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# Art. V.—*On the Drying of Timber.*

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(With 9 Text Figures.)

[Read 8th June, 1922.]

The drying of timber is governed by six factors, namely, Moisture Content, Diffusion of Moisture, Evaporating Surface, Thickness, Humidity and Temperature. The first two may be conveniently referred to as the biological factors since they are due to the plant's activity, and are quite beyond our control. The last two may be referred to as the mechanical factors, since we can vary them at will. The two intermediate factors, Evaporating Surface and Thickness, belong partly to both. We may cut a piece of timber to any thickness, or so as to expose more or less of one face than another, but having so cut it, its drying will be governed by the organization of the wood substance.

The work contained herein was commenced at Melbourne (Victoria) and was subsequently carried on at London. The work had its origin in the difference of opinion which exists as to the relative merits of air and kiln-drying of timber. The research had for its object a study of all the factors influencing the drying of timber, in order to ascertain what is involved in the phenomenon of seasoning. It may be here remarked that the term kiln seasoning involves widely different ideas and practices. In some kilns, wholly artificial conditions are used, the temperatures used, for instance, being far in excess of any found in nature. On the other hand, some kiln drying is carried on at about the maximum atmospheric temperatures. In this latter case, it is the continuance of the temperature, not the temperature itself, that is artificial. Timber in our State may be subject to a temperature of 123.5F, and at Melbourne itself to a temperature of 111°F.

There is no doubt in the mind of the wood worker as to the value of air-seasoned timber. Up to the present generation, all the finest wood work of the world has been carried out with air-seasoned timber. That is, in itself, quite a sufficient answer to the statements sometimes made that air-dried timber is inferior to kiln dried. However, modern civilisation demands a greater supply of seasoned timber than can be met by the old practice of air drying. The first aim, therefore, was a study of drying under conditions which have produced such satisfactory results in the past. The work, therefore, was carried on at such temperatures and humidities which, with slight exceptions, are found in nature.

*Moisture Content.*—In the seasoning of timber we are concerned not only with how much moisture there may be in the wood of a tree when it is felled, but also how that moisture is distributed in the tree, and also whether the moisture content is a constant all through the year. In other words, we are concerned with the quantity of moisture and its distribution both in space and time.

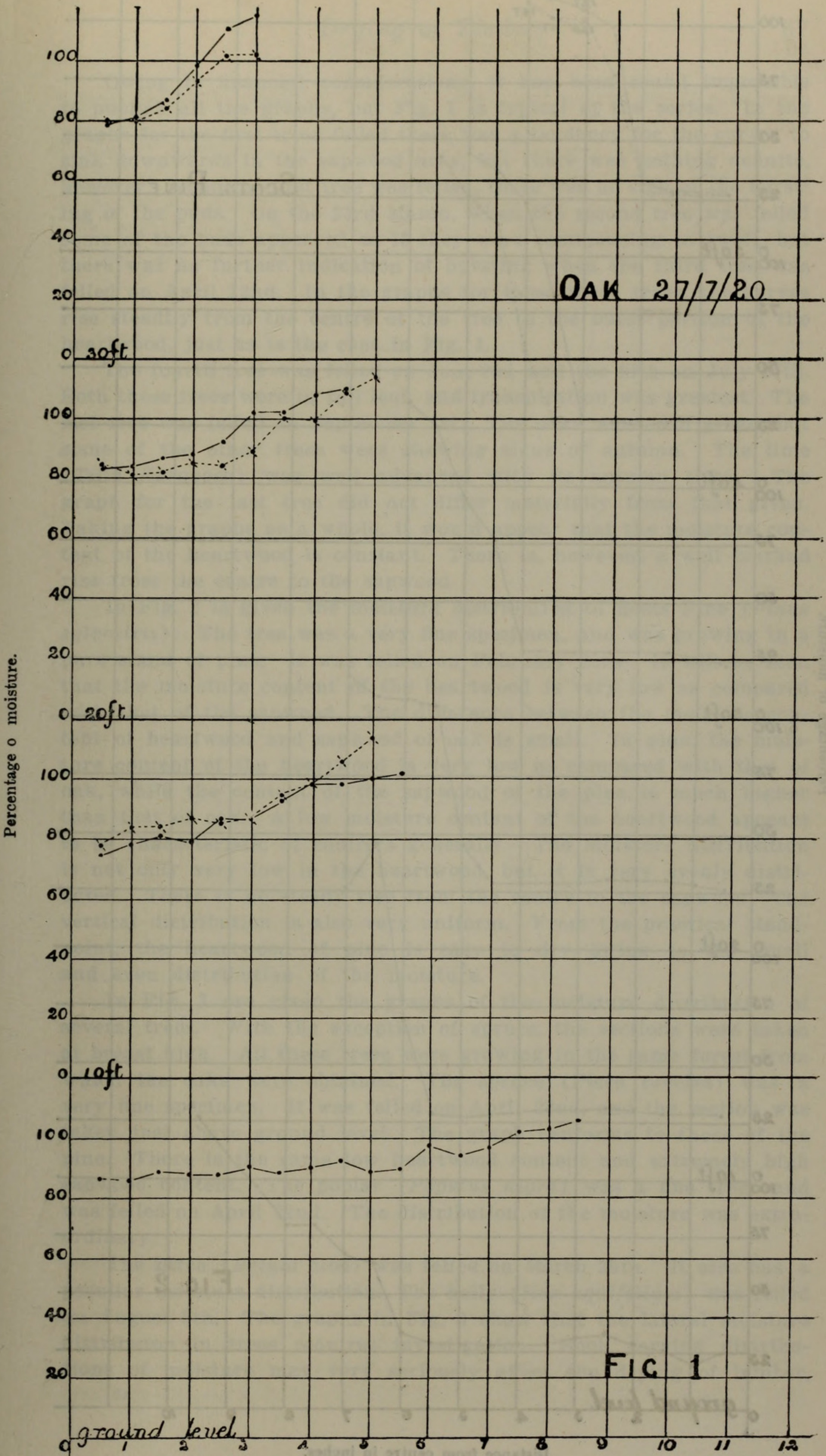
If the sapwood be the means by which water is transported in a living tree, then it should not matter at what time of the year a tree is felled, and if the heartwood be inactive, then we should expect the heartwood content to be a constant. It is obvious, however, that if the heartwood content does undergo a seasonal change, then there is a favourable period for felling. Ordinarily, however, when we speak of the sap as rising, we are considering only the sapwood, and not the heartwood.

It has recently been suggested(1) that the heartwood may play an important part in the moisture needs of the plant. It is suggested that the heartwood acts as a reservoir for the sapwood. This may be true for some trees, but it cannot hold for all. The giant eucalypt of Victoria, *E. regnans*, may have practically no heartwood at all, as it may have all rotted away, yet the tree may live for centuries. The trunk is a mere shell, yet the needs of the tree are met. It was quite a well-known belief among the tree-fellers in the Victorian forests that the central portion of the heartwood of our big trees contained more moisture than the outer portion of the heartwood. In many cases it was found that this central portion contained more moisture than the sapwood. This central portion is very prone to decay, and is rejected in timber milling. An examination of it microscopically shows that the fibres have comparatively thin walls. The percentages of moisture for one tree were as follow:—

| | |
|---|---|
| Central portion . . . . . . | 150 per cent. |
| Outer heartwood . . . . . | 77 per cent. |
| Sapwood . . . . . . . . . . | 110 per cent. |

The percentages are calculated to the dry weight of the wood.

The differential distribution of moisture in *Acer pseudoplatanus* was fully investigated at Edinburgh(1). The investigation was carried on during the dormant period of the tree, i.e., from October to March. The matter was further studied at London during 1920, and the results are given herein. The period of investigation was from February to September, that is, from the end of the winter to the beginning of the autumn. The trees selected for the main investigation were oaks (*Quercus robur*). In every case they were felled in the morning and cross sections, two inches thick, were taken every 10 feet. These sections were at once wrapped in grease paper and taken to the laboratory, where a strip one and a-half inches wide was cut from the centre to the bark. These strips were then split into half-inch pieces, commencing at the centre. If there was an odd width left at the sapwood end, this was considered as a half-inch, and is graphed accordingly. The small pieces were at once weighed and then dried. The percentage of moisture is calculated to the dry weight of wood. In some cases two strips were taken from the section, and these are given on the graphs. In Fig. 1 is given a typical moisture distribution in oak. The first tree was felled on March 2nd, 1920, and the last tree on September 1st. All the trees were taken from the same area and soil which was heavy clay.

