FORESTS DEPARTMENT WESTERN AUSTRALIA

Western Australia.

THE SEASONING OF WESTERN AUSTRALIAN HARDWOOD.

WITH SPECIAL REFERENCE TO THE STRUCTURE, PROPERTIES, AND AIR AND KILN SEASONING OF JARRAH AND KARRI.

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FOREWORD.

The good name of Western Australian hardwoods, particularly Jarrah, for uses other than railway sleepers and paving blocks, has suffered from a general failure to apply proper seasoning methods and tests. Climatic conditions are not conducive to rapid and consistent air drying, and, in consequence, avoidable trouble has resulted from the use of imperfectly seasoned timber for flooring, joinery and other higher grade uses. Experimental work in kiln and air seasoning, which has been carried on for some years, has shown that the unsatisfactory behaviour of local timbers for such purposes has not been due to any inherent defects in the timber, and the present publication is intended to provide the results of this research for the general guidance of sawmillers, architects, and timber users.

An endeavour has been made to set out clearly and concisely the correct treatment necessary to season timber, the tests which should be applied to determine when timber is fit for use, and the care necessary to ensure satisfaction from the use of seasoned timber. Many examples could be quoted of cases in which considerable time and money have been expended in seasoning timber, and the whole lost through lack of necessary precautions in subsequent handling.

Information is contained which should enable sawmillers and other manufacturers faced with seasoning problems to determine the most economical and efficient method to adopt in seasoning. Experimental work on such problems must continue and improved methods will undoubtedly result from further research, but our knowledge has advanced to a sufficient stage to enable all merchants handling timber, who desire to guarantee reasonable satisfaction to their customers, to introduce greatly improved methods. Certain chapters are of greater interest to the kiln operator, and will serve as a useful reference book on questions of construction and operation of kilns under Western Australian conditions. Standard drawings of Tiemann and Clarke kilns are in course of preparation, and these, in conjunction with the more general information contained in the bulletin, will supply all necessary data for the erection of commercial drying plants.

The Department is greatly indebted to Professors H. E. Whitfeld and N. T. M. Wilsmore, of the University of Western Australia, for their assistance and advice in connection with these investigations.

S. L. KESSELL,
Conservator of Forests.

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CHAPTER 1.

THE COMMERCIAL TIMBERS OF WESTERN AUSTRALIA.

The timber-producing trees are practically confined to the South-West corner of the State.* With the exception of a few unimportant species that, where obtainable, are prized on account of their beauty and suitability for the highest grades of work, all the trees milled are Eucalypts, and of these only two—Jarrah and Karri—are of prime importance. The study of the seasoning of wood in Western Australia, therefore, becomes almost entirely a matter of the seasoning of the Eucalypts.

JARRAH (Eucalyptus marginata).

The most important timber—Jarrah—is obtained from a tree growing to about 100 to 120 feet in height, with a diameter of 6 feet, and a clean bole of 50 or 60 feet. The prime forest covers about 2 to 2½ million acres, and no part of this is more than 60 or 70 miles from the coast. Compared with softwood forests in other parts of the world and with some of the Eucalypt forests of the Eastern States of Australia, the quantity of merchantable logs in the bush milled is comparatively low, varying from 250 to 3,000 cubic feet per acre.

Although an average tree provides a log of fairly regular form in length and in diameter, the small average loadage per acre, and the presence of certain faults and blemishes in the timber which result in an average recovery of only 30 to 40 per cent., are responsible for making the conversion of the timber a comparatively expensive undertaking. It is, therefore, essential that the methods of milling and subsequent utilisation should be so directed that the timber may be used to the maximum advantage.

Durability first brought Jarrah into prominence, with the result that the timber came to be used for those relatively lower grades of utility which require as their main requisite long life under adverse conditions. Thus forests were exploited for this class of material and, while the supply was still thought to be practically inexhaustible, the best trees only were selected. In addition, timber for this poorer work was cut free from blemish, under the erroneous impression that this was more durable. The comparative difficulty in seasoning Jarrah, due both to the somewhat refractory nature of the wood and to the climate, resulted in the use of imperfectly seasoned material, with consequent unsatisfactory service: this led to the belief that Jarrah was only suitable for these lower purposes, and stimulated the wasteful exploitation of the forests. It has, however, been proved that, with proper methods, Jarrah can be seasoned thoroughly, and that, when seasoned, it will behave just as any other better known timber: consequently, with the care which all dried timber must have, seasoned Jarrah is reliable.

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* A vegetation map of the South-Western portion of Western Australia, showing the forest zones, appears at the rear of this bulletin.

Nearly all of the Jarrah bole is heartwood, but, although the presence of knots is exceptional, there are other faults which add to the difficulties of milling. Gum veins, sometimes enlarged to gum pockets, falling and star shakes, and heart rot, have all to be avoided in obtaining unblemished material. Gum veins, which are caused by some interruption in the work of the cambium, resulting in the formation of comparatively large, more or less complete reservoirs filled with kino, do not affect the physical and mechanical properties to any serious extent, except when they are extraordinarily large. Owing to the fact that they lie along the annual rings, in this instance they reduce the shear strength and increase the tendency to cleavage in a tangential direction. Shakes have to be avoided in converting the logs, and this decreases the return of sawn material.

The presence of decay or incipient decay in the centre of large-sized Jarrah logs is common, and is referred to by the trade as heart rot. Although logs with sound heart throughout their length are quite usual, rot in some trees extends into the butt logs, while, in others, it may even cover the full length of the bole. In milling, the sound timber is cut from the log, any central portion affected by decay being discarded. This portion is never marketed (except for firewood), and is comparatively low in strength. Cuttings from the centre of the log, often containing a large percentage of this inferior material, are used extensively on mill railways for sleepers, etc., and have a life of 10 to 15 years.

In butt logs, tangentially cut timber is often flecked with black spots, like narrow elongated eyes in shape, and up to half an inch or more in length. On the transverse face these appear as black radial markings usually an inch or more long, and at first sight they might almost be taken for medullary rays. The latter in Jarrah are, however, very small and, except on close inspection, are invisible to the naked eye. The markings, which greatly enhance the beauty of the timber, are considered by some to be indications of full maturity in the wood. If due to incipient fungal attack, any further development seems to be arrested by the death of the tree, for there is no record that timber thus marked is less durable than the average class of Jarrah timber. Timber of this type is often more easily worked, less likely to warp in seasoning, or to vary in shape and size with bad treatment after drying; these advantages, together with the greater beauty of the timber, make it of particular value for work in which finish and appearance are a consideration.

The wood of the Jarrah tree is similar to other commercial timbers milled on a large scale in that it shows a fairly wide variation in properties from tree to tree. Strength and density vary between fairly wide limits, while different degrees of durability and regularity of grain are also found. Investigations carried out tend to show that trees from the ironstone ridges have denser and stronger timber than those from the valley, and that this is due to the fact that the former are slower growing. On the margins of the prime forest also, trees generally of smaller stature and of greater irregularity of grain produce this denser and more durable material.

Providing that the timber is straight-grained, the site of growth does not appear to have a great effect upon the seasoning of the timber. Where the grain is irregular, however, the prevention of deformation in seasoning is sometimes impossible, and it is, therefore, a profitable procedure to select for seasoning none but straight-grained material.

Mechanical and Physical Properties.

	Mean.
A. Transverse Bending Test (Beams of 20 sq. in. sectional area and at 12 per cent. moisture—	
Modulus of Rupture, lbs. per sq. in.	15,000
Modulus of Elasticity, lbs. per sq. in.	2,080,000
B. Compression Test along the Grain (ratio 24/1)—	
Crushing Strength, lbs. per sq. in.	7,700
C. Compression Test along the Grain (ratio 12/1 and under)—	
Crushing Strength, lbs. per sq. in.	9,100
Modulus of Elasticity, lbs. per sq. in.	1,490,000
D. Compression Test along the Grain (half-length of specimen loaded)—	
Fibre Stress at 3 per cent. deformation, lbs. per sq. in. ..	2,500
E. Shearing Test along the Grain—	
Shearing Strength { Method of Double Shear, lbs. per sq. in.	1,050
Shearing Strength { Method of Single Shear, lbs. per sq. in.	2,010
F. Density—	
Green, lbs. per cubic foot	68
Dry (at 12 per cent. moisture), lbs. per cubic foot	55

The working properties of Jarrah are such that it is suitable for all uses such as furniture, furnishings, interior trim, etc., and, in these branches of utilisation, its beauty of colour and grain is by no means unimportant. When green the timber cuts cleanly and easily with both power and hand saws along and across the grain; but, when dry, although it cuts cleanly, much more power is required to drive the saw. The timber machines or can be planed by hand to a smooth surface when green or dry, but sometimes semi-dry material machines badly, owing to tearing. Although the timber is hard, tools cut cleanly and it is therefore often turned or used for carved work.

Although weight is a disadvantage, Jarrah is essentially a furniture and cabinet wood, but its durability has led to its very extensive use for such purposes as structural work generally, sleepers, paving blocks, bridge and wharf timbers, and power and telegraph transmission poles. Its popularity for these latter purposes has obscured to a certain extent its possibilities in the higher branches of utilisation, and much timber of excellent quality is at present being used for purposes where durability alone is essential.

The tree regenerates freely, but constant firing of the forest in the past has done much damage to young growth. Conditions, however, are improving as reforestation measures, including fire control operations, are extended.

KARRI (*Eucalyptus diversicolor*).

The second most important timber tree in Western Australia is the Karri. This is a magnificent tree with a height of 200 feet or even more, the long clean bole being from 100 to 140 feet in length. The diameter is 8 to 10 feet. Unfortunately the habitat, which is in the extreme South-West corner of the State, covers a limited area, and the estimated extent of prime Karri Forrest is only some quarter of a million acres. The timber is very like Jarrah in appearance, but on the average, especially when first cut, it is much lighter in colour and sometimes almost white. Some darker shades of Karri and lighter shades of Jarrah are, however, indistinguishable by observation with the naked eye. Fortunately Jarrah and Karri are vastly different in the tree form and in the freshly cut state, so that the simple preventive measures now instituted to avoid confusion are quite reliable.

