330
Dry Storage	500	20,200	20	202	6,654	225	5,000
Forklift	20,000	61,416	4	5,849	2,333		4,374*
Sticker Handling	500	7,670	20	153	249	16	44,742
Misc. Equipment		1,000	5	40			

*Gallons (16,556 liters) diesel fuel consumed annually.

TABLE 2. Cost Input Data For Drying Techniques.

	Labor $/Yr.	Capital Investment $	Life Yrs.	Maint. $/Yr.	Tax & Ins. $/Yr.	Land Value and Tax $-$/Yr.*	KWH's Used KWH/Yr.	Degrade %
AIR YARD								
100% - 50%	16,765	169,291	20	3,385	25,345	3,224		.000
100% - 30%	23,525	237,553	20	4,751	40,457	4,524		.001
100% - 19%	30,285	305,815	20	6,116	60,338	5,824		.030
SOLAR KILN								
100% - 30%	38,320	1,413,300	20	21,200	72,442	2,110	7,745,187	.001
100% - 19%	56,940	2,100,000	20	31,500	107,640	3,120	11,508,450	.030
50% - 30%	18,335	676,200	20	10,143	34,660	1,005	3,705,721	.001
30% - 19%	18,867	695,825	20	10,437	13,144	1,034	3,813,270	.029
CONVENTIONAL KILN								
100% - 19%	17,472	960,000	20	28,800	44,352	273	1,750,966	.030
30% - 19%	5,400	400,000	20	12,000	18,480	135	545,469	.029

*Interest on land value is calculated as a cost in the program and added to land taxes per year.

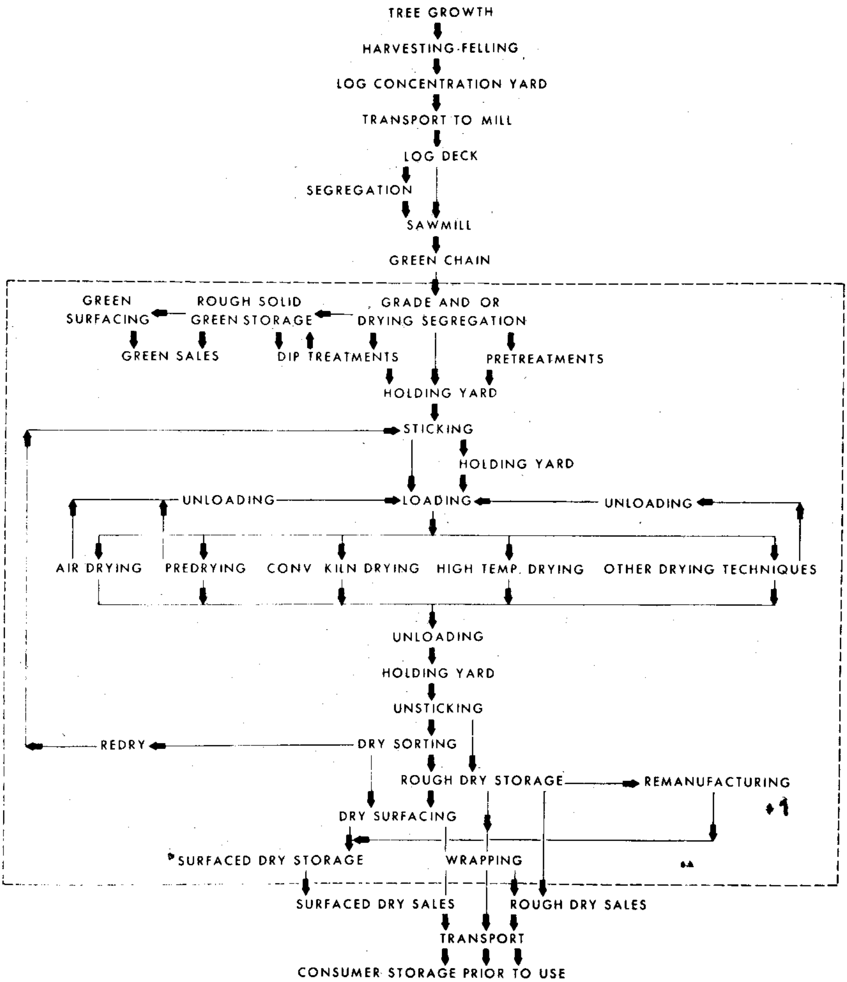
TABLE 3. Total Drying Cost For Each Drying Combination.

