

HIGH TEMPERATURE DRYING STUDIES OF LODGEPOLE PINE

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Introduction. Over the past fifteen years considerable research has been conducted in the area of high-temperature drying of wood. Of primary consideration in most cases has been the effect of high temperatures on such parameters as drying rate, moisture content uniformity, strength properties and defect occurrence. Although it is conceded generally that circulation velocity is important, there appears to be little published research as to the effect this variable has on material dried at temperatures above the boiling point of water.

The high-temperature drying literature has been adequately reviewed by Lowery (7) and Kimball and Lowery (4). All studies reviewed confirm that high temperature kiln drying will decrease the drying time, but the effects on lumber vary between species to such an extent that general statements concerning the effects on wood are meaningless. Strength properties of one species may increase while those of another may decrease; severe casehardening occurs in one species and not in another; discoloration degrades some hardwoods and is absent in some softwoods, and the effects of high temperature kiln drying on the shrinkage behavior varies with species. Despite these shortcomings, the increased drying rate is so significant that the wood-producing industries cannot overlook the possibility for more efficient production.

The effect of air velocity on drying rate is the subject of some disagreement in the literature. Carrier (1), Gaby (2), Stevens (9), and Torgeson (10) suggest a linear variation of drying rate with velocity. However, experiments by Lewis (6) and Sherwood (8) show drying rates should vary as a power of one-half to eight-tenths velocity.

This study was designed to ascertain certain basic information concerning the reaction of lodgepole pine studs to high temperature kiln drying. Particular emphasis was placed on the evaluation of the effects of air flow velocity on the drying rate and the uniformity of final moisture content.

Apparatus. The drying apparatus used was an experimental Standard Air-O-Speed dry kiln located in the Wood Utilization Laboratory at Colorado State University. This dry kiln is designed to be operated and function in the same manner as a commercial dry kiln. Inside dimensions permit drying of 8-foot lumber with adequate plenum chambers on each side of the drying unit. The kiln is a track loaded, internal fan, cross circulation kiln, heated and humidified by steam of a maximum pressure of 57 pounds per square inch.

Temperature, ventilation, and relative humidity are automatically controlled with duplex dry bulb control. Circulation is supplied by two 36-inch diameter, B-23⁰, TOR type fans, directly mounted on 14 hp. Louis Allis special kiln motors. A manually operated selector switch permits the selection of four separate fan speeds, while fan reversal may be pre-programmed on a Paragon automatic time controller.

The kiln is equipped with a Fairbanks-Morse, Type "S" built-in scale which permits weighing the drying unit at any time without disturbing the drying operation.

Air circulation rates were measured with a Hastings Model H-2 Air Meter, a hot-wire anemometer, at the air exit side of the circulation velocity zones. Measurements were taken between each layer within a circulation zone and an average of these readings determined the air velocity for that zone.

Procedure. Freshly cut 12-foot logs were selected at random from the log yard at East Side Lumber Company in Fort Collins and were taken immediately to the sawmill. The logs were sawed into studs which were tightly stacked without stickers and covered to prevent excessive drying.

Moisture content samples were cut from each stud approximately two feet from each end. The remaining 8-foot section was dried in the dry kiln.

Different circulation rates within a drying package were obtained by designing a special stacking system. By placing baffles within and between rows of lumber (Figure 1), three air velocity zones were obtained within each drying unit with a single fan speed. The stacking stickers were 3/4-inch thick and two inches wide.

During the stacking process each stud was inspected for visible defects. Surface and end checks present in the green lumber were marked along the entire length of the check. This made it possible to recognize those checks as being present before drying. Deformations such as crook, cup, bow, and twist were also noted in the green condition.

The drying package was then positioned on the scale platform and the initial weight of the unit recorded. All kiln baffles were positioned to direct the air flow, the fans turned on and the doors closed. Anemometer readings were made between each course of lumber on the air exit side within each circulation zone, and the average air velocity for each zone recorded to the nearest 100 feet per minute.