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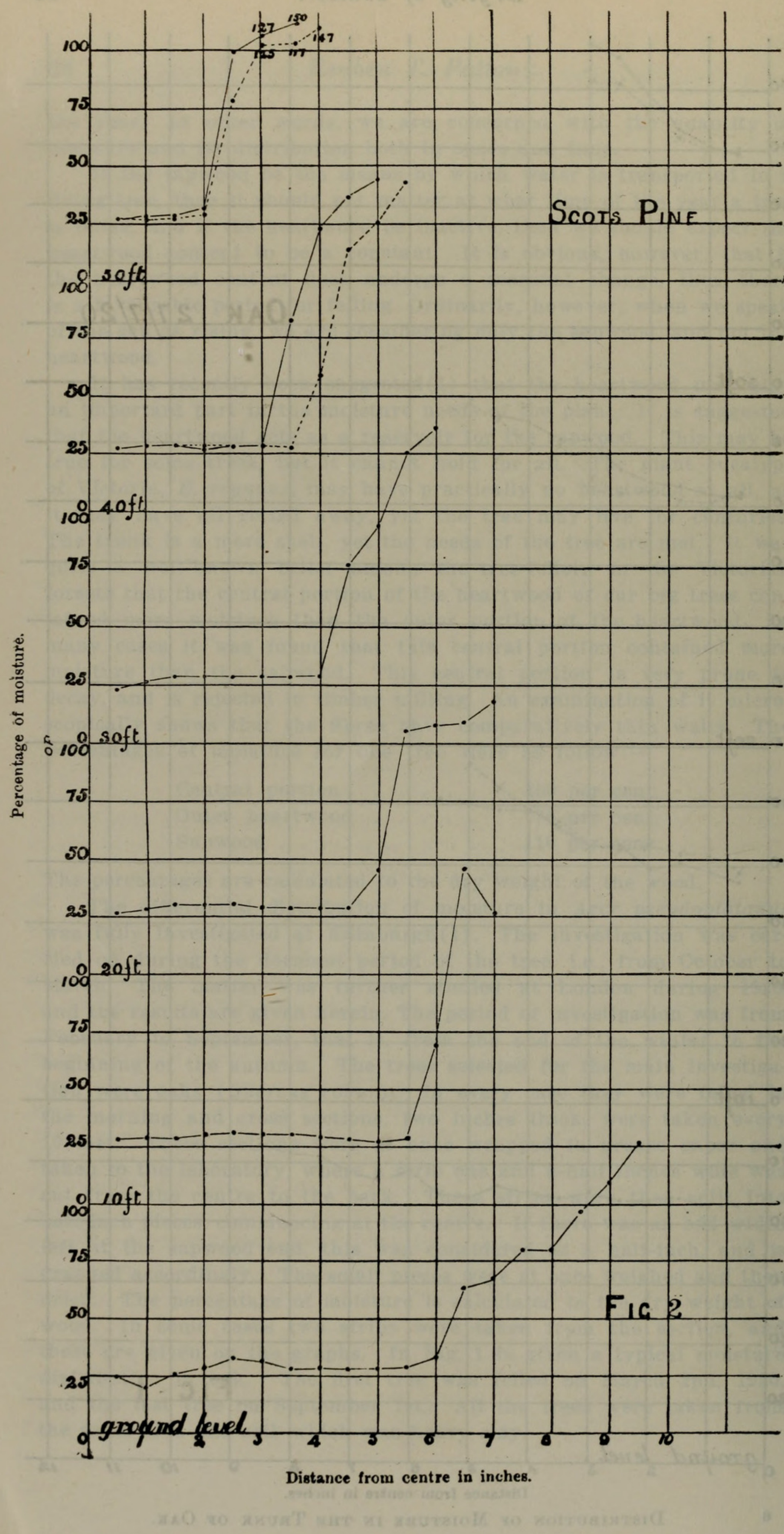
DISTRIBUTION OF MOISTURE IN THE TRUNK OF OAK.


Scots Pine
Percentage of moisture.
100
75
50
25
0
100
75
50
25
0
100
75
50
25
0
100
75
50
25
0
100
75
50
25
0
127
150
147
123
117
50ft
40ft
30ft
20ft
10ft
ground level
1
2
3
4
5
6
7
8
9
10
Fig 2
Distance from centre in inches.

Owing to financial considerations, it has been found impossible to publish all the graphs, but Fig. 1 is typical of the series. In the graphs for the first trees felled there was a tendency for the curves to sink downwards in the sapwood area, but there was nothing definite, however. When the first tree was felled, there was no sign of the bursting of the buds. On the 23rd March, when the second tree was felled some of the buds appeared as if they were commencing to swell, but there was no further indication of bursting when the third tree was felled on April 22nd. In the graphs for these three trees, the curves rise steadily from the centre of the tree to the outer portion of the heartwood, just as is the case in Fig. 1.

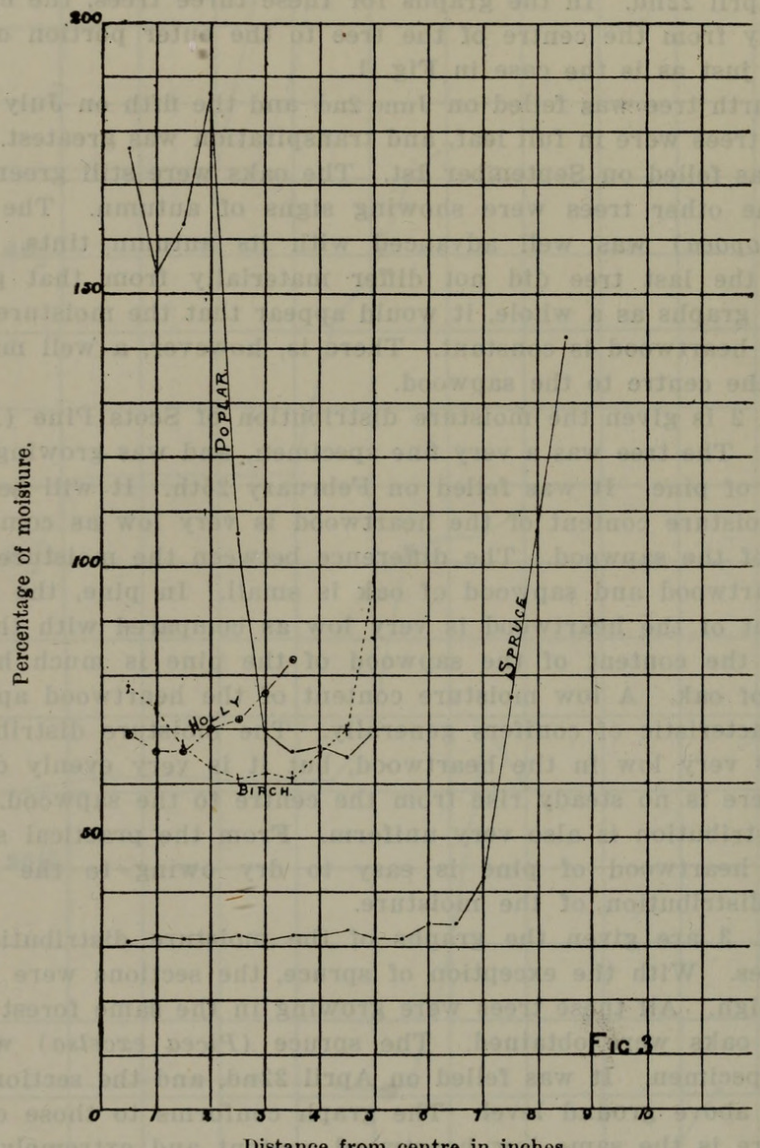
The fourth tree was felled on June 2nd and the fifth on July 27th. Both these trees were in full leaf, and transpiration was greatest. The last tree was felled on September 1st. The oaks were still green, but some of the other trees were showing signs of autumn. The lime (*Tilia Europoea*) was well advanced with its autumn tints. The graph for the last tree did not differ materially from that given. Taking the graphs as a whole, it would appear that the moisture content of the heartwood is constant. There is, however, a well marked rise from the centre to the sapwood.

In Fig. 2 is given the moisture distribution of Scots Pine (*Pinus sylvestris*). The tree was a very fine specimen, and was growing in a pure stand of pine. It was felled on February 25th. It will be seen that the moisture content of the heartwood is very low as compared with that of the sapwood. The difference between the moisture content of heartwood and sapwood of oak is small. In pine, the moisture content of the heartwood is very low as compared with that of oak, while the content of the sapwood of the pine is much higher than that of oak. A low moisture content of the heartwood appears to be characteristic of conifers generally. The moisture distribution is not only very low in the heartwood, but it is very evenly distributed. There is no steady rise from the centre to the sapwood. The vertical distribution is also very uniform. From the practical standpoint, the heartwood of pine is easy to dry owing to the small and even distribution of the moisture.

In Fig. 3 are given the graphs of the moisture distribution of several trees. With the exception of spruce, the sections were taken at breast high. All these trees were growing in the same forest from which the oaks were obtained. The spruce (*Picea excelsa*) was a very fine specimen. It was felled on April 22nd, and the section was taken just above ground level. The graph conforms to those of the pine. There is the same low heartwood content and extremely high sapwood content. The poplar (*Populus nigra*) was a fine tree, and was felled on April 22nd. The distribution of the moisture was extraordinary.