Drying Technique	Symbol	$/MBF
Air Yard	AY	$39.84
Solar Kiln	SK	54.11
Conventional Kiln	CK	43.24
Air Yard - Solar Kiln	AY-SK	43.35
Air Yard - Conventional Kiln	AY-CK	39.84
Solar Kiln - Conventional Kiln	SK-CK	50.20
Air Yard - Solar Kiln - Conventional Kiln	AY-SK-CK	46.49

TABLE 4. Cost Breakdown For Each Drying Combination (U.S. Dollars).

	Labor	Capital	Fuel	Maint.	Taxes & Ins.	Land	Elect.	Degrade	Int. on Lumber Invest.	Other	Total
AY	2.76	3.71	.05	1.30	3.16	.02	.28	14.73	12.25	1.58	39.84
SK	3.47	10.57	.02	2.10	4.72	.02	9.89	14.73	6.44	2.17	54.11
CK	2.15	6.09	9.04	2.01	2.62	.00	1.75	14.73	2.90	1.96	43.24
AY-SK	3.28	6.28	.07	1.63	2.95	.02	3.47	14.73	9.16	1.77	43.35
AY-CK	2.83	5.12	1.84	1.70	3.14	.02	.76	14.73	8.00	1.70	39.84
SK-CK	3.14	9.56	1.82	2.19	4.18	.02	7.20	14.73	5.29	2.08	50.20
AY-SK-CK	3.33	7.60	1.86	2.01	3.80	.02	3.82	14.73	7.41	1.91	46.49