The steam valves were opened and the automatic kiln controller set to a dry-bulb temperature of 230°F and a wet-bulb temperature of 200°F producing a relative humidity of 55 per cent and an equilibrium moisture content of 4.9 per cent. Periodic weighing of the charge and of the individual studs permitted the calculation of the current average moisture content and the plotting of time and moisture content curves.

The first two packages were conditioned after 48 hours for 6 hours at a dry bulb temperature of 200°F and a wet-bulb temperature of 190°F producing a relative humidity of 80 per cent and an equilibrium moisture content of 11 per cent. The remaining 8 units were removed from the kiln at the end of 48 hours without conditioning.

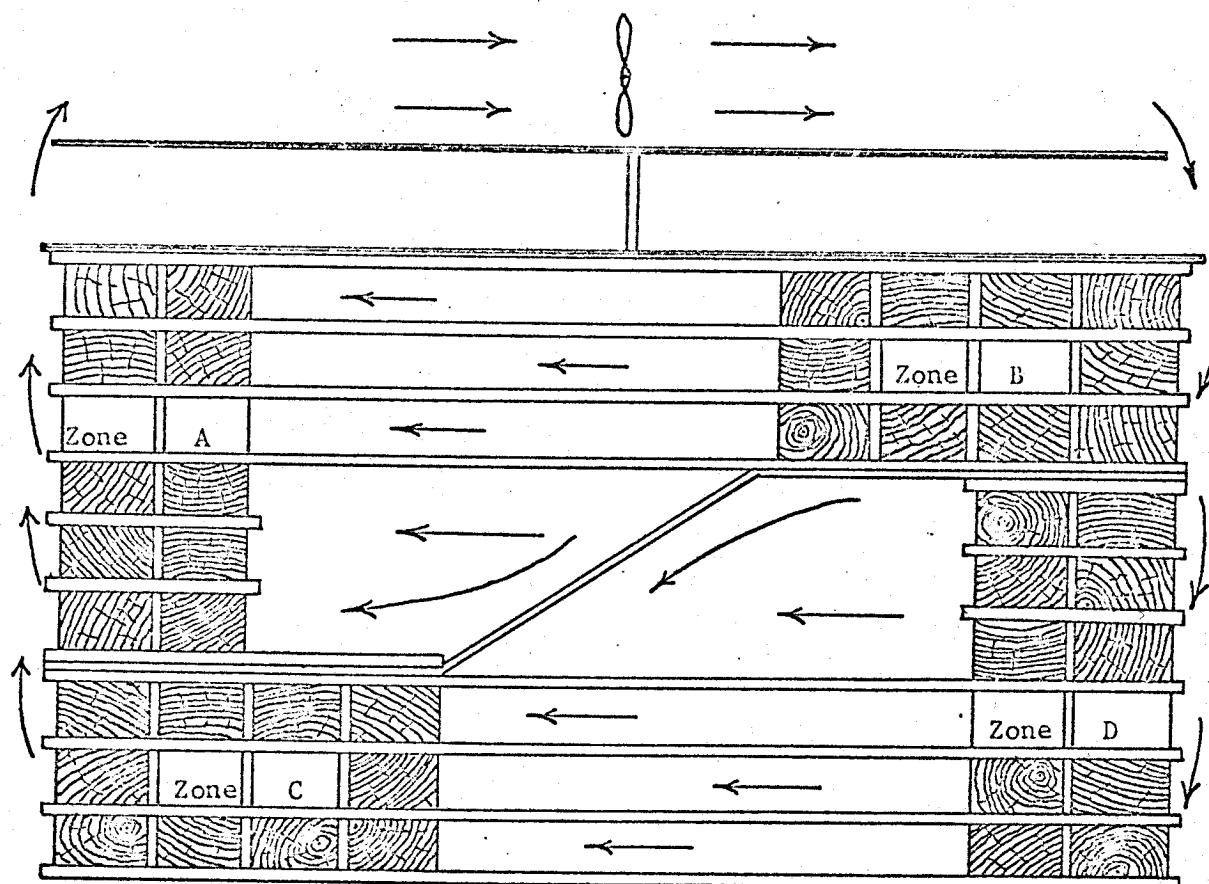
At the conclusion of the drying cycle each stud was examined for seasoning defects. Four studs were randomly selected from each circulation velocity zone for final moisture content analysis using the oven-dry method. In addition, ten moisture readings were taken on all studs to determine the uniformity of the final moisture content. These readings were made after the package had cooled for 24 hours. The dried material was then placed in a conditioning room at an equilibrium moisture content of 12 per cent prior to mechanical testing.