The danger from the confusion of Jarrah and Karri lies in the fact that, whereas Jarrah has a durability of world-wide renown, Karri is more readily attacked both by white ants and by rot-producing fungi. On the other hand, although Jarrah is a strong timber, the mechanical properties of Karri, particularly where cross-bending stresses are concerned, place it amongst the strongest of timbers. In the log form Karri has the same faults of gum, shakes, and rotten heart, as Jarrah, and the methods of milling of the two timbers are therefore very similar. In pure stands, however, Karri generally provides a very much higher loadage of merchantable timber amounting at times to 15,000 cubic feet per acre.

Mechanical and Physical Properties.

		Mean.
A.	Transverse Bending Test (Beams of 20 sq. in. sectional area and at 12 per cent. moisture)—	
	Modulus of Rupture, lbs. per sq. in.	17,300
	Modulus of Elasticity, lbs. per sq. in.	2,680,000
B.	Compression Test along the Grain (ratio 24/1)—	
	Crushing Strength, lbs. per sq. in.	9,400
C.	Compression Test along the Grain (ratio 12/1 and under)—	
	Crushing Strength, lbs. per sq. in.	10,200
	Modulus of Elasticity, lbs. per sq. in.	2,030,000
D.	Compression Test across the Grain (half-length of specimen loaded)—	
	Fibre Stress at 3 per cent. deformation, lbs. per sq. in. ..	2,800
E.	Shearing Test along the Grain—	
	Shearing Strength: Method of Double Shear, lbs. per sq. in.	1,050
	Shearing Strength: Method of Single Shear, lbs. per sq. in.	1,800
F.	Density—	
	Green, lbs. per cubic foot	72
	Dry (at 12 per cent. moisture), lbs. per cubic foot	58

Karri, although it is not as easy as Jarrah to work, cuts freely and can be made to give smooth surfaces. During machining it has a tendency to tear, particularly with semi-dry and quarter-cut material, but this can be overcome with suitable equipment.

In seasoning, Karri has a pronounced tendency to crack. In thick pieces, under adverse conditions, the cracks become very pronounced and deep. Owing, however, to the extraordinary way in which the grain is interlocked, the splitting of even a thin piece of Karri, by an externally applied force, is a very difficult matter. Besides being on Lloyd's list of ship-building timbers, Karri is used for wooden pipes, wagon scantling, and transmission-line poles and cross-arms. The powellised Karri railway sleeper is well known throughout the Southern Hemisphere, and on the Great Western Railway, linking South and Western Australia, it has proved itself superior to all others. Karri, on account of its very high beam strength and its long clean lengths, is used extensively in superstructural work, and for this purpose it is steadily coming more and more into favour. It makes excellent flooring on account of its strength and wearing properties, and is also used for furnishings, furniture and interior trim. For all purposes where it has been used in contact with the ground, Karri has in the past been powellised, by treatment in an open tank with a solution of sugar and arsenic. Recent investigations have shown that, while this treatment is very effective in preventing the ravages of the white ant, decay of the timber under adverse conditions still takes place. The process has, therefore, been replaced by a new one which has been developed in the State, and which is called Fluarising. The name is compounded from the two main constituents of the process, Sodium Fluoride, a well-known fungicide which is impregnated into the wood in sufficient quantities to prevent decay, and Arsenic, which, having proved its ability in the powellising process, is included in the new to give protection against white ants and other insects.

Karri regenerates itself well, and it forms the only forest in the State which carries a dense undergrowth of shade-bearing species.

OTHER EUCALYPT SPECIES.

The remaining Eucalypt timber-producing trees are to be found either scattered throughout the Jarrah belt or in isolated patches of the forest near its margins, or in the savannah forest which covers the lower rainfall belt east of the Jarrah and Karri forest areas. Associated with Jarrah are to be found Blackbutt (*Eucalyptus patens*), Marri (*Eucalyptus calophylla*), and Wandoo (*Eucalyptus redunca*), although the last-named is more typical of the savannah forest. Blackbutt and Marri are both trees not unlike Jarrah in appearance, approaching it also in height and the dimensions of the bole. Marri is very plentiful, but the milling possibilities of the timber at present are slight, owing to the large percentage of trees very seriously affected by gum veins and pockets. Blackbutt yields clean timber but supplies are limited and scattered. The physical and mechanical properties of both timbers resemble those of Jarrah. They are, however, light in colour with a yellowish tinge, and the woods, while durable, have not the extraordinarily long life of Jarrah and suffer by the comparison.

In small but pure stands are to be found the Tuart (*Eucalyptus gomphocephala*) and the Tingle Tingles. In the latter case, the forest is really a mixture of the two Tingle Tingles, which, although similar in the tree form, are very distinct species. Tuart is to be found on the limestone hills of the Western coastal plain southward from Perth, but only in few places are the trees anything but scattered in nature. Five thousand acres of the best Tuart country have been reserved at Wonnerup as State Forest. The timber is pale yellow in colour, and is strong and durable. The mechanical properties are slightly superior to those of Karri, the timber is harder, while the interlocking of the grain, which is a feature of Karri, is in this timber even more pronounced. The wood has a wonderful reputation for railway wagon substructural work, and smaller sizes are used in bodies of motor vehicles and for small turnery.

The prime Tingle Tingle forest is restricted to a small area some 5,000 acres in extent on the south coast in the vicinity of Nornalup Inlet. Red Tingle Tingle (*Euc. Jacksoni*) is a tree not unlike Jarrah in appearance, but it grows to a height of 180 feet with a diameter of 10 to 13 feet. The mechanical properties of this timber are similar to those of Jarrah, but the density is considerably lower. From the pure Tingle Tingle stands, the majority of the timber appears to have a density averaging about 45 lbs. per cubic foot. The timber is almost a rose colour, and is eminently suited for furniture and similar classes of work. Yellow Tingle Tingle (*Euc. Guilfoylei*) is very similar to Red Tingle Tingle in appearance, but attains a height of only 80 to 120 feet, with a diameter of 3 to 4 feet. It occurs on the margins and sometimes penetrates into the Red Tingle Tingle forest. The timber appears to resemble tuart in physical and mechanical properties. Owing to the isolation of the Tingle Tingle forest, the exploitation of those timbers has been delayed.

The trees of the true forests, Jarrah, Karri, Marri, Blackbutt, Tuart, and Red and Yellow Tingle Tingle, have high initial moisture contents. This is in all the timbers above 60 per cent., while in the case of Jarrah and Karri, it sometimes reaches 90 per cent. or 95 per cent. of the dry weight.

The more important Eucalypts of the savannah forest, Wandoo, Morrell, Salmon Gum, York Gum, Yate, all produce dense interlocked timbers of great strength. The moisture contents of the green wood are all low, being between 30 and 44 per cent. of the dry weight. Wandoo, which strongly resembles Tuart in physical and mechanical properties, is used for railway wagon substructures while, on account of its great durability, it also finds a ready market for railway sleepers. The other timbers are used in coach and wheelwright work, and the extent of utilisation is limited not by the lack of appreciation of the timber, but by the difficulties of milling owing to the scattered nature of the forest.

NON-EUCALYPTS.

Amongst the non-eucalypts, River Banksia (*Banksia verticillata*), Sheoak (*Casuarina Fraseriana*), and Native Pear (*Xylomelum occidentale*) are milled to the extent the restricted supplies allow. River Banksia, which is to be found along rivers and streams in the Jarrah and Karri forests, yields a prettily figured wood with pronounced medullary rays. It is used for furniture, panelling, and similar purposes. The timber is soft and easy to work. The moisture content of the green wood is sometimes very high, figures of 200 per cent. having been recorded. Sheoak is a harder timber, sometimes possessing a very bold, oak grain. It is used for furniture and also for shingles and cooperage stock. Native Pear is a soft wood with pronounced medullary rays and deep, red colour. Small, scattered, irregular and often fire-damaged trees restrict the supplies of what would otherwise be a very popular furniture timber.

CHAPTER 2.

STRUCTURE OF THE WESTERN AUSTRALIAN EUCALYPTS.

The trunk of a tree, which is the portion here to be considered, is a very complex structure. On general lines, starting from the centre, it can be divided into the pith or medulla, the heart wood, the sapwood, the cambium layer and the bark. The cambium is the growing portion of the tree and may be described as that delicate mucilaginous layer between the bark and the sapwood. The sapwood carries to the leaves the moisture charged with mineral and organic material absorbed by the roots. Carbon dioxide is taken from the air, and, by the agency of the chlorophyll or green colouring matter in the leaves, is broken up, the oxygen being discharged by the leaves and the carbon recombined into starchy substances. The sap, brought up through the sapwood, is enriched at the leaves and passes down inside the bark to feed the cambium. The main direction of motion of the sap is, therefore, upward in the sapwood and downward in the bark. There is, however, another minor direction of motion in a horizontal direction, which assists in the storage and secretion in the heartwood of food and discarded materials respectively. The cambium divides into new cell structures which are laid down on the outside of the sapwood, and in these cells changes gradually take place, the chief of which are thickening and strengthening. The only growth in the trunk is outwards, or by increase in diameter.

With this increase in diameter of the trunk, a cell becomes further and further from the cambium. While it is still in the sapwood, development of the cell takes place, but with the change from sapwood into heartwood, living processes in the cell cease, and the cell, apart from its mechanical strength, is apparently no longer essential to the life of the tree. A cell, when first formed at the extreme edge of the sapwood, consists of a very thin, imperforate membrane enclosing the living cell contents. As the tree grows, and the heartwood gradually approaches this cell, a secondary strength-giving thickening is laid on to the original wall. The secondary wall differs, however, from the primary, in that it has various types of pits which correspond in position to pits in the secondary walls of the adjacent elements which share the primary wall. The pits are of two kinds, simple pits and bordered pits: the former consist of a more or less parallel-walled passage between the two cells closed in the centre by the membrane of the primary wall; the latter have small mouths but are enlarged near the primary wall which is here a membrane thickened in the centre, presumably to form a check valve to close a mouth of the pit in the event of a sudden pressure on one side or other of the primary wall. A tertiary wall is often laid down, but in the Eucalypts it is a negligible quantity.