FIGURE 1. THE LUMBER DRYING SYSTEM



ARROWS DENOTE TRANSPORTATION

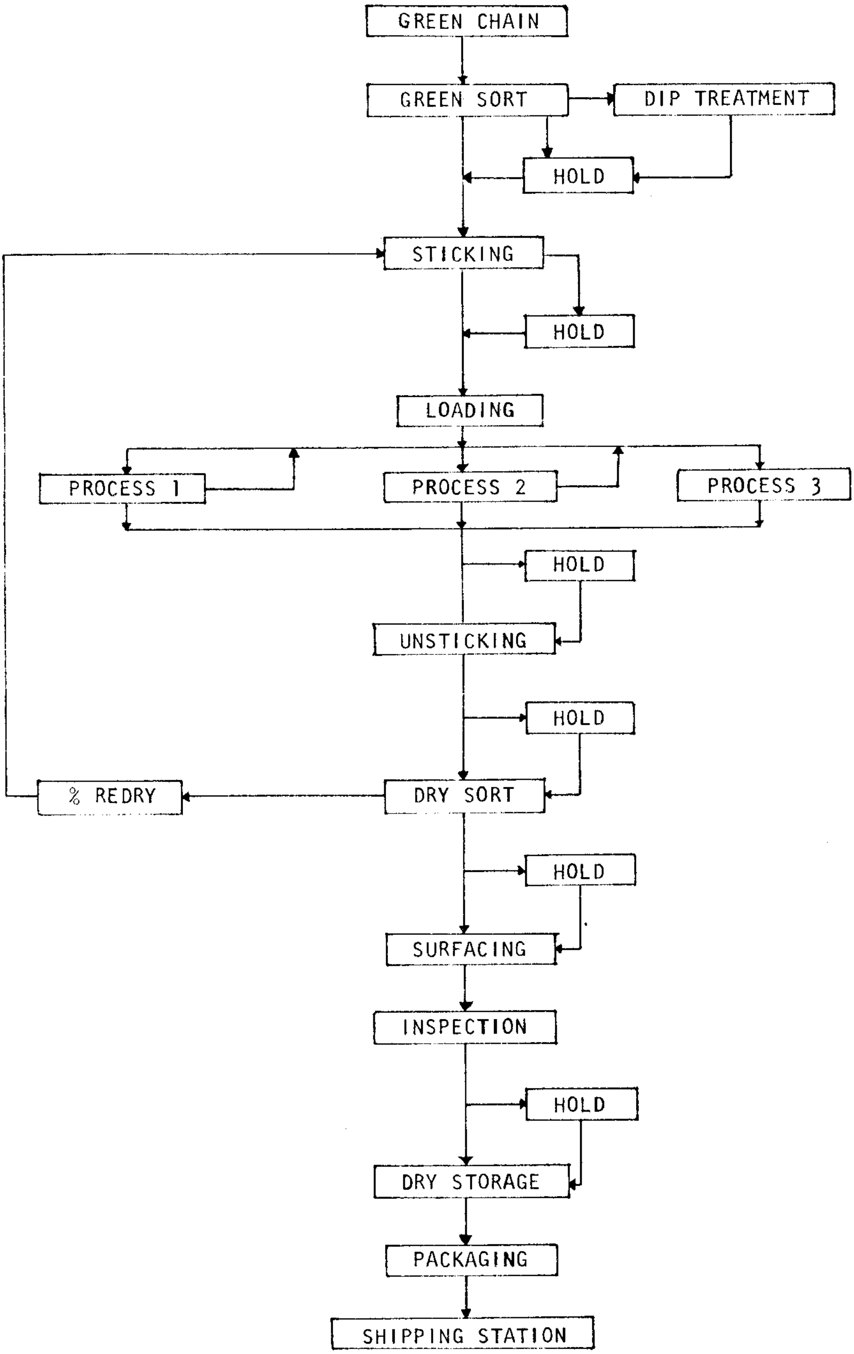


FIGURE 2. Lumber Drying Cost System.