Results and Discussion: High Temperature and Drying Rate. Ten drying packages, each consisting of 48 studs, were kiln dried at 230°F dry-bulb temperature with a wet-bulb depression of 30°F for 48 hours. Drying time of 48 hours is defined as the total length of time the drying unit is in the kiln.

To determine the mean drying rate of the 10 packages, the original and final moisture contents of each package was calculated (Table 1). Analysis of the data reveals a maximum drying rate of 1.25 per cent per hour and a minimum rate of 0.75 per cent per hour. The average rate is 0.94 per cent decrease in moisture content per hour of drying.

Table 1. Average moisture contents of 10 drying units before and after high temperature drying with a 48-hour schedule.

Drying Unit	Per Cent Moisture Content	
	Original	Final
1	55	12
2	73	13
3	53	8
4	54	11
5	57	11
6	54	16
7	48	9
8	56	10
9	60	10
10	48	10
Average	56	11



Drying Package

Velocity Zone	Velocity-feet per minute	
	Fan Speed 2	Fan Speed 4
A	300	400
B	500	1000
C	400	600
D	500	1000

Figure 1, End view of a drying package consisting of 48 studs, stacked and baffled to produce varying air circulation velocities with a single fan speed.

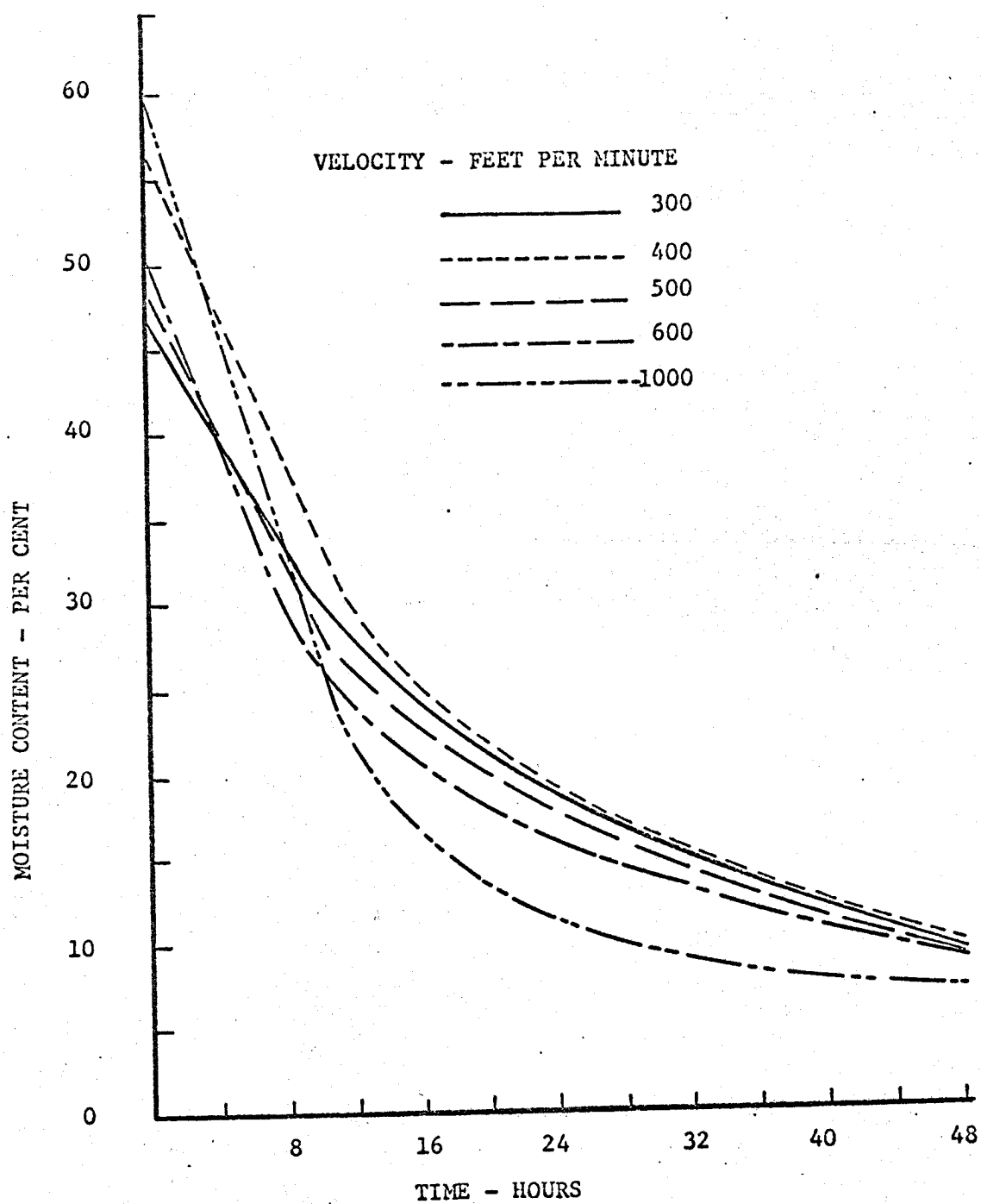


Figure 3. Mean drying curves plotted from periodic weighings of random samples selected from each circulation velocity zone.