At the time of the transition from sapwood to heartwood, a secondary growth in the formation of new cells inside some of the old ones sometimes takes place, and while this action apparently does not greatly affect the living processes of the tree, it has an appreciable effect upon the physical properties of the heartwood when the timber is subsequently converted. Thus the heartwood, which is the portion of the tree of economic importance from the timber standpoint as far as the Eucalypts are concerned, consists of an intricate structure of dead cells. It provides to a large extent the mechanical support of the tree, and is a depository for some of the waste materials of the living processes.

A piece of wood consists of a very large number of cells of different types arranged in more or less definite order. The microscopic structure of the wood may be likened to a bundle of drinking straws pressed so that there are no interstices between the individual straws, but which retain to some extent their round shape. The cells in wood are, however, very much more irregular with respect to length, diameter and shape, and to thickness of the cell wall, while, in addition, there is also interspersed a second set of cells with their long axes at right angles to those of the cells of the main set.

The cells in wood can be divided into a number of types according to their general form, disposition with relation to one another, and function.

The types of cells to be found in Eucalypts are as follow:—

Tracheae Vessels, or Pores.
Wood Fibres and Fibre Tracheids.
Wood Parenchyma.
Medullary Rays, Pith Rays or Rays.

The vessels or pores are usually very numerous in the Eucalypts, and can readily be seen as little holes in an end section. They are also apparent macroscopically on longitudinal faces of these timbers and resemble a mass of irregular fine scratches in the direction of the grain over the whole surface of the timber. These cells are comparatively thin walled and form the main conduits for the transmission of moisture from roots to leaves by way of the sapwood. The cell walls are pitted by bordered pits and overlap one another to provide the necessary continuity.

The manner of distribution of the pores on the transverse section of a piece of wood forms one of the means of macroscopic identification. Timbers are divided into two classes, viz., ring-porous, in which the pores are concentrated in rings corresponding in number with the annual rings, and diffuse-porous, in which the pores are distributed more or less evenly over the transverse section. The Western Australian Eucalypts are all diffuse-porous.

The most numerous and most important cells from the timber standpoint are the wood fibres, which form the main bulk of the wood and provide most of the mechanical strength of the tree. These elements in the Eucalypts are much smaller than the pores and have comparatively thick walls. The cell cavity or lumen is usually small and the continuity of the secondary wall is in most cases broken by simple pits only.

A modification of wood fibre cells is to be found in the fibre tracheids which resemble true tracheids. The latter, which are of extreme importance in, and are the principal element of, a class of woods, the Gymnosperms, to which the pines and most softwoods belong, are elongated taper pointed cells with bordered pits, and are peculiarly adapted for the transmission of water in the living tree. Fibre tracheids are infrequent in the Western Australian Eucalypts.

Interspersed more or less freely amongst the wood fibres and often grouped around the vessels are simple cells which have thin walls, and are only slightly elongated. These elements, which are known as wood parenchyma, have simple pits like the wood fibres.

All the above types of cells have, when in the tree, their long axes more or less vertical. The last class of wood element, the medullary ray, has its long axis at right angles to this direction and runs from the centre of the tree to the bark. The medullary rays in the Eucalypts are very small and numerous and are often indistinguishable to the naked eye. In both Karri and Jarrah, however, they can be detected on split radial faces, as a minute cross banding.

The vertical wood elements are either living in the sapwood or dead in the heartwood. The rays extend through the heartwood into the sapwood, and practically all have a living and a dead end. As the tree increases in diameter, the lengths of the rays increase. Since the horizontal spacing of the rays is more or less constant throughout the cross section of the trunk and since the tree increases in circumference with increase in diameter, new rays are continually being laid down. In a cross section of a tree, therefore, there are rays of all lengths from the just formed very short ones, to the primary rays which extend from the circumference to the pith or centre of the tree. A medullary ray does not, however, consist of a single cell: the individual cells of the ray are very similar to parenchyma cells but in the tree are laid in a horizontal instead of a vertical direction. Sometimes the ray cells have characteristic tracheid-like unevenly thickened cell walls.

Tylosis, previously referred to, as a secondary growth taking place during the transition from sapwood to heartwood, is very common in the Eucalypts. The choking of the lumen of the heartwood cells with secretions is also very often present, and with tylosis must undoubtedly tend to render difficult the movement of fluids through the timbers.

JARRAH.

The pores in jarrah are arranged irregularly throughout the cross section and are heavily tylosed and blocked by secretions. The wood fibres are thick walled with small cell cavities which are nearly always blocked by secretions. Sometimes the fibres are septate, that is they are divided into a number of shorter cells by transverse walls, which may resemble tyloses. The fibres are also in some cases slightly interlocked.

Parenchyma cells in jarrah are very rare or absent, but when present they have thin walls and an unchoked lumen.

The rays vary from about one to four cells in width and up to about 20 cells deep. Although tylosis is absent, the lumina are heavily blocked by secretion, particularly in the case of the central cells.

KARRI.

The pores in Karri like those in Jarrah are choked by tyloses and secretions and in a transverse section are often seen to have a more or less radial disposition. The fibres are interlocked to a much greater extent, but tyloses and secretions are absent. Parenchyma cells are common, particularly in association with the vessels, and have unchoked cell cavities. The rays are similar to those of Jarrah but they are generally small both in the size of individual cells and in the total size of the ray. The cells often have a tracheid-like uneven thickening of the wall and are always choked by secretions.

Upon the other timbers comparatively little work has been carried out. The relative importance of the different types of cells changes somewhat from timber to timber, while such features as interlocking of the fibres and choking of the lumina by secretions and tyloses vary between wide limits.

CHAPTER 3.

THE WOOD—WATER RELATIONSHIP.

It has been shown that a piece of Eucalypt timber is an extremely involved arrangement of different wood elements. These consist of a groundwork of cellulose, permeated with lignin, a substance or rather a collection of substances of complicated chemical composition. The cell walls formed of these materials have different types of pits and enclose cavities. In addition, there are secondary growths, secretions, colouring matter and water.

Where the presence of water in wood is permanent, its existence is not usually detrimental, but where change of moisture content is likely to take place, the consequences of this change are often so serious that the timber fails in the purpose for which it is being used. Seasoning is the removal of moisture from wood, until it reaches such a state that further preventable change will not take place, when the timber is used in the service for which it is intended. It may be mentioned here that under all natural conditions the wood retains some of its moisture, so that seasoning does not require the removal of all, but only of such a quantity that further avoidable loss will not take place. For example, it would be ridiculous to dry timber if it is to be used permanently under water, nor would it be more reasonable to dry material for furniture to the same extent if it were to be used in the comparatively cool, damp climate of the extreme South-West, as if it were required for the dry interior. The problem of seasoning is, therefore, the removal of a sufficient proportion of the water in wood, with as little deleterious effect such as warping, splitting, or cracking, as is possible.

Since reference will often have to be made to the quantity of water in a piece of wood, it will be necessary to define the moisture content of wood. In speaking of the seasoning of timber, reference is often made to the fact that a piece of wood loses a certain percentage of its weight. Such a description is very inconvenient, for the weight of a piece of wood is not a constant quantity, but varies with every change in moisture content. The weight of a length of timber at any instant consists of the weight of water present plus the weight of dry wood substance. Of these three weights, the first two must change with any change of moisture content, but the third, the weight of dry wood substance must always remain constant so long as the piece is not destroyed in any way. The weight of dry wood substance is therefore taken as the basis of moisture content percentages and is usually referred to as the "Dry weight" of the piece of wood. The moisture content of a piece of wood, therefore, may be defined as the weight of water present expressed in a percentage of the dry weight of the wood. For example, if a piece of wood weighs 125 lbs. and 25 lbs. of it are known to be water, the dry weight will be 100 lbs. and the moisture content 25/100 x 100/1 or 25 per cent. Similarly if a piece of wood weighs 75 lbs. and its moisture content is known to be 50 per cent., this 75 lbs. must represent 150 per cent. of the dry weight, which is therefore 75/150 x 100/1 or 50 lbs. It should be noted that the dry weight is not the air dry weight, or the kiln dry weight, but the weight of the timber with absolutely all the moisture, not chemically combined with the timber, removed. Kiln dry timber is usually at 8 per cent. to 12 per cent. moisture content and air dry timber at 12 per cent. to 15 per cent. moisture content or even higher.

For the purpose of convenience it is usual to consider water as existing in wood in two distinct ways: as water saturating the cell walls, called combined or hygroscopic moisture, and as moisture in the cell cavity, or free moisture. Consider then a single wood fibre. This fibre, in the green state, has moisture filling its lumen or cavity and moisture saturating its cell walls. If this cell is exposed to drying influences, some of the moisture is dried from the cell wall, but this is immediately replaced by water absorbed from the cell cavity. If the drying proceeds, the amount of moisture in the lumen becomes less and less until finally all has disappeared. This stage, when the water has all disappeared from the cell cavity but the wall of the fibre is still saturated, is called "Fibre Saturation Point." Normally, while there is still moisture in the cell cavity, drying produces no change in the physical and mechanical condition of the cell. After the free water has evaporated, however, and drying out of the water in the cell wall commences, shrinkage and hardening and strengthening of the cell are apparent.

Consider now a collection of cells or a piece of wood. If this piece of wood is in the green state, the moisture content will be practically constant throughout. Now if it is exposed to a mild drying influence, the free moisture in an outside cell is reduced, so that it is lower than that in an adjacent cell towards the interior of the piece. Moisture then tends to move from the cell of higher moisture content to the one of lower until equilibrium is established. This, however, lowers the moisture content of the second cell, and the cell adjacent to it towards the centre supplies moisture, and so on. Thus what may be termed a "Moisture Gradient" is established.

