T H E S I S

on

THE KILN DRYING OF OREGON SOFTWOODS

Submitted to the

O R E G O N A G R I C U L T U R A L C O L L E G E

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by

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INTRODUCTION

The objects of this thesis are: first, to present the importance and value of dry kilning lumber in Oregon; second, to present the fundamentals of kiln drying Oregon softwoods; third, to present the general kiln drying practice in Oregon.

At the present time there are approximately 400 dry kilns in the State of Oregon, with a total capacity of about ten million board feet of softwood lumber at one time. Over one-half of the softwood lumber production in the State of Oregon is kiln dried, which amounts to approximately 2,500,000,000 board feet annually. This sum represents an increase in the percentage of kiln dried softwoods of 35% over the amount kiln dried in 1922. The value of the present production of kiln dried softwoods is approximately $45,325,152.00. The general tendency in the State of Oregon is towards a greater production of kiln dried stock. These facts make evident the value of information leading towards better kiln drying, and the objects of this thesis are an attempt to furnish such information.

The sources of the information presented in this thesis are the writer's own experience and observations, kiln drying text books, government publications, trade journals, and dry kiln companies.

CHAPTER I

GENERAL

Why Lumber Must be Dried

Wood, in its natural state contains moisture varying in amount from 30% to over 200% of its "bone-dry" weight. This large moisture content makes wood heavy and unsuitable for many uses. It must be eliminated before wood can be used in houses or in manufactured articles, such as furniture.

There are four primary reasons for drying lumber. These are as follows:

1. To prevent checking, warping, and shrinking.
2. To prevent decay, stain, and insects from destroying the lumber or the appearance of the lumber.
3. To increase the strength and wearing qualities.
4. To reduce the weight.

Reasons For Drying Lumber with a Kiln.

Lumber may be dried in two ways, namely: air dried or kiln dried. The same elements which dry lumber in the air dry it in a kiln. The only differences fundamentally, between air drying and kiln drying, so far as the drying process is concerned, are, that in a kiln the three essentials for proper drying, namely; heat, humidity, and circulation, are regulated and produced more or less mechanically, while in air drying they are not.

Many millmen make the statement that air drying is the best, and base their statement on the so-called fact that natural ways are better than artificial ways; or in other words, do not try to improve on "mother nature". If this argument were true, man would still be traveling by means of his legs instead of riding in automobiles, trains, and airplanes, for nature intended man's legs for his means of locomotion, and nowhere produces an automobile or indicates the ways of producing one. In fact, the social world of man today would still be in its primitive form if some men had not deemed it possible to improve on "mother nature".

The very claim that air drying is a natural way is false, for "mother nature" never intended the trees to be cut, manufactured into lumber, and the moisture removed from the lumber. If she did, the air drying of lumber would not present the problems it does with rain and high humidified atmospheres prevailing the majority of the year in the Northwest, which hinders the air drying of lumber. Instead, air drying would be a smooth functioning process, characteristic of natural phenomena.

The control and regulation of natural elements has often been done by man to his decided advantage, and the kiln drying of lumber is no exception to this fact, as the following enumerated reasons for using a kiln in preference to air drying methods bear out:

1. Kiln drying requires less time to reduce the moisture content of lumber to that point necessary for its successful use.
2. The moisture content can be reduced to a lower per cent in a kiln process than in the air drying process.
3. Properly kiln dried lumber is less subject to attacks by fungi and insects.
4. Less checking, warping, case hardening and staining occurs in proper kiln drying than in proper air drying.
5. The high temperatures used in a dry kiln cause the pitch and resin of western conifers to come to the surface, and be removed in planing. This prevents that common occuring incident of pitch oozing out of woodwork in a house.
6. Properly kiln dried lumber is more easily glued, painted, and stained.
7. Greater strength qualities are found in kiln dried wood.
8. Less handling of lumber is usually possible by kiln drying methods.
9. Rush orders can be accepted when kiln drying

methods are used.

10. Kiln drying allows the definite determination of moisture contents which makes possible the acceptance of exacting orders specifying a definite moisture content.
11. Kiln drying is cheaper than air drying. From data collected in the Oregon pine region, it was found that kiln drying was $2.00 per thousand board feet cheaper than air drying, and records can be found to show a greater decrease in costs, due to kiln drying, not taking into consideration the underweights obtainable with kilns.
12. Kiln dried stock produces less degrade from machinery than air dried stock.

The Economics of Kiln Drying Lumber

The economic values of kiln drying lumber in Oregon may be divided into three primary values; those resulting from the fact that kiln drying is cheaper than air drying, those resulting from underweights, and those resulting from less degrade in kiln dried stock.

Never before in the history of the Oregon lumber industry has the economic value of kiln drying been more important to lumbermen than it is today. The reason for this is that economic forces have been operating which has resulted in a decided decrease in the market value of lumber. No attempt will be made to analyze these economic forces, but they will be briefly stated as follows: first, the supply is greater than the demand; second, keen competition has developed through the extensive advertising and selling organizations of lumber substitute companies. No longer does the lumberman inherit his market, he must develop it.

It is evident from the above cited economic conditions that any factor tending to reduce the cost of production or increase the value of lumber is of vital importance, and dry kilns are one of the factors which will accomplish this.

Kiln Drying vs. Air Drying Costs

Since lumber can be dried in only two ways, commercially, it is necessary to choose the cheaper of the two ways. Table 1 and 2 illustrate what can be done by kiln drying in the way of saving money.

Table 1. Kiln Drying and Air Drying Costs of Western Yellow Pine per M.

	Item	Kilns	Yard
1.	Sorting	$ 0.28	$ 0.59
2.	Transportation (to)	0.16	0.22
3.	Stacking	0.60	0.32
4.	Interest on fixed investment	0.45	0.24
5.	Interest on lumber	0.03	0.32
6.	Dep. on fixed investment	0.45	0.24
7.	Maintenance and repairs	0.19	0.31
8.	Power	0.52	0.00
9.	Kiln operation	0.30	0.00
10.	Unstacking and sorting	0.52	0.78
11.	Transportation from	0.14	0.16
12.	Insurance and taxes	0.08	0.28
13.	Overhead	0.12	0.21
	Total	$3.78	$3.98

Saving by kiln drying $0.20 per M.

Table 2. Kiln Drying and Air Drying Costs of Douglas Fir Common per M.

	Item	Kilns	Yard
1.	Sorting	$ 0.50	$ 0.68
2.	Transportation	0.30	0.50
3.	Piling	0.36	0.42
4.	Interest on Lumber on hand	0.30	0.90
5.	Interest on fixed investment	0.20	0.10
6.	Depreciation, fixed invest.	0.20	0.10
7.	Stickers and Pile covers	0.10	0.08
8.	Maintenance and Repairs	0.19	0.31
9.	Steam and Power	0.22	0.00
10.	Supervision and Operation	0.18	0.10
11.	Unpiling and Sorting	0.51	0.54
12.	Rough Storage	0.40	0.00
13.	Insurance and Taxes	0.09	0.30
14.	General Overhead	0.12	0.21
	Total	$ 3.67	$4.12

Savings by kiln drying $0.45 per M.

Underweights

In many mills today the only profit made is from underweights. Underweights are obtained by removing moisture from lumber which decreases its weight per thousand board feet below the standard weight per thousand. The buyer pays a freight cost based on the standard weight. The difference between the standard weight and the actual shipping weight of the lumber is the under-weight. Multiplying the underweight per 100 pounds by the freight rate to the locality the lumber was shipped, gives the underweight profit on the lumber. Table 3 gives the underweight value for different freight rates, and different underweights.

Table 3

Underweights Pounds Per M	Freight Rates 50¢	60¢	70¢	80¢
90	$0.45	$0.54	$0.63	$0.72
100	0.50	0.60	0.70	0.80
125	0.625	0.75	0.875	1.00
150	0.75	0.90	1.05	1.20
175	0.875	1.05	1.225	1.40
200	1.00	1.20	1.40	1.60
225	1.125	1.35	1.575	1.80
250	1.25	1.50	1.75	2.00
275	1.375	1.65	1.925	2.20
300	1.50	1.80	2.10	2.40
325	1.625	1.95	2.275	2.60
350	1.75	2.10	2.45	2.80
375	1.875	2.25	2.625	3.00
400	2.00	2.40	2.80	3.20
425	2.125	2.55	2.975	3.40
450	2.25	2.70	3.15	3.60
475	2.375	2.85	3.325	3.80
500	2.50	3.00	3.50	4.00

From data gathered in the Klamath Falls region on 6/4 pine, rough, the average weight for a year for air dried stock was 2510 pounds per M. The basic or standard weight for pine is 2500 pounds per M. The same grade of lumber kiln dried averaged for a year 2310 pounds per M., or a saving of 200 pounds per M. A 200-pound underweight is worth $1.40 profit on a 70¢ freight rate.

Data gathered in the Bend pine district from one specific mill showed the average weight of kiln dried pine to be 2050 pounds per M., some stock having been as low as 1900 pounds per M. The average underweight based on

2050 pounds average weight and 2500 pounds standard weight, was 450 pounds. On lumber shipped to New York with a freight rate of 88 cents per thousand, 450 pounds underweight amounts to $3.96 per thousand gained by kiln drying.

Table 4 and 5 show what can be done in the way of reducing the weight of lumber by kiln drying as compared to air drying.

Table 4
Average Underweights for Douglas Fir
Common and Dimension

No. 1 Common S4S	Green vs. Full Kiln Drying	Partial Air Drying vs. Full Kiln Drying	Average Air Drying vs. Full Kiln Drying
1 x 4	430	260	175
1 x 6	445	270	180
1 x 8	445	270	180
1 x 10	445	270	180
1 x 12	455	275	180
Avg. 1"	445	269	179
2 x 4	445	270	180
2 x 6	460	280	185
2 x 8	460	280	185
2 x 10	470	285	185
2 x 12	475	285	190
Avg. 2"	461	279	184

Table 5
Tabulation of Weights of Western Lumber

Weight Per M. in Pounds-1000 Bd. Ft.-83.3 Cu. Ft.

Kind of Wood	Green	Summer Kiln Dry 8%	Summer Air Dry 12%	Winter Air Dry 22%	Increase in Pounds for each % Moisture
Cedar (Port Orford)	2990	2330	2420	2635	21.6
Cedar (Western Red)	2235	1835	1905	2075	17.0
Fir (Douglas)	3250	2700	2800	3050	25.0
Fir (Noble)	3490	2060	2140	2330	19.1
Fir (White)	3900	2060	2140	2330	19.1
Hemlock (Western)	3500	2245	2330	2540	20.8
Pine (Sugar)	4220	1976	2050	2240	18.3
Pine (Western Yellow)	3750	2245	2330	2540	20.8
Spruce (Sitka)	2670	2160	2240	2440	20.0

To get weights of dressed stock per M board feet use ratio of actual cubic feet of wood to 83.3 and increase kiln dried figures 3% summer air dried figures 2½% and winter air dried figures 1% to cover increased density caused by shrinkage prior to dressing.

There is a general tendency developing, especially in the Willamette Valley district, for small mills cutting only second growth Douglas fir dimension, to install cheap dry kilns for the purpose of removing enough moisture to obtain underweight profits on their lumber. No attempt is made to reach a low moisture content which eliminates the necessity of having expensive kilns, and a skilled kiln operator.

In one installation using a single, practically home-made kiln, and drying for underweights only the kiln and equipment had paid for itself in one year's operation. The mill owner was receiving $1.90 per thousand profits on underweights.

Table 6 gives the average underweights of air dried Douglas fir for different months in the year.

Table 6
Underweights by months for Douglas Fir

Months	Pounds per M
January	114
February	98
March	118
April	149
May	200
June	248
July	256
August	289
September	331
October	291
November	205
December	148

Table 6 shows an average underweight of 205 pounds per thousand for the year, by kiln drying this could be raised to 400 pounds or better per thousand. This would mean approximately $1.40 more per thousand profit on a 70 cent freight rate.

Degrade

In drying lumber, there is always a certain amount of fall down in grade, due to defects developing, which were not present before the lumber was dried. A fall down in grade means a reduction in market value and waste of material.

Table 7 shows what degrade means in dollars and cents for different grades of air dried yellow pine

Table 7
Value of Degrade for Different Grades of Air Dried Yellow Pine

Grades	Percentage Degraded	Value Loss per M
B	25%	$2.30
C	25%	3.45
D	11%	2.20
1S	37%	3.70
2S	6%	.66
3S	5%	.50
1C	41%	5.74
2C	21%	2.10
3C	13%	1.30

The above table shows an average of $2.55 per thousand. An estimate of the degrade from kiln drying Yellow Pine showed a loss of $0.36 per thousand. This means a saving of $2.19 per thousand by properly kiln drying.

A survey made by the Forest Products Bureau in the Douglas Fir region, resulted in the following facts being made evident:

1. The depreciation in the air drying and machining one-inch select common averaged 23.75% with a loss in value from $0.22 to $0.98 per thousand board feet.

2. The depreciation in the air drying and machining

of two-inch select common averaged 27.91% with a loss in value of from $0.89 to $2.37 per thousand board feet.

3. The total depreciation in the No. 1 common averaged 25% for the one-inch and 6% for the two-inch with an average loss in value of $1.55 per thousand board feet in the one-inch and $0.30 per thousand board feet in the two-inch.

A survey conducted by the Forest Products Bureau in the kiln drying of Douglas fir common and finish showed the following results:

1. One-inch No. 1 Common 1.37% degrade
2. One-inch No. 2 Common 2.33% degrade
3. One-inch No. 3 Common .52% degrade
4. Two-inch No. 1 Common 2.35% degrade
5. Two-inch No. 2 Common 2.31% degrade
6. One-inch "B&B" finish 1.89% degrade
7. One-inch "C" finish 1.72% degrade
8. One-inch "D" finish .65% degrade
9. No degrade in two-inch No. 3 common.

The above results were obtained in internal fan kilns using automatic controls and edge stacking the lumber.

The average moisture content of the common lumber was 23% and of the finish 9.5%

The Economic Significance of Dry Kilning Lumber to the State.

Dry kilns are not of economic significance to the lumbermen alone, but they are a factor in the economic condition of the state as a whole. For every thousand feet of finish lumber reduced to common lumber by drying defects one thousand more feet of finish lumber must be cut, which results in the consumption of more timber. In other words, dry-kilns are a factor in the conservation of timber, which is directly related to the well-being of a state such as Oregon, whose primary resource is timber.

By the use of dry kilns, millmen save money and receive a greater profit for their lumber, which in turn, assures a continued operation of the mills, which is essential to the social welfare of the State of Oregon, where the payroll of the state depends for 60% of its total sum on the lumber industry.

Whenever a large mill must close, the prosperity of the community it supported must end also, and the mill laborers migrate to other sections of the country for work, possibly going into another state. Such action reflects on all other businesses in the state, such as clothing, food products, furniture, etc. In other words, the whole economic balance of the state is affected when the mills close, and if sufficient mills closed, the state would undergo a depression in the economic cycle of society.

Dry kilns may be the means of keeping a mill running, and, in fact, are keeping many mills in operation today by underweights and quick turnover of lumber.

CHAPTER II

THE STRUCTURE OF OREGON SOFTWOODS IN RELATION TO THEIR DRYING

Cellular Structure

It is essential in the kiln drying of wood that the kiln operator be familiar with the structure of the wood he is drying. The reason for this is obvious, since all the fundamental principles of kiln drying are directly or indirectly based on the structure of wood.

There are two distinct classes of wood used commercially, namely, hardwoods and softwoods. The distinction between these two classes is based on their cellular structure. Hardwoods are the most complex of the two classes. In Oregon the commercially used hardwoods are: cottonwood, alder, Oregon maple, myrtle, and Oregon ash. The commercially used softwoods in Oregon are: Douglas fir, western yellow pine, sugar pine, western hemlock, Sitka spruce, white fir, Port Orford Cedar, western red cedar, and incense cedar.

These two tabulations include only those woods which grow and are manufactured in Oregon. The manufacturing of hardwoods is on a very limited scale and for that reason will not be discussed in this thesis in connection with kiln drying.

All wood is composed of cells. A cell is a single element of plant tissue composed of a wall surrounding a cavity. The cells of wood differ in size, location, and function, yet all are woven together forming a compact porous mass a cross section of which, under a microscope, resembles a honeycomb.

In a living cell, the cavity contains a very complex chemical substance known as protoplasm. It is this protoplasm that carries on the living functions of a tree. In a dead cell the cavity may be filled with air, water, resin, gums, and various deposits of mineral matter.

Softwood is composed almost entirely of elongated cells known as tracheids. The tracheids of one species are very uniform in size. The average length of the tracheids in the commercially important softwoods of Oregon is given in Table 8.

Table 8
Length of Tracheids in Oregon Softwoods

White fir (Abies grandis)	4.15 mm
Port Orford cedar (Chamaecyparis lawsoniana)	3.60 mm
Incense cedar (Lybocedrus decurrens)	4.00 mm
Sitka spruce (Picea sitchensis)	2.85 mm
Sugar pine (Pinus lambertiana)	4.45 mm
Western white pine (Pinus monticola)	4.40 mm
Western yellow pine (Pinus ponderosa)	3.30 mm
Douglas fir (Pseudostuga taxifolia)	2.70 mm
Western Red cedar (Thuja plicata)	3.85 mm
Western hemlock (Tsuga heteraphylla)	3.05 mm

A millimeter is .03 plus of an inch.

If a smooth cross-grain cut is made on a piece of softwood the tracheids can be seen with the aid of a small hand lens as small holes.

Tracheids have small openings in their side walls, known as bordered pits, which allow a passageway for moisture and food substance from one cell to another.

Some softwoods contain an element known as a resin duct. The softwoods in Oregon that have resin ducts are: Douglas fir, sugar pine, western yellow pine, and Sitka spruce. A resin duct is an opening in the cellular structure extending parallel to the grain and more or less continuous. Occasionally resin ducts extend horizontally through medullary rays.

Resin ducts can often be seen in the pines on the cross section with the naked eye, where they appear as brown specks. The function of resin ducts is to transfer food substances for the trees' growth up or down the stem.

In kiln drying resin ducts play a limited part, functioning only in the bringing to the surface of pitch.

