PROCEDURES AND COSTS FOR SEASONING WESTERN HEMLOCK

R. M. Sharp
Engineer, Operations Research Section
British Columbia Research Council
Vancouver B. C.

During 1964 and 1965 a contract research project was performed for the British Columbia Lumber Manufacturers' Association by the Operations Research Section of the British Columbia Research Council. The B. C. Research Council is a non-profit Crown corporation established to provide research facilities, at cost, to industry.

The project, entitled "Procedures and Costs for Seasoning Western Hemlock", was done in two phases. In the first phase the costs of the total seasoning operation were broken down into their various components to establish the promising areas for cost reduction. In the second phase, a controlled experiment was undertaken to evaluate those areas suggested as most promising in the first phase study. I intent here to concentrate on the second phase, as this was the work I performed and am most familiar with.

Phase I

First, here is a brief resumé of the first phase. The first phase presented an analysis of the existing practice and a detailed breakdown of the costs of kiln drying Hemlock at five medium-to-large sawmills on coastal British Columbia. The procedures and costs for processing 2-inch Common lumber were gathered for three mills which dried this grade. In addition 1-inch and 2-inch Clears were studied at the five mills. Each mill chosen had a different model of kiln and different lumber handling procedures. The costs considered included all definable costs from after the sawmill green chain to final shipping, including handling, surfacing, drying, and grade recovery. Data for the first phase were gathered from many sources.

Production records and direct observation provided operating times and output volumes for various components in handling and surfacing the lumber. Extensive instrumentation was used to measure air circulation, electric power, steam consumption, temperature and humidity in the kilns. Finally, accounting records provided wage rates, power costs and capital investment.

The grade recovery portion of the study was performed through the cooperation of the Vancouver Laboratory of the Forest Products Research Branch of the Department of Forestry and the grade supervisory group at the B. C. Lumber Manufacturers' Association.

The results of the first phase survey are shown on Tables 1 to 3 which show the production costs and losses of potential revenue for 2-inch Common Hemlock, 2-inch Clear Hemlock, and 1-inch Clear Hemlock respectively. For 2-inch Commons the total production costs shown on Table 1 (handling, drying and surfacing from green chain to final shipment) averaged $13.80 per Mfbm. These costs include direct labour, materials, and a 20 percent return on capital when the system operates at capacity. The losses of potential revenue could be due to overthickness, overgrade (the inclusion of Clear lumber in the Common loads), seasoning degrade, and wet stock. For 2-inch Commons these averaged $16.20 per Mfbm, for a total of costs and losses of $30.00. Grade losses were charged at prevailing market prices for kiln dried lumber.

As shown on Table 2 production costs for 2-inch Clears averaged $18.70 per Mfbm and revenue losses $14.30 for a total of $33.00 per Mfbm. As shown on Table 3 the production costs for 1-inch Clears averaged $24.80 per Mfbm and revenue losses $18.00 for a total of costs and losses of $42.80 per Mfbm.

The general conclusion from the first phase was that the greatest potential for cost reduction lay in the improvement of grade recoveries. When the second phase was commissioned our efforts were directed to concentrate on this area and limit the further work to 2-inch Clears, apparently the area which industry had indicated as being of greatest common interest.

TABLE 1

Production Cost and Loss of Revenue for Kiln-Drying 2-inch Common Hemlock

	Mill A	Mill B	Mill C	Average
	$/Mfbm	$/Mfbm	$/Mfbm	$/Mfbm
Cost of Lumber Handling & Surfacing				
Green chain to green storage	1.60	2.50	1.90	2.00
Blanking to kiln to dry storage	3.10	1.10	7.50	3.90
Planer to shipment	4.60	3.30	6.60	4.80
Total	9.30	6.90	16.00	10.70
Cost of Kiln Operation	3.20	3.50	2.60	3.10
Loss of Potential Revenue due to:-				
Overthickness	0.00	2.40	Not	1.20
Over-grade	10.70	6.40	Known	8.60
Seasoning degrade	1.00	2.30	3.70	2.30
Wet stock	7.00	3.80	1.40	4.10
Total	18.70	14.90	-	16.20
Total Costs and Losses	31.20	25.30	-	30.00