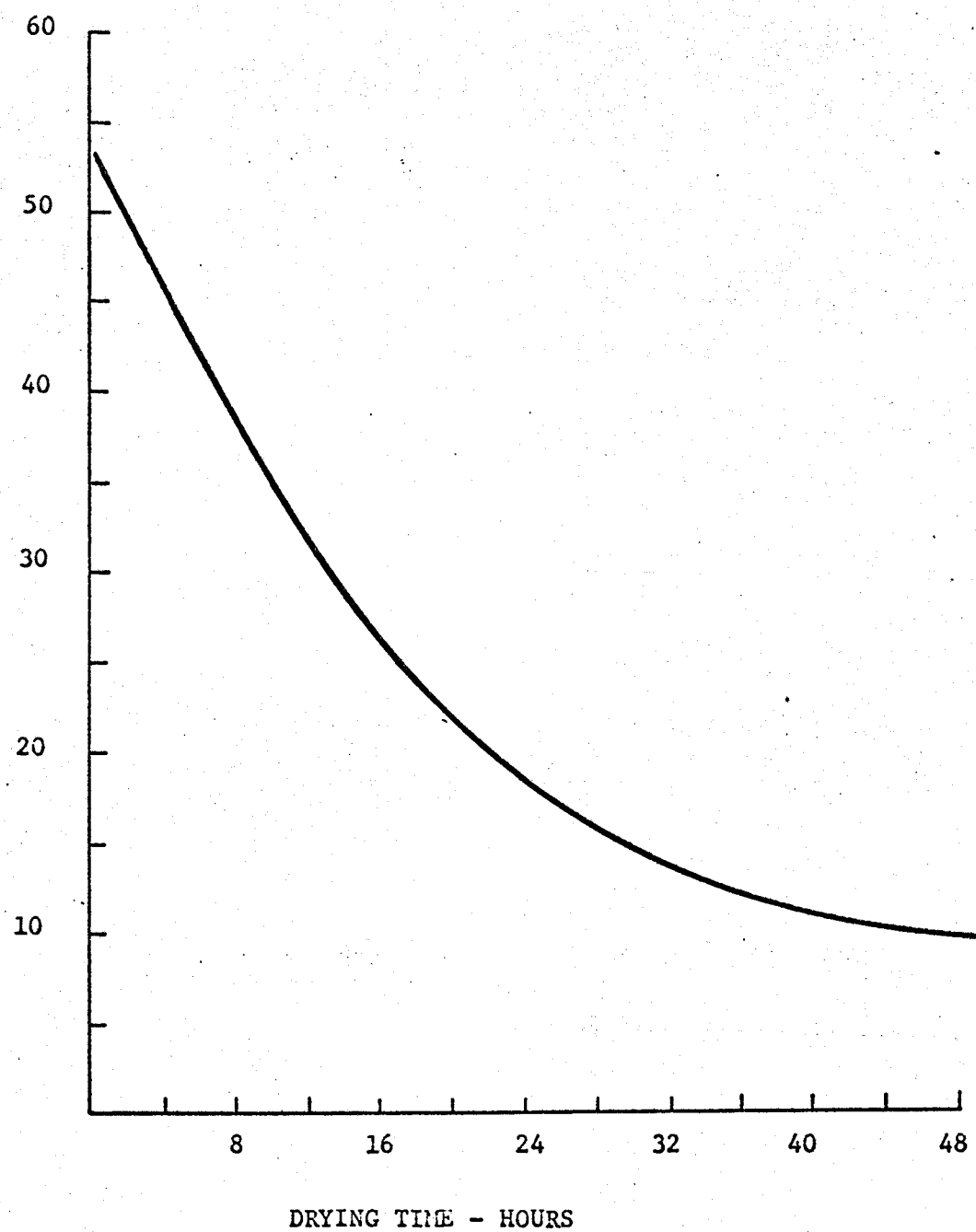


Figure 2. Mean drying curve for 10 drying packages plotted from periodic weighings of each drying package.

Lodgepole pine studs can be kiln dried from the green condition to an average moisture content of 11 per cent in 48 hours using the above schedule. High temperature drying reduces the drying time by 1/3 to 1/2 that of the conventional kiln schedules for lodgepole pine.

The drying rate may also be expressed graphically by plotting weight as a function of time. The composite drying curve for 10 packages is shown in Figure 2. The distinguishing features of the curve are the constant drying rate of approximately 2 per cent per hour during the first 16 to 18 hours of drying, and the gradually decreasing rate of drying for the remainder of the drying schedule. The point at which the drying rate deviates from a linear relationship with time corresponds closely with the fiber saturation point. Hamm (3) reports similar results obtained from high temperature drying small samples of yellow poplar by a method other than a dry kiln.

Air Circulation and Drying Rate. Increasing the rate of air circulation increases the kiln drying rate of eastern Canadian softwoods (Ladell, 5). Present thinking indicates that this may be true only within specific limits of circulation velocity. Our study investigated the effects of circulation rate on drying time within the range of 300 to 1000 feet per minute using the high temperature schedule described above.