If the drying is continued very gradually, practically the whole of the free moisture in the piece of wood can be removed, before the outside cells dry below fibre saturation point. If, on the other hand, drying from the surface is very rapid, the moisture is removed from the cavity of an outside cell much faster than it can be supplied from the inner cells. The fibre saturation moisture therefore of the outer cell is used to supply the deficiency. With the removal of this combined water, there are the accompanying features of shrinkage, hardening, and reduced ability to transmit moisture. Under severe drying conditions a number of cells, from the surface inwards, may have lost a considerable amount of fibre saturation water and have hardened. These cells will tend to form a case of reduced penetrability to water. Continued drying from the surface will then not greatly affect the centre, but will tend to reduce even further the moisture content of the case cells. Thus the case will become harder and more resistant to moisture transmission.

Solely from the standpoint, therefore, of obtaining the greatest drying rate for the whole piece of wood, it will be evident that the moisture content of the surface cells must not be allowed to fall too much below that of the central cells, or in other words the moisture gradient must not become too steep. On the other hand, other things being equal, the greater the difference in moisture content between two cells, the greater will be the rate at which one transmits moisture to the other.

Between these two contrary influences a balance must be struck to obtain the maximum rate of moisture transmission.

In practice, however, there are other factors to be considered. It has already been shown that in a piece of wood with a steep moisture gradient the outside elements may be below fibre saturation point, while the inside cells still contain free moisture. As drying continues, the outside cells, if they were unrestrained, would harden and shrink, because combined moisture is being removed. Harden they can, but in shrinkage they are restrained, for the central portion of the wood being still above fibre saturation point tends to retain its original dimension. The outside cells harden, therefore, in a stretched condition. In other words, the hard case of the wood consisting of these cells is larger than it would have been if their shrinkage were unrestrained. If this restraining of the cells from shrinkage is greater than they can stand, checks or cracks occur. Surface checks are therefore an indication that the drying is too severe in the early stages.

If drying of the piece of wood under consideration is continued, there will come a stage when the central portion will have lost all its free moisture, and, with the drying of its hygroscopic moisture, shrinkage will tend to occur. The central fibres will not, however, be able to shrink as much as they desire, for the stresses of the initial stages of drying have resulted in this material being surrounded by a too large case of hard, dry wood. The central cells in their restraint from shrinkage tend to compress the case and close the surface checks which were formed during the early stages of drying. This closing of surface cracks is a normal feature of the later stages of drying of timber which received too severe treatment at the commencement of drying. If, however, the stretching of the case were very severe, or if the drying of the central portions were very rapid, the restraint to shrinkage of the central cells would be more than the structure of the wood could withstand and cracks would form inside the wood. This is known as "Internal Checking," or, in very bad cases, as "Honeycombing."

In the condition described above, the outer layers of the timber are subject to compressive stress and the inner layers are in tensile stress. The severity and extent of these stresses is such that they balance one another, and the piece of timber as a whole is in a state of equilibrium. This condition of stress is known as "Casehardening." If, however, a casehardened piece of timber is sawn in half longitudinally, the state of equilibrium is destroyed. Each half consists of a board of timber with compressive stress on one side and tensile stress the other. Now if the cause of compression is removed from a material it tends to expand. For example, a squeezed sponge when the pressure is removed increases in size. Also a stretched material, or one subject to tensile stress, contracts when the stress is removed. For example, a stretched piece of rubber contracts when released. Hence the compressive or "out" side of each half of the original board tends to swell and the tensile or "in" side tends to contract. The two halves, therefore, warp into arcs of circles, the concave sides being the original inside of the timber, *i.e.*, the surfaces formed by the dividing cut. The presence of casehardening in a board of timber may thus be recognised by reducing the board by one longitudinal cut through the centre into two thinner boards and noting the behaviour of these boards immediately after cutting.

It should be recognised that it is not necessary for the board to be sawn in two to upset the equilibrium of the forces in the timber. If one side is planed, sufficient compressive material may be removed to upset the balance, and cupping towards the planed face will result. Similarly, if both faces are surfaced but from one is removed more timber than from the other, movement may also occur. Casehardening, therefore, is a very undesirable feature in seasoned timber which is to receive further treatment such as resawing or planing.

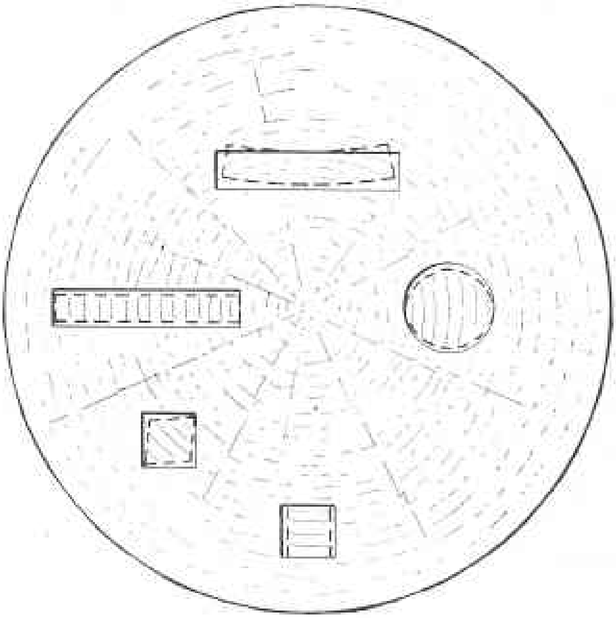
SHRINKAGE.

It will be evident that shrinkage is a most important feature in the behaviour of timber in seasoning and that further consideration is warranted. Consider, therefore, the behaviour of a single wood element, say a fibre. When this fibre is in the green state the cell walls are saturated with moisture and moisture is also present in a free state in the lumen. As drying commences the free water gradually disappears from the cavity, but no other change takes place at this period. When fibre saturation point is reached the cell still has its original dimension and no alteration of condition other than loss of free water has taken place. As soon, however, as the hygroscopic moisture commences to dry from the cell, stiffening, hardening and shrinkage of the fibre are apparent. These effects continue so long as drying proceeds, providing of course that the medium producing the drying has no destructive effect upon the fibre. If the shrinkage of this wood element is studied carefully, it will be found that although reduction in the width and thickness takes place there is no appreciable change in length. This peculiar difference in behaviour between the small and the large dimensions of the fibre is due apparently to the structure of the cell, but the immediate cause has not definitely been determined.

If the drying of a collection of cells, *i.e.*, of a piece of wood is considered from the green state, no shrinkage will be noticed until some of the cells fall below fibre saturation point. In other words if all the cells in a piece of wood were reduced to fibre saturation point together, no shrinkage of the piece would take place during this process. When a commencement is made on the drying out of the combined moisture, shrinkage is immediately apparent. Incidentally it may be mentioned here that it is because of the difficulty of drying all cells down to fibre saturation point together that shrinkage and, what is probably more important, shrinkage stresses and strains, in cells still above fibre saturation point are produced. This tends to disguise the fibre saturation point and has been responsible for a disinclination on the part of some observers to accept its existence. As would be expected, shrinkage in length, *i.e.*, para'lel to the axes of the fibres and vessels, is rarely appreciable, but, contrary perhaps to expectations, after a cursory examination, the shrinkage is not equal in all directions in the cross sectional plane. The shrinkage in the radial direction or across the annual rings is much less than that in the tangential direction or along the annual rings. Thus a quarter or radial cut board shrinks less in width than a tangential or back cut board. The reason for this behaviour will be clear from a consideration of the structure of the wood. It has already been mentioned that in addition to the main series of cells, the vessels and fibres, which have their axes more or less vertical in the standing tree, there is another set, the rays, which have their axes at right angles to those of the vessels and fibres. The axes of the rays are more or less in a horizontal plane in the standing tree, and they extend in a radial direction. These rays, which during the seasoning of the timber tend to retain their original length (*i.e.*, their end shrinkage tends to be negligible), restrain the shrinkage of the wood in the radial direction. Hence the shrinkage is greater along the annual rings than across them.

While this differential shrinkage in radial and tangential directions does not at first sight appear to be of great importance, it has yet a much greater effect upon the ultimate shape of a freely shrinking piece of timber than is generally recognised. For example, a scantling of square cross section tends to shrink to a rectangular or rhomboidal form, while boards other than those cut on the quarter tend to show a greater or lesser amount of curvature depending upon the inclination of the board face to the direction of the annual rings. Thus when back cut boards are produced in a flat state after seasoning, they have been subjected to artificial restraining influences which have prevented the curvature which would naturally occur.

Fig. 1 shows the effect of differential shrinkage upon the shape of unrestrained pieces of timber from different positions in the cross section of a log.



EFFECT *of* DIFFERENCE BETWEEN RADIAL & TANGENTIAL SHRINKAGE

FIG. 1

When it is realised not only that restraint by the medullary rays reduces shrinkage in a radial direction and that in the production of a flat tangentially cut dry board normal shrinkage must in some parts be reduced and in others increased in the prevention of the natural tendency to warp, but also that in instances where casehardening is present there are considerable variations in the shrinkages of different portions of the timber, it is not surprising to find that the shrinkage of any particular piece of timber is not a quantity which can definitely be stated in any constant terms, and which is dependent entirely upon the structure of the timber, but is something which can vary between fairly wide limits according to the treatment received during the drying process. A simple confirmation of this can be obtained by taking a piece of green 12in. x 1in. jarrah board, drying it *rapidly* until about 30 per cent. moisture content is reached, then sawing it into, say, three 12in. x ¼in. panels and allowing these to dry under sufficient restraint to prevent warping. Incidentally when the board reaches 30 per cent. it is not essential to resaw the whole of the board, but a short length, say, ¾in. long, cut well clear from an end, can be obtained, and sawn into three pieces in such a way as to produce three representative lengths of panel about 12in. x ¼in. but only ¾in. long. It will be found that when the three panels are thoroughly seasoned, the one obtained from the centre of the section will be much narrower than the others, and in some cases this difference in width may equal half an inch or more. The reason for the final difference in shrinkage is of course due to the fact that the external layers of the timber, owing to the rapid drying, set in a stretched condition as pointed out in the explanation of casehardening. As these layers are well below fibre saturation point in moisture content, the inside and outside panels can be considered as two distinct panels of timber both of the same width, but one nearly dry while the other is still above fibre saturation point. Naturally the green or inside panel shrinks more than the outside. A further experiment is to place a green board so that drying from the upper and lower faces is uneven. This can be done by putting the board in such a location that the upper surface is exposed to the sun's rays and the lower surface has a circulation of air under it. At first the board cups upward owing to the greater drying and shrinkage of the exposed face. After a while, however, the board straightens and then becomes concave downwards. This is due to the fact that the shrinkage of the upper surface was restrained in the early stages by the rest of the board, so that it set in a condition with a shrinkage less than normal. Uneven drying of opposite faces of a piece of timber is therefore likely to cause warping, and must be avoided.