TABLE 2

Production Cost and Loss of Revenue for Kiln-Drying 2-inch Clear Hemlock

	Mill A	Mill B	Mill C	Mill D	Mill E	Average
	$/Mfbm	$/Mfbm	$/Mfbm	$/Mfbm	$/Mfbm	$/Mfbm
Cost of Lumber Handling & Surfacing						
Green chain to green storage	1.60	1.90	2.70	2.60	2.80	2.30
Stripping to kiln to dry storage	2.80	3.30	2.70	1.70	4.20	3.00
Planer to shipment	6.30	6.70	7.20	9.10	8.00	7.40
Total	10.70	11.90	12.60	13.40	15.00	12.70
Cost of Kiln Operation	5.90	5.40	6.40	5.20	7.00	6.00
Loss of Potential Revenue due to:-						
Overthickness	2.50	4.90	0.60	2.30	6.30	3.30
Seasoning degrade	5.60	9.10	11.90	6.90	9.40	8.60
Wet stock	6.80	0.40	0.00	4.80	0.00	2.40
Total	14.90	14.40	12.50	14.00	15.70	14.30
Total Costs and Losses	31.50	31.70	31.50	32.60	37.70	33.00

TABLE 3

Production Cost and Loss of Revenue for Kiln Drying 1-inch Clear Hemlock

	Mill A	Mill B	Mill C	Mill D	Mill E	Average
	$/Mfbm	$/Mfbm	$/Mfbm	$/Mfbm	$/Mfbm	$/Mfbm
Cost of Lumber Handling & Surfacing						
Green chain to green storage	2.20	2.60	3.30	2.70	2.90	2.70
Blanking to kiln to dry storage	6.30	4.70	9.40	3.80	4.90	5.80
Planer to shipment	8.80	9.50	9.30	12.10	12.00	10.40
Total	17.30	16.80	22.00	18.60	19.80	18.90
Cost of Kiln Operation	8.60	5.60	5.20	Not Known	4.40	5.90
Loss of Potential Revenue due to:-						
Overthickness	-	-	-	-	-	4.00
Seasoning degrade	-	-	-	-	-	14.00
Wet stock	-	-	-	-	-	0.00
Total	-	-	-	-	-	18.00
Total Costs and Losses	-	-	-	-	-	42.80

Phase II

Description of Test

One conclusion drawn of phase one was that comparisons of features of kiln geometry under similar kiln conditions would be useful to management. Information was sought to determine the effects upon season degrade losses of such kiln factors as: 1. Air velocity in the slots. 2. Pre-blanking. 3. Pre-sorting to length. 4. Method of kiln-car assembly. 5. Sticker thickness. As high slot velocities were one of the conditions to be studied, it was most convenient to run the test in a mill with relatively high velocity kilns. Consequently a test charge was assembled from one mill run of hembal at Mill E of the previous study, utilizing that lumber which fell into the classification as follows: Hemlock and Balsam, Industrial Clears; Random Width: 3 inches to 12 inches; Semi-Random Length: 13 to 16 feet (a majority of 14's and 16's); Nominal Thickness: 1 1/2 inches.

This lumber, taken at random as received from the green chain, was assembled into kiln car loads as quickly as possible to minimize effects of air drying in the mill yard.

The test charge is shown schematically in Figure 1, where other pertinent data are also recorded. As the mill stacker was able to produce only standard piling, the carrier package loads had to be assembled by hand. Where block length loads were needed, fourteen and sixteen foot lengths were hand-sorted from the 13 to 16 random lengths prior to stacking. Stickers were spaced at alternate two and four foot intervals as is standard practice at the mill where the study was conducted.

All pieces of lumber were identified by coloured marks on the even end of the load (end nearest the head of the kiln). Prior to charging the kiln, the lower half of car one was wrapped in polyethylene sheet and in the kiln, the sides were reinforced with light plywood. Other plywood baffles were errected in the side plenum chambers between cars one and two, to achieve the higher air velocities in the portions of car one which were not blocked off.