The birch (*Betula alba*) was felled on March 25th. It also has a peculiar moisture distribution. The holly (*Ilex aquifolium*) was felled on August 5th. The graphs in Fig. 3 show that the lateral moisture distributon in trees requires investigation. Such varying distributions of moisture may very seriously affect the drying of lumber, especially if the drying is uneven, due to circulation of the air being bad.

So far as the graphs for oak and pine are concerned, it would appear that it does not matter when the trees are felled. There does not appear to be any movement of the moisture in the heartwood of oak, and it is inconceivable that the heartwood of pine can ever contain a great amount of moisture to meet the needs of the tree.




LATERAL DISTRIBUTION OF MOISTURE IN VARIOUS TREES.

As already mentioned, the big trees of Victoria frequently have very little heartwood, as it has rotted away.

*Diffusion.*—The second biological factor is that of the power of any particular timber to lose its moisture. When it is said that a wood is difficult to season, all that is meant is that the wood loses its moisture either too slowly or too quickly. If it loses the moisture too rapidly, then the wood is very apt to warp, especially if the drying be at all uneven. This appears to be the case with elm (*Ulmus campestris*). On the other hand, if the moisture be lost very slowly, any attempt to hurry up the drying will lead either to warping or cracking, as in the case of oak, where the medullary rays tend to open out. Wood that contains a low percentage of moisture is not difficult to season.

We have already seen that different species contain different amounts of moisture. Hence we cannot compare their rates of drying. However, moisture is lost by diffusion, and we know from the laws of diffusion that the amount of moisture lost is proportional to the gradient of the concentration, and the area of the evaporating surface. It is expressed mathematically as—

$$dx/dt = \mathrm{D}d\,\mathrm{C.A}/dl.$$

Where for timber $x$ is amount of moisture lost in grams, $t$ is time in days, $c$ is concentration of the moisture, $l$ is length in inches, A is area of diffusing surface in sq. inches, and D is the diffusion constant.

The amount of moisture diffused will also be affected by Temperature and Humidity, but these may be omitted if the conditions are kept constant.

If this formula can be applied to the drying of wood, then the value of D will give us a measure of the ease or difficulty with which any particular timber parts with its moisture. Owing to the many difficulties in applying such a formula to timber drying, it was not expected to obtain any very accurate results. In fact, accuracy is impossible. But what might be expected is that values would be obtained which would give an indication of the relative powers of diffusion of the various timbers. For the experimental work, blocks of straight grained, freshly felled timber were cut into sizes approximately 2 x 2 x 3 inches. The 2 x 2 face was tangential and the length, 3 inches, was in a radial direction. The four 2″ x 3″ sides were coated with the mixture recommended by Tiemann(2). The blocks were placed in an oven at 40°C. and at a 50 per cent. humidity. They were weighed at the same time every day, and the loss of weight plotted so that any irregularity of loss might be noticed. While the blocks were still actively drying, the sides were cut off and the blocks split up into one quarter of an inch sections. These sections were at once weighed and then dried, and the moisture percentage calculated to the dry weight. These percentages were plotted as in fig. 4, and the moisture gradient was obtained by drawing a tangent at the extremity of the curve. The value of the gradient was substituted in the equation for $d\mathrm{C}/dl$. Half of the amount lost in the previous 24 hours was taken as the value of $dx/dt$.

The value of D obtained from the formula is by no means accurate, as the values obtained are somewhat wide. This was expected for various reasons. The width of ring varies greatly, even in the same specimen, and may even vary widely in two adjacent rings. In a pile of Red Oak (*Quercus rubra*) which was ready to go into a kiln the width of ring varied from one-half to one-tenth of an inch.

The material was inch timber, and quite a number of the boards had only two rings of growth. It may reasonably be expected that there would be, in such timber, a great variation in the rate of diffusion. No material could be obtained, however, to investigate this matter.

In Table I. are given the results of the calculations for D. for various timbers at 40°C. and 50 per cent. humidity.

TABLE I

| Timber | Botanical Name | Values of D | | | | | | Average |
|---|---|---|---|---|---|---|---|---|
| Oak | *Quercus robur* | .0012 | .0026 | .0032 | .0048 | .0056 | .0057 | .0038 |
| Birch | *Betula alba* | .0049 | .0067 | — | — | — | — | .0058 |
| Beech | *Fagus sylvatica* | .0061 | .0072 | .0092 | .0113 | .0142 | .0169 | .0108 |
| Elm | *Ulmus campestris* | .0084 | .0102 | .0169 | — | — | — | .0118 |
| Scots Pine | *Pinus sylvestris* | .0051 | .0115 | .0195 | .0240 | .0266 | — | .0173 |

The average values of Oak, Beech and Pine generally indicate the positions of these timbers as regards drying in practice. Both Elm and Beech are said to be difficult to dry, as they warp badly while drying. Both Beech and Elm have a high moisture content, and as we have found a high diffusion constant. These timbers lose moisture rapidly, and unless the drying be uniform warping will result. The cause of the warping of Elm is said to be due to its twisted grain, but an examination of a large amount of elm lumber does not bear this out. It is true that twisted grain will produce warping, and this is freely borne out by such a timber as River Red Gum (*Eucalyptus rostrata*). It is doubtful if any other timber even approaches this for irregularity of grain. A twisted grain, however, does not appear to be a character of the elms. The warping of elm is most likely to be due to uneven drying.

In Victoria our timbers warp a great amount due to bad stacking. The green sawn timber is frequently stacked in a mass, and no provision is made for circulation of air through the pile. The stack is exposed to the fierce rays of the summer sun, and the top timber warps badly in consequence. The pieces of timber in the interior of the stack can only dry by their exposed ends, and these crack badly. All kinds of timber are stacked out in the open in Eastern U.S.A., but the stack is properly ventilated. There is a space between each board laterally and vertically. The top of the stack is roofed with off cuts from the logs. The timber comes out of these stacks in perfect condition.

Oak is difficult to dry because it has a high moisture content and a low power of diffusion. Pine, on the other hand, has a low moisture content, but a high power of diffusion, hence drying is rapid.

If we knew the moisture content of a species of timber and its diffusion constant, we might then be able to predict the time necessary for drying, and we could, if kiln drying, prescribe the necessary treatment. Until we know more about the diffusion of moisture in wood, formulas for drying are more or less guesswork.

In general the diffusion constant will vary with the specific gravity of timber. Dense heavy timbers are generally slow in drying, and therefore we may expect a low diffusion constant. The cell walls in conifers are on the whole much thinner than the walls of the fibres of hardwoods. The walls of the tracheides are comparable to the walls of the vessels.

Tissues, engaged in water conduction, must have relatively thin walls. Water conducting elements have their walls freely pitted, while strength elements such as the libriform fibres are sparsely pitted. Coniferous timber has a higher power of diffusion than most dicotyledonous timbers, because the elements concerned in drying, the tracheides, are the water conducting elements, while in the hardwoods the elements concerned in drying are the fibres or strength elements. The movement of water in a tree is, in some intimate way, closely associated with the cell walls, and if a hardwood consisted of vessels only, we should find this timber drying as quickly as coniferous.