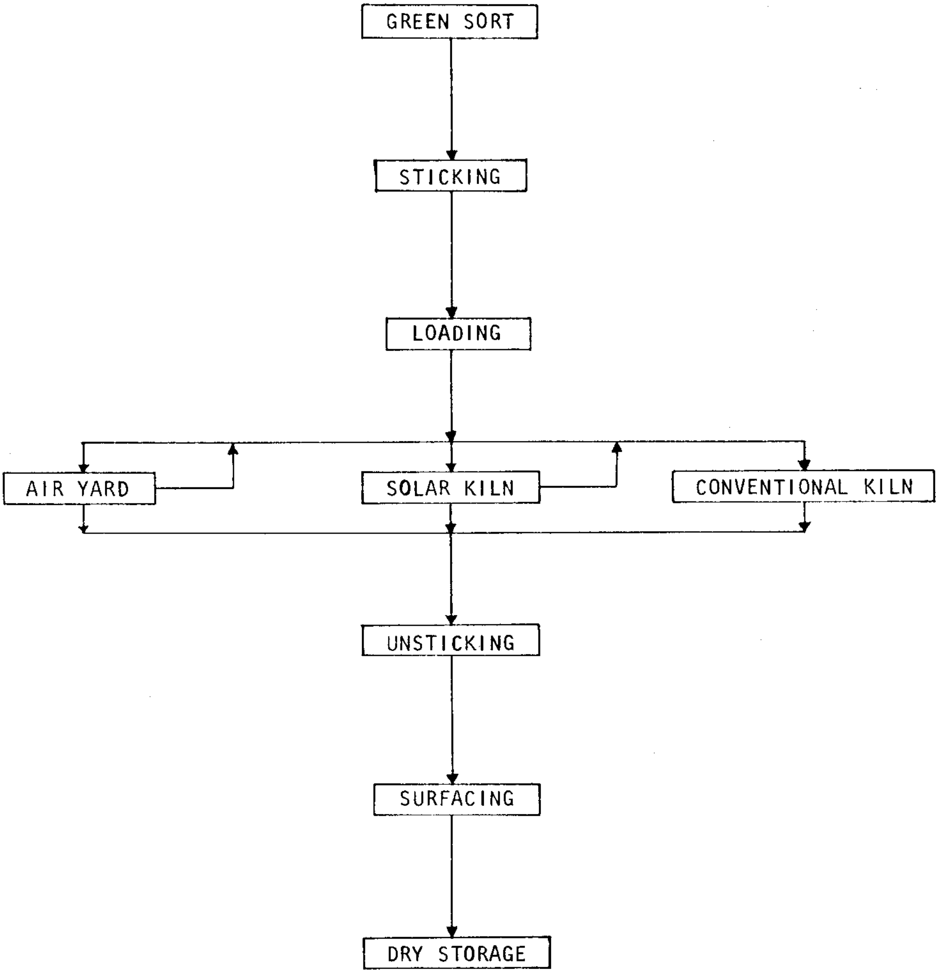


FIGURE 3. Processes in An Example Lumber Drying Operation.