At the other end of the kiln, lower velocities were achieved by shutting off two of the overhead fans. The use of cars two and seven as fillers to isolate the velocity effects was fairly effective as can be seen from the velocities recorded on Figure 1. As in Phase I, the velocities were measured with an Alnor Velometer. The test kiln charge was dried 130 hours so that all lumber, regardless of sorting, surfacing or stacking received essentially the same drying schedule, the normal one for that mill.

Subsequent to drying and 2 days in the cooling shed, the loads were unstripped and sorted to width prior to planing. The test lumber was then sent to dry storage for a week, as a temporary shortage of capacity prevented immediate scheduling on the planer. Lumber was then planed to final thickness but neither trimmed nor ripped, to maintain full information for grading. The lumber was sorted back to colour identifications and returned briefly to dry storage prior to grading.

Methods of Analysis

After unstacking and planing, the pieces of lumber were examined individually by a qualified grader, using the double grading methods advocated by the Forest Products Laboratories and used in Phase I of this study. Initial and final grades were recorded along with reasons for any change in grade during drying.

Lumber from cars 3 and 4, which were random length piled, received special grading attention. In addition to the recording of all seasoning faults present, such faults occurring at either end of the piece were identified as EE or RE, referring to the even-piled end or the ragged-piled end of the kiln car. Thus the faults caused by inadequate restraint of the lumber at the ragged end of the car could be identified separately.

The study contained some 52 Mfbm, each piece of which required individual analysis. The grade and fault data were converted first to board feet to show the percentage of common, trim and rip which had been included in the load. This represents lumber containing natural faults which should not have been taking up kiln capacity in a load of clear lumber.

TABLE 4

Lumber Percentage Change in Grade
for 1 1/2 Clear Hemlock and Balsam

	Load Segment Identification	Weighted Percentage Change in Grade Hemlock	Balsam	Combined Total	Size Standardized Total
A	High Velocity, Standard Piled Block Length	11.42	9.52	11.01	8.86
B	High Velocity, Preblanked S1S, Standard Piled, Block Length	4.09	5.39	4.29	5.79
C	Standard Piled, Random Length	13.45	20.58	15.25	14.22
C/EE	Faults occurring in the even piled end of Load C	0.96	0.00	0.72	0.77
C/RE	Faults occurring in the ragged end of Load C	2.40	2.17	2.34	2.33
D	Carrier Package, Random Length	9.90	15.24	10.98	11.58
D/EE	Faults occurring in evenly piled end of Load D	0.92	0.46	0.83	0.86
D/RE	Faults occurring in raggedly piled end of Load D	3.11	8.27	4.15	4.76
E	Carrier Package, Block Lengths, top one third of car	7.91	18.70	11.41	8.81
F	Preblanked S1S, Carrier Package, Block Lengths, middle one third of car	3.70	5.25	3.95	4.81
G	Carrier Package, Block Lengths, bottom one third of car	4.94	9.58	6.12	5.91
H	1/2 inch Stickers, Standard Piled, Block Lengths, top one third of car	8.48	16.22	10.22	9.04
I	3/4 inch Stickers, Standard Piled, Block Lengths, middle one third of car	8.02	0.00	6.88	7.82
J	One inch Stickers, Standard Piled, Block Lengths, bottom one third of car	4.90	3.35	4.55	3.58
K	Low Velocity, Standard Piled, Block Lengths, top one third of car	13.83	20.34	15.55	15.26