Besides varying in different directions and according to the treatment during seasoning, shrinkage also varies from tree to tree and in different portions of the same tree. Any figure given for the shrinkage of a timber, for example Jarrah, is not of much value unless the figure is known to be the average of a considerable number of pieces and unless the conditions of drying are known. Maximum and minimum values for any class of timber are, of course, often of greater value, but here again is there necessity for a large number of observations to provide figures of value.

Sometimes in the drying of a piece of wood it will be noticed that in the early stages of drying the radially cut surface develops a number of parallel depressions, the whole effect resembling a very irregular washboard. This condition is spoken of as "Collapse."

Collapse is known to be different from ordinary shrinkage and it has been suggested that it is due to a falling in of the cell walls when water is removed. The cell is considered as being analogous somewhat to a canvas firehose which, when full of water, is distended, but which, when the water is removed, collapses to a flat state. The force, however, required to produce the failure of a cell would need to be very much greater than the atmosphere pressure responsible for the flattening of the hose. It has been further suggested that this force is supplied by the surface tension of the water. In other words, when water is removed from a cell cavity, which was originally full, if air cannot enter to take its place, the water tends still to fill the lumen of the cell. Since the water cannot expend to any appreciable extent, to accomplish this it tends to draw in the cell walls, thus causing collapse. It has been estimated that surface tension under favourable conditions can be responsible for a stress of many hundreds of lbs. per square inch, so that it would appear that here is a possible explanation for this feature of drying.

On the other hand, it must be remembered that the cell must be completely filled with water for this force to be exerted. Thus, while this condition of completely filled cells is likely to result from the high initial moisture content (200 per cent.) of such a timber as the American Western Red Cedar, from tests on which the theory was evolved, it must be taken into consideration that many of the timbers affected by collapse have initial moisture contents only as high as 70 per cent. to 90 per cent. In the case of Karri, one of the Western Australian timbers comparatively susceptible to this fault, the initial moisture content is usually in the neighbourhood of 70 per cent. or 80 per cent. From a study of density figures, and the structure of the wood, it would appear that the lumen of the cells of this timber are on an average filled with water to about 50 per cent. only of their capacity. Unless, therefore, the free water is distributed very unevenly throughout the cells, some cells or cell types being filled to capacity, others practically empty, it is difficult to see how the theory of surface tension is applicable. Since, however, the rate of moisture transmission in these timbers is comparatively low, and practically always when seasoning, the outside layers are well below fibre saturation point while the centre is still very high in moisture content, the stress producing collapse might be provided by the external compressive force on the inner cells caused by the shrinkage of the surface layers. That shrinkage stresses could be sufficiently great to produce this failure of the cell walls seems very probable.

It has been mentioned that collapse is distinct from ordinary shrinkage. One of the most prominent differences between the two types is that shrinkage due to collapse can in nearly every case be removed. This is effected by subjecting a collapsed piece of timber to wet steam until it reabsorbs moisture to a sufficient extent to raise its moisture content slightly above fibre saturation point. During this process the timber swells and the irregularities of form due to collapse disappear. During subsequent drying the washboarding effect does not appear and the total shrinkage to the seasoned state is less than it was originally. Tests have shown that the steaming treatment permanently removes collapse from a piece of timber, providing the treatment is carried out when the timber has been reduced to fibre saturation point or below it. Steaming above fibre saturation point will not remove collapse.

It has been stated that wood cells do not tend to shrink until all free moisture has been removed from the cell cavity. In the case of the Eucalypts this contention is not correct, for if the behaviour of a jarrah board, for example, is noted, it will be found that during the early stages there is a shrinkage apparently greater than can be accounted for by the fact that some of the outside cells have fallen below fibre saturation point, and in tending to shrink are compressing the remainder of the board. There is every reason to believe that this initial shrinkage of Eucalypts is not a true shrinkage, but is due to some other action. It is generally considered that this initial shrinkage is a form of collapse, but while it certainly has features in common with the irregular shrinkages known by that name, the connection has not been definitely proved. On the other hand, it has been considered by some that this initial shrinkage indicates that the Eucalypts have not a fibre saturation point like other woods, and that the shrinkage is, therefore, an indication that the free and combined water both commence to dry out from the inception of seasoning. This opinion is destructive rather than constructive, for while it discards the fibre saturation idea which explains many of the features of the behaviour of the Eucalypts equally as well as with other timbers, it provides no substitute.

If it is assumed that the shrinkage in the early stages of drying indicates the loss of combined moisture, it would be expected that Eucalypts would show improvement in their strength properties during the early stages of drying. From determinations of the strength and moisture content relationships of West Australian Eucalypts, it would appear at first sight that this is so, but the increase in strength is probably more apparent than real and due to the standards of calculation. Suppose, for example, a piece of green jarrah 1in. square is taken which will support a maximum load of 13,500 lbs. in tension. The tensile stress as calculated would be 13,500 lbs. per square inch. If this piece were dried down to fibre saturation point, even although it would still support no greater load than

13,500 lbs., if it shrank its apparent strength would increase. For example, if it shrank to 0.91 square inches cross sectional area, the calculated strength would be 15,000 lbs. per square inch, although the piece of timber is actually no stronger. Hence, it will be seen that any shrinkage, whether it be accompanied by an actual increase in strength or not, will result in an apparent increase in strength of the timber in question. In the case of jarrah, such shrinkage data available has, when combined with the moisture content-strength data, indicated that this increase in strength of jarrah with drying above fibre saturation point is only apparent, and that the shrinkage, therefore, is occurring irrespective of any change in the mechanical properties. Further evidence on this question would be very desirable.

As the shrinkage of a piece of wood varies in the length and tangential and radial faces, so also does the rate at which moisture is transmitted in different directions vary. As would be expected, cells transmit moisture more freely along their length than across their breadth, and for this reason drying from the transverse end of a piece of timber takes place more readily than from a longitudinal face. Unfortunately, except where very short pieces of timber are being dried, advantage cannot be taken of this property; in fact under many circumstances it becomes a disadvantage. The tangential face of a piece of timber has, however, exposed on it the ends of the ray cells, and as these assist the transmission of moisture in a radial direction, it will usually be found that under similar conditions the rate of drying of a back cut board will be greater than that of a quarter cut, for in the latter board water must be transmitted across the rays instead of along them.

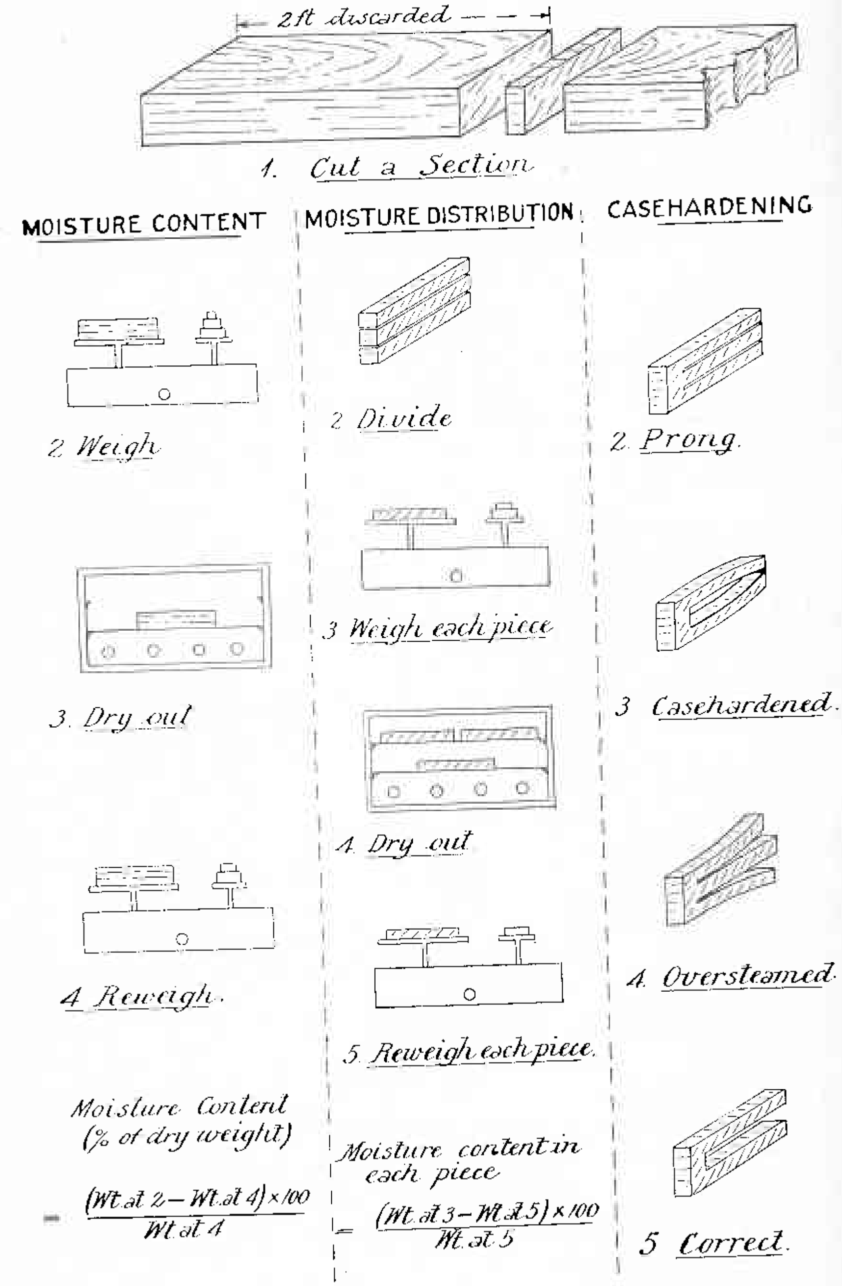
Particularly in cases where ends are exposed more than sides, the end drying of wide boards or heavier timber often results in end checking or "popping." This is due to the fact that the cells at the end of the board, as a result of drying, tend to shrink to a smaller dimension. In this they are restrained by cells farther from the end, which tend to force them to retain their original dimension. If the stresses resulting from these two contending forces are too severe, one or more end checks commence, and these, as end drying proceeds, extend for a variable distance along the length of the board. The cure for end checking is to prevent the exposure of ends, or, where such a course is insufficient or impracticable, to coat the ends with some material which will prevent or greatly reduce end drying. For air seasoning, paraffin wax is one of the best materials available, but as this must be applied hot, some substance such as crude petroleum jelly, which can be applied cold, is usually used. In the kiln, special end paints similar to those suggested later for the ends of sample boards, are necessary on account of the high temperature.