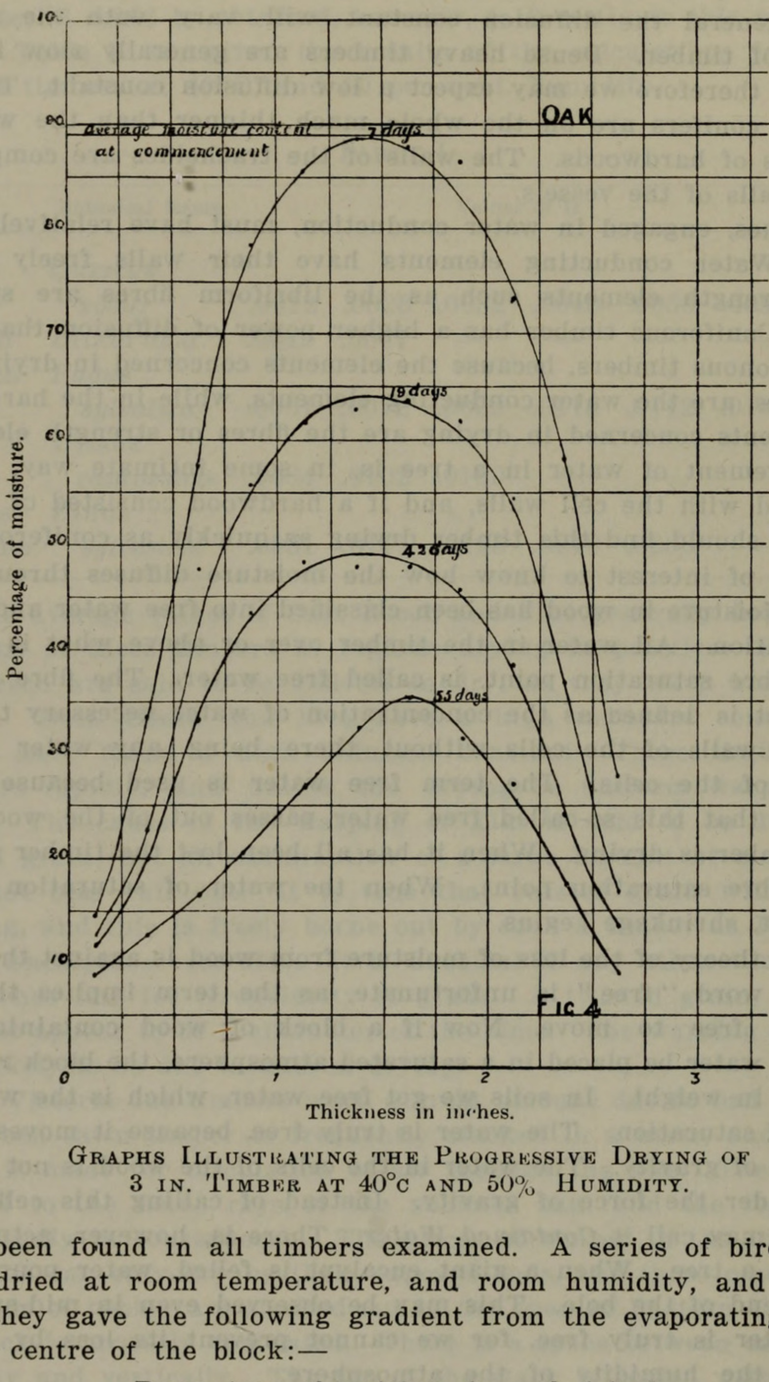
It is of interest to know how the moisture diffuses through the wood. Moisture in wood has been classified into free water and water of saturation. All water in the timber over or above what is known as the fibre saturation point, is called free water. The fibre saturation point is defined as the concentration of water necessary to saturate the walls of the cells without there being any water in the cavities of the cells. The term free water is used because it is assumed that this so-called free water passes out of the wood first when timber is drying. When it has all been lost the timber is then at the fibre saturation point. When the water of saturation begins to be lost, shrinkage begins.

This theory of the loss of moisture from wood is against the facts.

The word "free" is unfortunate, as the term implies that the water is free to move. Now if a block of wood containing this so-called water be placed in a saturated atmosphere, the block remains constant in weight. In soils we get free water, which is the water in excess of saturation. The water is truly free, because it moves under the force of gravity. The water in the cells of the wood is not free to move under the force of gravity. Instead of calling this cell water free, we may call it *Contained Water.* There is, however, actual free water in a tree. When a giant eucalypt is felled, water pours from the cut end of the bole. This may be observed even in mid-summer. This water is truly free, for we cannot prevent its loss by merely altering the humidity of the atmosphere.

Free water occurs in birch, and the phenomenon of weeping is well known. This free water has all been lost by the time the logs get to the mill. We may define Free Water as the water which escapes from the lumber not as vapor, but as a liquid. The loss is due to the force of gravity. Free water, as here defined, must readily escape from the cut ends of the vessels, when full, of such timbers as Eucalptus, for in these the vessels are very large.

As will be seen from Fig 4, as soon as drying commences a gradient is established. It does not matter at what temperature or at what humidity the wood be dried, a gradient is established. Gradients




GRAPHS ILLUSTRATING THE PROGRESSIVE DRYING OF 3 IN. TIMBER AT 40°C AND 50% HUMIDITY.

have been found in all timbers examined. A series of birch blocks were dried at room temperature, and room humidity, and after 55 days they gave the following gradient from the evaporating surface to the centre of the block:—

Percentage of moisture in each ¼ inch.

| | | | | | |
|---|---|---|---|---|---|
| 16 | 23 | 29 | 34 | 37 | 39 |

Drying was very slow, nevertheless a graidient was formed.

If a graident be formed, then there can be no such condition as fibre saturation. It is believed that no shrinkage takes place until this so-called fibre saturation point is reached. As a matter of fact, in all timbers examined shrinkage follows the gradient. This can be readily seen if blocks of timber be coated on four sides so that the moisture can only escape in one direction, preferably the radial. Shrinkage can be measured under such conditions. A block of beech 2″ x 2″ x 3″, drying at 40°C., gave the following amounts of shrinkage at the times and positions given. The 2 x 2 face was tangential, and the shrinkage occurred in the tangential direction.

TABLE II.

| | Shrinkage at each distance from end. | | | | |
|---|---|---|---|---|---|
| Days | ¼ in. | ½ in. | ¾ in. | 1 in. | 1½ in. |
| 2 | .02 cms. | .02 cms. | .01 cms. | — | — |
| 5 | .05 | .03 | .01 | — | — |
| 7 | .08 | .06 | .02 | .01 | — |
| 11 | .11 | .08 | .05 | .04 | .03 |
| 19 | 13 | .11 | .10 | .10 | .10 |

Amount of shrinkage in a beech block when drying.

In Fig. 4 are given the results of drying a series of similar oak blocks under the same conditions—40°C. and 50 per cent. humidity. The blocks were approximately 2″ x 2″ x 3″, and the longest side was in the radial direction. The four long faces were sealed, and the two 2″ x 2″ faces were exposed. Blocks were cut up at the times shown on the graphs. The distribution of the moisture was obtained as before. It will be seen that the gradient was steep at the commencement. It may be argued that such a condition indicates case hardening, but as a matter of fact no such condition existed. It will be shown later that the conditions of drying were very favourable, and that these same conditions permit of a greater amount of shrinkage than lower temperatures and higher humidities. The graphs indicate that drying is accompanied by a moisture gradient, and that no such condition as fibre saturation is reached.

Instead of a piece of timber losing its contained water until fibre saturation is reached, we may say that as soon as a surface of green timber is exposed to the air, it immediately tries to come into equilibrium with the air moisture. The vapour tension of the moisture in the wood is greater than the vapour pressure of the air, and moisture is lost. This loss is made good from the contained water of the cells immediately next to the surface. This water passes out through the outer cell wall. As soon as this water is lost a gradient begins to be established. The walls begin then to lose moisture, and as wood is hygroscopic the cell walls draw moisture from the next layer of cells. The contained water in the cells passes to the outside by means of the cell walls, not through the cavities of the empty cells. This process goes on from cell to cell. The steepness of the gradient depends partly on the rate at which the moisture is being lost, and partly on the rate at which moisture can move through the wood to the evaporating face.

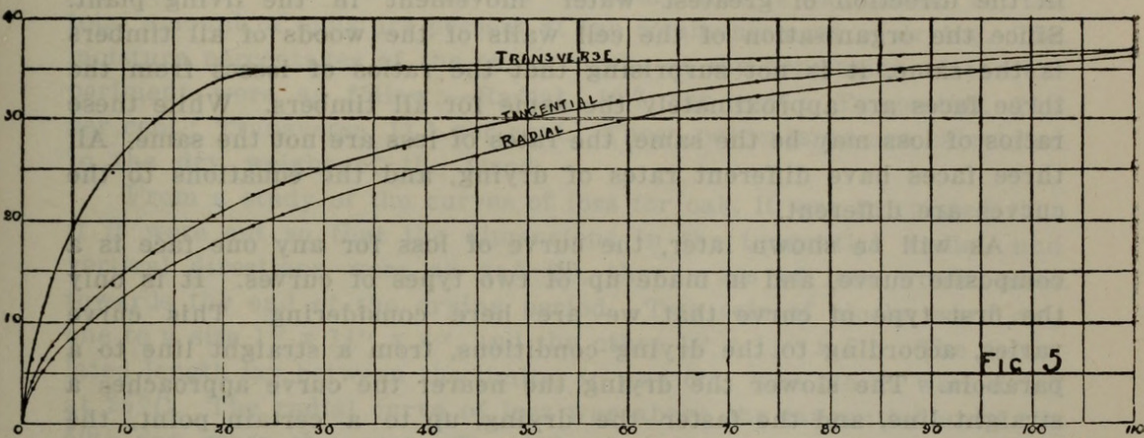
If the contained water passed from cell to cell as is necessitated by the fibre saturation theory, then there would have to be osmotic substances present in the cavities of the cells, and these do not exist. There is only one path for the moisture to reach the exterior, and that path is along the cell walls. This loss continues until the vapour pressure on the outside of the face is equal to the vapour tension of the face.

In other words, when the moisture in the wood and the moisture of the air are in equilibrium, the wood is seasoned. When exposed to the air, the weight of a piece of seasoned timber is not a constant, however, as it varies with the humidity of the atmosphere.

*Evaporating Surface.*—The third factor influencing the drying of timber is the face or surface exposed. There are three faces in timber—the transverse, the tangential, and the radial; and it is well known that these have different rates of drying. Wagner(3) says: " A very moist piece of pine or oak will, during one hour, lose more than four times as much water per square inch from the cross section, but only one half as much from the tangential as from the radial section." Tiemann(2) says: " The transfusion endwise of the grain is very much greater, probably ten or twenty times as rapid as it is across the grain." Again, Tiemann says: " Quarter sawed lumber will generally require 25 to 50 per cent longer to dry than plain sawed." These two authors differ widely in their opinions.