TABLE 5

Lumber Value Losses for 1 1/2 inch Clear
Hemlock and Balsam

Weighted Losses - \$/Mfbm

Load Segment Identification		HEMLOCK	BALSAM	COMBINED TOTAL	SIZE STANDARDIZED TOTAL	SIZE & GRADE STANDARDIZED TOTAL
A	High Velocity, Standard Piled, Block Length	3.75	0.73	3.10	2.21	3.22
B	High Velocity, Preblanked S1S, Standard Piled, Block Length	0.58	3.77	1.06	1.48	1.26
C	Standard Piled, Random Lgth	5.90	7.44	6.29	6.13	5.65
C/EE	Faults occurring in even piled end of Load C	0.48	0.00	0.36	0.41	0.43
C/RE	Faults occurring in ragged end of Load C	1.40	2.50	1.68	1.62	1.52
D	Carrier Package, Random Length	4.60	7.01	5.09	5.20	5.18
D/EE	Faults occurring in evenly piled end of Load D	0.55	0.99	0.64	0.67	0.59
D/RE	Faults occurring in ragged end of Load D	1.62	3.82	2.07	2.22	1.90
E	Carrier Package, Block Lengths, top one third of car	4.39	10.28	6.30	4.87	5.47
F	Preblanked S1S, Carriage Package, Block Length, middle one third of car	1.86	4.10	2.22	2.97	2.07
G	Carrier Package, Block Lengths, bottom one third of car	3.01	5.05	3.53	3.54	3.16
H	1/2 inch Stickers, Standard Piled, Block Lengths, top one third of car	4.10	11.57	5.77	5.22	4.49
I	3/4 inch Stickers, Standard Piled, Block Lengths, middle one third of car	2.59	0.00	2.22	2.27	3.26
J	One inch Stickers, Standard Piled, Block Lengths, bottom one third of car	3.12	2.95	3.08	2.46	2.44
K	Low Velocity, Standard Piled, Block Lengths, top one third of car	11.29	10.75	11.10	10.41	8.65

The grading data were then accumulated by initial grade and size classification in terms of board feet and converted to percentage degrade for each classification. The total percentages are shown for each load segment in Table 4.

It was realized, however, that the distribution of lumber widths might not be constant in each segment and might therefore introduce a bias. If, for instance, one segment contained a larger proportion of ten and twelve inch widths than another, it might logically be expected to contain more degrade, both as a percentage and as dollar loss. Therefore, the size distribution of the over-all charge was used to calculate a Size Standardized Total, shown on Table 4.

Using the same cost basis as Phase I of the study, these figures were converted to losses in dollars per Mfbm. Value loss figures developed for each load segment by species and the combined total are shown in the first three columns of Table 5. Similar to size distributions, grade distributions in each segment may have an equally biasing effect, especially on the value losses. In other words, load segments which contained a higher proportion of B and C clears valued at $140.00 per thousand would be expected to show greater losses than one with a low percentage of B and C and a higher percentage of lower valued D. The segments with the greatest initial potential value would thus be expected to show the greatest dollar degrade. In order to remove bias which might be introduced through grade distributions, the value losses were weighted by the size and grade distribution of the over-all charge. These are summarized in the last column of Table 5.

Results

1. Air velocity in slots

Air velocity effects gave the most significant results in terms of potential reduction of degrade. As shown on Figure 2, degrade was reduced by approximately 40 percent for each doubling of slot velocity. Load Segment K had $8.65 per Mfbm of seasoning degrade at 270 f.p.m. average slot velocity, while segment E had $5.47 per Mfbm at 530 f.p.m. and segment A had $3.22 per Mfbm at 870 f.p.m. In other respects, each of these segments had 7/8 inch slots, was block length, and was approximately the top 1/3 of a car. Although segment E was a carrier packaged load whereas A and K were standard piled, it was shown in our report that little difference in degrade exists between these piling methods. A similar comparison of loads B and F (middle 1/3 of car, block length, 7/8 inch slots) reinforces the 40% figure. It should be noted here that no conclusions should be drawn from the relative positions of the two curves on Figure 2 as each refers to segments having different positions in the kiln car.

Although some additional power costs can be expected to accompany high velocities, these can be minimized by improvements in fan design and baffling. While theory predicts a large increase in power requirements, practical measurements taken in kilns during the first part of the study suggest that a very high proportion of the power delivered to the kiln motors was lost in fan inefficiency and by-passing of the slots caused by poor baffling.