Four random samples were selected from each circulation zone. (Figure 1) The average original and final moisture contents of the four samples are presented in Table 2. The mean moisture contents from Table 2 are assembled into the zones of actual circulation rate and the mean computed for each zone. These data are presented in Table 3. Although there appears to be tendency of decreasing final moisture content with increasing circulation rate, the circulation rate has no statistically significant effect on the drying rate of lodgepole pine studs.

Table 2. Average moisture contents of random samples selected from zones of equal circulation velocity within each drying unit.

Drying Unit	Fan* Speed	Moisture Content (per cent)							
		Zone A		Zone B		Zone C		Zone D	
		Original	Final	Original	Final	Original	Final	Original	Final
1	2	57	11.6	58	9.9	52	10.5	54	10.4
2	2	75	9.7	63	11.9	80	16.5	78	10.8
3	2	57	9.3	40	8.5	63	11.3	42	9.8
4	4	64	9.1	57	7.8	62	9.7	53	11.7
5	4	53	8.4	76	8.4	49	8.1	65	8.2
6	4	44	10.2	57	9.7	69	11.9	53	11.0
7	2	46	10.3	51	9.2	52	8.9	43	9.2
8	4	62	10.7	63	9.6	54	10.8	48	9.4
9	2	60	10.2	54	8.9	61	10.5	63	9.6
10	4	52	9.6	48	10.5	45	9.6	45	8.8