There is another type of cell in softwoods which lies horizontally in groups, each group forming what is known as a medullary ray. The medullary rays of softwoods are very narrow and inconspicuous with a few exceptions, where they contain horizontal resin ducts, when they are wider and are known as fusiform rays.

In some softwoods the medullary rays may be seen on the radial surface or vertical grain surface as minute brownish lines.

The function of the medullary rays is to transfer food substance and water across the grain and to store up a supply of food for the tree.

The medullary rays play an important part in the kiln drying of lumber as will be shown later.

Another element found occasionally in softwoods is wood parenchyma. This element is very scarce and occurs in the shape of a single cell scattered rarely through the wood known as a resin cell, and in a row of cells circling a resin duct. Wood parenchyma cells are storage cells for highly concentrated food substances. Their importance in kiln drying lumber is nil. In Oregon, cedar is the only softwood containing resin cells.

Springwood and Summerwood

The growth of a tree takes place only in a thin layer of cells known as the cambium.

Trees in the temperate zone do not grow continually the year around, but only in the spring and summer of each year. At these seasons of the year the cambium produces a layer of wood and bark. The wood first produced in the spring is composed of large thin-walled cells, and forms the springwood. Later, as the summer advances, the tree loses some of its vitality and smaller, thicker walled cells are produced, which form the summerwood. The springwood and summerwood together form what is known as an annual ring. In some species there is a distinct line of demarcation between the springwood and the summerwood, the former being much lighter in color and softer in texture than the latter. Table 9 gives the classification of Oregon softwoods as to distinction of springwood and summerwood.

Table 9
Classification of Oregon Softwoods According to Distinction of Summerwood from Springwood

Distinct line of Demarcation	No distinct line of Demarcation
Douglas fir	Western hemlock
Western Yellow Pine	Sitka Spruce
Port Orford cedar	White fir
Western red cedar	

The durability and strength of a piece of wood depends on the amount of summerwood present. Many grading specifications state a definite per cent of summerwood.

The grain of lumber depends on the relative width of the growth rings as well as the uniformity in arrangement of the cellular elements.

Figure I gives an illustration of the elements found in Oregon softwoods.

FIGURE 1

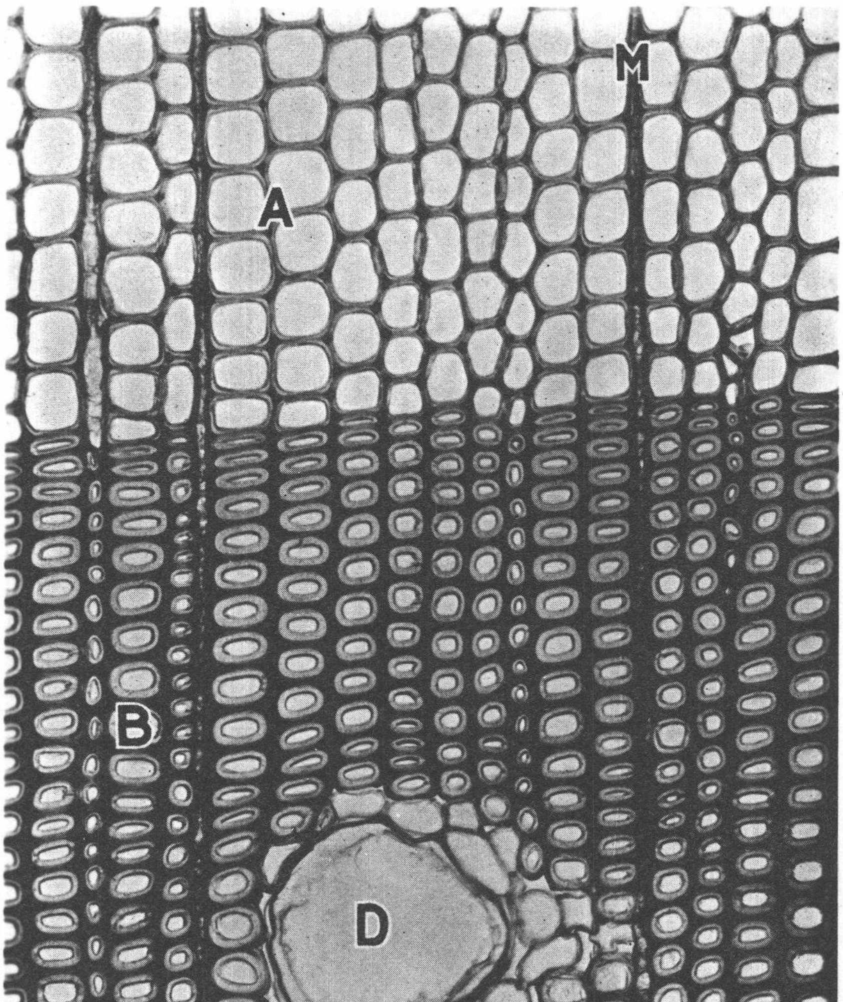
A Cross Section of Highly Magnified Yellow Pine

A. Springwood Tracheids;

B. Summerwood Tracheids;

D. Resin duct;

M. Medullary ray.


M
A
B
D
M

Knots

Knots are formed by limbs growing from the main trunk of the tree. Most limbs start at the center of the tree and grow by laying on a layer of wood annually, which is a continuation of the layer of wood grown by the main trunk. For this reason a knot starting from the center of a tree takes on the shape of a cone, as it extends on out to the surface.

Generally speaking, there are two types of knots found in lumber, "encased knots" and intergrown knots". As a tree grows its lower branches die and are broken off leaving a branch stub. After a branch dies, the wood layer, being added annually to the trunk, no longer continues out the branch as a cellular structure, but grows around the branch stub in the same manner that a tree grows around a spike driven in it. The result of this formation is an encased knot, since that part of the dead branch stub occluded by the subsequent growth has no connecting cellular growth with the main trunk.

In time the entire branch stub is grown over and from then on the much desired clear lumber is produced. This is the reason for more clear lumber being cut from the butt logs than from any other part of the tree.

Encased knots are often held tightly in a board, because the tree in growing around the branch stub, grew tightly against the stub, and usually deposited pitch around it. When a board, containing encased knots, is kiln dried the natural shrinkage loosens the knots and the high temperatures used melt the pitch which oozes out and nothing is left to hold the knot in the board. This loosening of encased knots forms the main problem in kiln drying common boards.

Intergrown knots in a board are those in which their cellular structure is a continuation of the cellular structure of the rest of the board. An intergrown knot is that part of a branch which was alive when that section of the tree, from which the board was cut, was growing.

Vertical-grain and Flat-grain Lumber

Due to the presence of annual rings in wood, two distinct types of lumber may be cut from it. Lumber may be cut parallel to the medullary rays across the grain, that is, from the bark to the center of the log, producing what is known as vertical-grain lumber or edge-grain lumber; or it may be cut at right angles to the medullary rays, that is, tangential to the annual rings, producing what is known as flat grain, or plain sawed lumber.

Flat-grain lumber dries faster than vertical grain lumber because of having more medullary rays exposed for moisture to travel to the surface on. In vertical-grain lumber, the medullary rays run more or less parallel to the surface of the lumber and do not bring moisture to the surface as readily as in flat-grain lumber.

The advantages of flat-grain lumber are:

1. A more beautiful figure is obtained in those species having a distinct line of demarcation between the springwood and the summerwood.
2. Wider "clear" lumber can be cut.
3. If knots are present, they are round instead of spike knots.
4. It is cheaper to cut at the mill.
5. It does not collapse so easily in drying (This is explained in later chapters).

The advantages of vertical-grain lumber are

1. It wears better than flat-grain lumber.
2. It does not twist or warp as easily.
3. It does not shrink as much in width.
4. It does not check, split, or casharden as easily, which allows it to be dried faster by subjecting it to more severe drying schedules.

Heartwood and Sapwood

The cross section of a tree usually shows a light colored outer ring of wood, and a darker colored area within this ring. The light colored portion is the sapwood, the dark colored portion is the heartwood. Some species such as spruce, do not show a distinct line of demarcation between the sapwood and heartwood, while other species such as fir show a decided difference in color.

The growth and development of wood cells is primarily the same regardless of their shape, location, or function. They originate in the cambium, grow larger with a thickening of the cell walls, manufacture and transport substance for the tree's growth and ultimately die and serve the tree only in the capacity of support. The sapwood of a tree trunk is composed of the living cells, while the heartwood is composed of the dead cells. When the wood cells no longer function in the living processes of the tree, they lose their protoplasmic content, and an infiltration of resins, gums, and other substances takes place which accounts for the change in color, and increase in weight of heartwood over sapwood of the same moisture content.

Sapwood contains considerably more moisture than heartwood, with the exception of a central core running through the center of western white pine, which it has been found, contains a high percentage of moisture, although not as great as the sapwood. In many cases, the sapwood will contain over 100% more moisture than the heartwood.

Pure sapwood lumber is kiln dried with less trouble than heartwood because of the fact that the moisture transfuses easier through the cells of the sapwood than the cells of the heartwood. However, lumber containing both sapwood and heartwood is more difficult to kiln dry than pure heartwood lumber or pure sapwood lumber because of the great variation in moisture content of the two.

CHAPTER III

MOISTURE IN WOOD AND ITS RELATION TO KILN DRYING

Moisture and the Wood Cell

The wall of a wood cell is supposed to be constructed of fine thread like fibrils running in a spiral manner the length of the cell. These fibrils are so small that they cannot be seen even with the highest powered microscope. The theory of their presence is proved, however, by the fact that fine spiral striations can be seen in a cell wall with a microscope. Also, when a cell wall dries and checks, the checks can be seen to run in a spiral manner.

Fibrils are very numerous in a cell wall and have a very strong affinity for one another. In wet wood, the fibrils are separated by the water contained in the cell wall and seem to have a greater attraction for water than for one another which accounts for the difficulty in removing moisture from wood and the ease with which wood absorbs moisture.

When wood dries, the moisture leaves the inter-fibril spaces in the cell wall causing the fibrils to draw together, which accounts for the shrinkage of wood. The absorption of moisture causes the converse of the above action resulting in a swelling of wood.

It is a known fact that there is a limit to the amount of moisture wood will hold. This has been explained by the following theories advanced by Koehler and Thelan in their book, "The Kiln Drying of Lumber."

1. As the distance between the fibrils increases on account of the absorption of moisture, the force of attraction of the fibrils for each other and for additional water decreases. But the attraction for moisture decreases more rapidly than the attraction of the fibrils for each other, so that a balance is established, and the limit of absorption and swelling reached.
2. The water "dissolves" in the wood until the "solution" reaches saturation when no more water can be taken up by the cell wall although the cell cavities may become filled by the capillary flow of water.
3. It is very probable that the fibrils are not entirely separated from each other like the fibrils in a cotton twine, but are intergrown to some extent, forming somewhat of a network. Because of this intergrowth there is a limit to the amount of moisture wood can absorb. Whether the fibrils themselves absorb any moisture is doubtful. If they do, it probably is only a comparatively small amount.

How Moisture Leaves Wood

Moisture in wood is held in two ways, namely, that which is present in the cavity or lumina of the cell, and that which is held in the cell wall.

When wood is dried the moisture first leaves the lumina of the cell. No moisture leaves the cell wall until all the moisture in the lumina has left. This point where the lumina is empty but the cell wall still retains its original moisture content is known as the "fiber saturation" point, and is one of the most important points in the drying process. No change in the physical condition of wood occurs until after this vital point has been reached. The shrinking, honey combing, collapsing, checking, and increase in strength of wood occurs always after the fiber saturation point has been reached. This point varies for different species of wood. The average moisture content of western hemlock and douglas fir respectively at their fiber saturation point is 29% and 23%.

The only way moisture can leave wood in any quantity is by traveling along the cell walls, which limits the paths of travel to (1) along the tracheids to the end grain, (2) across the vertical walls to the tracheids and the horizontal walls of the medullary rays to the tangential face on the flat grain surface, (3) across the vertical walls of the thracheids to the radial face or vertical grain surface.

Moisture leaves the end grain faster than it does from the flat grain or vertical grain surface, since in traveling in that direction there are more cell walls to travel on. This accounts for the rapid drying and checking on the ends of boards.

The tangential or flat grain surface permits of faster drying than the radial or vertical grain surface because in traveling in that direction the moisture has the vertical cell walls of the tracheids to travel on and the horizontal walls of the medullary ray cells. This accounts for the faster drying of flat grain lumber over vertical grain lumber.

It is evident that in drying lumber the area of the end grain is very small which makes it necessary for practically all the moisture to travel across the grain. This fact is important for an operator of kilns to remember.

How to Determine the Moisture Content of Lumber.

One of the most important things for a kiln operator to know is how to tell when the lumber he is drying has reached the moisture content desired. This becomes more vital every day as the tendency is growing amongst retailers of lumber to specify definitely in their orders the average moisture content above which they will not accept the lumber.

Not only is it important to be able to tell the moisture content of lumber after it leaves the kiln, but it is also of advantage to the operator to know the moisture content of his lumber before it enters the kiln, since such knowledge has a bearing on the drying schedule used.

It is evident in obtaining the moisture content of a kiln charge of lumber that each board cannot be measured, so it becomes necessary to select samples from the charge representative of the majority of the lumber in the kiln. The following considerations should be made in placing samples:

1. Select samples showing evidence of having an extremely high moisture content, such boards are very likely to be pure sapwood boards.
2. Select samples showing evidence of having a very low moisture content.
3. Select samples showing evidence of having an average moisture content.
4. Select samples exposed to the average conditions in the kiln.

5. If flat grain and vertical grain lumber are in the same charge select samples of both.

6. If different widths are in the same charge select samples from the average width.

It has been found satisfactory to select in one "crib" of flat-piled lumber, containing about 5000 board feet, nine samples located three across the top, three across the center, and three across the bottom. The average moisture content of the nine samples accurately gives the average for the "crib" for all practical purposes. The same principal of location should be used in vertical stacked lumber.

It is not always possible or practical to fulfill all the above considerations in sample selection in commercial kiln drying, but the operator should keep them in mind and attempt to fulfill them as near as practical. The usual practice is for the operator to select two or three boards from the truck of lumber just inside the kiln door for his samples. This is better than taking no samples at all, but the moisture content obtained is not always representative of the kiln charge. Operators have been found selecting their samples from the dry chain as the lumber is unstacked. This permits of very accurate selecting of samples, but does not allow the correcting of the moisture content of the lumber if found too high.

After the moisture samples are selected, the following steps give the moisture content of the samples:

1. Cut off two feet from the end of the sample board and discard it.
2. From the remaining portion cut a strip 3/4 of an inch wide from the same end as the two feet were cut from. This strip is known as a moisture sample. If the moisture distribution in the lumber is desired cut another 3/4 of an inch strip. This strip is known as a moisture distribution sample. It is good practice to cut more than one sample. Care should be taken not to include in the samples cut any abnormalities such as pitch pockets, pitch streaks, knots, rot, or any similar defect which would not have a representative moisture content.
3. Number all samples.
4. Remove all slivers, and weigh the samples singly to .01 of a gram. Record this weight as the original weight. Cut the moisture distribution sample into L's so as to separate the outer portion from the inner portion, and weigh each part, and record its weight. The outer samples comprise what is known as the "shell". The inner piece is known as the "core".

5. Place all pieces and moisture samples in a drying oven set at a maximum temperature of 212° F. Allow the samples to remain in the oven until they record a constant weight which can be determined by frequent weighings.
6. After the samples have reached a constant weight, remove them from the oven and weigh them immediately to .01 gram. This weight is known as the "oven dry" weight, or "bone dry" weight.
7. Subtract the "oven dry" weight from the original weight. This difference is the weight of the moisture lost.
8. Divide this difference by the oven dry weight and multiply by 100. This gives the moisture content in terms of per cent of the oven dry weight.

It is possible to base the moisture content on the original weight by dividing the difference between the oven dry weight and the original weight by the original weight. It is the universal practice in Oregon, and in fact, in all dry kiln work to base the moisture content on the oven dry weight. In all cases in this thesis the moisture contents expressed are based on the oven dry weight.

Apparatus for Determining the Moisture Content of Lumber.

For drying samples to obtain their oven dry weight, there are two instruments in wide use today, both of which are very satisfactory. These two instruments are the "Electric Drying Oven" and "The Ten Minute Tester".

The drying oven consists of an asbestos composition box bound with metal which is heated by electricity, either direct or indirect current. The temperature of the oven is thermostatically controlled.

The "Ten Minute Tester" consists of a series of electric plates one above the other which are movable in a frame. The moisture sample is placed between the plates.

Several other devices for determining the moisture content of lumber are being perfected at the present time. The "Fullmeter" which consists of a device by means of which the shrinkage of the board, through an establishment of electric contacts, flashes a light, outside the kiln or in the kiln operator's office, or otherwise indicates the completion of the drying process.

The "Shrinkometer" is another device which indicates directly through shrinkage or swelling the moisture content of the lumber.

A third device is being perfected by the writer which consists of a machine which may be clamped on a board and the moisture content determined immediately. This device is based on the electric conductivity of wood.

The Variation in Moisture Content

The moisture content in wood varies according to the following factors: location in tree, heart or sapwood, atmospheric conditions, size of piece, and species.

Lumber from the butt logs of a tree contains more moisture than lumber from the top logs. The excess of moisture in the butt logs of some species is evident from the "sinkers" found in redwood, sugar pine, and western hemlock.

Experiments conducted by the Forest Products Laboratory showed redwood butt logs to contain 136% to 154% moisture and top logs .66% to 81%.

It is a common belief among lumbermen in general, that the season of the year in which the logs have been cut influences the amount of moisture in the lumber, the belief being that winter cut logs contain less moisture than summer cut logs. This has been proved erroneous as Table 7 shows.

Table 10
Moisture Content at Different Seasons of the Year
of Freshly Cut Douglas Fir

Month	Moisture Content in %
January	40
February	47
March	49
April	38
May	40
June	33
July	28
August	30
September	no data
October	34
November	42
December	30

Table 10 is based on the average of 200 ties cut each month, except September, near Tacoma, Washington.

The variation in the moisture content of sapwood and heartwood has already been dealt with in a previous chapter.