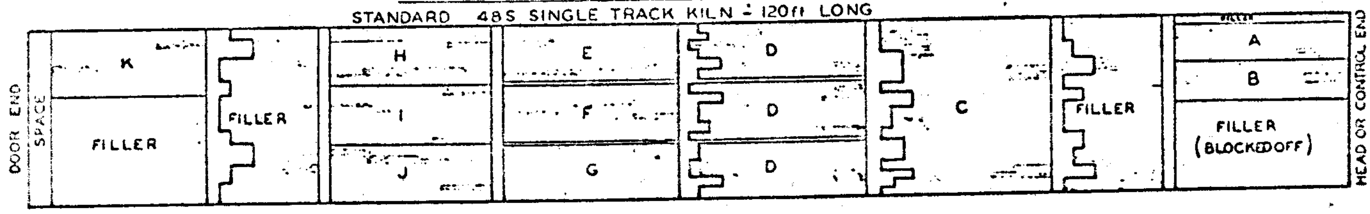
Plotting data, collected during Phase I of this report as shown on Figure 3, suggest that electrical power costs would increase to about $1.75 per Mfbm for velocities in the order of 1000 f.p.m. Careful charging of the kiln and good baffling (which would be necessary at these velocities) might be expected to lower this figure somewhat. One U.S. manufacturer of high velocity kilns (who is also reporting reductions in degrade), claims to have developed a more efficient fan for this purpose.

Two-speed fans have been suggested by some researchers[1] who advocate high velocities during the initial stages of drying (until lumber is dried below the fiber saturation point) and lower velocities during the latter stages. Presumably such a scheme would reduce anticipated power cost increases somewhat.

It has been suggested that higher velocities might also permit shorter drying schedules, with an accompanying decrease in kiln costs. No evidence to this effect was gathered in our test as all load segments were tested in one kiln charge under a common schedule.

FIGURE I. SCHEMATIC OF TEST CHARGE

STANDARD 48S SINGLE TRACK KILN - 120 ft LONG



CAR NO.	8	7	6	5	4	3	2	1
LENGTH	14 ft. BLOCK	6-9 ft. RANDOM	14 ft. BLOCK	16 ft. BLOCK	13-16 ft. RANDOM	13-16 ft. RANDOM	6-9 ft. RANDOM	16 ft. BLOCK
PILE CONFIGURATION	STANDARD	STANDARD	STANDARD	CARRIER PACKAGE	CARRIER PACKAGE	STANDARD	STANDARD	STANDARD
STICKERS	$\frac{7}{8}$	$\frac{7}{8}$	H - $\frac{1}{2}$ I - $\frac{3}{4}$ J - 1	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$
COLOUR CODE	K - COPPER		H - BLUE I - BLACK J - PURPLE	E - DARK GREEN F - FLUOR GREEN G - YELLOW	D - RED	C - RUST (RED OXIDE)		A - ORANGE B - FLUOR ORANGE
SURFACE PREPARATION.	ROUGH SAWN EXCEPT	SHOWN	AS	F BLANKED S1S				B BLANKED S1S
VELOCITIES IN SLOTS	LOW		MEDIUM	MEDIUM	MEDIUM	MEDIUM		HIGH
AVERAGE IN CAR (fpm)	226		421	480	452	505		923
AVERAGE FOR PORTION (fpm)	K - 270		H - 410 I - 412 J - 439	E - 531 F - 470 G - 423	D - 452 TOP - 496 MIDDLE - 425 BOTTOM - 420	C - 505 TOP - 575 MIDDLE - 485 BOTTOM - 451		A. - 870 B - 964

2. Pre-blanking

Pre-blanking, by surfacing green lumber on one side (SIS), reduced degrade by about $1.90 per Mfbm. There is good evidence that greater savings could be expected from blanking on two sides. As an additional benefit, a grade separation test showed that with SIS blanking, about half of the commons formerly classified as Clears when rough green could now be detected. At the test mill, this would have been worth $0.90 per Mfbm of Clears. There would be possible financial advantages through increased kiln utilization, or through any chip-recovery of blanking with chipper-heads, but these would depend greatly on the mill sawing accuracy and have not been included here. Less sticker breakage and easier handling are also claimed but these were not costed.

There is considerable supporting evidence from elsewhere that green surfacing significantly reduces the tendency of lumber to develop checks during seasoning. Gaby[2] and Leney[3] showed that different green surface finishes affected the amount of checking during drying of white and red oak. Stevens[4] reported that when SIS green surfacing of hembal clears was introduced at Eburne Sawmills (justified economically on reductions in sorting labour and better grade separation prior to drying) a definite improvement was noted in the kiln dried product. Since then blanking S2S has been tried and was adopted when a further improvement in the seasoned product was noted. It must be emphasized that these were simply observations of the mill grading personnel. No controlled degrade tests were performed at Eburne.