In order to ascertain what were the actual rates of loss from each face, cubes were used, and for these freshly felled timber was obtained. The timber was cut square, usually 2″ x 2″, two faces being parallel to the annual rings, and two parallel to the medullary rays. This can be done if timber from large trees be used. The length was cut transversely into cubes. Thus each cube had the same annual rings. Each cube had four faces sealed, and two corresponding faces exposed. For sealing, paraffin is undoubtedly the best material to use. The paraffin was heated to a temperature just above the boiling point of water, and the face of the cube brought into contact with it for a moment. The surface layer of moisture was evaporated, and the paraffin then came into intimate contact with the wood. All four faces of the cube were sealed in this way. After the paraffin set, the cubes were given a second coating. By this means a perfect seal was secured. For higher temperatures, the seal recommended by Tiemann(2) was used. This mixture is unsatisfactory for the first few days, when high humidities are used, as it sticks to the supports. It has this advantage, however, in that it readily indicates the shrinkage of wood, for as the wood shrinks the seal forms very fine wrinkles. When the cubes were coated they were placed in a saturated atmosphere for 24 hours at the temperature at which they were to dry subsequently. When the cubes were dried it was found in all cases that the transverse face lost the most moisture in a given unit of time. A large number of timbers, both European and Australian, have been tried, and they all give the same type of drying curves as shown in Fig. 5. A study of these curves of loss shows that the curve of loss for the transverse face always rises very sharply, and turns over rather abruptly into a straight line. The curve for the radial face is always the lowest, but the tangential curve of loss is always close to it. The tangential curve is above the radial, not below, as indicated by the statement of Wagner. The general equation to the curves is

OAK.




Time in days

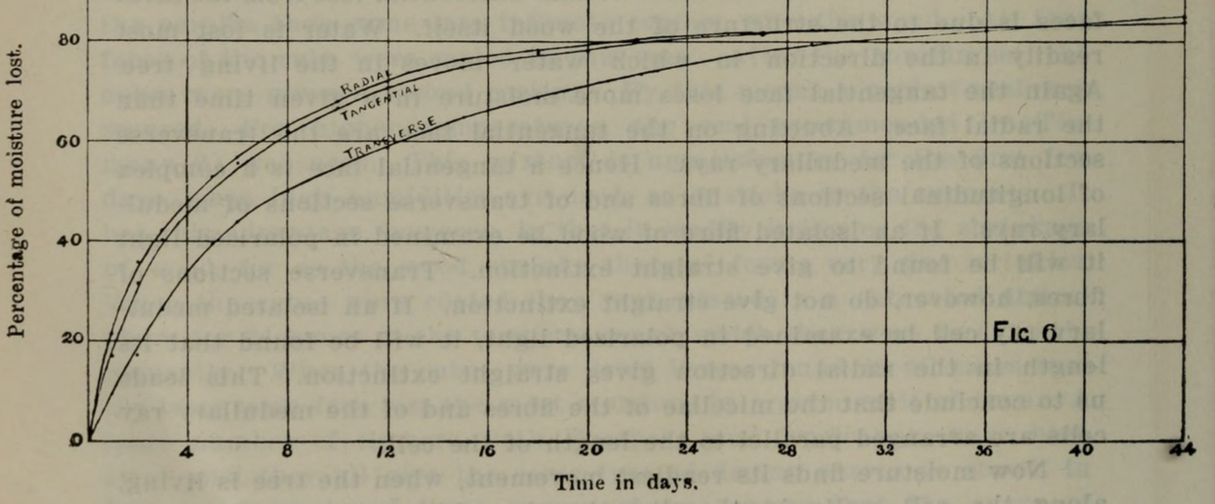
CURVES OF LOSS OF MOISTURE FROM THE TRANSVERSE TANGENTIAL AND RADIAL FACES OF CUBES OF WOOD.

$l = at^b$ where $l$ is the loss in weight in grams in time, "*t*," "*a*" is the loss for the first day, "*t*" the time in days, and "*b*" the index varies in value from unity to ·5, but is constant for any one curve, provided the conditions of drying are kept constant. The transverse curve has the greatest "*a*" value, and the greatest value for "*b*." When "*b*" is unity, the curve is a straight line, and when ·5 it is a parabola. The radial curve approaches a parabola, while the transverse curve approaches a straight line. The curves of loss for both softwood and hardwood cubes are similar. The transverse face of pine, as stated by Wagner, loses moisture, relatively just as readily, when compared with the radial, as does that of a hardwood. Hence, we are compelled to assume that the cause of this differential loss from the three faces is due to the structure of the wood itself. Water is lost most readily in the direction in which water moves in the living tree. Again the tangential face loses more moisture in a given time than the radial face. Abutting on the tangential face are the transverse sections of the medullary rays. Hence a tangential face is a complex of longitudinal sections of fibres and of transverse sections of medullary rays. If an isolated fibre of wood be examined in polarised light it will be found to give straight extinction. Transverse sections of fibres, however, do not give straight extinction. If an isolated medullary ray cell be examined in polarised light, it will be found that its length in the radial direction gives straight extinction. This leads us to conclude that the micellae of the fibres and of the medullary ray cells are arranged parallel to the length of the cell.

Now moisture finds its readiest movement, when the tree is living, along the cell walls in the direction in which the micellae are arranged. Were it not for the medullary rays, the tangential face would lose moisture at the same rate as, or even less than, the radial. The micellae of the walls of the medullary rays are arranged in a radial direction, and it is in this direction that the water moves in them when the tree is alive. The movement of water in the plant is in some way closely associated with the structure of the cell wall, and we find in the drying of timber that the greatest losses in unit time are in the direction of greatest water movement in the living plant. Since the organisation of the cell walls of the woods of all timbers is the same, it is not surprising that the ratios of losses from the three faces are approximately the same for all timbers. While these ratios of loss may be the same, the rates of loss are not the same. All three faces have different rates of drying, and the equations to the curves are different.

As will be shown later, the curve of loss for any one face is a composite curve, and is made up of two types of curves. It is only the first type of curve that we are here considering. This curve varies, according to the drying conditions, from a straight line to a parabola. The slower the drying the nearer the curve approaches a straight line, and the faster the drying, up to a certain point, the nearer the curve approaches a parabola.

Not only does each face lose moisture at a different rate, but each rate of loss decreases differently. The face with the greatest initial loss, the transverse, has also the slowest rate of decrease. Hence we cannot cut a piece of timber so that all three faces will have the same rate of loss. Of course they could be cut so that all faces would have the same initial loss, but the losses on the subsequent days would be different. However, it is possible so to cut a piece of timber that all the curves of loss shall meet, or just cross each other, towards the end of the drying period. The curves of loss for White Birch were studied, and it was considered that if a piece of this wood was cut so that the dimensions in the tangential radial and vertical directions were as 5 : 6 : 30, the curves of loss would meet towards the end



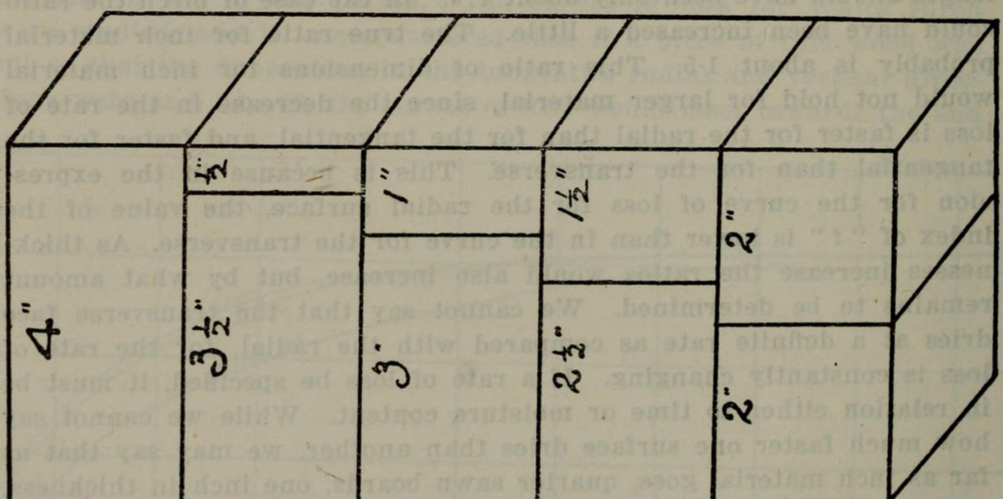

CURVES OF LOSS FOR BLOCKS OF BIRCH $1\frac{3}{8}'' \times 1'' \times 5''$

of the drying period. A length of straight grained, freshly-felled birch was cut 1⅜″ thick radially and 1″ tangentially. This was then cut into three 5 inch pieces. One length had the two transverse faces exposed, and the sides sealed, in the second the tangential faces were exposed, and in the third the radial faces were exposed. The blocks were dried at 25°C. Fig. 6 gives the result of the experiment. The percentage of moisture lost is calculated to the total amount of moisture present at the commencement of drying. The moisture percentages of the three blocks at the conclusion of the experiment were as follow:—Radial, 10.7 per cent.; Tangential, 11.4 per cent.; Transverse, 11.1 per cent. These percentages are calculated to the dry weight of the wood.