The atmospheric effect on the moisture content of lumber is very important, especially so in a climate like the Northwest. Wood will give off or take on moisture in direct ratio to the temperature and humidity of the air, until an equilibrium has been reached between the wood and the air. This ability of wood to lose moisture or absorb it is known as the hygroscopicity property of wood.

Tables 11 and 12 show the effect of the season of the year on the drying of Douglas fir. These tables were compiled by the Forest Product Laboratory in connection with a survey of the air drying of Douglas fir common. The large variations in drying time is due to the climatic conditions of the Northwest.

Table 11
Moisture Content and Weight of Rough Douglas Fir Common Lumber[1]

Size of Stock	Drying Period: Date Put Up	Drying Period: Date Taken Down	Drying Period: Days Up	Moisture Content Based on Ovendry Weight: Rough Green %	Moisture Content Based on Ovendry Weight: Rough Dry %	Weight Per Thousand Feet: Rough Green #	Weight Per Thousand Feet: Rough Dry #	Weight Per Thousand Feet: Loss#
1x8"--16'	Aug. 7, 1923	Oct. 11, 1923	65	33.7	19.6[2]	3,040	2,740	300
1x8"--16'	Nov.16, 1923	June 2, 1924	199	34.1	13.0	2,939	2,477	462
1x8"--16'	Jan.17, 1924	June 5, 1924	140	42.9	18.8	3,204	2,662	542
1x8"--16'	Mar.19, 1924	June 10,1924	83	35.0	16.2	2,787	2,398	389
1x8"--16'	June 8, 1924	Oct. 22,1924	136	37.3	18.4[2]	3,113	2,684	429
		Average...	125	36.6	17.2	3,017	2,592	424
2x12"-16'	Aug. 7, 1923	Oct. 11,1923	65	34.8	23.9[2]	2,750	2,526	224
2x12"-16'	Nov.16, 1923	June 2, 1924	199	32.3	15.3	2,704	2,357	347
2x12"-16'	Jan.17, 1924	June 5, 1924	140	40.2	15.6	2,944	2,428	516
2x12"-16'	Mar.19, 1924	June 10,1924	83	32.5	16.5	2,854	2,506	348
2x12"-16'	June 8, 1924	Oct. 22,1924	136	36.3	20.6[2]	3,132	2,788	344
		Average...	125	35.2	18.0	2,837	2,481	356
1x12"-16'	Apr.17, 1925	July 29,1925	93	39.7	12.5	3,246	2,614	632
1x12"-16'	July 30,1925	Oct. 23, 1925	76	34.7	18.6[2]	3,146	2,770	376
		Average...	84	37.2	15.5	3,196	2,692	504
2x8"--16'	Apr. 17,1925	July 29,1925	93	37.3	13.0	3,215	2,647	568
2x8"--16'	July 30,1925	Oct. 23,1925	75	34.2	19.2[2]	3,038	2,697	341
		Average...	84	35.7	16.1	3,126	2,672	455

Table 11- continued

Size of Stock	DRYING PERIOD			Moisture Content Based on Ovendry Weight		Weight per Thousand Feet		
	Date Put Up	Date Taken Down	Days Up	Rough Green %	Rough Dry %	Rough Green #	Rough Dry #	Loss#
1x8"--14'	May 1, 1925	July 10,1925	71	32.6	13.7	3,476	2,980	496
1x8"--14'	July 16, "	Oct. 20,1925	96	32.7	15.6[2]	3,381	2,946	435
		Average..	84	32.6	14.6	3,429	2,963	465
2x8"--14'	May 1, 1925	July 10,1925	71	36.3	14.8	3,596	3,029	565
2x8"--14'	July16,1925	Oct. 20,1925	96	34.1	17.0[2]	3,545	3,092	453
		Average..	84	35.2	15.9	3,570	3,060	509
		Grand Average..	106	35.7	16.7	3,048	2,627	417

[1]Based on whole-board sample.

[2]Stock took on some moisture before the piles were taken down: 5 per cent, 1-inch Unit 1, Yard No. 1; 4.5 per cent, 1-inch, Unit 5, Yard No. 1; 1.5 per cent, 1-inch, Unit 2, Yard No. 2; 2 per cent, 1-inch, Unit 2, Yard No. 3; 1 per cent, 2-inch, Unit 1, Yard No. 1; 1.5 per cent, 2-inch, Unit 5, Yard No. 1; 1 per cent 2-inch, Unit 2, Yard No. 2; 1 per cent, 2-inch, Unit 2, Yard No. 3.

Table 12
Estimated Time Required to Air-Season Douglas Fir Common at Different Periods of the Year[1]

Thickness of Stock	Date Piled	TIME REQUIRED FOR DIFFERENT MOISTURE CONTENTS					
		20 to 22 Per Cent		17 to 19 Per Cent		14 to 16 Per Cent	
		Date Unpiled	Time Required Days	Date Unpiled	Time Required Days	Date Unpiled	Time Required, Days
1"	Jan. 1	Apr. 15	100	Apr. 25	115	May 27	147
2"	Jan. 1	Apr. 20	110	May 17	137	June 15	166
1"	Feb. 1	Apr. 20	79	May 1	90	June 1	120
2"	Feb. 1	May 1	89	May 15	104	June 20	140
1"	Mar. 1	Apr. 25	56	May 10	71	June 5	97
2"	Mar. 1	May 5	66	May 25	86	June 20	112
1"	Apr. 1	May 5	35	May 15	45	June 10	61
2"	Apr. 1	May 10	40	May 25	55	July 1	92
1"	May 1	May 25	20	May 30	30	June 15	46
2"	May 1	May 30	30	June 10	41	July 1	61
1"	June 1	June 20	20	July 1	30	July 10	40
2"	June 1	June 30	30	July 15	45	July 25	55
1"	July 1	July 20	20	July 30	30	Aug. 9	40
2"	July 1	July 30	30	Aug. 9	40	Aug. 24	55
1"	Aug. 1	Aug. 15	15	Aug. 25	25	Sept. 15	46
2"	Aug. 1	Aug. 25	25	Sept. 15	46	June 15	319
1"	Sept. 1	Apr. 10	222	Apr. 25	237	May 27	269
2"	Sept. 1	Apr. 20	232	May 17	259	June 15	288
1"	Oct. 1	Apr. 10	192	Apr. 25	217	May 27	239
2"	Oct. 1	Apr. 20	202	May 17	229	June 15	258
1"	Nov. 1	Apr. 10	161	Apr. 25	176	May 27	208
2"	Nov. 1	Apr. 20	171	May 17	198	June 15	227
1"	Dec. 1	Apr. 10	131	May 17	146	May 27	178
2"	Dec. 1	Apr. 20	141	Apr. 25	168	June 15	107

[1]Variation of 10 to 20 days may be expected due to seasonal and local differences in climatic conditions.

It is possible by knowing the humidity and temperature of the air, to determine the maximum moisture content wood will ultimately attain. The Diagram in Figure 2 gives the moisture content for different humidities and temperatures. This diagram also is useful for determining the moisture content attainable in a kiln.

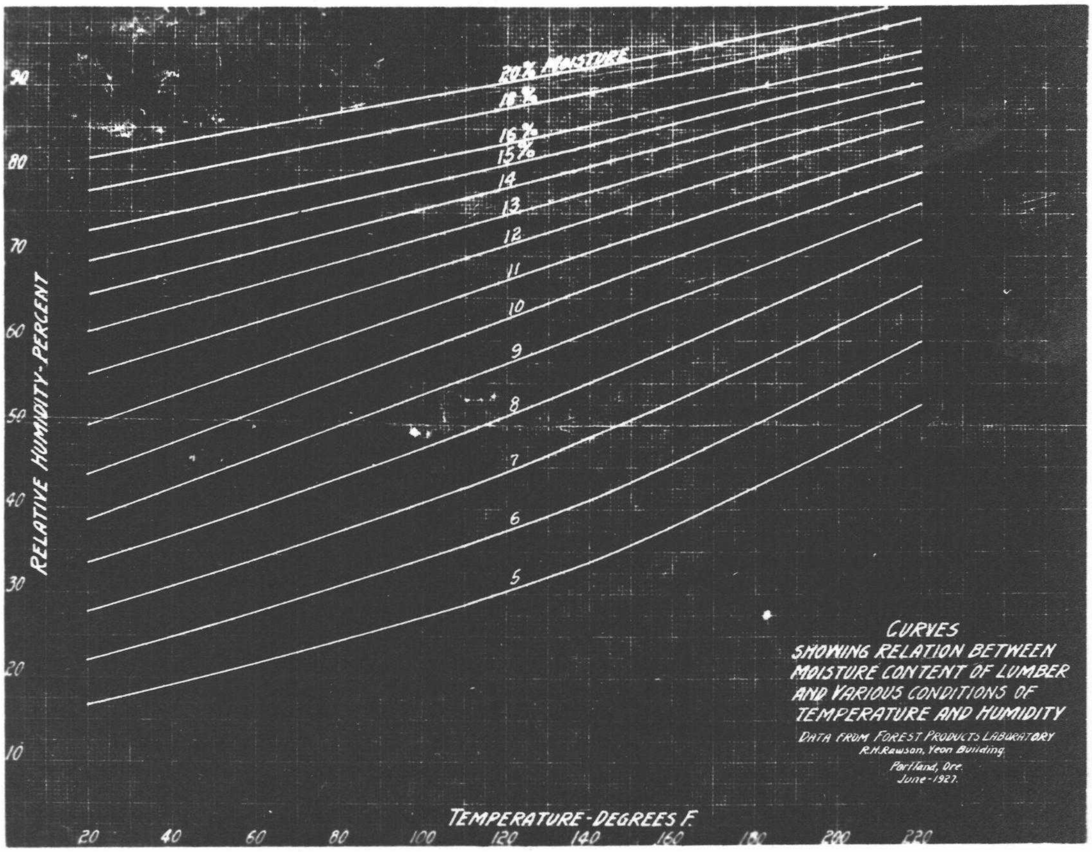
In the Oregon pine district, lumber will pick up from 4% to 3% moisture after leaving the kilns in the winter time, and 1° to 1½° in the summer time. Broom handle stock has been found to pick up as much as 8% in the winter time.

The relation between the atmospheric conditions and the lumber when taken from the kiln could be used to more advantage by kiln operators, especially in drying orders for nearby markets. It is useless to dry lumber down to 7% moisture content when it will pick up 5% soon after leaving the kiln.

The size of lumber affects its moisture content. Experiments conducted by the Forest Products Laboratory revealed the facts that after two years, air seasoning 12 by 12 inch and 8 by 16 inch yellow pine bridge timbers contained an average moisture content of 18% in the portion extending from the surface half way to the center, and 28.7% in the central core. It is also evident that the

FIGURE 2

Graph Showing Relationship Between Temperature, Humidity and Moisture Content of Lumber


20% MOISTURE
18%
16%
15%
14
13
12
11
10
9
8
7
6
5
RELATIVE HUMIDITY-PERCENT
90
80
70
60
50
40
30
20
10
TEMPERATURE-DEGREES F.
20
40
60
80
100
120
140
160
180
200
220
CURVES
SHOWING RELATION BETWEEN
MOISTURE CONTENT OF LUMBER
AND VARIOUS CONDITIONS OF
TEMPERATURE AND HUMIDITY
DATA FROM FOREST PRODUCTS LABORATORY
R.H. Rawson, Yeon Building,
Portland, Ore.
June-1927.

larger the stock the longer time required to dry it. Two-inch lumber takes longer to dry than one-inch lumber. For lumber over three inches, the drying time increases more rapidly than the thickness. For example, four-inch lumber requires longer than twice the time required for two-inch lumber.

For stock less than 3/4 of an inch, the drying time is less than the thickness. For example, 1/4 inch stock dries in less time than ½ of the time required to dry ½ inch stock.

Lumber which is square in dimensions dries faster than lumber which is wider, but of the same thickness. The reason for this is that in a square piece of lumber, the moisture transfuses nearly equally to all surfaces, whereas in a wider piece of the same thickness, the center moisture is evaporated principally from the two wide surfaces.

Moisture Content and the Use of Lumber

Since wood reacts to the temperature and humidity it is exposed to, it becomes essential in using lumber to have it at a moisture content suitable to the conditions under which it will be used. Wood to be used in the interior of houses should be drier than wood used in the open.

For interior finish and flooring, a moisture content of from 6% to 9% should be used.

For sheathing, roofing, and common lumber in general, a moisture content of 10% to 25% is suitable.

For uses such as airplane parts where tight joints are essential, a moisture content of about 7% is desirable.

Box lumber should contain from 12% to 15% moisture, since it has been found that best results are obtained with lumber containing this percent.

The Effect of Kiln Drying on the Strength of Lumber

For a long time the general belief was prevalent among lumbermen that kiln dried stock was not as strong as air dried stock because of its much lower moisture content. Thorough experimentation by the Forest Products' Laboratory has dispelled this belief, for it has been found that after reaching and passing the fiber saturation point in drying lumber its strength increases.

Table 13 shows the result of the Government experiments with Douglas fir.

Table 13
Summary of Moisture-Strength Tests
Average Strength Values at Important Moisture Conditions

(The ratios of increase in strength over the green condition are given below each strength value)

Moisture Condition	Moisture	Compression parallel to grain: Crushing strength (#per square inch) Douglas fir	Compression parallel to grain: Stress at elastic limit (# per square inch) Douglas fir
	Per cent		
Green or soaked cold while green	Over 30	4,500 1.00	3,500 1.00
Normal air dry	12	7,640 1.70	5,450 1.60
Kiln dry, at 130° to 145° F.	3.5	11,900 2.60	7,920 2.30
Resoaked after drying	Over 30	......	.....
Number of tests used		60	60
Specific gravity kiln-dry wood		.58	.58
Number rings per inch		6.2	6.2

Moisture Condition	Mois.	Bending: Modulus of rupture (# per sq.inch) Douglas fir	Bending: Stress at elastic limit (# per sq. inch) Doug.fir	Bending: Modulus of elasticity (thousand # per sq. inch) Doug. fir
	%			
Green or soaked cold while green	Over 30	9,230 1.00	5,650 1.00	1,630 1.00
Normal air dry	12	13,550 1.50	9,250 1.60	1,980 1.20
Kiln dry, at 130° to 145° F.	3.5	14,800 1.60	11,670 2.10	2,130 1.30
Resoaked after drying	Over 30	------	------	-----
No. of tests used		36	36	36
Specific gravity kiln-dry wood		.57	.57	.57
No. rings per inch		9.1	9.1	9.1

Chapter IV.

THE SHRINKAGE OF WOOD IN RELATION TO KILN DRYING

Measuring the Shrinkage of Wood

Wood does not shrink uniformly; if it did, the drying of lumber would be comparatively simple. No one property of wood is responsible for more trouble than that of its natural tendency to shrink and swell. Since in kiln drying the swelling of wood does not take place, it will not be considered here.

It is impossible to prevent wood from shrinking, but a thorough understanding of the nature of shrinkage enables a kiln operator to so adjust his drying schedule and treatment of lumber as to prevent it from becoming useless, or the grade lowered by physical changes taking place, due to shrinkage.

The cellular action when wood shrinks, has been discussed in Chapter II in connection with fibrils.

The shrinkage in width of lumber may be measured by drawing a straight line across the face of a board and measuring it periodically while the board is drying. To obtain a good average, several boards should be measured.

The shrinkage in thickness may be measured with a caliper. Care should be taken to measure the board at the same place each time.

The shrinkage in volume can be measured by immersing the wood in water before drying, and after drying, and immediately upon immersion measuring the displacement of water.

The shrinkage of wood in relation to its moisture content can be expressed in terms of percentages based either on its original size or on its dry size. The general practice is to base it on its original size.

Wood shrinks in an indirect ratio to its moisture content below the fiber saturation point.

Table 14 shows the relation between shrinkage and the moisture content of western woods.

Table 14.

The Relation of Shrinkage to Moisture Content of Northwest Soft Woods.

Kind of wood	From Green to 22% M.C.	From Green to 18% M.C.	From Green to 12% M.C.	From Green to 8% M.C.
Douglas Fir and Western Hemlock				
a. % of shrinkage	0.95%	2.28%	4.11%	5.37%
b. Shrinkage in 12" widths in 32nds	3.65 / 32nds	8.76 / 32nds	15.8 / 32nds	20.6 / 32nds
Sitka Spruce and Idaho White Pine				
a. % of shrinkage	0.89%	2.08%	3.85%	5.04%
b. Shrinkage in 12" widths, in 32nds	3.41 / 32nds	7.98 / 32nds	14.78 / 32nds	19.35 / 32nds

Table 14. (Cont.)

Kind of Wood	From Green to 22% M.C.	From Green to 18% M.C.	From Green to 12% M.C.	From Green to 8% M.C.
Western Red Cedar (Shingle Cedar)				
a. % of shrinkage	0.61%	1.43%	2.66%	3.47%
b. Shrinkage in 12" widths, in 32nds.	2.34/32nds	5.49/32nds	10.21/32nds	13.32/32nds
California White Pine and Pondosa Pine				
a. % of shrinkage	0.77%	1.79%	3.32%	4.35%
b. Shrinkage in 12" widths, in 32nds.	2.95/32nds	6.78/32nds	12.74/32nds	16.70/32nds
Sugar Pine				
a. % of shrinkage	0.71%	1.65%	3.06%	4.01%
b. Shrinkage in 12" widths, in 32nds.	2.72/32nds	6.33/32nds	11.75/32nds	15.39/32nds

Note:-To get shrinkage of 4" stock use 1/3, 6" 1/2 and 8" 2/3 of the 32nds shown for 12" for each species and moisture per cent. The above averages interpolated for moisture since shrinkage is a true index of moisture between green and dry wood of the same species and varies but slightly for density.

The Relation of Shrinkage to the Grain of Lumber.

Wood shrinks in different proportions in different directions. The shrinkage parallel to the grain is so little that for practical purposes it is considered negligible. The greatest shrinkage occurs at right angles to the grain, and tangential to the annual rings. Flat grain boards shrink more in width than vertical grain boards, and vertical grain boards shrink more in thickness than flat grain boards. Table 15. shows the per cent of shrinkage in Oregon Softwoods based on the green dimensions.

Table 15.