Further evidence supporting the advantages of blanking S2S may be drawn from a comparison of the reductions in percentage change in grade reported by Mathur[5] with those encountered in our test. Mathur reported 19 to 26 percent reductions in loss of grade in 2 x 4's and 60 percent reductions for 2 x 6 and wider Hemlock for S2S green surfacing. Our test, with S1S, produced only about 30 percent reduction in change of grade for 3 to 12 inch random width hembal.

It is believed that pre-blanking achieves its lower degrade through the more constant thickness and through the smoother surfacing.

Constant thickness permits: Better restraint by stickers; More even alignment of slots, especially in carrier packages; Faster and more uniform drying because the lumber is thinner. These benefits could also be achieved by more accurate sawing, if this were a feasible alternative.

The smooth surfaces permit: Better contact between kiln air and lumber surface; No saw tears on wood surface to start checking.

3. Sticker Thickness

The results from our sticker thickness tests and from the literature are inconclusive. Sticker thickness was varied in the component loads of Car 6. The thinner stickers were used in the top loads and the thicker ones were used at the bottom so as to maintain similar slot velocities throughout the car. The degrade was in fact higher at the top, but the difference was not greater than would have been expected due to the positioned effect within the car.

Dineen[6] has reported a 12 percent increase in kiln-capacity at Weyerhaeuser Mills through changing from 3/4 inch to 1/2 inch stickers. He reports no apparent change in degrade. The use of 1/2 inch laminated stickers would increase slot velocities and it is possible that any tendency to degrade through thinner stickers is compensated by the higher air velocity.

On the other hand, Herman and Rasmussen[7] used thicker stickers, and took advantage of more uniform drying to reduce cycle time and make a net increase in capacity. This suggests that Dineen should have been expected to increase cycle time to obtain a satisfactorily uniform product, or that the cycle times in his mills were too long originally.

In attempts to explain these results, I made calculations of Reynold's Numbers (see Appendix), a measure of the tendency of a fluid to develop turbulent flow. When applied to Dineen's reported figures of velocity increases and sticker size, it is interesting to note that no significant increases in Reynold's Number took place, suggesting that turbulence, heat transfer and moisture removal rates were largely unaffected by the change.

In summary, therefore, the question of optimum sticker thickness and the associated drying cycle time is unresolved, but tentatively, thinner stickers look attractive.

4. Pre-sorting to length

Pre-sorting to length was found to reduce drying costs by about $1.75 per Mfbm. This saving consists of $1.20 through reduced degrade and $0.55 due to increased kiln-capacity.

The reduction in degrade losses of about $1.20 per Mfbm can be determined from several comparisons: Using carrier packaged loads, random length load D with $5.18 per Mfbm for a difference of $1.25 per Mfbm in favour of block piling, if the differences in degrade losses attributable to the ends of load D are calculated (EE being the even-piled end and RE the ragged end) the difference of $1.30 represents the excess of degrade occurring on the ragged end. A similar calculation for the two ends of load C, the standard piled random length car, gives a difference of $1.10 per Mfbm.

5. Kiln Car Assembly

There is little cost difference between the two chief methods of kiln car assembly, carrier packaging and standard or solid piling. Management choice can therefore be determined from indirect considerations of convenience for mill layout, flexibility and the like. Standard piling appears to gain $0.80 per Mfbm or 12 percent in kiln capacity, but los $0.35 in handling and $0.45 in degrade leaving it exactly comparable with carrier package assemblies.

The handling advantage of carrier package assemblies to the average mill stems from the elimination of extra handling through an unstacker, sorting and dry storage prior to planing. There are minor offsetting disadvantages due to the higher costs of sorting lumber to width while green which uses more labour than sorting dry lumber and slightly higher handling costs in charging and emptying the kilns. The net handling advantage in favour of carrier packages is about $0.35 per Mfbm, depending on the mill.

The advantage in degrade of $0.45 per Mfbm is established by comparing the standard piled load C, having losses of $5.65 per Mfbm, with carrier packaged load D at $5.18 per Mfbm.