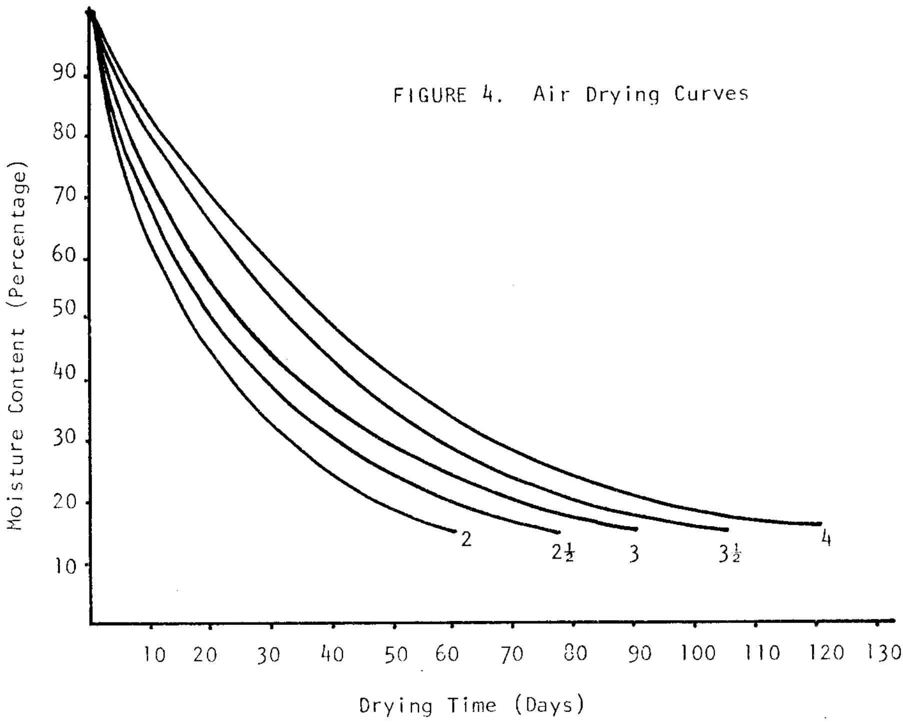


FIGURE 4. Air Drying Curves

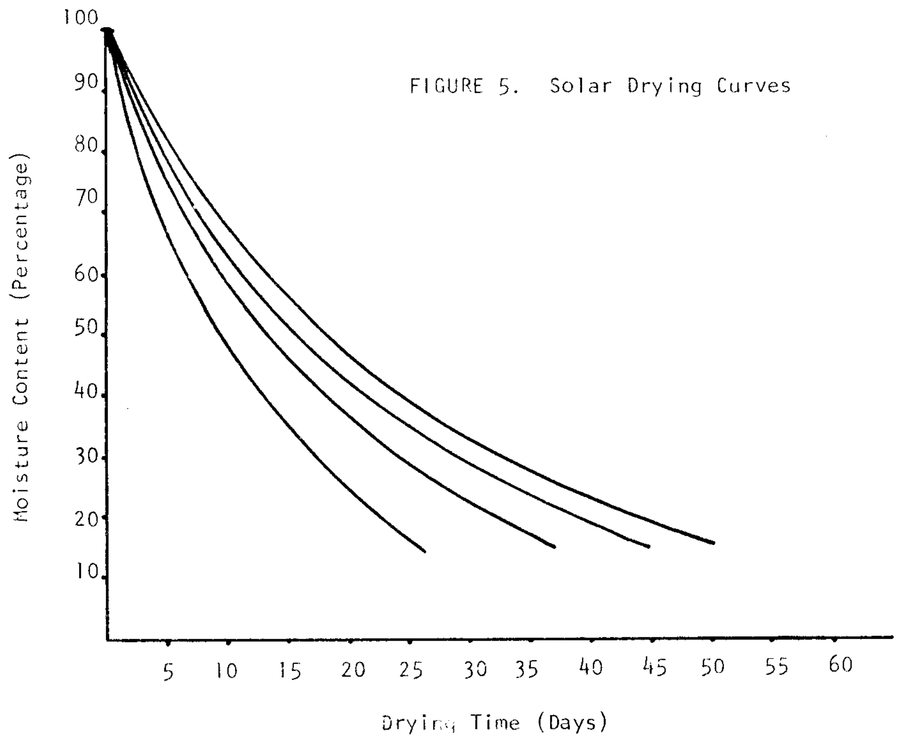


FIGURE 5. Solar Drying Curves

FIGURE 6. Conventional Kiln Drying Curve

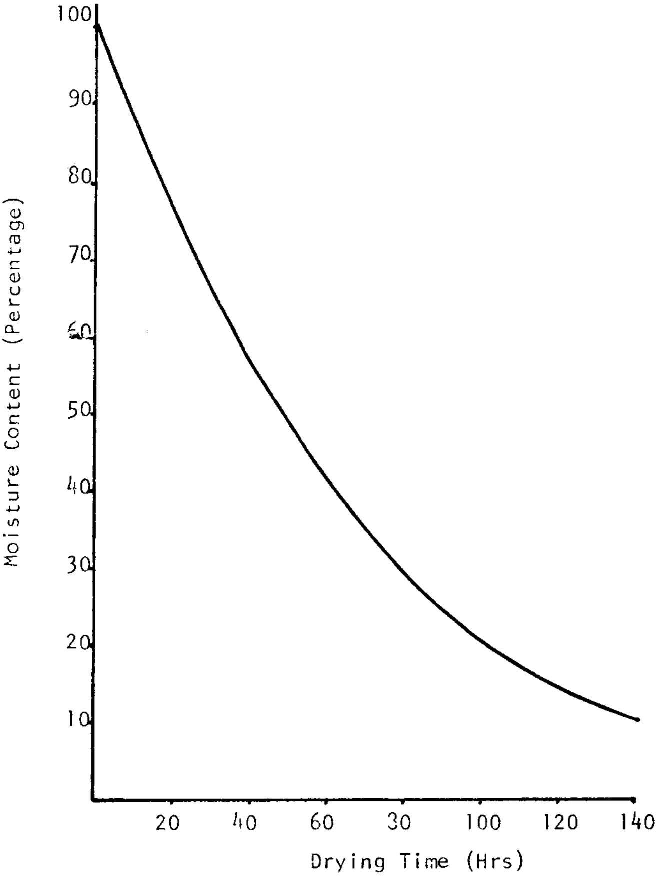