From a study of the curves of loss for oak, it was calculated that if it were cut so that the dimensions in the tangential radial and vertical directions were as 4: 5: 20, the curves of loss would meet towards the end of the drying period. Two sets of blocks were cut, one to a size 1″ x 1¼″ x 4″, and the other 1″ x 1¼″ x 6″. The calculated length lay between the limits, 4″ and 6″. The blocks were dried at 25°C. The radial curve of loss was above the tangential until the 50th day, when they met. The differences thereafter were very small. The curve for the transverse face, in the case of the 4″ set, crossed the other curves on the 92nd day. In the 6″ set the curve for the transverse loss was still below the other curves on the 104th day, when the experiment finished. In the 4″ set, at the close of the experiment, the percentages of moisture, calculated to the dry weight of wood, of the radial, tangential and transverse specimens, were respectively 11·8 per cent., 11·5 per cent., and 11·4 per cent. In the case of oak it appears that the ratio of the radial dimension to that of length should have been only about 1:4. In the case of birch the ratio could have been increased a little. The true ratio for inch material probably is about 1·5. This ratio of dimensions for inch material would not hold for larger material, since the decrease in the rate of loss is faster for the radial than for the tangential, and faster for the tangential than for the transverse. This is because in the expression for the curve of loss for the radial surface, the value of the index of "*t*" is lower than in the curve for the transverse. As thicknesses increase the ratios would also increase, but by what amount remains to be determined. We cannot say that the transverse face dries at a definite rate as compared with the radial, for the rate of loss is constantly changing. If a rate of loss be specified, it must be in relation either to time or moisture content. While we cannot say how much faster one surface dries than another, we may say that as far as inch material goes, quarter sawn boards, one inch in thickness, will take as long to season as tangentially cut boards about 1¼″ in thickness. Normally, most timber seasons by lateral drying, but at times end drying is important, as for instance, when large dimension material is to be used in short lengths. As an example, a kiln was being charged with long lengths of 9″ x 9″ lumber. This was to be used subsequently in 3½ ft. lengths. In this case if the timber had been cut into short lengths first, time would have been saved, as the manufacturing length was less than five times the width.

End drying is important in this state owing to the loss which is caused, both in stacks of sawn timber, and in logs, through the large cracks occurring in the ends. Much of our tall, straight-grained timber is very fissile, and, therefore, splits much more easily than most timbers. The cause of the cracks at the ends of both logs and stacked timber is mainly the prevention of lateral drying. In the log, lateral drying is prevented either by the bark or by the thickness of the log, or by both. In stacked timber lateral drying is prevented, if no ventilation is provided for. Only the outside pieces can dry laterally, and then only from one side. As we have already seen, shrinkage commences as soon as a gradient is formed. Shrinkage, however, is prevented from taking place where only end drying is occuring, owing to the rigidity of the adjacent portions of the timber. End drying affects only a few inches, and the timber in this short length is held in position by the remainder of the length. As the wood is drying, it tends to occupy a smaller volume, but if it cannot do so as a whole it must do in parts, and it therefore splits. That some of our timber will split even when correctly stacked is true, and this can only be overcome by sealing the ends with paint, or with Tiemann's mixture. In usual commercial sizes this does not affect time taken in drying, as the length is generally very many times greater than the thickness. In commercial sizes lateral drying is almost always the means by which timber is dried.

*Thickness.*—The fourth factor concerned in seasoning is that of thickness. For the study of the effect of thickness on time taken in drying, lengths of straight grained, freshly felled timber were used. Thicknesses up to five inches have been used. The timber was cut as in the diagram:—




The sides were coated as in the previous experiments. Where possible, three of each thickness were used, and the average loss of the three taken as the loss for that thickness. Each thickness had the same evaporating surface, and the various blocks differed only in thickness.

In Table III. are given the results of the first experiment. The timber was messmate (*Eucalyptus obliqua*), and the evaporating faces were four inches square. The thicknesses ranged from half an inch by half inches to three and a-half inches. The blocks were left to dry on the laboratory table. The experiment commenced in the middle of summer, and the effect of winter is seen by the decrease in

TABLE III.

| Time in Days | Total losses of each thickness. | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3½ in. | 3 in. | 2½ in. | 2 in. | 1½ in. | 1 in. | ½ in. |
| | gms. | gms. | gms. | gms. | gms. | gms. | gms. |
| 1 | 9 | 12 | 11 | 11 | 11 | 10 | 11 |
| 2 | 15 | 19 | 17 | 17 | 18 | 16 | 17 |
| 3 | 22 | 25 | 23 | 21 | 23 | 21 | 20 |
| 5 | 29 | 33 | 31 | 31 | 30 | 28 | 24 |
| 7 | 35 | 39 | 38 | 37 | 36 | 34 | 26 |
| 11 | 45 | 47 | 47 | 47 | 45 | 42 | 26 |
| 18 | 61 | 62 | 61 | 63 | 60 | 53 | 28 |
| 25 | 72 | 73 | 72 | 74 | 69 | 59 | 27 |
| 32 | 81 | 82 | 81 | 83 | 77 | 62 | 27 |
| 39 | 87 | 89 | 87 | 89 | 81 | 61 | 26 |
| 46 | 93 | 94 | 92 | 94 | 84 | 61 | 26 |
| 53 | 99 | 100 | 98 | 99 | 89 | — | — |
| 69 | 112 | 113 | 112 | 111 | 96 | — | — |
| 87 | 123 | 124 | 122 | 120 | 98 | — | — |
| 115 | 142 | 142 | 139 | 134 | 102 | — | — |
| 141 | 148 | 149 | 145 | 137 | 101 | — | — |
| 195 | 168 | 168 | 161 | 145 | 102 | — | — |

Each thickness loses approximately the same amount of moisture in a given time.

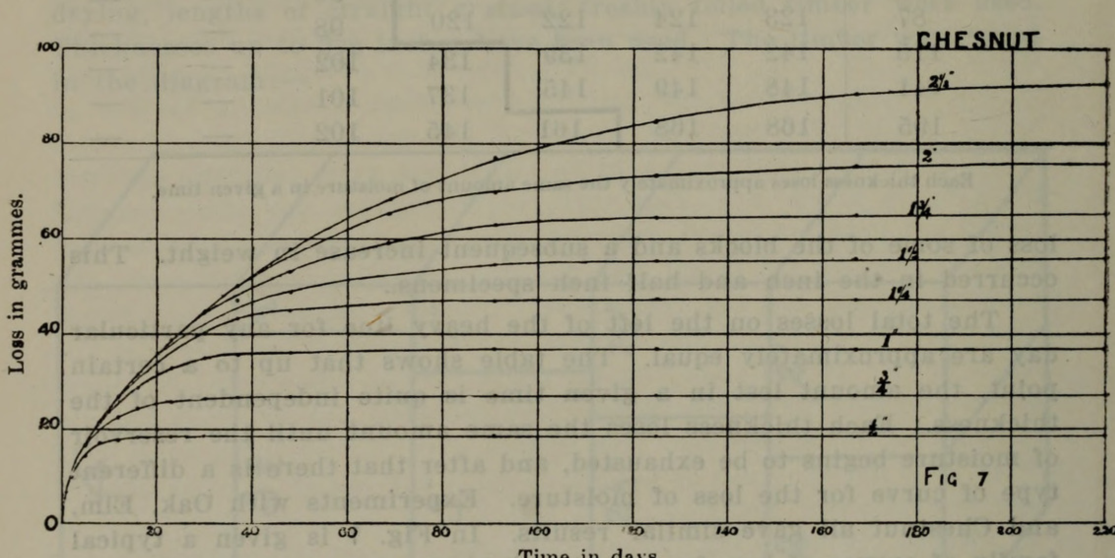
loss of some of the blocks and a subsequent increase in weight. This occurred in the inch and half inch specimens..