Conclusions

Despite the use of the mathematical standardization techniques to extract maximum information from the data gathered, the sample sizes in some segments are undeniably small. Where a sample is deficient or lacking in a particular classification a source of error may have been introduced. Where this is the case, however, the classification usually had a very low representation in the total charge and the effect of such error is thereby minimized in the results.

For the forest products researcher the results indicate the most fruitful areas for further studies into kiln geometry effects using larger samples for those wishing more exacting figures.

For the mill manager or kiln operator wishing a comparison of the relative merits of various kiln geometry factors, the figures here are suitable to his purpose. If he wishes to extract data to accurately apply to his mill, he must go back to the degrade figures by species, size and grade in our report and apply these to the average mix in his mill, and the current selling prices. That is, he must standardize, as we did for the test mill, to an average mix, representative of his mill. Fortunately, this would be necessary only for those loads on which comparisons are to be made. Of course, the Research Council would be pleased to assist mill managements in relating the data to the operation of their particular mill.

APPENDIX

REYNOLDS NUMBER FOR KILN CONDITIONS

SLOT THICKNESS (INCHES)	de (ft.)	VELOCITY (f.p.m.)								
		200	300	400	500	600	700	800	900	1000
1/2	.082	1240	1865	2480	3110	3730	4350	4970	5590	6210
5/8	.102	1550	2320	3090	3860	4640	5410	6180	6960	7730
3/4	.123	1865	2800	3730	4660	5590	6520	7460	8390	9320
7/8	.143	2170	3250	4330	5420	6500	7590	8670	9750	10830
1	.163	2470	3700	4940	6180	7410	8650	9880	11120	12330

SAMPLE CALCULATIONS

$$N_{Re} = \frac{VD}{\nu} \quad (1)$$

where N_{Re} = Reynolds Number (dimensionless)
V = Mean Velocity of Fluid (ft./sec.)
D = Hydraulic or Equivalent dia. (ft.) = $\frac{4A}{P_w}$ (2)
A = Crossectional area of slot
P_w = Wetted perimeter of slot
ν = Kinematic Viscosity of fluid (sq.ft./sec.)

For dry air at 170°F, $\nu = 2.2 \times 10^{-4}$ sq. ft./sec. (3)

For 3/4" Stickers, 4 ft. spacing $D = 4 \times 4 \times 3/4 \,/\, 2(4 + 3/4 \times 1/12) =$ .123 ft.

For 500 f.p.m., $N_{Re} = \frac{500}{60} \times \frac{.123}{2.2 \times 10^{-4}} = 4660$

(1) A.S.H.R.A.E. Guide and Data Book, 1965-66, Pg. 88.
(2) Giedt, W.H., Principles of Engineering Heat Transfer, Pg. 109.
(3) A.S.H.R.A.E. Guide and Data Book, 1961, Pg. 93, Fig. 4.

LITERATURE CITED

[1] Salamon, M. 1965. Four Day Drying of Hemlock. Proc. of Kiln Drying Seminar of British Columbia Lumber Manufacturers' Association. October 1965.

[2] Gaby, L. I. Surface Checking of White Oak as Related to Mechanical Processing, Forest Products Journal, 13, No. 12. p. 529, 1963.

[3] Leney, L. Checking of Planed and Rough Red Oak during Kiln Drying, Forest Products Journal, 14, No. 3, p. 103, 1964.

[4] Stevens, J. A. Economics of Blanking Prior to Kiln Drying, Proceedings of Kiln Drying Seminar of B. C. Lumber Manufacturers' Association, October 1965.

[5] Mathur, Dr. V. N. P. Prevention and Reduction of Seasoning Degrade, Wood Products Research and Development, MacMillan, Bloedel and Powell River Limited, 1965.

[6] Dineen, N. J. Effect of Kiln Sticker Thickness on Drying of West Coast Hemlock, Proceedings of Kiln Drying Seminar of B. C. Lumber Manufacturers' Association, October 1965.

[7] Herman, Albert and Rasmussen, Carl. Some Factors Affecting Rate of Airflow in Western Pine Dry Kilns, Research Note 4.223, August 1959, Western Pine Association.