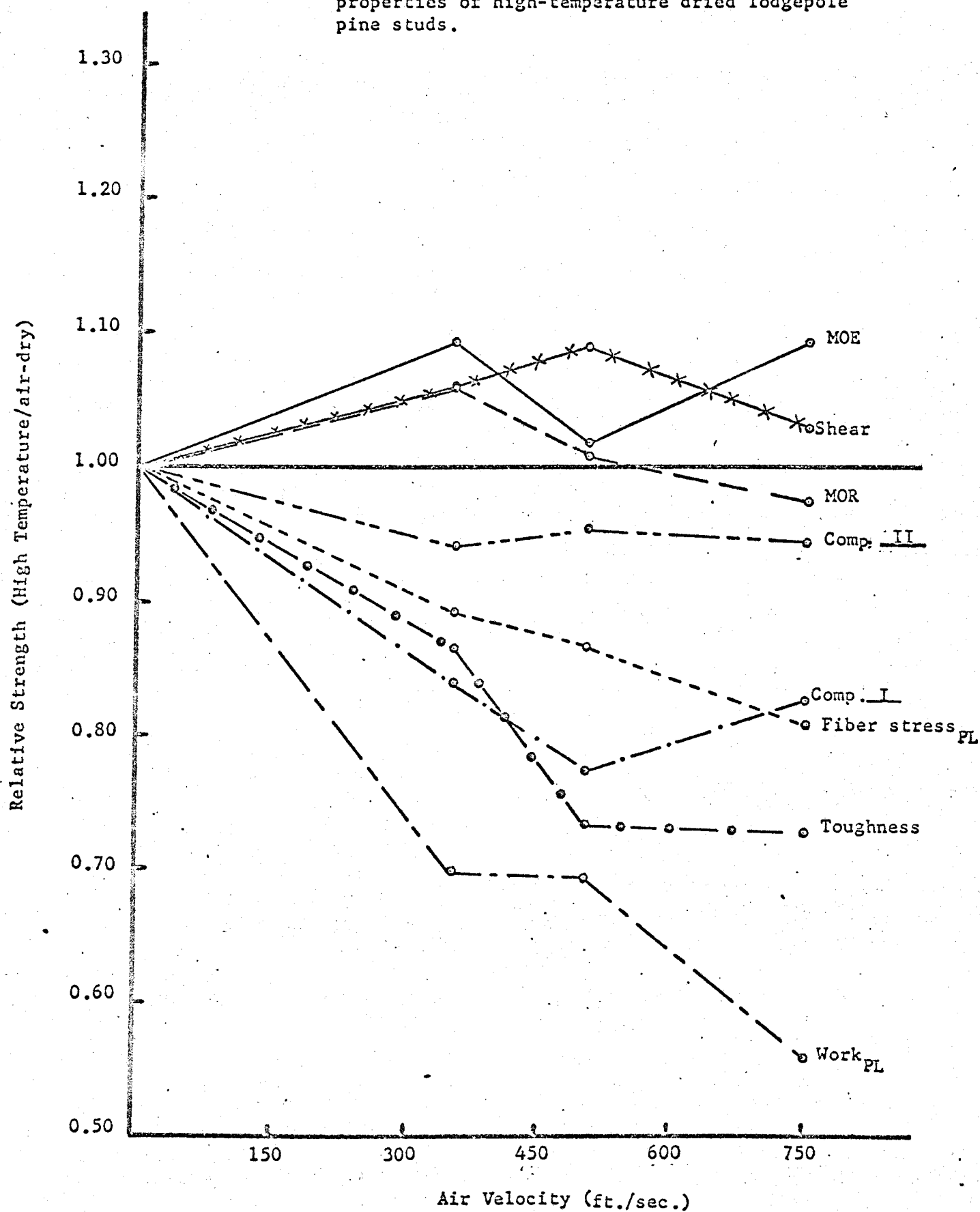
*Settings on the variable speed fan switch producing the velocities described in Figure 1.

Table 3. Mean moisture contents of random samples from all drying units grouped according to circulation velocity.

Circulation Rate (Feet per minute)	Moisture Content (per cent)	
	Original	Final
300	58	10.2
400	58	10.6
500	55	9.8
600	55	10.0
1000	57	9.3

Figure 4.

Effect of air velocity on certain mechanical properties of high-temperature dried lodgepole pine studs.