The Shrinkage of Oregon Softwoods

	Vol.	Rad.	Tang.
Incense cedar	7.6	3.3	5.7
Port Orford cedar	10.7	5.2	8.1
Western Red cedar	8.1	2.5	5.1
Douglas fir	12.6	5.5	7.9
Grand fir	10.6	3.2	7.2
Noble fir	13.6	4.9	9.1
Western Hemlock	11.6	4.5	7.9
Lodgepole pine	11.5	4.5	6.7
Sugar pine	8.4	2.9	5.6
Western Yellow pine	10.0	3.9	6.4
Western White pine	11.5	4.1	7.4
Sitka Spruce	11.2	4.5	7.4

It is evident from the above table, that the radial shrinkage is much less than the tangential shrinkage. This is due to the medullary rays which, as previously stated, run at right angles to the grain, and like the tracheids, shrink very little longitudinally. This tends to prevent the tracheids from shrinking to their full extent radially, since they are structurally held by the medullary rays.

Heartwood and sapwood, when of the same density, shrink equally with equal changes in moisture content. However, sapwood responds more rapidly to kiln conditions, which cause it to shrink more rapidly than heartwood. This action of heartwood and sapwood is the cause for trouble when both occur in the same board, since the sapwood dries faster than the heartwood.

The shrinkage property of wood can be reduced by subjecting it to high temperatures. The higher the temperature the more effective the treatment. For this reason, kiln dried stock shrinks very little if any, when removed from the kiln.

Lumber cut from logs which have remained in the log pond from 8 to 12 months does not shrink as much as lumber cut from fresh logs.

Chapter V

STRESSES ARISING IN WOOD WHEN DRYING

Types of Stresses

It has already been stated in Chapter IV that wood does not shrink uniformly; the result of this is that various internal conditions are set up in lumber, which cause it to cup, twist, check, case-harden, honeycomb, and collapse.

Cupping

By cupping is meant the curving up of two edges of a board without changing the parallelism of the edges. It is due to the following causes:

1. One side of the board drying and shrinking more than the other. This often occurs in the top tier in flat piled lumber.
2. One side shrinking more than the other even if dried uniformly. In flat grain lumber, the side nearest the center of the tree more nearly resembles vertical grain than the side fartherest from the center of the tree. Since the shrinkage radially is much less than the shrinkage tangentially, the board tends to cup away from the side nearest the center.
3. Lumber which is drier in the center than on the surface will tend to cup away from the saw when

resawed. This will be discussed more fully under casehardening.

4. Lumber having more surface dressed off one side than the other will tend to cup.

Cupping due to uneven drying is not serious, since the lumber will, upon becoming uniformly dry, resume its original shape.

Twisting

Twisting is very similar to cupping, but differs in that the edges are not parallel. It is chiefly caused by spiral grain, interlocked grain, or uneven drying. Interlocked grain is rarely found in Oregon softwoods. It is more generally found in hardwoods, such as sycamore, beech, red gum, and cottonwood. Spiral grain is found in Oregon softwoods although not in any great amount.

The best provision in kiln drying to prevent twisting, or warping, is to place the stickers close together, and sort the lumber as to lengths. Care should be taken in flat piled lumber to see that the stickers are alligned one over the other and that the ends of the lumber are flush with one another.

In edge piled lumber, the lumber should be sorted as to lengths with one length to a truck. Stickers should be placed flush with the end and the entire crib held compact throughout the drying period by spring binding irons.

Vertical grain lumber twists less than flat grain lumber.

Checking

The checking of lumber is due to either one of two things, namely: uneven drying or the natural tendency of wood to shrink more tangentially than radially.

The best provisions for preventing checking is to keep a high relative humidity with a slow drying schedule. The degree of humidity or the speed of drying will vary with different localities, species, and operation, and can best be determined by the individual kiln operator, by experimentation, what humidities and temperatures are best to prevent checking in his stock.

The checking of wide flat grain "clears" is one of the main problems of kiln operators throughout the state.

Casehardening

If, in drying lumber, the surface dries faster than the interior, due to improper kiln conditions, the fiber saturation point is reached in the surface layer before it is reached in the interior. As already stated, shrinkage does not take place until after the fiber saturation point has been reached; therefore, the surface layer of lumber, reaching the saturation point before the interior, tends to shrink, but is prevented by the interior which has not reached the shrinkage point yet. This action results in strong tension stress being set up in the outer layer of lumber and a compression stress in the interior.

If a disk is cut across grain from a board in this condition about one-fourth of an inch thick and five saw cuts made as shown in Figure 3 with two of the prongs broken off, the outer two prongs will tend to curl outward. This is a temporary casehardening, due to a dry exterior and a wet interior. After leaving the disk for a while in a dry room, the outer prongs will tend to cup inward, and the inner prongs will be shorter. This is due to the inherent condition of wood which causes it when dried in a certain set condition to hold that condition. In this type of casehardening illustrated in Figure 3, the outer layer has become set, while the inner core is still free to dry slowly, which allows it to shrink more than the outer layer originally did before the piece was cut into prongs because the outer layer was prevented from shrinking its maximum amount by the wet core.

If drying continues in a board where stresses of the nature of those illustrated in Figure 4 are present, the core will keep on drying slowly, which will result in a reverse of the stresses. The slower wood dries the more it shrinks, therefore, the core drying slower than the surface, which has already set, tends to shrink more than the surface, but is prevented by the exterior portion of the board. This results in a compression stress being set up in the exterior layers and a tension strength in the interior. If the tension strength of the wood across the grain is sufficient to withstand this interval stress, the wood will dry permanently with an internal stress. But if the tension strength of the wood is not sufficient to withstand this internal stress, it will split apart in the interior along the medullary rays, which results in what is known as honeycombing, illustrated in Figure 4.

If a disk is cut from a board having a tension stress in the center and a compression stress in the surface layers, and cut as illustrated in Figure 3, the two outer prongs will cup inward, and the center prongs will cup outward. If the disk is left in a dry room, the inner prong will resume a straight condition, but the two outer prongs will remain cupped inward. This is the final stage of casehardening.

From the above explanation of casehardening, it is

FIGURE 3

First Stage in Case-Hardening

A. Surface dried below the fiber saturation point and in a state of tension. Interior containing free water and in compression. Tension stress indicated by minus signs; compression stress indicated by plus signs.

B. If disk A be immediately sawed by fine slits as shown, it will at once spring into this shape.

C. If B be now dried in an oven in warm room the tongues will finally bend into this shape.

FIGURE 4

Final Stage in Case-Hardening and Honey-Combing.
This is the Condition of Permanent Case-Hardening.

A. Permanent internal stress remaining after the wood is dried.

B. Honey-combing resulting from the stresses shown in A.

C. If disk be sawed by fire slits, as shown, it will immediately assume this form and bind on the saw.

FIGURE 5

End View of a Case-Hardened Board

A. Stresses present in the board.

B. Form which board will assume after resawing.

C. Test for internal moisture--note the bending outward of the center tongues upon exposure to dry air. They will ultimately turn inward as in Figure____.

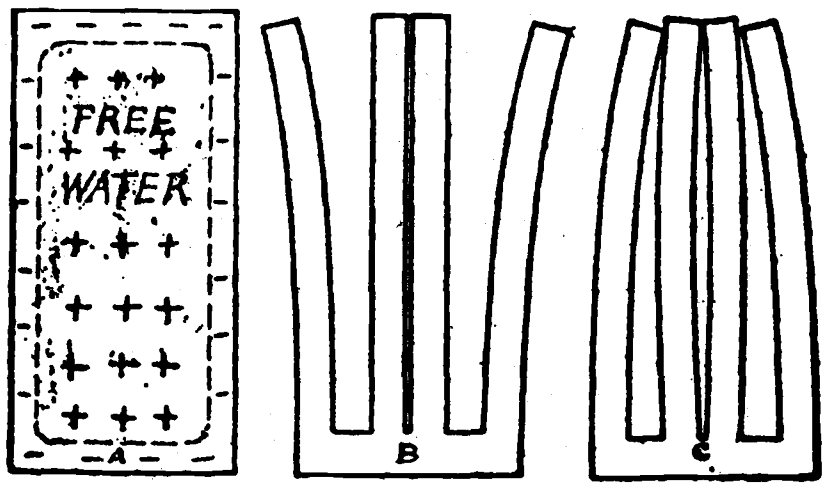


Fig. 3

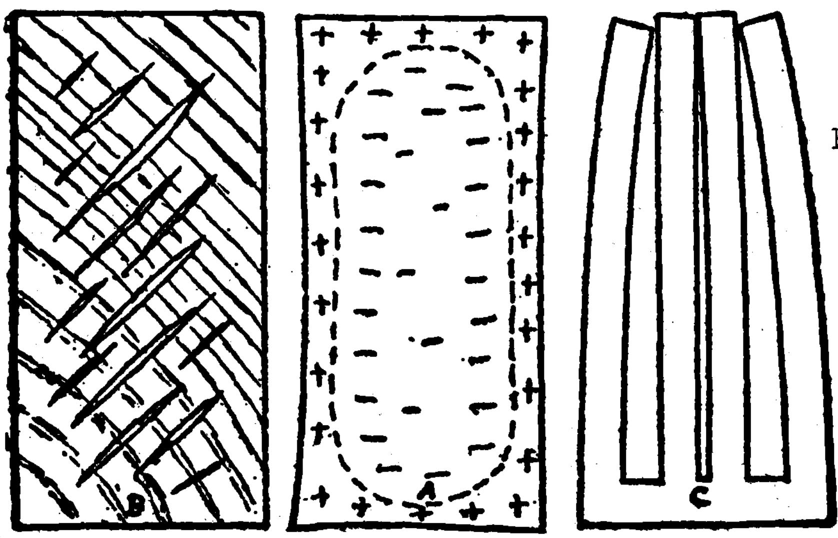


Fig. 4

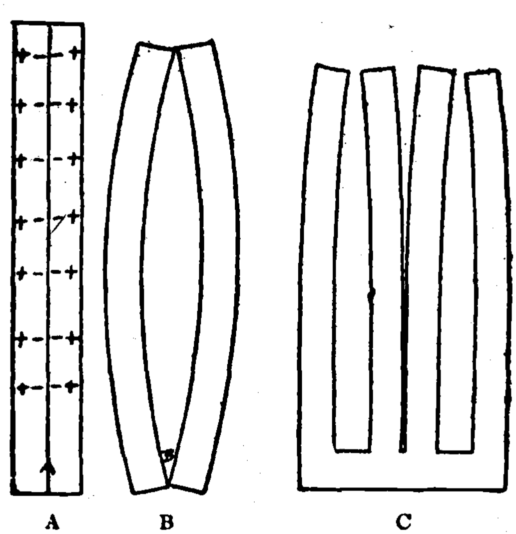


Fig. 5

evident that for lumber to be resawed or put through a planer, it must be free from casehardening, else the result will be cupped boards, coming from the resaw, and split boards coming from the planer.

Casehardening is a serious defect in lumber to be manufactured, and it is therefore essential that the kiln operator take care to prevent casehardening. If casehardening exists, it may be relieved by subjecting the lumber to as near 100% humidity as can be obtained.

The length of time such a treatment is to be applied varies with the dimension of the lumber. Usually for Oregon softwoods a 100% humidity treatment for 2 to 5 hours will relieve casehardening.

If, when an operator makes a casehardening test as illustrated in Figure 3, the prongs remain straight it is evident there is no stresses in the lumber, or, in other words, casehardening does not exist.

If a kiln operator will bear in mind the structure of wood and its method of drying, and that high humidities and temperature make wood plastic in his hands, many of the problems of kiln drying could be solved and especially casehardening.

Collapse

It sometimes occurs in drying wood that what seems to be abnormal shrinkage takes place, the sides of the board seem to cave in. This phenomena is not due to shrinkage, but is due to collapsing of the cell walls, wherefore, its name collapse. The only wood in Oregon subject to collapse is western red cedar.

This cause of collapse is explained as follows: In very wet wood, the cells are entirely filled with water, and in drying the water held in the cell cavity is removed before the water in the cell walls and air should naturally take the place, but it is very difficult for air to enter the cell cavity when the cell wall is still saturated with water. As a result the cell walls draw together in the same manner as when water is drawn out of a rubber tube without admitting air. It is not the air pressure which causes the cell walls to collapse, but the water leaving the cell cavity drawing the wet cell walls together, due to the attraction of water for water. The cohesive strength of water has been estimated to be from 150 to 4,500 pounds per square inch.

Collapse takes place in kiln dried lumber because the heat makes the lumber more plastic and soft, and under such conditions collapse readily takes place. It can be prevented by using a milder schedule or partially air drying the lumber to begin with.

Chapter VI.

HEAT, HUMIDITY AND CIRCULATION AND THEIR RELATION TO KILN DRYING.

Heat.

Why Heat is Necessary in a Dry Kiln.

In order for lumber to be dried, heat must be applied to it. This is true whether the lumber is air dried or kiln dried. In air drying the heat is supplied by the sun; in kiln drying by steam.

Heat is necessary in dry kilning for the following reasons:

1. To evaporate the moisture as it comes to the surface of the lumber. When water is evaporated, it uses heat. This is known as the latent heat of evaporation. The amount of heat used in evaporating one pound of water is 1000 British Thermal Units at ordinary temperatures and becomes less at high temperatures. A British Thermal Unit is the amount of heat required to raise the temperature of one pound of water 1°F. In a dry kiln, therefore, where large quantities of water are evaporated, much more heat is necessary than that needed to replenish the radiation from the kiln. For example: A truck of lumber having 1500 pounds of water to be evaporated out of it, would require 1,500,000 B. T. U's without considering any other loss of heat. In

actual practice it would require from two to ten times that amount of heat to remove 1500 pounds of moisture from a load of lumber.

2. Heat aids the transfusion of moisture to the surface. Hot water passes through wood faster than cold water. This is probably due to a decrease in its viscosity and an increase in vapor pressure due to the heat expanding the air in the cell cavities and inter-cellular spaces. Since the speed with which lumber dries depends on the rate of transfusion of moisture to the surface, it becomes evident that high temperatures greatly increase the speed of drying providing the surface does not become too dry to allow the passage of moisture through it.

3. Heat is required to separate moisture from wood below the fiber-saturation point. This is a small amount, usually about 34 B. T. U!s per pound of wood dried from saturation to complete dryness.

4. It is a known fact that by raising the temperature of air it can hold more moisture. This is another reason for the necessity of heat. Table 16 shows the relationship between the temperature of air and the moisture it can hold. This table is from the "Kiln Drying of Lumber" by Koehler and Thelan.

Table 16.

Amount of Moisture Air can Hold at Different Temperatures

Degrees Fahrenheit	Number of grains of moisture per cubic foot of air when saturated.
20	1.24
40	2.86
60	5.80
80	11.1
100	20.0
120	34.0
140	57.0
160	91.0
180	140.0
200	208.0
220	302.0

Although greater moisture capacity is obtained by heating the air to high temperatures, it must be remembered that this is somewhat offset by the high humidities necessary in kiln drying.

5. In all kilns without forced circulation, heat is absolutely necessary to obtain a movement of the air within the kiln. Hot air rises and cold air falls. No circulation can take place in a kiln when there is not a difference in temperature of the air between one part and another. Often in the construction of "home made" dry kilns without any mechanical means for creating circulation the principles of the natural movement of air is overlooked.

6. The use of high temperatures prevents the

fungical staining, decaying, or molding of lumber while drying. If any of these saprophytes have already attacked the lumber before it is put in a kiln they will be killed by the temperatures used. The following results found by experimentation at the Forest Products Laboratory reveal the action of high temperatures on fungi:

A. Decay does not make any appreciable progress above 105°F and growth is entirely stopped at 115°F with but few exceptions. Temperatures used toward the end of the run of western softwoods will kill any fungi present in the lumber so that it must be reinfected after drying.

B. Steaming lumber for short periods of time will also sterilize it. A temperature of 145°F and 100% humidity will in three hours kill any wood destroying fungus.

C. Blue stain fungi are the most resistant to heat but schedules used in drying western softwoods will kill these fungi.

D. Molds growing on lumber may be killed by temperatures of 135°F or more.

7. The high temperatures used in kiln drying western softwoods will kill any insects present in the lumber at the time of drying.

Heat is supplied in all modern kilns by steam coils. Either "high pressure" or "low pressure" steam is used. The general tendency in Oregon is to use high pressure steam. High pressure steam is steam above 10 pounds, while low pressure steam is below 10 pounds.

The heating coils are either under the lumber extending the full length of the kiln, or they are external to the kiln chamber depending on the type of kiln. The requirements of a good steam coil installation in a dry kiln are:

1. It must be large enough and located so that it can supply sufficient heat for the kiln chamber.
2. It must be durable.
3. It must allow for expansion and contraction.
4. It must be so installed that good drainage condensation is possible. One inch per 100 feet of pipe length is ample drainage.
5. It should be so connected that various units of it can be opened or closed without closing the steam supply to the entire system.

The types of heating systems used in Oregon will be discussed under the types of kilns used in Oregon.

Auxilliary Heating Apparatus

Various auxilliary apparatuses are used in connection with the heating system of dry kilns. The most important of these are: Steam valves, reducing valves, steam traps, air relief valves, and temperature control and recording instruments. There are many different types of these auxilliary instruments on the market, and no attempt will be made here to give a description of each or the merits of each, although a brief description of the use and the general functioning of such instruments will be given.

Steam Valves

Steam valves are the means for opening or closing the steam flow into the kiln chamber or the by-pass connected with the steam trap. The steam valves used with automatic controls are generally diaphragm valves. Other steam valves are hand operated and are either of the gate type or globe type.

Reducing Valves

Reducing valves are used where the steam in the main from the boiler is of too high a pressure for satisfactory kiln use. Such valves are located between the main and the steam valves opening the flow to the kilns. Their purpose is evident from their name -- they reduce the steam pressure. Intelligent manipulation of steam pressure reducing valves assists materially in maintaining a good temperature control in the kiln, as they assure a uniform steam pressure.

Steam Traps

The purpose of steam traps is to release the condensate from the heating system but trap the steam. They are located at the lowest point in the heating system. The usual practice is to return the condensate to the boilers.