The total losses on the left of the heavy line for any particular day are approximately equal. The table shows that up to a certain point, the amount lost in a given time is quite independent of the thickness. Each thickness loses the same amount until the reservoir of moisture begins to be exhausted, and after that there is a different type of curve for the loss of moisture. Experiments with Oak, Elm, and Chestnut all gave similar results. In Fig. 7 is given a typical family of curves of loss for a series of blocks, having 2″ x 2″ faces, and ranging from half an inch by half inches to two and a-half inches. The outer curve or envelope is the curve of loss for the thickest specimen. The equation to this curve is approximately, $l = 6{\cdot}75t^{\prime 554}$, where $l$ is the total loss of weight in grams in time "$t$," 6·75 is loss in weight in grams for the first day, and "$t$" is time in days. The irregularities of the secondary curves at the point of junction with the main curve have been smoothed out. In this series only one specimen was used for each thickness. The differences between the values of the calculated losses and those actually obtained by weighing are given in the following table:—

TABLE IV.

| Time in Days. | Calculated Loss $l=6.75t^{.554}$ | Actual Loss. | Difference. |
|---|---|---|---|
| 5 | 16.46 gms. | 16.35 gms. | +.11 gms. |
| 8 | 21.35 | 21.45 | —.10 |
| 16 | 31.35 | 31.40 | —.05 |
| 23 | 38.34 | 38.65 | —.31 |
| 37 | 49.87 | 50.10 | —.23 |
| 48 | 57.62 | 57.80 | —.18 |
| 69 | 70.52 | 69.20 | +1.32 |

From an examination of Fig. 7 it will be seen that drying commences and continues for a while as if the supply of moisture was inexhaustible. However, in a given thickness the amount of moisture is limited, and therefore the curve of loss leaves the initial curve, and finally becomes a straight line. Where the one curve leaves the other it is difficult to say. In the small thicknesses the change is somewhat abrupt, but as thicknesses increase the change becomes less and less abrupt. This is because the secondary curve does not leave the main curve at the same moisture content in each case. In the small




SERIES OF CURVES ILLUSTRATING LOSS OF MOISTURE FOR VARIOUS THICKNESSES OF TIMBER.

sizes the moisture has only a small distance to diffuse, in order to reach the surface, and hence the curve of loss for thin sections coincides with the envelope for a relatively longer period than do the curves of loss for thicker sizes. The rate of loss is greater on the main curve than on the secondary, and hence these sizes dry rapidly. This was observed by Tiemann(2), for he says: "For one half inch or less the time should be decreased as the square of the fractional part of an inch." Again, he says, for thickness above an inch, "The time ordinate should be increased in proportion to the thickness up to three inches, and about one and a-half times the thickness for thicknesses over three inches."

*Humidity and Temperature.*—The fifth factor with which drying is concerned is that of humidity, and with this we may conveniently consider the sixth factor, temperature. Humidity is not a satisfactory variable to use, since it is only a relative quantity. When we speak of a humidity we must always specify a temperature. The same humidity at different temperatures gives very different drying conditions. Drying depends on the difference between the vapor pressure of the air surrounding the wood and the vapor pressure at saturation. At a temperature of 50°C. and a relative humidity of 90 per cent., there is a difference in pressure between that actually existing and that at saturation point of 9.25 mm. of mercury. At a temperature of 20°C. and the same humidity, namely, 90 per cent., there is only a difference of 1·75 mm. Hence there is a very great difference in the rate of drying of timber, when placed under these two sets of conditions. A high humidity at a high temperature may cause timber to dry at a much faster rate than a low humidity at a low temperature. Thus blocks drying at 80 per cent. humidity at 50°C. were losing moisture faster than those at 10 per cent. humidity at 20°C. This point is frequently lost sight of in kiln drying, when it is recommended to commence the seasoning at a high temperature and a high humidity.

Experiments were carried out at different humidities, at the temperatures 20°, 30°, 40° and 50°C. For the experimental work blocks approximately 2″ x 2″ x 1″ were used. For any one experiment the blocks were cut from the same length of timber. Only straight grained, freshly felled material was used. The sides of the specimens were sealed, leaving the 2″ x 2″ faces exposed. The exposed faces were always radial surfaces. To obtain the various humidities, solutions of sulphuric acid were used. After each weighing, the solution in each desiccator was brought up to strength by adding the amount of acid corresponding to the loss of weight of the specimen. For desiccators, tall gas cylinders were used, and the specimens were supported on glass rods. The humidities used ranged from 95 per cent. down to 2 per cent. There were two humidities below 10 per cent., namely 7 per cent. and 2 per cent.

In the experiment at 20°C. losses increased with decreasing humidity. The greatest loss occurred at the lowest humidity, that is at 2 per cent. At the other temperatures, however, the maximum loss occurred at 7 per cent., and the curve of loss bent downwards from the 7 per cent. to the 2 per cent. humidity. This is shown in Fig. 8, which gives a typical series of losses. Similar graphs were obtained with beech, elm, and chestnut. A duplicate experiment with oak at 50°C. gave precisely the same type of graph. Owing to limitations of space and material, only single specimens could be used at each humidity, but the greatest care was taken in the selection and cutting of the material. In the case of Fig. 8 the heaviest specimen was 64:5 gms., and the lightest 64:12 gms., so that the differences in the weight of the specimens were negligible.

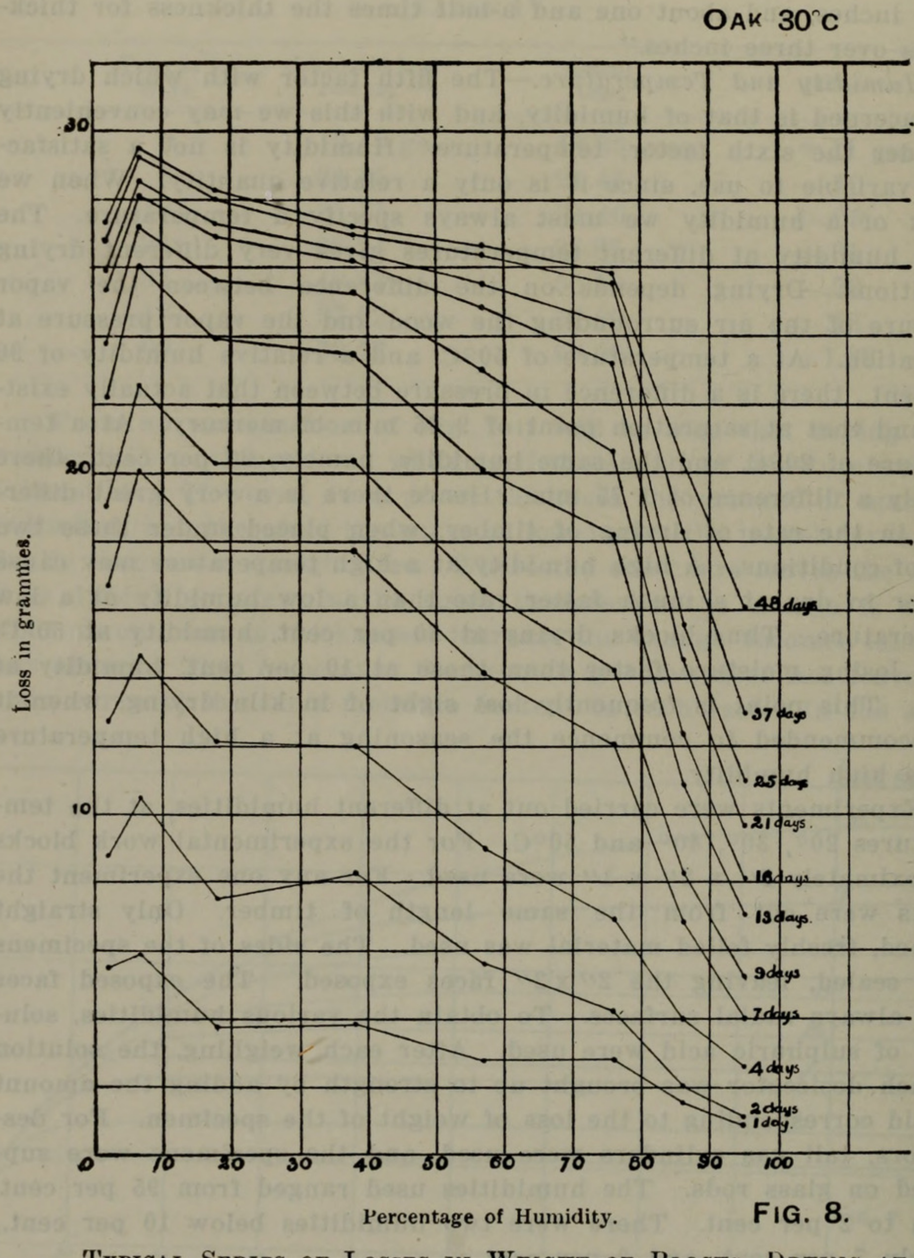



FIG. 8.

TYPICAL SERIES OF LOSSES IN WEIGHT OF BLOCKS, DRYING AT VARIOUS HUMIDITIES.

Since in all the experiments, except that at 20°C, the graphs bent downwards between the 7 per cent. and the 2 per cent. humidities, there does appear to be a limiting humidity below which drying is retarded. Low humidities rarely occur in nature, though it is believed as low a humidity as 4 per cent. has been experienced in this State. As far as air drying in this State is concerned, therefore, we may say that drying would never be retarded. It has already been remarked that the curve of loss is a composite curve, and is made up of two types of curves. The first part of the curve of loss gives the losses when the wood is actively drying. These losses will now be considered. In Table V. are given the ratios of the loss of weight on the first day to those on subsequent days. In this experiment the blocks were dried at 90 per cent. humidity.