Periodic weighing of sample studs during the drying cycle gives sufficient data to plot drying curves for the various velocities (Figure 3). These drying curves indicate that there is possibly a small effect on the drying rate due to circulation velocity. However, again, there is no statistical significance in the differences between the curves.

One factor that was noted, but not measured, in this study was the effect of heartwood and sapwood. There appears to be a relationship between the amount of sapwood and heartwood present in a stud and its original moisture content. Though this relationship is not defined it appeared that those pieces composed primarily of sapwood had the highest original moisture content and also the most rapid drying rate.

High Temperature and Seasoning Defects. A total of 480 studs were dried in the 10 drying packages using the high temperature schedule. Of this total 114 pieces showed some warp and two pieces surfaced checked beyond usefulness as a stud, representing a degrade due to all seasoning defects resulting from high temperature drying of 24.2 per cent. It should be emphasized that in nearly every case deformation occurred in pieces not restrained adequately by the stickers or could be directly attributed to natural defects such as knot size and position, and the presence of compression wood. Surface checking was present in sapwood only and end checking was not excessive. The defects developed at approximately the same frequency in each of the air circulation zones.

For comparison purposes, studs cut from similar material by the same sawmill were stacked 10 pieces high and 10 pieces wide to air-dry to 11 per cent moisture content. The air dried material showed a warp degrade of 17 per cent compared to the 24 per cent that occurred in the high temperature dried material. Less than one per cent of the pieces were surface checked and end checking was minimal.

Casehardening samples were cut from randomly selected pieces in each drying package. Those samples from drying packages 1 and 2, which were conditioned, were stress free while samples from the remaining drying packages exhibited slight casehardening. Because the casehardening was so slight a conditioning period is not recommended after high temperature drying of lodgepole pine studs.

One of the most notable features of the high temperature dried material is the pitch exudation around knots and from pitch pockets. Upon first examination most knots appear dark brown to black and somewhat enlarged. Closer examination reveals that pitch has exuded from around the knots, darkened, and set on the surface of the board. Planing removes this surface blemish and the planed board has the same knot appearance as air dried material. Material dried at high temperatures is slightly darker in color in the rough dry condition, but no color difference is apparent when compared with air dried material after planing. Individual pieces containing a high pitch content throughout were slightly darker than similar air dried pieces after planing.

High Temperature, Air Circulation, and Strength. Small clear samples were taken from studs selected randomly from three of the circulation velocity zones. These samples were tested and compared to test values of air-dried material. The results of the tests are shown in Figure 4. The data for the strength tests show little or no reduction in such strength properties as modulus of elasticity in bending, modulus of rupture in bending, compression parallel to the grain and shear parallel to the grain. Fiber stress at proportional limit in bending, work to proportional limit in bending, and toughness properties were all reduced. These data seem to follow closely as to what is published for the species for high temperature dried material.

Although no attempt was made to statistically separate the effects on strength of high temperature and air circulation velocity, there does appear to be a relationship between strength reduction and circulation velocity. When plotting the strength reduction over air circulation velocity, one notes that in most cases higher circulation velocity corresponds to lower strength values. The highest reduction occurs for work to the proportional limit in bending where some of the values were approximately one-half those of air dried material.

Conclusions. Lodgepole pine studs may be kiln dried from a green condition to a final average moisture content of approximately 11 per cent in 48 hours by the use of a constant temperature schedule of 230°F with a wet-bulb depression of 30°F. The reduction in drying time when compared to conventional kiln schedules is from 1/3 to 1/2. Because conditions, other than temperature within the kiln are similar to conventional schedules, the rapid drying rate is attributed to the high temperature.

Varying air circulation velocity between 300 and 1000 feet per minute has no significant effect on the drying rate when tested using the stacking design employed in this study.

Seasoning defects resulting from high temperature kiln drying are only slightly more prevalent than in air-dried material. Pitch exudations around knots and from pitch pockets cause discoloration in the immediate area but are removed in surfacing. Casehardening is so slight that conditioning is not necessary.

The reduction in various strength properties due to exposure to high temperature is similar to that reported in the literature for this species. However, there does appear to be a relationship between air circulation velocity and strength with the lower strength material being dried under the higher air velocities.

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