The most prevalent trap used in Oregon is the bucket type of steam trap. This consists of an iron receptacle containing a bucket connected to a valve, the opening of which is into the return line to the boiler, or into the open. As the condensate gathers in the receptacle, it gradually rises until it begins to flow into the bucket. As the bucket fills, it tilts to one side, due to the fact that it is only supported at one side with the valve connection. The tilting of the bucket opens the valve, which allows the condensate to be driven out and the return of the bucket to its original position, preparatory to a refilling of condensate, closes the valve.

Air Valves

Air valves are steam traps, permitting the passage of air from the heating system and trapping the steam. All air valves operate thermostatically. They should be placed at the lowest point in the heating system, but care should be taken to place them on top of the condensate pipe running to the steam trap, else the condensate flowing to the same locality will destroy their action.

Thermometers

Thermometers are means of telling the temperature of the air in the kiln. They are of two types, "indicating" and "recording".

Indicating thermometers are usually of the common mercury type, and for kiln use are protected by metal to prevent breakage. The best indicating thermometers are those with the graduations etched on the glass.

Recording thermometers used in kiln drying are of the extension tube type, and are provided with a clock movement. In instruments of this kind, the sensitive element is a bulb placed in the kiln and connected with the recording device outside the kiln, by means of a capillary tube inclosed in a flexible metal tube, ending in a spring capsule in the recording case. A change in temperature causes a change in internal pressure in the capillary tube, which in turn, acts on the spring capsule, which transmits its movement through a series of levers to the recording pen arm, which moves over the face of a chart rotated by the clock works of the instrument and graduated into hours and degrees.

There are three distinct types of recording thermometers depending on the material used in filling the bulb. The three types are: Mercury filled, gas filled, and vapor filled. Of these three types, the vapor filled has proved the most satisfactory.

Automatic control of temperature is very desirable in kiln drying, and many kiln installations in Oregon use automatic controls with a tendency toward a greater use in the future. The advantages of automatically controlling the temperature is obvious, since all variations due to human control are eliminated, and the desired temperature maintained steadily.

Automatic controls are of two types, "self contained" and "air operated". The self contained controls operate by the action of vapor on liquid through a diaphragm motor upon the valve stem.

Air operated automatic controls, which are used almost entirely in Oregon, are operated by means of the transmission of the capsule action to a small air valve, which permits the flow of air at 15 pounds pressure to operate on the motor of a diaphragm valve.

Many instruments for automatic control combine a temperature and humidity control in the same instrument. Figure 6 shows a typical installation of an automatic humidity and temperature control instrument.

The Horsepower Required for Kiln Drying

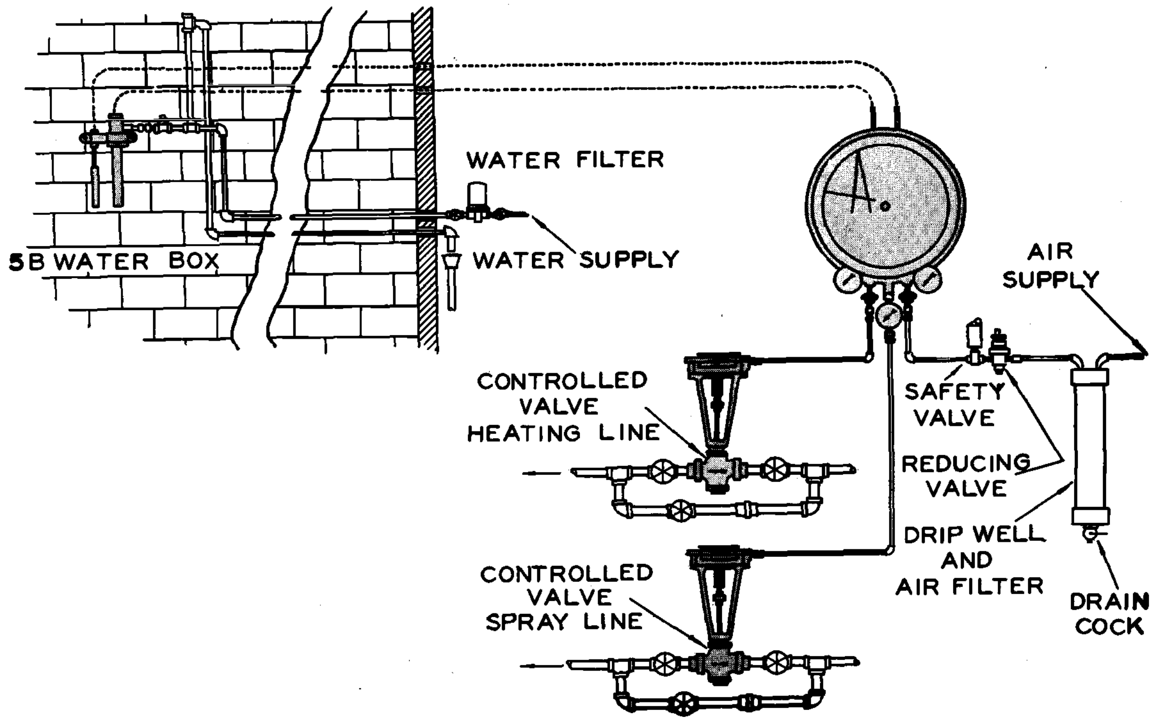
No definite amount of horsepower can be specified for kiln drying, because there are too many variables which enter into the question in each individual installation. Some of these variables are: The type of kiln, the species of wood, the size of lumber to be dried, the radiating surface to be used in the kiln, the boiler capacity of the plant at present, and the efficiency of the kiln. The average efficiency of softwood dry kiln operations has been estimated to be about 65 per cent.

An example of horsepower consumption required due to the difference in stock, can be shown by 10/4 western yellow pine B and B grade, which in a forced draught kiln

FIGURE 6

A Typical Installation of Humidity and

Temperature Recording, Automatic Controls


WATER FILTER
5B WATER BOX
WATER SUPPLY
AIR SUPPLY
CONTROLLED VALVE HEATING LINE
SAFETY VALVE
REDUCING VALVE
DRIP WELL AND AIR FILTER
DRAIN COCK
CONTROLLED VALVE SPRAY LINE

was found to require only 20 horsepower at the start of the drying period, while box lumber required 90 horsepower at the beginning of the run.

The horsepower required for any particular drying job can be roughly estimated on the basis of the amount of water to be evaporated from the lumber in a given time and the efficiency of the drying operation.

The method of calculating consists in determining the amount of moisture to be evaporated in an hour, divide this by the efficiency of the drying operation, and then divide by 34.5 (the number of pounds of water evaporated per hour, from and at 212° F for 1 boiler horsepower. The result is the boiler horsepower required.

Humidity

Why Humidity is Necessary in a Dry Kiln

The following reasons are those which make humidity one of the three fundamentals of kiln drying:

1. To prevent checking both on the surface and the ends.
2. To prevent casehardening and to relieve casehardening.
3. To hasten the transfusion of moisture. If the surface layers become too dry as already pointed

out in Chapter V. the interior moisture is prevented from coming to the surface. Humidity keeps the surface layer moist.

4. To even up the moisture content within the lumber, 100% humidity accomplishes this.
5. To regulate the dryness of the lumber. The final moisture content desired can be regulated by the humidity. From the graph in Figure 2, it is evident that at 170°F, for example, and 50% relative humidity, the moisture content of the lumber cannot go below 7%.

Explanation of Relative Humidity

Relative humidity is the ratio or relationship between the amount of moisture in the air at a certain temperature, and the maximum amount of moisture the air could hold at that temperature. When the air contains all the moisture it can hold at a certain temperature, it is called saturated, and has a relative humidity of 100%. If at the same temperature the air only held half as much moisture as it could hold, it would have a relative humidity of 50%. For example, at 164°F the air can hold 100 grains of moisture per cubic foot. If there are only 75 grains of moisture in the air, the relative humidity would be 75%. An increase in temperature lowers the relative humidity since the higher the temperature the more moisture the air can hold.

The relative humidity is directly related to the evaporation of water. At a low relative humidity the evaporation from the surface of a wet board is much faster than at a high relative humidity; since at the low humidity there is still room for more moisture to be taken up by the air. For example, at a low humidity of 25% there is still 75% more moisture that the air can take up from the lumber.

From the above discussion, it is evident that heat and relative humidity are inseparable for good kiln drying. The two must at all times be considered by the kiln operator.

Determining the Relative Humidity

The relative humidity is determined by means of a humideik which consists in two ordinary thermometers set in a frame with the bulb of one enclosed with a clean cotton cloth wick or silk wick, the end of which is immersed in water. If any evaporation takes place, the bulb with the wick surrounding it will become cooler and the thermometer show a lower reading than the one without a wick. Tables have been worked out to show the relative humidity at various differences in reading between the wet and dry bulb, also, for various combinations of wet and dry bulb readings.

Where automatic controls are used, the wet and dry bulb principle works the same as with a humidsik. The bulb of the wet bulb thermometer is inclosed in a porous sleeve which is supplied with water. The water seeps through the porous sleeve, which is usually made of crockery, and if any evaporation takes place, the wet bulb thermometer shows a lower reading than the dry bulb thermometer. The action of the wet bulb thermometer is identically the same as described for the dry bulb thermometer under automatic temperature controls. The action opens the diaphragm valves on the steam spray lines, which permit the escape of live steam in the kiln. The operator knowing what humidity and temperature is desired, sets the control hands of the automatic instrument for a temperature and humidity which will give him the desired humidity. Figure 6 illustrates both the wet and dry bulb installation.

Supplying Humidity to the Kiln

The amount of moisture present in the air in a kiln may be increased by admitting live steam or by opening the fresh air vents. Both means are used. By closing the roof vents, the humidity can be raised, since this prohibits the escape of the moisture laden air coming from the lumber. However, this is not always sufficient to raise the humidity to the desired point, especially near the end of the run. The quickest and most satisfactory way of controlling the humidity in a kiln is by the use of live steam, either automatically controlled or hand operated.

A recent invention called the "Cone Roof Ventilator" works automatically by compressed air with the action of the wet and dry bulb thermometer. These roof vents prevent the waste of heat and make possible a more steady humidity and temperature.

In hand operated steam spray lines it is good practice to have a reducing valve in front of the hand valve. This allows for a more uniform flow of steam, as well as allowing the hand valve to be opened completely. This prevents the wear on the valve due to "wire" drawing when the valve is just "cracked" or slightly opened.

Steaming Lumber

The steaming of lumber at various periods in its drying is considered good practice when such steaming is for the purposes of relieving stresses present in the lumber. Steaming is accomplished by so setting the wet and dry bulb controls as to obtain a 100% humidity.

Steaming green lumber at the start of the kiln run is practiced by some operators, and not by others. It is advisable in drying thick stock to steam it first. The reason for this is that the stock is heated through quickly without injury to it, which results in quicker transfusion of the moisture to the surface.

A general rule to follow in steaming stock is to allow one hour for each inch in thickness. Temperatures 25° higher than that intended for drying can be used during the 100% humidity treatment. After steaming the stock the humidity should be gradually lowered to that used in drying the stock.

Often when steaming stock in a ventilating kiln moisture laden steam gathers under the roof, which, with a lowering of the temperature, tends to condensate on the ceiling of the kiln later to drop on to the lumber. This can be prevented by gradually opening the roof vents as the temperature is reduced to that used in drying.

It often becomes necessary in order to meet with rush orders, for example, to kiln dry stock which has been partially air dried. In all cases where this is necessary such stock should be submitted to a 100% humidity treatment at the beginning of the run, in order to relieve any stresses which might be present from air drying. Partly air dried stock is harder to kiln dry than green stock.

High humidities are the only means of relieving casehardening and checking. Necessity for steaming to relieve casehardening can be determined by casehardening test described in Chapter V. Koehler and Thelen have advanced the following rules for steaming to relieve casehardening.

1. If the center of the stock contains over 17% moisture, 100% humidity for one-half to three hours should be used unless the stock is checked, in which case 85% to 95% humidity should be used for ten to twenty hours.
2. If the center of the stock contains 15% to 17% moisture, 75% to 85% humidity should be used.
3. If the center of the stock contains below 15% moisture, 60% to 70% humidity should be used.

In case two and three the specific temperature and humidity should be maintained for from twenty to thirty hours, the time depending on the thickness of the stock and the depth to which the outer layer extends.

Circulation

Necessity for Circulation

The third fundamental element for proper kiln drying is circulation. The reasons for having circulation in a dry kiln are:

1. To maintain a uniform temperature and humidity throughout the kiln.
2. To carry off the excess moisture in the air. This is very important at the beginning of the kiln run, as green lumber evaporates a great deal of moisture.

Supplying Circulation

There are two ways of obtaining circulation in a dry kiln, namely, by the natural flow of air and by forcing the air with fans. Both systems are in use in Oregon.

Of the two methods of creating circulation, the forced draught is the best, however, very satisfactory results are obtained with natural draught kilns.

In a natural draught kiln, the circulation is caused by the entering of cold air at the bottom and the escape of hot air at the top. Often in natural draught kilns, the circulation is aided by steam jet lines.

Measurement of Circulation

It is possible to specify and maintain a definite temperature and humidity in a kiln, but it is rather difficult to maintain a definite circulation.

The circulation desired in a kiln depends more or less on the type of stock being dried. In drying Douglas fir common stock a considerably higher circulation is required than in drying Douglas fir finish. The rate of circulation also depends on the method of stacking. For vertically stacked lumber, a higher circulation is need than for flat piled lumber, since the air must travel farther, usually from 7 to 9 feet. The rate for vertically piled lumber should be 100 feet per minute; however, very good results are obtained with a much slower rate of circulation. The minimum rate of circulation below which the lumber is in danger of improper drying is 25 feet per minute.

There are two ways that the rate of circulation in a kiln may be measured, namely, by the use of an anemometer and a smoke machine. The most common method is to use a smoke machine. This consists of two bottles, held in a frame, one of which contains hydrochloric acid and the other ammonia. The hydrochloric bottle is corked with a tube running into the ammonia bottle and another tube through which the operator blows, blowing the hydrochloric fumes into the ammonia bottle. The result of this is a white smoke. By watching the direction, the smoke travels and timing the passage of it over a known distance the direction and rate of circulation is obtained.

Chapter VII.

TYPES OF DRY KILNS USED IN OREGON AND KILN CONSTRUCTION AND LOCATION.

Types of Kilns Used in Oregon

Kilns may be classified according to the method of charging and discharging, or according to the means for obtaining circulation.

Progressive and compartment kilns are the two classifications according to the method of charging and discharging. In a progressive kiln, the lumber is put in at one end and gradually moved forward in the kiln, which is so operated as to have the conditions in one end more severe than in the other. In this way the lumber is gradually exposed to higher temperature and lower humidities until it is removed from the kiln. This type of kiln is almost obsolete in Oregon, and, in fact, in all dry kiln operations.

In a compartment kiln, the entire charge is put in at once and removed at one time. Uniform conditions prevail throughout the kiln. This type of kiln is the one mostly used in kiln installations today.

Kilns classified according to method of obtaining circulation in Oregon are natural draught kilns, external fan kilns and internal fan reversible circulation kilns.

The largest number of kilns in use in Oregon are natural draught kilns. This is not because of better drying, but because of cheaper costs of installation. The general tendency is toward the use of more forced circulation kilns, since better drying can be done with them. Figures 7, 8, 9, 10, and 11 illustrate the three types of kilns used in Oregon.

The advantages and disadvantages of the internal fan kiln and the external fan kiln practically balance one another. Both types of kilns, if properly run, will successfully kiln dry lumber. Throughout the state of Oregon there is no universal judgment in favor of internal over external fan kilns. The following statements made by different kiln operators bring out some of the disadvantages and advantages of these two types of forced circulation kilns:

1. If a bearing is broken or other accident occurs in an internal fan kiln, the kiln must be opened and the temperature reduced, since the kiln must be entered to repair the broken part.
2. The circulation in an external fan kiln is not always uniform throughout the kiln, since the air must be forced from one end to the other,