TABLE V.

| Temp. | Time in Days. 4 | 9 | 15 | 25 |
|---|---|---|---|---|
| 20 | 4 | 9 | 16 | 22 |
| 30 | 3.1 | 6.6 | 9.0 | 11.8 |
| 40 | 2.9 | 3.7 | 5.6 | — |
| 50 | {3.6 | 7.0 | 8.7 | — |
| | {3.2 | 6 6 | 7.8 | — |

Ratios of loss at 90% Humidity.

It will be seen that in the case of the specimen at 20°C. the ratios are the same, except the last, as the time in days. In other words, the curve of loss is a straight line. As will be seen in Fig. 9, when this happens drying is very slow. It will also be seen that the higher the temperature the less the ratio, although it may be noted that an exception occurrs at 40°C. This happened with every specimen at 40°. There was no material available for a second experiment. The second experiment at 50°C. gave similar results to the first.

In Table VI. are given the ratios of loss for specimens drying in a 50 per cent. humidity.

TABLE VI.

| Temp. | Time in Days. 4 | 9 | 16 | 25 |
|---|---|---|---|---|
| 20 | 3.6 | 7.4 | 12.5 | 17.1 |
| 30 | 2.9 | 5.1 | 6.4 | 7.1 |
| 40 | 2.0 | 3.0 | — | — |
| 50 | {2.8 | 4 4 | 5 1 | — |
| | {2.5 | 3.6 | 4.5 | — |

Ratios of loss at 50% Humidity.

The ratios in the case of 20°C. are somewhat removed from the values of the time in days. There is again a decrease in the ratios with increasing temperature. In Table VII. are given the ratios of loss for specimens drying at 10 per cent. humidity.

TABLE VII.

| Temp. | Time in Days. 4 | 9 | 16 | 25 |
|---|---|---|---|---|
| 20 | 3.5 | 7.1 | 10.1 | 12.5 |
| 30 | 2.5 | 3.9 | 4.7 | 5.0 |
| 40 | 2.0 | — | — | — |
| 50 | {2.4 | .4 | — | — |
| | {2. | 3.2 | — | — |

Ratios of loss at 10% Humidity.

The ratios are only calculated for the period of active drying. In the last table it will be seen that the values of the ratios approach the value of the root of the time. In the 40° experiment the ratio is actually $t$. From all the tables it will be seen that the ratio of the first day's loss to any subsequent loss always lies between "$t$" and "$\sqrt{t}$." It never goes outside these limits. With high humidities the curve of loss always approaches a straight line. The nearer, however, that the curve of loss approaches a straight line the slower

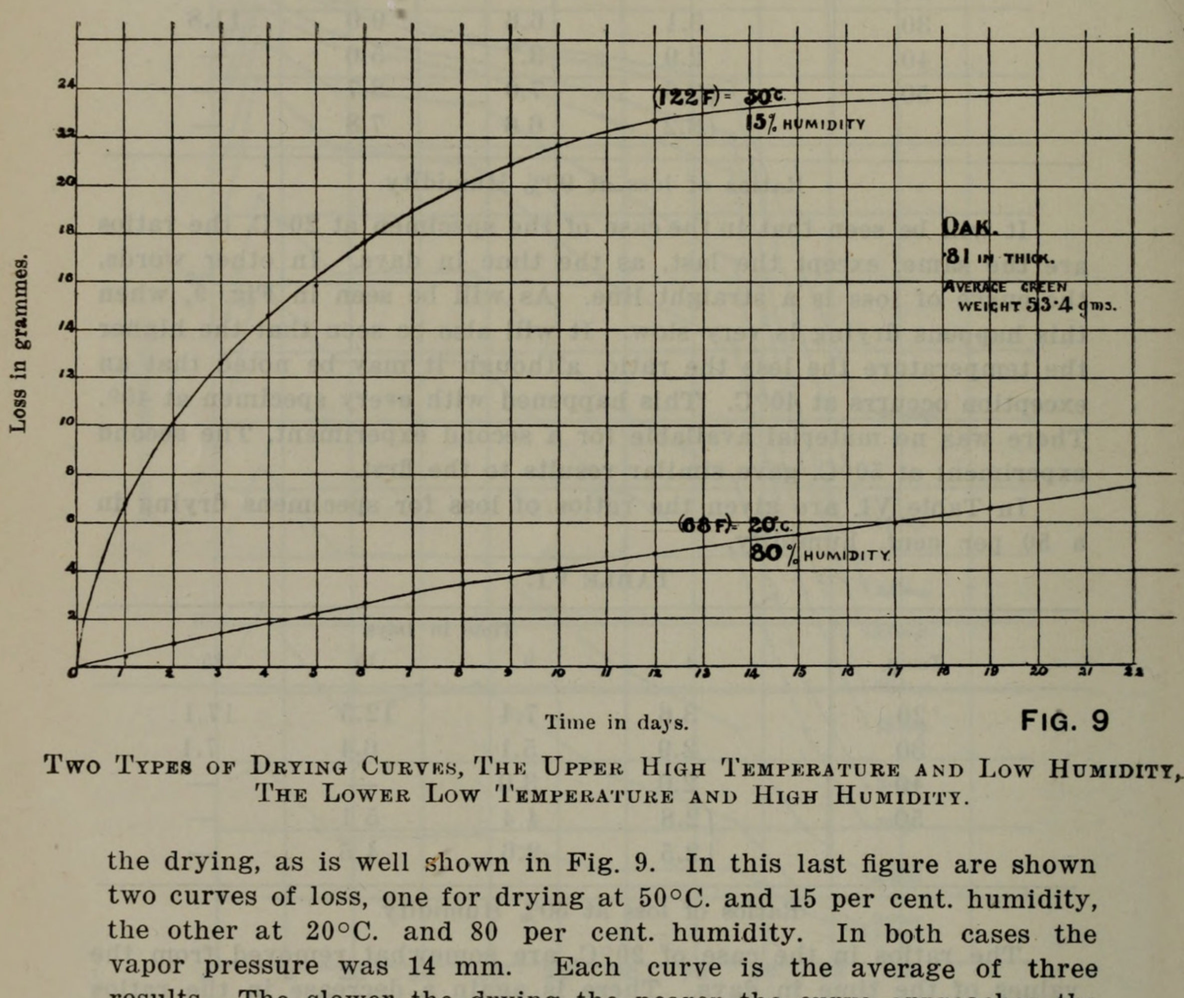



FIG. 9

Two Types of Drying Curves, The Upper High Temperature and Low Humidity, The Lower Low Temperature and High Humidity.

the drying, as is well shown in Fig. 9. In this last figure are shown two curves of loss, one for drying at 50°C. and 15 per cent. humidity, the other at 20°C. and 80 per cent. humidity. In both cases the vapor pressure was 14 mm. Each curve is the average of three results. The slower the drying the nearer the curve approaches the time axis. The general formula for this period of drying is $l = at^b$ where $b$ varies from unity to ·5. As $b$ increases in value from ·5 to 1, the value of "$a$" decreases. The smaller the value of "$b$" within the limits stated the faster the rate of drying. Rapid drying, however, although advantageous from the point of view of saving of time increases the amount of shrinkage. This is not surprising, for it is quite conceivable that the higher temperatures make the wood somewhat plastic. Increase of shrinkage is very undesirable from a commercial point of view. What has recently been termed collapse in timber is in many cases undoubtedly due to high temperatures in the kiln. In Table VIII. are given the amounts of shrinkage for a series of oak blocks, averaging 2·06 cms. in thickness. Three blocks were dried at each temperature, and at the humidities given in the table. After the completion of the experiment the blocks were left on the shelf in the laboratory for twelve months, before the final measurements were made for the amount of shrinkage. The moisture contents of the blocks at the final measuring were very similar.

TABLE VIII.

| Temperature. | Humidity. | Shrinkage. |
|---|---|---|
| 2[illegible]°c. | 80% | .13 cms. |
| 30° | 44 | .15 |
| 40° | 25 | .17 |
| 50° | 15 | .20 |

Amount of shrinkage increases with better drying conditions.

That the greatest amount of shrinkage occurred at the highest temperature is evidence that there was no case hardening, so-called. It has been shown (4) that a rapid loss of moisture from the surface prevents shrinkage to a certain extent. It has also been shown (4) that steaming timber prior to seasoning induces shrinkage. Both high temperatures and steaming are recommended in ordinary commercial operations in kiln drying. In Fig. 9 are given the drying curves of two series of blocks, one drying at 20°C. and other at 50°C. The drying conditions of the series at 50°C. are representative of the best drying conditions found in nature in this State during the summer. The highest temperature recorded in this State is 123·5°F. The equivalent temperature of this in degrees centrigrade is 51°.

Humidities lower than 15 per cent. are frequently recorded. The blocks were radially cut, and were ·81 inches thick. This thickness would take about the same time to dry as tangentially cut specimens one inch thick. The lower curve is representative of drying under more or less average weather conditions. The upper tends to prove what has already been pointed out(4) that inch boards can season in this State in a few weeks.

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