FIGURE 7. Degrade Function For All Drying Techniques

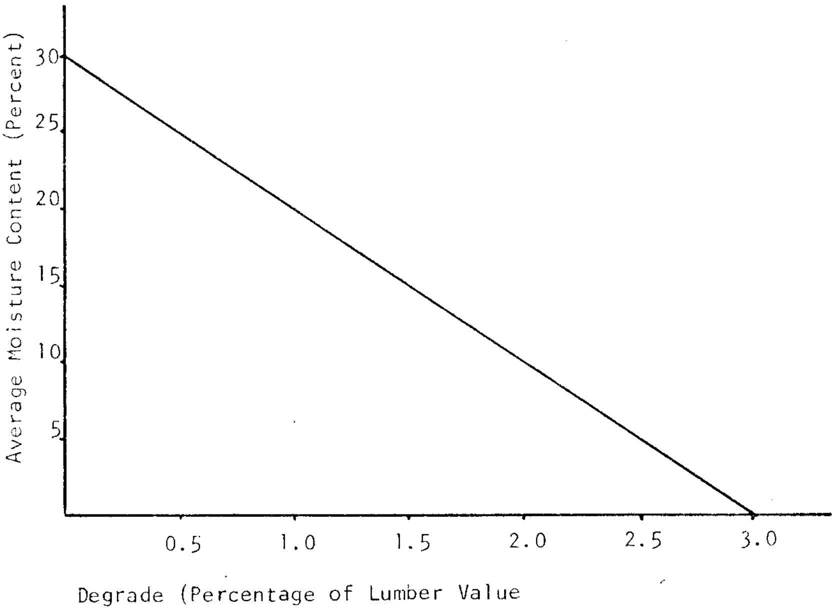


FIGURE 8. Sensitivity of Change in Interest Rate on Cost of Lumber Inventory.

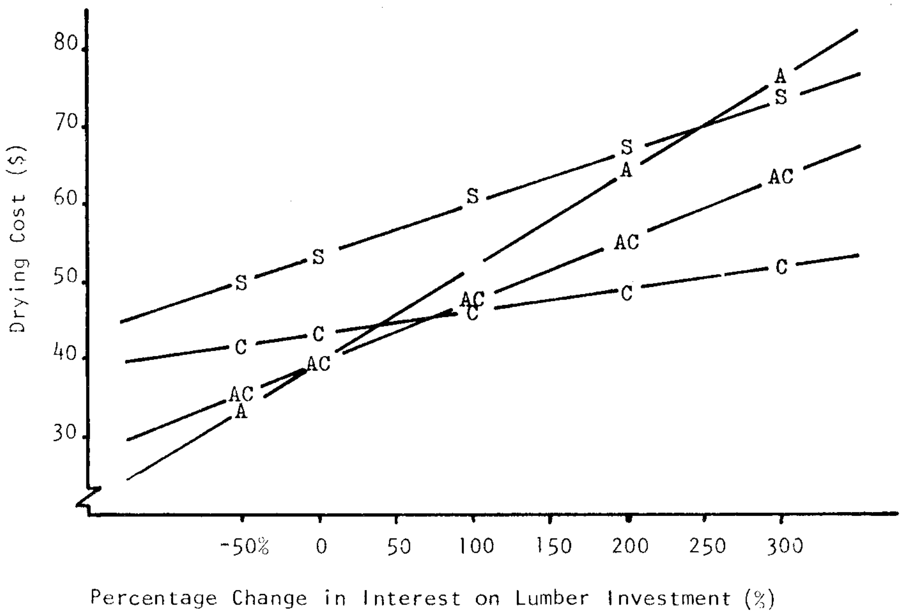


FIGURE 9. Sensitivity of Change in Fuel Prices