TESTS TO DETERMINE THE DEGREE OF SEASONING IN ANY PIECE OF TIMBER.

Moisture Content.

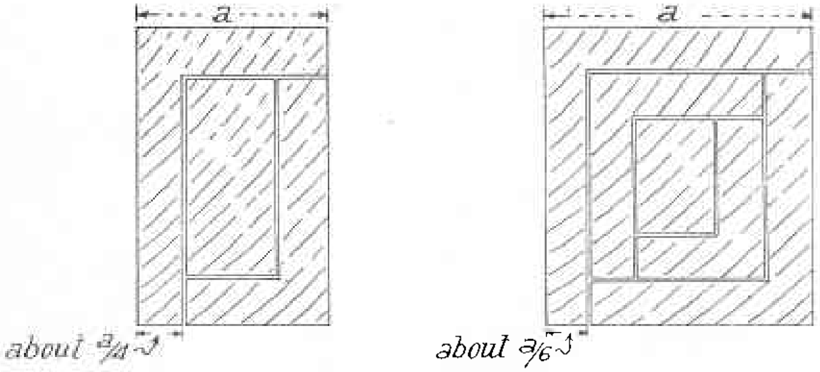
Moisture content is defined as the ratio of water to the ratio of dry wood substance in a piece of wood expressed as a percentage. To determine a moisture content it is therefore necessary to find out the amount of water present in a piece of wood and the oven-dry weight of the wood. If then a piece of wood is weighed, oven-dried and reweighed, the amount of moisture present is given by the loss of weight. In practice it is not convenient to dry out a whole piece of wood, so a representative section only is taken for the determination.

A typical procedure would be as follows:—A section about ½in. to ¾in. long is cut from the piece to be tested, loose fibres and sawdust are removed, and it is weighed on a chemical balance or other weighing mechanism with an accuracy of

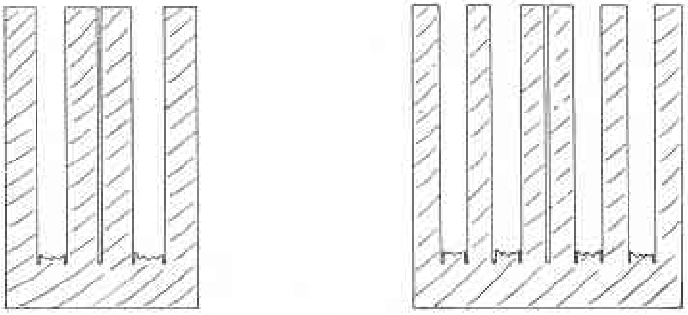


SEASONING TESTS
FIG. 2

approximately 1 in 1,000. Suppose the weight is 97.3 grammes.: the piece is then placed in an oven heated to a temperature of 212° F. to 220° F. and dried until no further loss of weight takes place. This normally requires from 24 to 48 hours. Suppose this dry weight is 87.2 grammes: the moisture present will weigh 97.3 — 87.2 or 10.1 grammes, and the moisture content is, therefore, 10.1 over 87.2 multiplied by 100, or 11.6 per cent. Care must be taken that moisture content sections are weighed immediately after cutting, for, owing to their short length, end drying causes rapid loss of weight. In cutting the section it is necessary to discard 18in., or with thick material, 2ft., in order that a portion unaffected by end drying may be selected for the test.



Moisture Distribution



Casehardening

THICK STOCK

FIG 3

Sometimes it is necessary, in addition to knowing the average moisture content of the piece, to find out the moisture content of the outside and centre. In the case of 1in. timber this is done by cutting a section about 1in. long with the precautions mentioned above and then slitting it by two saw cuts parallel to the original board faces into three strips each about ¼in. thick. Each of these three pieces is weighed, dried and reweighed, so that the moisture percentages of the outside and inside can be calculated. For thick stock the section should be cut into zones, as shown in Fig. 3. In the case of the outer and intermediate zones, the two pieces can be weighed together to give an average moisture content determination of the whole zone.

Casehardening or Prong Test.

A casehardened piece of timber is popularly known as a piece in which the outside is harder than the centre as the result of excessive drying of the surface at some stage in the seasoning process. Casehardening is also the name given to a condition of stress brought about by too great an initial drying rate, which results ultimately in the central portion of the wood being in a state of tension and the outside in compression. It is to this latter definition that reference is made when speaking of the casehardening or prong test, for this test is devised to detect the presence of these stresses.

A piece of casehardened wood, although under the influence of two sets of stresses, is in a state of equilibrium. The presence of the stresses is demonstrated by upsetting this state. For example, if the central portion of a casehardened board is removed the outside will expand, and if the outside is removed the centre will contract A more spectacular result can, however, be obtained by cutting the wood in such a way that the stresses on opposite faces of the pieces produced are different. For example, if a casehardened board is ripped into two thinner boards each outer face, which was originally in compression, will expand and each inner face, which was originally in tension, will contract until equilibrium in each of the two halves is established. The original outside face of each half will become convex and the contracted or inside face will be concave. This slitting of a piece into thinner pieces virtually constitutes a prong test, although it is usually more convenient, except in very thin timber, to increase the number of saw cuts.

A typical prong test of a board for casehardening would be as follows:—A section about ½in. long is cut about 2ft. from the end, as for a moisture content test, and this section is then slit by two saw cuts running parallel to the original board faces. The cuts are stopped about ½in. from the end of the section to leave the three prongs thus formed bound together by a piece of wood. The centre prong is broken out and the behaviour of the two outside prongs noted. If the prongs remain straight or incline towards or away from one another to a small extent, the timber is not casehardened and the stresses present are not sufficient to be deleterious. If, however, the prongs nip in and bind on one another, the timber is casehardened. Casehardened timber during a kiln seasoning process should be subjected to steaming or high humidity treatment until a good prong test is obtained. If a casehardened state is found in timber which has been tested as a preliminary to utilisation the timber should be rejected, unless it is to be used in such a way that the presence of casehardening is immaterial. Such timber can be corrected by a steaming process, but as this is usually a somewhat expensive procedure once timber has been unloaded from the kiln, it is more usual to stack the timber for further air seasoning until a sufficient time has passed for the stresses to be alleviated. Fig. 2 shows diagrammatically the average moisture content, moisture distribution, and casehardening tests.

If a band saw is not available the pronging of a section can be facilitated when using a hand saw by placing the section on top of a piece of ½in. board as a support and by cutting both section and board, or by making previously a saw cut in the ½in. board. It is sometimes convenient, when cutting with a hand saw, to make the section less than ½in. long. As drying of the section is not so deleterious as in the case of moisture content tests, such practice is allowable. For timber thicker than 1 or 1¼in. it is usual to increase the number of saw cuts, for it is then possible to obtain a better idea of the distribution of stresses. Fig. 3 shows prong tests of thick stock.

It is absolutely essential when making casehardening tests that the timber should be in a state of temporary equilibrium as far as its physical condition is concerned. For example, carehardening tests are sometimes taken on timber recently removed from a hot kiln. Such tests are worse than useless, for temperature effects lead to erroneous indications in the behaviour of the prongs. If a test is to be made on hot timber the necessary test pieces should be selected and allowed to cool down before test sections are cut. If it is undesirable to return cold test pieces to the kiln, short lengths of about 6 or 8 inches can be cut from them, away from ends, the test pieces being returned immediately to the kiln; the prong sections can be cut from the middle of the short lengths after they have cooled. In experimental work in Western Australia it has been usual with 1in. timber to allow 24 hours cooling outside the kiln before pronging. This has been found to give consistent results, but a shorter period may be sufficient. It must be remembered, however, that timber in the stack cools very much more slowly than individual pieces. In air seasoning tests, seasoned timber which has become wet and has increased in moisture in the outside layers has often been found to give a pronounced casehardening prong. In this case the condition of the timber could be corrected by redrying the absorbed moisture. It will be seen therefore that, while the casehalrdening test is a very valuable one, it must be used with intelligence or erroneous conclusion may be drawn.

In the early stages of the drying of a piece of wood, when the outside cells have been dried below fibre saturation point and the inside is still very green, the prongs of a casehardening test section may spread or bend outwards. This is due to the fact that the outside in tending to shrink is in a state of tension, while the inside is compressed in opposing this tensile force. Upon cutting, the original faces of the board contract and cause the opening out of the prongs. As drying of a piece of wood proceeds from this state, the moisture content of the centre becomes lower and shrinkage of this portion becomes appreciable. A state will then be reached in which casehardening test will give straight prongs. This usually occurs in one-inch jarrah when the moisture content is between 30 and 40 per cent. If drying of the piece proceeds continuously further casehardening tests will give prongs beginning to nip, this nip increasing as the timber becomes drier unless preventive measures are taken.