FIGURE 7

Cross Section of Natural Drought Kiln

Showing Circulation of Air

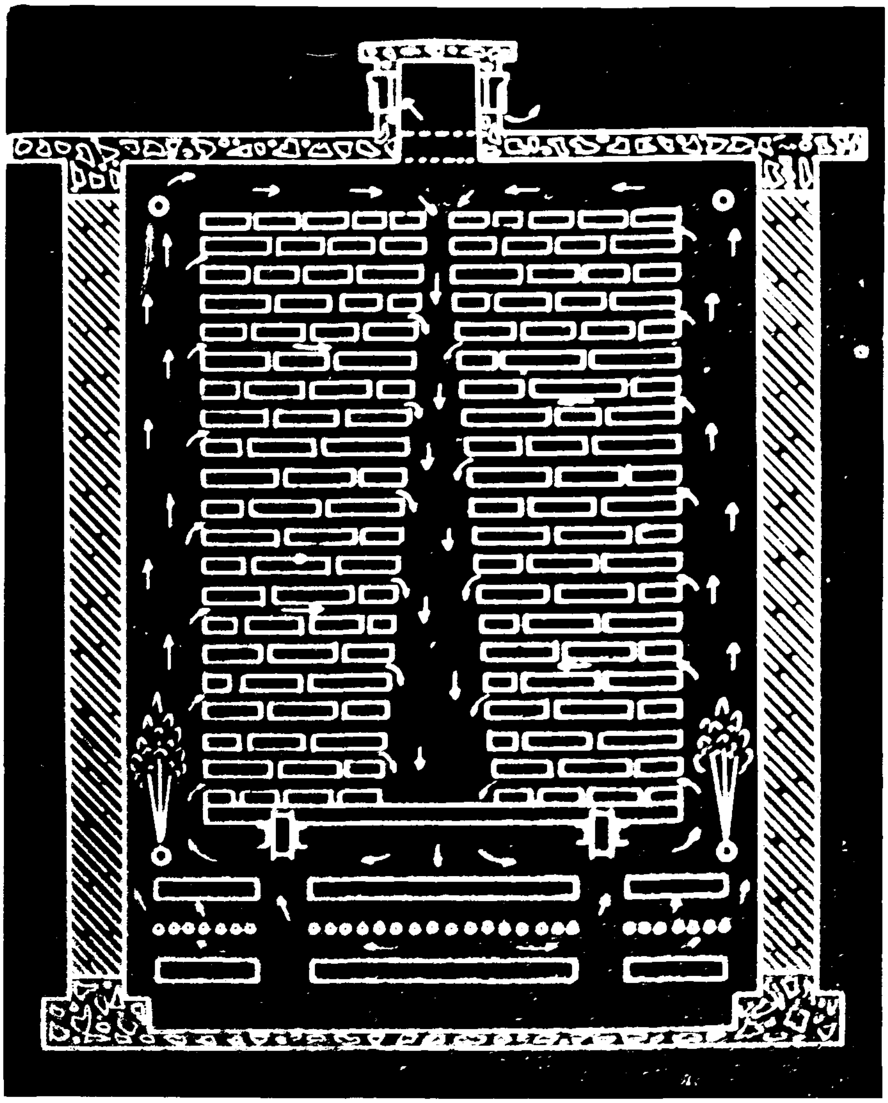


FIGURE 8

End View of External Fan Kiln For Edge Stacked Lumber

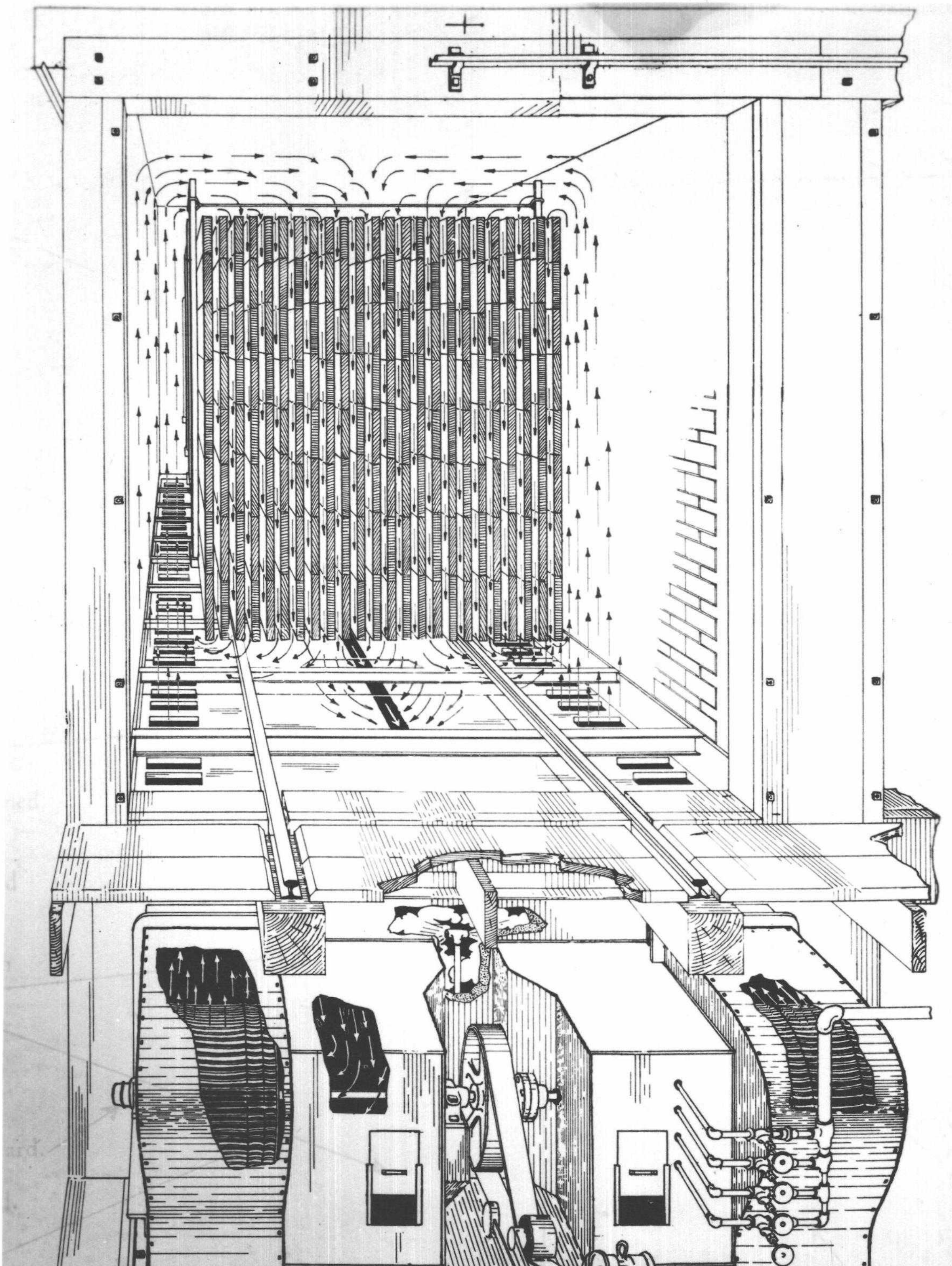


FIGURE 9

End View of External Fan Kiln For

Flat Piled Lumber

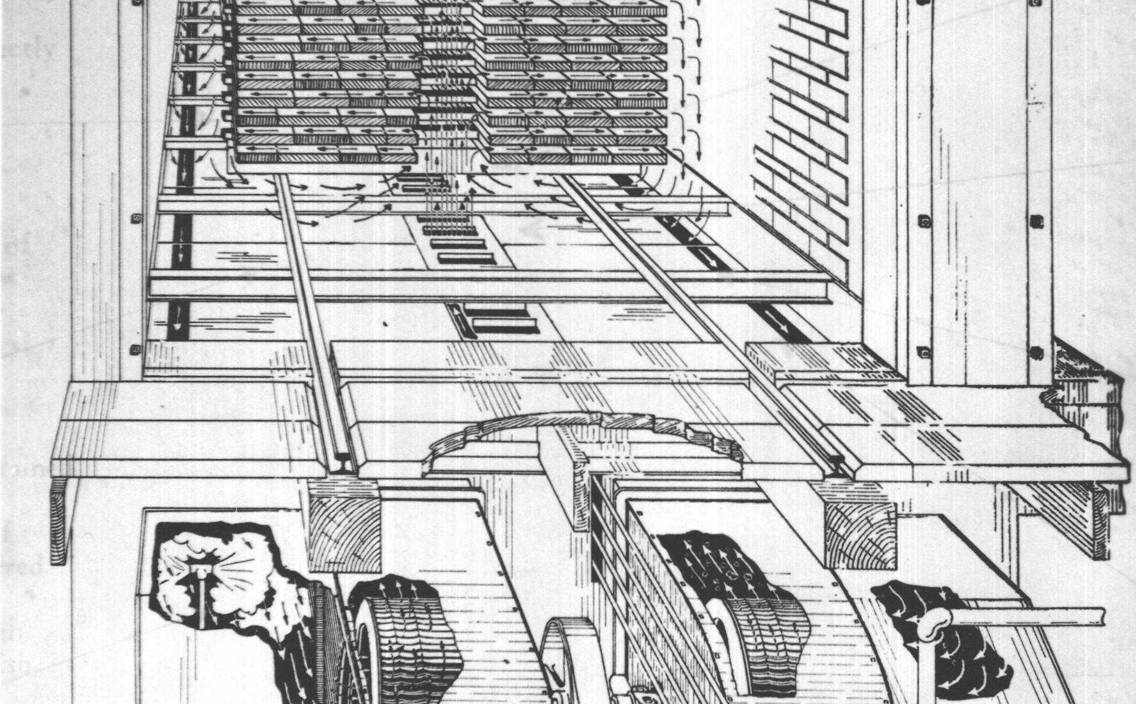
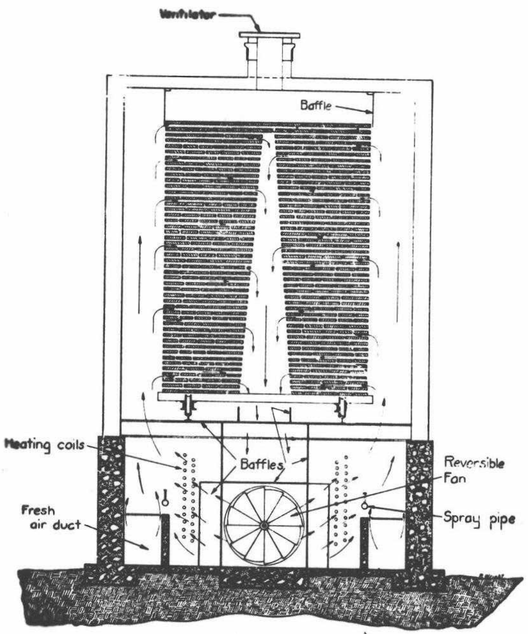
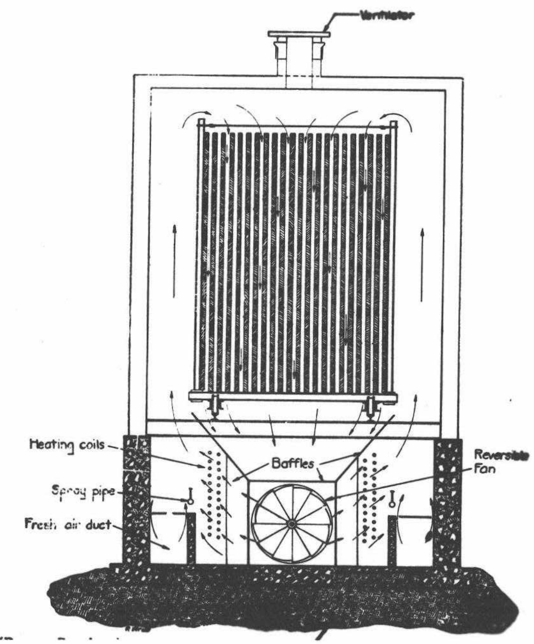


FIGURE 10

Types of Internal Fan Kiln Both for Edge Stacked Lumber and Flat Stacked Lumber


Ventilator
Baffle
Heating coils
Baffles
Reversible Fan
Fresh air duct
Spray pipe


Ventilator
Heating coils
Baffles
Reversible Fan
Spray pipe
Fresh air duct

and this often builds up a static condition at the end opposite the fan.

3. More air is turned over with an internal fan kiln.

4. The mechanical devices of an external fan kiln are more easily reached, as they are all external to the kiln chamber.

These statements pro and con, are based on the experience of kiln operators using both types of kilns.

The advantages and disadvantages of forced draught kilns over natural draught kilns may be summarised as follows:

Advantages

1. Quicker drying can be done.
2. More uniform circulation can be kept.
3. Drying conditions can be kept more uniform throughout the kiln.
4. Less degrade, if properly operated.
5. More adaptable to drying common lumber.
6. Desired temperature and humidity can be more quickly reached.
7. Require less steam and less radiating surface.

Disadvantages

1. Initial costs are greater.
2. Upkeep is more expensive.

3. Cost more to operate.

4. Not adapted to small operations.

Dry Kiln Selection and Location

Selection

There are many different kinds of building material used in constructing dry kilns. No attempt will be made to give the values of the different materials, but the various factors entering into the building of a dry kiln will be brought out in the following paragraphs.

Intelligent consideration should be given each factor connected with a dry kiln before any attempt is made to build one. The following enumerated points should be considered for on them rests the type of kiln to be built:

1. Permanence of operation.
2. Type of lumber to be dried.
3. Amount of lumber to be dried.
4. Boiler capacity of the heating plant.
5. Use of dried stock.
6. Insurance rates
7. Financial condition of the firm.

Location of the Dry Kiln Unit.

It is just as important to have the dry kiln unit of a mill located properly as it is to have the edger in a saw-mill properly located.

A forward progress of lumber is advisable; that is, to the green storage, through the kilns, to the dry storage, to the unstocker, and finally to the planing shed. Whenever it is necessary for the lumber to retrace its route increased cost usually develops.

In locating the kilns consideration should also be given to the foundation. If the kiln is located on marshy ground, it will settle, causing cracks to develop in the kiln, fan shafts to get out of line, and water to seep into the kiln, and collect on the floor. Therefore, sound foundations are very important for a kiln unit.

If the prevailing wind in a particular locality is from the north, for example, it would be unwise to so locate a battery of kilns, that either end would face north. It is a known fact that the atmospheric conditions influence a great deal the conditions in a kiln. In a battery of kilns it is harder to maintain a certain temperature and humidity in the kiln with a wall to the outside than it is in a kiln having other kilns on either side.

The greatest leakage of outside air in a kiln is around the ends. For this reason in the example given above it would be poor judgment to locate the kilns with an end facing north.

Insurance companies govern their rates for fire insurance to a certain extent on the connection between the surrounding buildings and the kilns. If the kilns are surrounded with other wooden buildings the rate is higher than if the kilns are connected only in one direction with other inflammable buildings. This is another factor worthy of consideration in locating a battery of kilns.

CHAPTER VIII

PILING AND STORAGE OF LUMBER FOR KILN DRYING

Two Types of Piling

There are at present two types of lumber piling on dry kiln trucks, namely; flat piled and vertical piled, sometimes called edge stacked. The general tendency is toward more flat piling than vertical piling in Oregon. The proper methods and the advantages and disadvantages of each type of piling will be discussed in the following paragraphs. Since practically all kilns in Oregon are compartment kilns, end piling is used exclusively. In end piled lumber the length of the boards is parallel to the sides of the kiln.

Flat Piling

Flat piling is done both by hand and by a combination of hand and machinery. In hand piling, a piling track is located in conjunction with the kilns upon which the flat piling is done. The lumber is brought up to the pilers by lumber carries of various description from the green chain.

With a combination hand and machine piling operation the lumber is usually brought to the pilers by chains direct from the green chain. The truck being piled, is located on a platform which is raised and lowered as the pile increases in height, depending on whether the elevation of the transfer track is above or below the piling platform.

The platform upon which the truck of lumber is being piled is fitted with rails, which coincide with the transfer tracks when the platform is raised or lowered to the same elevation as the transfer tracks. This enables the loaded truck to be removed easily. A typical semi-hand operation being used in the more modern kiln installations in Oregon is here set forth.

The lumber for the kilns passes down the green chain and is raised on conveyor chains into the stacking shed where it reaches a sorting table. Here one man sorts the lumber as to grade, width, and thickness. The sorterman places the lumber in different slots which take off from the end of the sorting table. The lumber is carried along a narrow shute on edge and is automatically sorted to lengths in two-foot divisions by means of trip locks.

The sorted lumber slides off the rollers down on a slanting table over which conveyor chains run.

When a sufficient number of boards are piled on the conveyor chains of one length division to build a crib, the stackermen operate the conveyor chains and move the lumber down onto a conveyor belt which carries it to the stacking table. When the lumber reaches the stacking table it is conveyed by chains up to the stackermen, and slid out upon the kiln truck by means of metal slides. The stackermen arrange the lumber on the truck. As the pile grows, the platform containing the truck is lowered.

Stickers are placed on end in bins convenient to the stackermen from the storage tracks below the stacking shed.

When dried, the lumber is brought from the kilns and is placed in a dry storage shed where it remains for twenty-four hours.

The unstacking machine is purely automatic. The kiln truck is run onto a raisable platform, which is raised until the top tier of lumber comes in contact with a series of three chains having catch links one truck width apart. As the chains revolve they catch a tier of lumber and slide it off onto the dry chain. The platform raises automatically each time in order for the chains to catch the next tier of lumber.

The stickers are shoved onto a conveyor belt which carries them to a bin under which a kiln truck may be run, and a load of stickers removed by opening the bottom of the bin. The stickers are then transferred back to the stacking shed and placed by hand in the bins of the stacking platform.

The above description is an actual installation. Other similar installations differ but slightly from the one described.

The necessity for having the ends of lumber on kiln trucks flush with one another is too often overlooked in kiln operations. Regardless of the method of piling the ends of the lumber on a crib should be even, and a sticker flush with the ends also. If the lumber is not sorted it should be so piled as to have square ends to the cribs. The importance of this precaution in piling lies in the fact that unsupported ends will, in most cases, warp; also, by uneven ends the kiln trucks cannot be brought together closely in a kiln which allows a broken passageway at the end of each truck with a consequent short circuiting of the circulation.

In flat piled lumber, it is also essential that sufficient room be left between each board in a tier for a free circulation of air. If the lumber is all of one width these spaces should be one above the other. If the lumber is to be dried in a natural draught kiln, these spaces should be from one-quarter to one-third the width of the board.

It is absolutely essential also, in flat piled lumber, to leave a flue up through the center of the load. This flue should be graduated from the bottom up to within three or four tiers from the top of the load, where it ends. The flue at the bottom should be from 18 to 20 inches wide. If the pilers are not sufficiently skilled to construct this flue a form can be used as a guide. The purpose of the flue is to obtain a more uniform circulation through the pile.

In kilns using forced cross circulation, no central flue need to be built. This is a comparatively new type of kiln in which the air enters at one side, rises up and across the lumber and down the other side of the kiln.

Stickers being used for flat piling lumber are 1 9/16 by 2 1/2 inches, 1 1/4 by 2 inches, 1 1/4 by 4 inches. Usually 5-6 stickers are used per tier, in some cases seven. It is better to use too many stickers than too few. Sufficient stickers should be used to prevent any ends in unsorted lumber from being unsupported.

The spacing of stickers in any case should not be less than four feet. Thin stock or easily warped stock should have stickers every two feet. It is unadvisable to use square stickers as they have a tendency to roll.

Not only should flat piled lumber be square on the ends, but the cribs should be of the same width. Trucks of different widths put in the same kiln cause a breaking up of the air currents, and a non-uniformity of drying conditions.

Stock of different thicknesses and grade should not be piled on the same truck or put in the same kiln, as each grade and thickness requires a different schedule. It also is not good practice to put wide stock in with narrow stock.

The advantages and disadvantages of flat piled kiln lumber are as follows:

Advantages:

1. Simplest piling method
2. Requires less expensive equipment
3. Is well adapted to small installations
4. Better drying results obtained with wide flat grain
5. More lumber can be put in a kiln
6. Is better adapted to piling of thick stock

Disadvantages:

1. Requires longer time for piling than vertical piling
2. Is not adapted to natural circulation kilns as well as vertical stacked lumber
3. Requires longer to unpile unless done automatically

Edge Stacked Lumber

Edge piling is done entirely by machinery except the placing of stickers.