Sometimes a dry piece of timber when cut will have opening prongs. A slight opening is a common feature of air seasoning boards from which moisture absorbed by the surface layers as a result of wetting has recently been redried. This opening is not sufficient to indicate an unsatisfactory condition of the timber. If, however, in kiln drying, heavy reabsorption of moisture by the outer layers of the timber takes place during a steaming process, subsequent drying off of this water may tend to cause shrinkage of the surface and result in tensile stresses sufficient to cause a wide divergence when a section is pronged. This is a very unsatisfactory condition and is usually known as "Oversteaming" or "Reversed Stress." If severe it may have as deleterious effects in utilisation as casehardening, with the additional disadvantage that it is harder to remove. It can be removed by prolonged steaming and redrying, but the more economical method would probably be to stack for air seasoning until the stress disappeared to a sufficient extent.

A useful practical application of the prong test is in a rough determination of moisture distribution. If a pronged section, without any of the central prongs removed, is placed in a warm dry place, further drying and shrinkage of the timber will occur. If the central portion is higher than the outside in moisture content, the central prongs will shrink to a greater extent, and *vice versa*. If, therefore, after drying there is a marked difference between the length of the prongs, it is an indication that the moisture distribution is uneven. Sometimes when the distribution is uneven in the outer layers the outside prongs will curve, and in some cases this curvature may be sufficiently great to fracture a prong at its base. The fact that prongs upon further drying can simulate the casehardening prongs is an indication that in making a casehardening determination the condition of the prongs must be noted soon after cutting, before drying of an uneven moisture distribution can affect their shape.

CHAPTER 4.

THE EVAPORATION OF WATER FROM WOOD.

Before considering the evaporation of water from wood it will be advisable to consider the simple case of evaporation from the surface of water. Take for example the case of a boiler, in which the pressure is maintained at atmospheric and the steam and water are in equilibrium, that is, no boiling is taking place. The temperature of the water and of the steam will then be 212°F. If the water in the boiler is heated, so that its temperature is raised slightly, some of the water will be turned into steam. The amount of water evaporated will be in proportion to the amount of heat added; in other words for every pound of water evaporated approximately 1,000 British Thermal Units must be added. (One British Thermal Unit or B.Th.U. is the amount of heat required to raise 1 lb. of water 1°F.) It should be noted that the 1,000 B.Th.U. are not expended in raising the temperature of the water or of the steam, but solely in changing water from the liquid to the gaseous state at the same temperature. This quantity is therefore called the heat of vaporisation of water or usually the latent or hidden heat of steam.

Now suppose that the pressure in the boiler is raised and maintained at some higher figure, for example, 20 lbs. gauge. The temperature of the steam and water will now be 258°F. If heat is added as before, water will be evaporated, but the same proportion as before will approximately be maintained, namely, 1 lb. of evaporation per 1,000 B.Th.U. added. Similarly if the boiler pressure is reduced and maintained below atmospheric, for example, at slightly below 1 lb. pressure absolute, the temperature of the steam and water will then be about 100°F., but approximately the same evaporation proportion will remain. In other words, it will require about 1,000 B.Th.U. to evaporate a pound of water and no evaporation will take place at this pressure unless the temperature of the water is raised above 100°F.

It will be seen that for evaporation to take place the temperature of water must be raised above that of the water vapour in contact with it, and for every 1 lb. of water to be evaporated, approximately 1,000 B.Th.U. must be supplied to the water to provide the latent heat of the vapour. The fallacy of the idea that evaporation of water can be continued indefinitely simply by maintaining a high vacuum will thus be readily appreciated. The effect of the vacuum is simply to lower the temperature at which evaporation takes place.

In these considerations, the water vapour or steam has been saturated, that is, it is in that state in which cooling, however slight, would immediately result in the commencement of condensation. If the water vapour or steam is not saturated, *i.e.,* it is superheated, the amount of heat in this superheat is available for transfer to the water with consequent evaporation, until the steam is reduced to the temperature of the water in a saturated condition. Drying with superheated steam at atmospheric pressure, while it has been found to have appreciable advantages in connection with the drying of some softwoods, results in the employment of temperatures so high that they are likely to have a serious deleterious effect upon timber such as the Eucalypts, and it is therefore unnecessary to consider this method further here. There is, however, another method of evaporation which fulfils all the requirements enumerated above and this is by replacing the water vapour in contact with the water, with a mixture of water vapour and air.

Take the case of the boiler under 1 lb. pressure absolute. If air is admitted to the boiler at atmospheric pressure it will be found that the quantity of air and water vapour establish an equilibrium with one another. The atmospheric pressure is now made up of two partial pressures, the one the partial pressure of the water vapour which remains at 1 lb. per square inch absolute, and the other the partial air pressure which makes up the balance of the 15 lbs. atmospheric pressure, viz., 14 lbs. per square inch absolute. The quantity of water vapour present is the same as it would be if there were no air present at all. If now the water is heated, as soon as its temperature commences to rise, evaporation will take place. The rate of evaporation will, however, be slower owing to the presence of the air. Moreover, as with water vapour alone, so with air, it is not necessary to apply the heat directly to the water. As the steam was superheated, so can the air be heated and by imparting this heat to the water provide the heat for vaporisation. Since the presence of air complicates matters somewhat it will be advisable before going further, to study the relationship between water vapour and air.

Consider again the case of the boiler at 100°F. The pressure of water vapour in the boiler at this temperature was stated to be 1 lb. per square inch absolute, but it can more accurately be given as 1.93 inches of mercury where 29.92 inches represents the height of the barometer at normal atmospheric pressure. Since the water vapour and water in the boiler are in equilibrium the space above the water in the boiler has as much water vapour as it can carry at this temperature. Now when the air is introduced into the boiler, the quantity of water vapour present remains the same, and this quantity is the maximum which the space and hence the air can carry at this temperature. This air is then said to be saturated. If this saturated air, maintained at atmospheric pressure is cooled it will immediately commence to deposit moisture, as dew is deposited by cooling of the atmosphere. The temperature of saturation is therefore said to be the "Dew Point." On the other hand if this air saturated at 100°F. is heated, for example to 140°, but is maintained at atmospheric pressure, the partial pressure due to the original water vapour will still be 1.93 inches. The vapour pressure of boiling water at a temperature of 140°F. is, however, 5.88 inches, and if air were saturated at 140°F. it would contain sufficient vapour to produce this pressure. Since it contains only enough vapour to produce a pressure of 1.93 inches. it is said to be unsaturated, and the degree of saturation is measured by the percentage relationship between the water it does contain and the water it can contain when fully saturated. As these quantities are proportional to the vapour pressures, in this case the percentage relationship is 1.93/5.88 x 100/1 or 33 per cent. This relationship is called the *Relative Humidity*. The term relative humidity is often contracted to "Humidity," although humidity strictly speaking is the weight of water present per unit of volume of air. Obviously saturated air or air at its dew point at any temperature has 100 per cent. humidity, and thoroughly dry air 0 per cent. humidity.

Suppose now a quantity of this air at 140°F. and 33 per cent. relative humidity is taken and passed over water at an initial temperature, for example, of 140° F. Since the air is not saturated, evaporation will take place, part of the heat required for the latent heat being supplied by the air and water vapour and part by the water so that both are cooled. If this process of supplying air at 140°F. and 33 per cent. relative humidity is continued, the water will fall in temperature with a decreasing rate until a constant temperature is reached. All the heat for vaporisation is now being provided by the air and its moisture, and the air besides cooling itself is absorbing moisture. If the air were being cooled without the absorption of moisture, it would become saturated at its dew point, 100° F. If it were absorbing moisture without cooling it would become saturated at 140° F. In this condition of spontaneously cooling and absorbing moisture it will become saturated at some temperature intermediate between the dew point and its original temperature. This intermediate temperature is called the Wet Bulb Temperature, because it is measured by the temperature of a thermometer placed in the air stream under investigation, the bulb of the thermometer being maintained in a wet state. The Wet Bulb temperature in the case quoted above would be 106° F. It will be noted that to obtain the correct Wet Bulb temperature it is necessary to have a continuous stream of the air over the water being considered. In using a Wet Bulb thermometer, therefore, the precaution must be taken of providing a sufficient circulation of air past the bulb. For accurate work an air velocity of 15ft. per second is necessary, but velocities much less than this give sufficiently accurate determinations for kiln work.

As Relative Humidities and Wet and Dry Bulb temperatures are of considerable importance in problems of seasoning, a chart for determining the relationship between these factors is included at the back of this Bulletin.

The relative humidity can be determined if the ordinary air (dry bulb) temperature and either the wet bulb temperature or the saturation temperature are known.

Having considered the evaporation of absolutely free water, it is now necessary to study evaporation from the surface of a piece of wood. While the uncombined moisture is being dried from the surface of a piece of wood, the process is practically the same as evaporation from the surface of water. Thus heat must be supplied to the wood from unsaturated air, and the timber remains approximately at the wet bulb temperature. Below fibre saturation point an additional factor enters. Wood has an affinity for its combined moisture and must be made to part with it. This affinity increases as the moisture content becomes lower. Hence in drying below the fibre saturation point the temperature of the wood rises above the wet bulb, the discrepancy increasing as the moisture content decreases.

The features to be noted are that to dry a piece of wood it is necessary to have air with a humidity below 100 per cent., and that, the lower the humidity, the greater is the drying power of the air and the more rapidly does drying from the surface proceed.

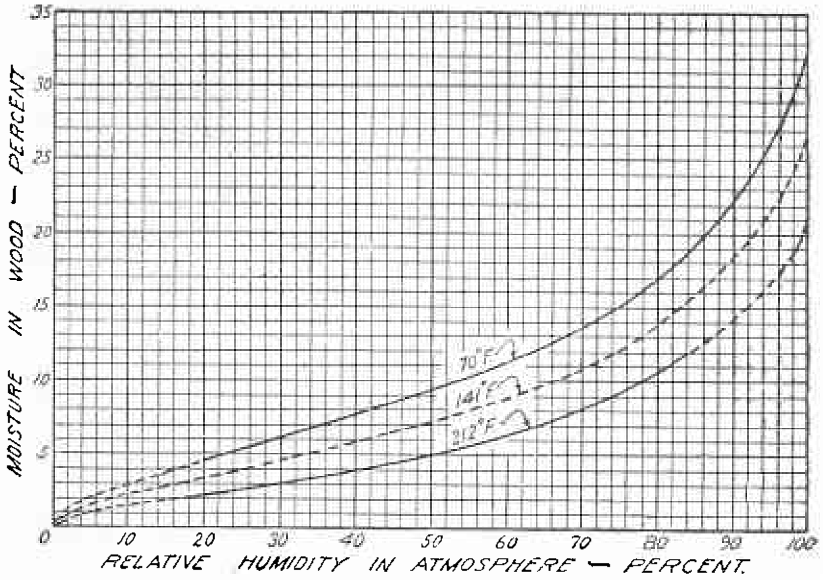
Circulation.