Two types of edge stackers are found in Oregon. In one type the lumber is brought to the stackerman on chains from which it is slid edge to edge onto a rack, upon which stickers have been placed. When the rack is filled, the lumber is raised by mechanical action onto the kiln truck by raising the rack. The stickers on the rack are caught at the top and bottom and thus hold the lumber in place against two or more side irons placed in the kiln trucks. The stackerman places the stickers on the rack by hand from a convenient pile. The kiln trucks are on a movable platform which is moved backward as the pile increases in thickness. The stackerman controls the movement of the platform and the rack by levers. When the truck is finished, the platform is brought flush with the transfer rails and the truck removed to the green storage tracks.

The second type of edge stacker consists of a cradle rotated on a frame. The kiln trucks are placed on the platform of the cradle with binding irons in place on one side. The cradle is then rotated until the binding irons coincide with a slide down which the lumber falls onto the kiln truck with the guidance of the stackerman. The stackerman places the stickers after each tier is loaded. As the pile increases in size, the cradle is rotated to keep the last tier in line with the slide. When the last tier of lumber has been placed, the binding irons are put in place and the cradle rotates back to a horizontal position which brings the rails of the platform flush with the rails of the transfer track.

Edge stacked lumber must be unstacked mechanically. The unstacking machine consists in a movable platform on which the truck is run. The unstackerman, after removing the binding irons on the top and one side, brings the lumber up against a series of chains having hook links one truck height apart. The hook links catch the bottom board in one tier and lift it up against guides which guide it up and over onto the dry chain. The unstackerman removes the stickers as they are released and keeps the lumber tight against the chains.

For successful drying with edge stacked lumber, it is necessary to have the kiln trucks equipped with shrinkage take-up devices to keep the crib of lumber tight throughout the drying period.

A common device for binding the load consists of two chains joined by a spring. When the load is complete the stackerman hooks the chains over the side binding irons which expand the spring. As drying proceeds with the natural shrinkage the spring draws the side irons together.

At the bottom of the load the shrinkage is taken care of in somewhat the same manner. The sockets, into which the side irons are placed, are joined by a spring which is extended when the truck is filled with lumber. As the load shrinks, the spring draws the sockets together.

The following difficulties are prevalent when shrinkage take-up devices are not used:

1. The load leans over to one side, which causes it to catch on supporting pillars of the dry shed, or the door frames of the kiln.
2. Stickers fall out of the load and catch on the rail supports in the kiln, resulting in broken stickers and often derailed cars.
3. Loose loads are more difficult to unstack than tight loads.
4. Warping takes place as the lumber is not held tightly in place.

The advantages and disadvantages of edge stacking may be enumerated as follows:

Advantages:

1. Readily adaptable to the natural flow of air in

natural draught kilns.

2. More lumber can be handled in a day.

3. Less stickers required.

4. If properly piled, the lumber is held more firmly in place.

Disadvantages:

1. Requires high velocity of circulation for best results.

2. Expensive equipment needed.

3. Not adaptable to small installations.

4. Warping occurs if shrinkage take-up devices are not used.

5. Wider stickers required.

6. If lumber is not sorted many ends will be unsupported which allows warping.

The stickers being used with edge stacked lumber are: 3½ by 5/4 inches, 1½ by 1½ inches, 4 by 4½ inches, 3 by 4/4 inches, and 5 by 1½ inches. In many cases too wide a sticker is used, which results in checking under the sticker. A sticker 3½ by 1 inch is sufficiently large.

Stickers

In Oregon the general practice is to use Douglas fir stickers since they are the strongest and can stand more abuse than other wood stickers. In some operations white fir stickers are used. The argument in favor of white fir is that it does not splinter as much as Douglas fir when dry, however, it is a question whether the tendency to splinter less over-balances the lack of strength in white fir stickers or not.

One operation in Oregon use steel stickers 1¼ by 1¼ inches in size, and hollow through the center. These stickers cost 50¢ a-piece. The arguments advanced for their use are that they last longer, that the hollow center aids circulation, and that they can be easily repaired when broken. In the company using the steel stickers, $7000 a year is saved by their use. Most operations find them too expensive to use. The biggest objection to steel stickers in the Douglas fir district is their tendency to chemically stain fir and hemlock.

A grooved wooden sticker for edge piling is used in one of the large pine mills of Oregon. The groove is made on both sides of the sticker. The theory sponsoring their use is that very little sticker surface is in direct contact with the lumber and the air can circulate up under the sticker. This is a very satisfactory sticker, but it is a question whether the cost of manufacturing them warrants their use.

The qualifications of a good sticker for meeting all

all the requirements may be summarized as follows:

1. Vertical grain should be used.
2. Pitch streaks, pitch pockets, decay or stain should not be present.
3. All the stickers used in one operation should be of the same size.
4. No knots should be present.

Storage of Kiln Lumber.

All lumber intended for kiln drying should be protected from rain, wind, and direct sunlight from the time it leaves the green chain until it is put in the kiln. This makes it imperative that the green storage shed be covered. If green lumber is left exposed to the weather on kiln trucks, it will check during the summer months especially. Such checking is often blamed on the kilns when it really is the improper storage facilities that should be blamed.

When lumber is removed from a dry kiln it should remain in a dry shed for at least twenty-four hours before sent through the planers, in order that an equilibrium of stresses may take place in the lumber.

The necessity of protecting kiln dried lumber from the weather is obvious. The entire benefits of kiln drying may be lost by exposing the stock to the weather especially during winter months.

Kiln Trucks

Several makes of kiln trucks are used all of which are very satisfactory in meeting the main requirements of dry kiln trucks, namely; durability.

With a little care dry kiln trucks will last many years, however, the general tendency in most kiln operations, is to throw kiln trucks about with little regard for their destruction.

Kiln trucks should be oiled after each run. Any grade of lubricating oil will answer the purpose. One make of truck now on the market, is fitted with an alemite system, which requires oiling only at long intervals of time. Such a truck proves very satisfactory provided it is not thrown about and the nipple for the alemite system broken off.

Kiln trucks which have become loose, often cause the derailing of kiln loads of lumber. A derailed car means a waste of time and can in some instances, cause a hold up in the entire transfer system.

CHAPTER IX

KILN DRYING PRACTICE IN OREGON

Douglas Fir Region

The following grades and dimensions of softwood lumber are being kiln dried in the Douglas fir region:

Douglas fir.

1. Flooring strips, both flat grain and vertical grain.
2. Finish, all widths and thicknesses.
3. Stepping, all widths.
4. Dimension, all widths.
5. Shop, all thicknesses and widths.
6. No. 1 common boards.
7. No. 2 common boards.
8. No. 3 common boards.
9. Lath.

Sitka spruce.

1. Beveled siding, all widths.
2. Finish, all widths and thicknesses.
3. Dimension, all widths.
4. Box, all widths.
5. Common boards.

Western Hemlock.

1. Flooring both flat grain and vertical grain.
2. Siding, all widths.
3. Dimension, all widths.
4. Box, all widths.
5. Common boards.

Western Red Cedar.

1. Siding stock.
2. Finish.
3. Common boards.

It is impossible to provide a standard kiln schedule for the various grades and dimensions of lumber. Therefore, the schedules presented in this thesis are not to be considered ideal for any locality, but are presented as a guide in the development of schedules. The schedules presented are those being used in Oregon with success. A few schedules presented are those compiled by the Forest Product Laboratory. The schedules presented for drying finish, shop, and flooring are for obtaining a moisture content of 7% to 10%. The common schedules are for drying down to 20% moisture content.

Douglas fir schedules and Problems in Drying

Schedule 1. 4/4 clear finish F. G. (Forced draught)

Hours	Dry Bulb Temp.	Wet Bulb Temp. o F.	Relative Humidity in Per cent
0	Start steaming at 150°		
9	Finish steaming		
12	150	147	92
30	155	147	81
42	160	147	71
60	160	140	58
78	165	140	52
96	170	140	45
108	170	130	33
134	Reverse Circulation		
150	Steam 170°		
152	Out		

Schedule 2. 4/4 flooring strips (Forced draught kiln)

Hours	Dry Bulb Temp.	Wet Bulb Temp.	Relative Humidity Per cent
0	Start steaming at 180°		
4	190	186	90
8	190	180	80
12	190	176	75
16	190	176	75
20	196	170	62
24	200	175	56
28	200	171	51
32	200	156	45
36	210	166	37
40	210	164	35
44	210	162	33
48	210	162	33
52	210	162	33
54	210	162	
56	Out		

Schedule 3. 6/4 Clear (forced draught)

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
4	170	170	100
8	176	174	95
12	180	176	90
16	186	178	85
20	190	180	80
24	190	179	78
28	190	177	76
37	190	176	74
36	190	175	72
40	190	173	69
44	190	171	66
48	190	169	63
52	190	168	60
56	190	165	58
60	190	164	56
64	190	162	54
68	190	161	52
72	190	158	50
76	190	156	47
80	190	154	44
84	190	152	42
88	190	150	39
92	190	148	37
96	190	146	35
100	190	144	33
104	190	142	30
108	190	142	30
112	190	142	30
116	190	142	30
120	190	142	30
124	190	142	30
128	190	142	30

Schedule 4. 8/4 Clear (forced draught)

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
4	160	160	100
8	170	168	95
12	170	166	91
16	175	168	87
10	175	168	87
24	175	166	83
28	180	170	79
32	180	170	79
36	180	170	79
40	180	170	79
44	180	170	79
48	180	170	79
52	180	170	79
56	180	170	79
60	180	170	79
64	180	170	79
68	180	170	79
72	180	170	79
76	180	170	79
80	180	170	79
84	180	170	79
88	180	170	79
92	180	170	79
96	185	172	72
100	185	168	68
104	185	168	68
108	185	168	68
112	185	168	68
116	185	168	68
120	185	165	65
124	185	165	65
128	185	165	65
132	185	165	65

Schedule 5. 4/4 Clear V. G. Natural draught kiln

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
1-24	184	168	69
24-48	194	156	42
48-72	204	148	27
72	Out		

Schedule 6. 8/4 Clear V. G. Natural Draught

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
1-120	180	164	72

Schedule 7. 4/4 Clear F. G. Natural Draught

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
1-12	160	154	85
12-48	170	150	60
48-72	180	135	30

Schedule 8. 1 5/8 V. G. Stepping (Natural Draught)

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
1-12	156	148	81
12-48	166	146	59
48-72	176	130	28

Schedule 9. Lath (Natural Draught)

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
1-72	206	148	24

This schedule dries coast Douglas fir down to 46 pounds per 100 lath.

Schedule 10. 1-inch Common Douglas fir (Forced Draught)

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
0	125	114	70
40	125	114	70
48	Out		

Schedule 11. 2-inch Common Douglas Fir (Internal Fan Kiln)

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
0	175	156	62
24	175	150	53
40	Reverse Circulation		
48	Out		

Schedule 12. 1-inch Common Douglas Fir (External Fan Kiln)

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity %
0	150	150	1000
4	150	146	90
12	150	144	85
16	150	140	76
20	160	146	67
24	160	146	69
28	160	146	69
32	Out		

Schedule 13. 2-inch Common Douglas Fir (External Fan)

Hours	Dry Bulb Temp.	Wet Bulb Temp. °F.	Relative Humidity Per cent
0	160	160	100
4	170	168	95
8	170	166	91
12	170	164	86
16	170	162	83
20	170	162	83
24	170	158	74
28	170	156	70
32	170	156	70
36	170	156	70
40	170	160	78
44	175	160	78
48	175	160	78
52	Out		

The greatest troubles encountered in kiln drying Douglas fir are the checking of wide flat grain and the loosening of knots in common.

The checking of wide flat grain is being prevented by the use of high humidities with rapid circulation. In many mills where severe checking is occurring, it is the result of too fast a schedule and poor circulation. The solving of this problem, and it can be solved, requires a detail study by the individual kiln operator of his particular operation in view of the fundamentals of kiln drying as covered in earlier chapters in this thesis. No general statement can be made to eliminate this problem other than it depends on finding the right humidity and temperature with proper circulation.

The kiln drying of common Douglas fir lumber is a recent advance in the art of kiln drying. There are two reasons for the fact that the kiln drying of common has not been widely accepted. These are: first, it has been considered impracticable from the standpoint of value received for money expended, and second, the difficulty of drying common without a heavy degrade due to loosened knots. Today the first of these impediments has been practically removed due to the greater demand for kiln dried common and the price premium received. The second impediment has been recently practically eliminated by the very successful drying of common lumber by A. C. Knauss, kiln operator of the Oregon-American Lumber Co. at Vernonia, Oregon.

The loosening of knots in common lumber with the subsequent knot holes after planing, is due to the natural shrinkage of the lumber and the melting of the pitch surrounding the encased knots. By using a temperature mild enough to prevent the pitch around the knots from coming to the surface, and a humidity high enough to prevent excessive shrinkage, the difficulty of loosened knots can be solved. The schedules given for Douglas fir common lumber in this thesis take into consideration the prevention of the above described difficulties. However, there is still great need for more research to be done in the field of kiln drying common.

Some of the principal advantages claimed for kiln drying common are:

1. It enables quicker turnover.
2. It costs less to produce.
3. It degrades less in seasoning.
4. It weighs less for shipping.
5. It is more uniformly dried.
6. It is of more uniform size upon delivery.
7. It is of better appearance when received, no weathered ends.
8. It is more easily sold by retailers.
9. It brings a price premium.

Other problems encountered locally in kiln drying Douglas fir consisted of case-hardening, honey-combing of the end of thick stock, and warping. All of them were due to improper kiln drying on poor kiln equipment, and could be eliminated by installing new and modern equipment and revising the drying schedules and stacking systems.

A very common source of poor drying is caused by mill superintendents insisting on an order being dried in a certain length of time in order to meet time specifications on delivery. Often this necessitates the pushing of stock which should be dried slow to prevent the development of checks and case-hardening.

Sitka Spruce Schedules.

The following schedules were obtained by experimentation by the Forest Products Laboratory. They are based on the moisture content.

Schedule 1. 4/4 - 6/4 Spruce Vertical-Grain

Moisture Content in Per cent	Dry Bulb °F	Wet Bulb °F	Relative Humidity in Per cent
Initial	180	173	85
30	190	168	60
13	200	150	30

Schedule 2. 4/4 - 6/4 Wide Flat-grain Spruce

Moisture Content in Per cent	Dry Bulb °F.	Wet Bulb °F.	Relative Humidity in Per cent
Initial	160	154	85
35	170	150	60
16	180	135	30

Schedule 3. 7/4 - 9/4 Vertical-grain Spruce

Moisture Content in %	Dry Bulb °F.	Wet Bulb °F	Relative Humidity in Per cent
Initial	180	173	85
30	190	168	60
13	200	150	30

Schedule 4. 7/4 - 9/4 Flat-grain Spruce

Moisture Content in Per cent	Dry Bulb °F.	Wet Bulb °F.	Relative Humidity in Per cent
Initial	160	154	85
35	170	150	60
16	180	135	30

Schedule 5. 10/4 - 12/4 Spruce

Moisture Content in Per cent	Dry Bulb °F.	Wet Bulb °F.	Relative Humidity in Per cent
Initial	135	129	85
25	150	132	60
16	175	140	40
12	175	130	30

Western Hemlock Schedules.

In most fir mills practically the same schedule is used for hemlock as is used for fir. However, due to the much greater moisture content of hemlock it generally requires a little longer to dry. The schedules given in this thesis were obtained from the Forest Products Laboratory.

Schedule 1. 4/4 - 6/4 Stock

Moisture Content in Per cent	Wet Bulb Temp. °F.	Dry Bulb Temp. °F.	Relative Humidity in Per cent
Initial	173	180	85
40	168	190	60
20	150	200	30

Schedule 2. 7/4 - 9/4 Stock

Moisture Content in Per cent	Wet Bulb Temp. °F.	Dry Bulb Temp. °F.	Relative Humidity in Per cent
Initial	173	180	85
35	168	190	60
16	150	200	30

Schedule 3. 10/4 - 12/4 Stock

Moisture Content in Per cent	Wet Bulb Temp. °F.	Dry Bulb Temp. °F.	Relative Humidity in Per cent
Initial	129	135	85
30	132	150	60
20	140	175	40
15	130	175	30

Western Pine Region.

Practically all the lumber dried in the western pine region of Oregon is western yellow pine. A small amount of sugar pine is dried in connection with yellow pine. The same schedules are used for both.

The following grades and dimensions of western yellow pine and sugar pine are being successfully kiln dried.

1. Selects, all widths and thicknesses.
2. Pattern stock.
3. Box lumber, all widths and thicknesses.
4. Shop, all widths and thicknesses.
5. Common boards, all widths and thicknesses.
6. Lath.

Schedules used in Drying Western Yellow Pine and Sugar Pine with Problems Encountered.

The following schedules are for drying down to 7% to 10% for selects and shop, 12% - 15% for box, and 18% - 20% common.

Schedule 1. 6/4 Shop and Better. (External Fan Kiln)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity Per cent
24	108	96	67
48	118	106	62
72	126	106	51
96	130	108	48
120	164	124	32
144	188	128	20

Schedule 2. 8/4 Shop and Better. (External Fan)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
24	96	86	70
48	106	96	70
72	112	98	67
96	124	102	46

Schedule 2 - continued

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
120	130	100	35
144	156	110	24
168	174	114	17
198	194	138	23

Schedule 3. 4/4 Common (External Fan)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
24	158	150	81
48	158	150	81
72	158	142	65
96	170	146	54
120	192	144	30
142	196	140	24

Schedule 4. 4/4 Shop and Better, (External Fan

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
24	110	100	70
48	112	104	70
72	132	118	65
96	150	122	43
120	166	120	26
143	196	142	27

Schedule 5. Lath

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
24	140	116	47
48	146	120	45
72	148	120	41
96	160	120	31
120	166	116	23
144	178	116	16

Schedule 5 - continued

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
168	190	120	14
192	192	110	9
216	198	108	5
240	202	106	3
256	205	100	0

Schedule 6. 8/4 Shop and Better. (Internal Fan)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
0	116	104	63
24	120	108	67
48	132	116	61
72	136	120	61
96	148	124	49
100	158	130	48
144	170	134	37
168	160	124	35
192	Out		

Schedule 7. 6/4 Shop and Better. (Internal Fan)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
0	132	110	49
24	146	124	52
36	164	132	41
72	170	132	35
96	176	122	21
120	Out		

Schedule 8. 10/4 - 12/4. Shop (Internal Fan Kiln)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
0	125	120	85
48	130	120	73
72	135	120	63
96	140	120	54
120	145	120	47
148	150	120	41
196	Reverse Circulation		
220	Out		

Schedule 9. 4/4 Shop and Better (Internal Fan)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
0	132	114	57
24	150	124	47
36	164	136	54
72	174	140	41
96	Out at 1% moisture content		

Schedule 10. 5/4 Shop - (External Fan)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
0	182	162	62
4	180	152	50
24	192	140	26
48	202	124	13
78	Out Moisture content approximately 8%		

Schedule 11. 4/4 Shop (External Fan)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
0	182	164	65
4	182	152	48
18	190	130	26
64	Out		

Schedule 12. 8/4 Shop (External Fan)

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
0	180	160	62
4	180	152	52
28	180	140	35
42	190	140	28
56	190	135	26
74	190	125	17
80	196	125	15
84	Out		

Schedule 13. 6/4 Box

Hours	Dry Bulb Temp. °F.	Wet Bulb Temp. °F.	Relative Humidity %
0	150	140	76
24	178	154	55
62	150	135	64
135	Out		

The outstanding universal problem in the western pine region is the prevention of brown kiln stain. This stain occurs in western yellow pine and sugar pine. It does not show in rough kiln dried lumber, but is exposed when the lumber is planed. There is always a clear outer margin which does not contain the kiln stain. This margin is very narrow which accounts for the exposure of the stain when the lumber is planed. The stain is generally concentrated just within the white margin of the surface and the ends. In wainy boards the stain occurs just below the bark. In a board containing both heartwood and sapwood the stain will be found where the heartwood and sapwood meet.

Many explanations as to the cause of kiln stain are advanced by kiln operators. The most feasible explanation and that generally considered to be the cause by lumber technologist is the pinitol, a chemical compound found in sugar and yellow pine, ~~which~~ is carried about by the moisture. When drying the moisture moves toward the driest portion of the board which in pure sapwood lumber, would be the surface. As the water reaches the surface, it turns to vapor in which form it can no longer hold the pinitol compound. The pinitol is therefore deposited at that point where the water turned to vapor, which is just below a thin layer of fibers on the surface. The high temperatures used in the kiln turn this pinitol brown, due to its sugary nature.

In a board containing both heartwood and sapwood, the tendency is for the moisture to run from the sap into the heartwood, since the heartwood is considerably drier.

This results in the same condition as if the board had been cut at the junction of the heartwood and sapwood.

The above theory of kiln brown stain has been more or less proved by Ernest E. Hubert of the University of Idaho, yet much experiment work must be done yet before the causes and nature of brown stain are fully understood or its control possible.

It is believed by some operators that brown stain occurs at the beginning of the run, but observations made by A. Herman of the Western Pine Manufacturers' Association indicated that brown stain occurred toward the end of the run.

At the present time, operators are modifying the presence of brown stain by the use of slow drying schedules, with comparatively high humidities. Also, operators can be found using high temperatures and high humidities, so it would seem that little is known concerning the control of brown stain.

The age of the stock and the length of time the logs have been in the pond affect the amount of brown stain that will occur when stock is dried. Lumber cut from old logs or logs stored in the mill pond for six months or more, is sure to develop brown stain.

Other than brown stain, no serious problem is confronted in kiln drying pine, except local problems, which are the result of poor kiln operating or poor kiln equipment.

Many kiln operators in the pine region have no set schedule which they follow, but have a general schedule which they modify according to the stock to be dried. This type of kiln drying is very good providing the kiln operator is thoroughly familiar with the stock he is drying and its reaction to kiln drying.

Chapter X.

THE COST OF KILN DRYING IN OREGON

The cost of kiln drying lumber is a very flexible figure. No one cost can be stated as representing the average cost. The reasons for this are: 1. That no two operations have the same type of lumber handling system or drying system. 2. Few mill superintendents keep a separate cost account of their dry kiln unit. 3. Where dry kiln costs are kept, different mills base their costs differently.

The cost of kiln drying is stated as so much per thousand board feet. It is the general practice to include in dry kilning costs all cost from the stacking operation to the unstacking operation inclusive. Enumerated, these various costs which in totum represent the dry kiln cost are:

1. Transportation
2. Stacking
3. Operation of kilns (labor and supplies)
4. Unstacking
5. Oil and grease
6. Steam
7. General supervision
8. Fire protection

9. Insurance and taxes

10. Maintenance

11. Depreciation

12. Electrical power

13. Interest on fixed investment.

An example of an actual operation cost in Oregon, drying all grades of western yellow pine and Douglas fir, except common, in blower kilns both external and internal, and in natural draught kilns, is as follows:

1.	General supervision	$0.280 per M
2.	Stacking	.414 per M
3.	Operation, including labor and supplies other than oil	.357 per M
4.	Unstacking, including sorting and grading	.287 per M
5.	Transportation from mill to kilns	.193 per M
6.	Oil and grease	.005 per M
7.	Steam	.236 per M
8.	Fire protection	.049 per M
9.	Fire insurance	.137 per M
10.	Depreciation and obsolescence	.670 per M
11.	Maintenance	.062 per M
12.	Electrical power	.110 per M
	Cost of kiln drying - Total	$ 2.78 per M

The cost of general supervision in the above tabulation of costs was arbitrarily set. The cost of depreciation was worked out on a basis of completely writing equipment off the books when it no longer functioned efficiently. The cost of obsolescence was arbitrarily set. The cost of electrical power was based on the cost of the total voltage used by the mill. From this total was deducted the amount used in running the motors of the kilns.

The cost of kiln drying for a mill drying yellow pine only in external fan blower kilns was found to be $2.40 per M.

An example of costs for kiln drying Douglas fir common and representing as near an average as kiln costs can, are as follows:

Sorting	$0.50 per M
Transportation	.30 per M
Piling	.36 per M
Interest on lumber on hand	.30 per M
Interest on fixed investment	.20 per M
Depreciation	.20 per M
Stickers	.10 per M
Maintenance and repairs	.19 per M

Steam and power	.22 per M
Supervision and Operation	.18 per M
Unpiling and sorting	.51 per M
Insurance and taxes	.09 per M
General overhead	.12 per M
Total cost of kiln drying	$ 3.67 per M

Actual dry kiln costs of one of the largest and most efficient mills in the fir district was found to be as follows:

Supervision	$ .017 per M
Steam	.221 per M
Electricity	.060 per M
Pipe fitting	.017 per M
Labor	.067 per M
Repairs	.040 per M
Electrical repairs	.008 per M
Light	.002 per M
Water	.001 per M
Clean up expense	.009 per M
Incidentals	.006 per M
Plant supervision	.005 per M
Transportation to sorter and out of kilns	.500 per M

Stacking	.900 per M
Unstacking	.750 per M
Total dry kiln cost - - - -	$2.603 per M

It is evident from the above tabulations of actual kiln costs that no uniformity of costs exist and that no two operations include the same items of cost. However, a general idea of dry kiln costs can be obtained by analysing the above tabulations.

The importance of keeping detailed cost accounts for the dry kiln unit of the mill is in most cases overlooked; in fact, many mill superintendents do not keep cost accounts of the dry kiln unit. It should be remembered that only by detail cost accounting can costs be reduced.

Chapter XI.

DRY KILN OPERATING

Requirements of Kiln Operator

It is better to have poor kilns with a good kiln operator than good kilns with a poor kiln operator. The requirements which go to make up a successful kiln operator may be summarized as follows:

1. A thorough knowledge of wood and its reaction to drying.

2. A thorough knowledge of the fundamentals of kiln drying.

3. Sound judgment.

4. Honesty.

5. A fair knowledge of lumber grades.

6. Efficient

7. Ability to agreeably associate with fellow workmen.

8. Ability to use authority wisely.

9. A willingness and a desire to accumulate more knowledge regarding kiln drying.

10. A general knowledge of the functioning of a sawmill.

Dry kiln operating is not a "cut/and dried" process depending on the mere following of a definite schedule; it is an art. The kiln operator may be compared to a painter; his lumber is his picture, his kilns and equipment his brush, and humidity, temperature, and circulation his paint. A poor stroke of the brush or the wrong mixture of paints when applied to the picture may ruin it beyond repair. Rightly placed strokes with the proper mixture of paints will produce a beautiful picture. The more skilled the painter the more beautiful the picture. Too many millmen and kiln operators today are overlooking the fact that kiln operating is not a matter of turning on certain steam valves for a certain definite length of time, but is decidedly the reverse when done correctly.

Relation of the Dry Kiln Operator to Rest of the Mill Operation.

Many mill superintendents make the mistake of giving the dry kiln operator one or more responsibilities besides the kiln unit of the mill. The result of such a method is obvious. The kiln operator does not have the time to properly look after his kilns or check the conditions of the lumber in the kilns. A kiln operator to be successful must be responsible for the dry kiln unit only of a sawmill. Whenever a mill superintendent thinks he is cutting down cost of production by having the kiln operator in charge of the planing mill, the yard, or other units around the mill, he is in most cases increasing his costs due to fall downs in the kiln dried stock.

Another error made by many mill superintendents is to have the kiln operator responsible to several foremen, for example, the planing mill foreman, or the yard foreman. This again is a poor policy since in most cases the yard foreman or the planing foreman or other similar authoritative individuals do not know the first principle of kiln drying. The result is, for example, that the yard foreman goes to the kiln operator and demands an order put through the kilns within a certain length of time, regardless of whether the kiln operator knows that such a thing is impossible to do without greatly injuring the stock. When the order is pushed through the kilns and arrives in the planing mill in a poor condition, the planing mill foreman proceeds to exercise his authority and seriously reprimands the kiln operator, and often complains to the mill superintendent. The sum total of such methods of personnel management is a dissatisfied, non-interested, lax and inefficient kiln operator.

A hard and fast rule may be stated, which would materially benefit many mills, to the effect that the kiln operator should be responsible to the mill superintendent only.

Other Suggestions to Aid in Producing Satisfactory Kiln Dried Lumber.

1. Moisture samples should be taken of every run. Samples should be selected with a consideration of the factors brought out in Chapter III.

2. Frequent checks should be made on all instruments to see that they are functioning properly. The dry bulb thermometer should be checked by placing an indicating thermometer along side it during a period when it is recording a steady temperature. If the dry bulb thermometer checks with the indicating thermometer it is functioning properly; if not, it may be corrected by adjusting the stylus of the recording instrument or noting plus or minus the degrees the recording thermometer is off and correcting each reading accordingly.

Another way and a more accurate way of testing a recording thermometer is to place the bulb of the recording thermometer in a bucket of water along with an indicating thermometer. If, when the water is heated, the two thermometers read the same, the recording thermometer is functioning properly; if not, adjust it as stated above. The wet bulb thermometer may be tested by comparison with a humideik and adjusted the same as the dry bulb thermometer.

3. Steam traps should be checked frequently for if improperly functioning the temperature is difficult to maintain in a kiln. Leaky steam pipes also develop from poorly operating steam traps.

4. Steam valves should be kept in the best of working conditions. A leaking valve makes accurate temperature and humidity control impossible.

5. Water should not be allowed to collect on the floor of kilns for it prevents the maintaining of definite humidities.

6. It is absolutely essential for the wet bulb to function properly that it be supplied with clean water regardless of whether it is a porous sleeve wet bulb of an automatic control, or the wet bulb of a humideik. To assure clean water for automatic control, a filter should be installed in the feed line to the porous sleeve and the filter stone thoroughly washed at the beginning of each run or more often if necessary.

7. After a small amount of observing and studying the kiln operator may use his recording charts as an aid

for checking on his kiln. The three charts in Figure 12 illustrate some examples of trouble determination by recording chart examination.

8. It is advisable to check the entering air and leaving air to determine how uniform the drying conditions in the kiln are. There will always be some difference in the temperature and humidity of the entering air and the leaving air. If there is a large difference it indicates that the rate of circulation is too slow or the air is being short circuited. It may be advisable to place the wet and dry bulb of the automatic controls so as to register the entering air only, instead of placing them on the side of the kiln. When placing thermometers to register entering air, care should be taken to see that they are protected from direct radiation from the heating coils.

9. The circulation should be checked occasionally by a smoke machine. Sluggish circulation, short circuited circulation, or "dead pockets" may be causing casehardening, checking, or uneven drying of the kiln charge. In natural draught kilns improper circulation may be corrected or at least aided by installing steam jets over the heating coils or revising the stacking

FIGURE 11

Examples of Trouble Determination by Action of Recording Pen

Chart No. 1

Imperfect control due to condensed steam accumulating in heater coils. The kiln was slow in reaching the set temperature and then fluctuated from one side to the other of the set temperature. This is due to water accumulating in the coils and then being blown out and thereby increasing the amount of radiation which was effective when the control valve closed.

Chart No. 2

This type of temperature recording may be due to leaking steam valves, or dirt in air supply holding controller valve open.

Chart No. 3

A record of this type indicates a partial failure of the water supply to the wet bulb.

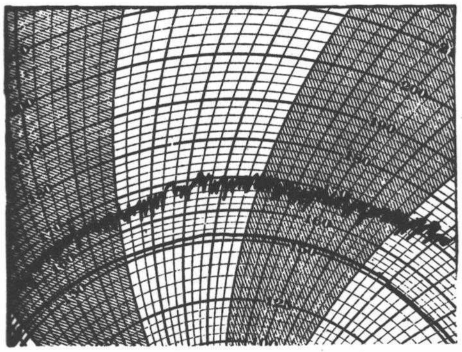


Chart No. 1

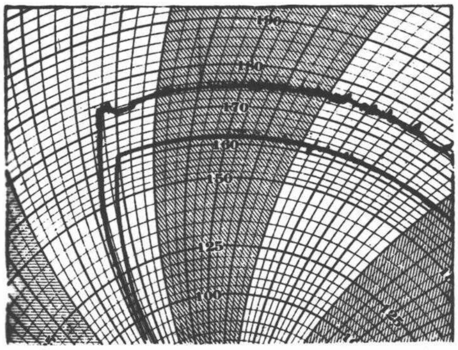


Chart No. 2

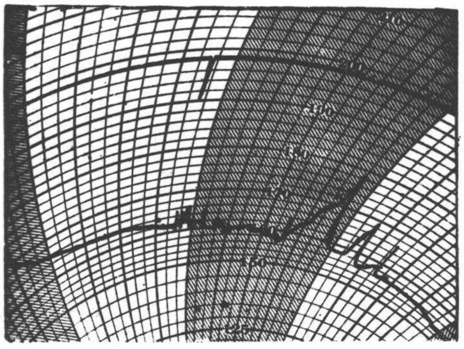


Chart No. 3

method to conform to the rules for stacking as outlined in Chapter VIII.

10. Many dry kiln troubles can be traced to poor conditions existing in the kiln building and equipment. Leaky kilns almost prevent the maintaining of definite temperatures and humidities, especially in cold weather.

No part of a dry kiln is more subject to wear than the doors, and no part of a kiln allows more leakage than dilapidated doors. For this reason, dry kiln doors should be kept in constant repair. They should be painted both outside and inside with kiln door paint, obtainable from any commercial dry kiln company, at frequent intervals.

Doors which do not fit properly not only hinder good drying but waste time and labor.

The walls and ceilings of kilns should be painted periodically with the same paint as used on the kiln doors.

11. Rails and rail supports, pipes, vents, and runways should be kept in repair as they all have a direct or indirect bearing on the action and handling of the kiln. The neglect of some of these minor parts of a kiln can cause in the aggregate as much trouble as some of

the major factors of the kiln unit.

12. When complaints are received from the planing mill or head office relative to checks, end splits, etc., the kiln operator may often save himself much embarrassment by marking the various defects showing in the lumber before it is kiln dried. It is a simple matter then to check up on the defects resulting from kiln drying. It is often the case that the defects complained of by the planing mill foreman were not due to the kiln drying at all, but were due to mistreatment of the lumber before entering the kilns. Often exposed green storage space for loaded kiln trucks presents this problem. Its remedy lies not in the kilns but in constructing a green storage shed to protect the lumber from the direct rays of the sun and the wind.

13. The kiln operator should see that at all times the green storage space, the kilns, the dry storage space, the kiln office, and the operating pits are free from rubbish, broken stickers, discarded samples, broken kiln trucks, etc. Slovenly surroundings encourage poor work on the part of the kiln assistants as well as reflecting on the efficiency of the kiln operator himself.

Kiln Records

No progress is made without detail records of what has been tried or accomplished in the past. No where does this rule hold more true than in dry kilning. If a particular kiln run is successful, a record of it aids in securing another similarly successful run.

Many kiln operators after keeping a few records discard the practice after becoming familiar with their kilns, and keep only the recording thermometer charts. This is indeed a poor practice, for although a kiln operator may be turning out satisfactory lumber, he is making no effort to turn out better lumber, nor is he protecting himself from false accusations as to his methods and no kiln operator has reached the ultimate goal of perfection in the art of kiln drying so as to be beyond reproach.

The kiln operators in Oregon today who are recognized as desirable kiln operators and who are producing results which tend toward better kiln drying are those operators who keep records other than the recording charts.

A recording thermometer chart should be kept, but it only tells a small part of the story relative to a particular kiln charge.

Many types of kiln records can be secured from kiln companies. If a kiln operator desires to make up his own record blanks, he should consider the following items:

1. Company's name

2. Operator's name

3. Date of entering and leaving the kiln

4. Run number

5. Kiln number

6. Size, species, and grade of stock.

7. Locality in which stock was grown, also length of time in mill pond.

8. Condition of stock before entering the kilns.

9. Final moisture content desired.

10. Original and final weights, calculations and content of moisture samples.

11. Temperatures and humidities desired and temperatures and humidities actually occurring every two hours in the kiln.

12. Running record of condition of the stock, stress determinations, steaming and high humidity treatments used.

13. Final condition of stock.

14. Time in dry shed before sent to planing mill.

15. Miscellaneous.

Recording thermometer charts should be filed with each record, also the test samples for stresses should be kept until the stock is planed.