If a quantity of unsaturated air is allowed to remain in contact with a piece of green wood, it will take up moisture from the wood until it is saturated. Drying from the wood will then cease, and before it can be recommenced, providing no heat is available from outside sources, it will be necessary to remove the saturated air and substitute a fresh supply of unsaturated air. In other words, for drying to be continuous there must be a circulation of air over the surface of the piece of wood. To obtain some idea of the magnitude of the circulation which is necessary, the example can be taken of air at 140° F. and 33 per cent. humidity. This air, as mentioned above, can supply heat for vaporisation until it is cooled to its Wet Bulb temperature. To supply the heat required to vaporise 1 lb. of water (approx. 1,000 B.Th.U.) would require nearly 2,000 cubic ft. of this air. Moreover, while it would be desirable for maximum thermal efficiency to utilise the air until it were saturated, in actual practice only in some cases can this ideal be closely approached, so that generally the quantity of air required at 140° F. and 33 per cent. relative humidity would be far greater than 2,000 cub. ft. It will, therefore, be realised that circulation is a most important factor in atmospheric drying.

Temperature and Humidity.

The conditions necessary for drying of the surface of a piece of wood to commence and to continue have been studied. It has also been shown, when considering the transmission of moisture from the centre to the surface, that for the drying rate of the piece as a whole to be a maximum, the drying rate of the surface must be controlled, so that it does not exceed the rate at which moisture can be forwarded from the centre. The question of the method whereby the surface drying can be controlled now arises.

Previous mention has been made of the fact that in drying below fibre saturation point wood shows a greater disposition to retain its moisture, and more severe conditions are necessary in order to effect drying. This affinity of wood for moisture is called "hygroscopicity," and is a property by no means restricted to wood alone. The dampness of sugar and common salt, and the clamminess of cotton goods when the atmosphere is very moist, are all evidences of this property. If a piece of wood of moisture content slightly below fibre saturation point is placed in a closed container filled with dry air, under suitable temperature conditions, some of the moisture in the wood will be evaporated and will pass into the air. If, on the other hand, a piece of thoroughly dry wood is placed in a container full of moist air, the wood will absorb moisture from the air. In other words, wood and air share their moisture according to their relative moisture con-



From Bulletin 1136, U.S.A. Department of Agriculture.

Relation between the moisture in wood and the relative humidity in the surrounding atmosphere at three temperatures. Solid lines are based on actual data.

Fig. 4.

tents and their relative affinities. For example, air at 70 F. and 50 per cent. relative humidity will balance with wood at approximately 10 per cent. moisture content. Temperature is a complicating factor, for, if the relative humidity is kept constant but the temperature is increased to some higher figure, the moisture content of wood which is at balance with these new conditions will be lower. Fig 4 shows how temperature, relative humidity, and the moisture content of wood are related. It will be noted that by increasing the relative humidity at any given temperature the balance moisture content of the wood, or the moisture content at which it can be dried under those conditions, is raised, and by lowering humidity at the given temperature, the balance moisture content of the wood is lowered. Hence it is possible by regulating temperature and humidity to control the moisture content to which the surface can be dried.

Temperature.

Besides having an effect upon the balance moisture content of wood, temperature has another very important effect upon the rate of seasoning. As the temperature is increased, timber becomes much more plastic. It is for this reason that material to be bent is heated by steaming or boiling. From the seasoning standpoint, the importance of the property is due to the fact that wood in its more plastic condition transmits moisture more freely, and so allows the moisture to be conducted from the centre to the surface at a greater rate. Other things being equal, therefore, the higher the temperature, the more rapidly the seasoning can be effected.

There are, however, limits to which the temperature of wood can be raised. In some timbers, the limit is imposed largely by the temperature at which destruction of some of the constituents of the timber commences, but in the case of the Eucalypts other factors impose a temperature far below this. In the first place, at high temperatures the accuracy with which the drying quality of the air can be controlled is decreased, and secondly, high temperatures have a very pronounced effect upon collapse. Collapse, as previously mentioned, is explained as being due to some external or internal force causing falling in of the cells, when the free water is being removed. It is obvious that, if this is the case, the process of making the wood plastic, besides having the desirable effect of increasing the possible rate of seasoning, will also have the deleterious effect of increasing the tendency to collapse. This property then may be the deciding factor in fixing the temperature at which drying of the timber is to take place.

The Three Essentials of Drying Control.

Now that the various factors influencing drying have been considered, the desirable conditions for the drying of a piece of wood can be studied. It has been pointed out that in the early stages of drying, while the timber is above fibre saturation point, the rate of drying must be retarded, so as to be comparable with the maximum rate at which moisture can be transmitted from the centre. While in the later stages, particularly when the necessary seasoning has neared completion, drying conditions must be made more severe, to overcome the affinity of the wood for moisture. The rate of drying at any given temperature, in the early stages, is retarded by limiting the amount of heat which is available for evaporating moisture from the timber. This limitation of available heat may be brought about in two ways. Firstly, the surface of the timber may be supplied with a small quantity of air at comparatively low relative humidity. This method will have the obvious disadvantage that it is possible for surface to be dried to an extent far below that desirable. A further practical disadvantage is the difficulty of controlling a low circulation within the desired limits. The second method would be to supply a large quantity of air with a low drying power, that is, a high relative humidity. Owing to the high humidity, the moisture content at the surface of the timber cannot fall far below fibre saturation point, for the balance moisture content for these conditions will be in the neighbourhood of 20 or 25 per cent. unless the temperature is very high. If the quantity of air is reduced by, say, 25 per cent., the rate of drying will not be greatly retarded, while if the rate of air circulation is greatly increased, the rate of drying will to all intents and purposes remain unaltered, for it will depend upon the rate of transmission from the centre. By the use of a high humidity, therefore, the drying in the early stages can readily be controlled.

Although below fibre saturation point the drying rate is very much lower than above, the problem of drying is comparatively simple. Providing drying in the earlier stages has been satisfactory, relative humidities considerably below the ideal do not result in serious stresses in the timber, and it is usual to take advantage of this, by employing comparatively dry air and reducing the circulation, with consequent heat economy.

For the best drying conditions throughout the seasoning operations, it is therefore essential that temperative, relative humidity, and circulation must be under control.

The question now arises, "How far are these conditions fulfilled in air seasoning?"

The atmospheric temperature in the vicinity of Perth varies from 40° F. to 100° F., although occasionally this range is exceeded. Moreover, it is not uncommon for the relative humidity to be as low as 20 per cent. and as high as 100 per cent. Often the low temperature is associated with the high humidity and the high temperature with the low humidity. The drying quality of the air therefore varies indiscriminately from nothing to a very high figure. The circulation of the air may vary from that resulting from a wind velocity of 60 miles per hour or more, to zero when the air is still, and this variation is more or less independent of the temperature, and humidity. Drying condition in the open air must therefore be regarded as very haphazard.

Unless due precautions are taken, timber is likely to be subjected to very severe drying conditions while the timber is still comparatively green; and in material other than quarter cut or narrow boards the shrinkage stresses may cause very deleterious cracking and warping. Even if dangerous drying conditions do not occur, the timber will be subjected to both short and long periods of idleness when temperatures and rates of air movement are too low, or relative humidities too high for drying to proceed. The time of drying is therefore unduly prolonged, and especially in the case of thicker stock this increases the hazard of encountering severe drying conditions before the timber is sufficiently low in moisture content to withstand them.

The extent to which the air seasoning of local timbers can be made satisfactory by suitable precautions will not be known until further investigation has been carried out, but data now available indicates that thorough drying by air seasoning alone of wide boards and thicker sizes is likely to be a procedure sufficiently costly to warrant the search for a better method. Since the variations of the atmosphere do not provide satisfactory drying conditions, it is not surprising to find that attempts have been made to place timber in a chamber insulated from the outside air, and to reproduce in this chamber conditions ideal for seasoning. This is what kiln drying amounts to, for a kiln is merely a room with special and more or less effective provision for the control of temperature, relative humidity, and circulation.

For theoretical purposes kilns may be divided into three classes, according to the pressure at which they are operated:—

(a) Kilns below atmospheric pressure.
(b) Kilns at atmospheric pressure.
(c) Kilns above atmospheric pressure.

In the case of kilns below atmospheric pressure, or vacuum kilns, it has already been pointed out that low pressure alone cannot cause drying, and that the heat required for the drying process must still be supplied to the timber. In the case of a small experimental kiln of this type the quantity of heat required for evaporation can, usually without difficulty, be supplied to the timber by radiation from the walls of the chamber, and by a suitable disposition of heating elements. With the design of a commercial unit, the problem becomes much more difficult. For economical working, a large quantity of timber must be stacked in each charge, but since wood is a fair insulator and will, therefore, not conduct sufficient heat from board to board, and since the disposition of heating elements for the supply of heat by radiation to each board is not now economically possible, other means must be employed. The usual method is to convey the heat to each board by means of the gas filling the kiln chamber, and this gas is largely water vapour with a small admixture of air. It has been pointed out that with air at atmospheric pressure heated from a saturated condition at 100° F. to 140° F. nearly 2,000 cub. ft. are required in order that the air and vapour in cooling to the Wet Bulb temperature 106° F. may provide sufficient heat for the evaporation of 1 lb. of water. If the case of a kiln working below atmospheric pressure filled with water vapour alone, with a vacuum of 27.6 inches corresponding to a boiling temperature of water of 106° F. is taken, then the quantity of water vapour superheated from 106° F. to 140° F. required to evaporate 1 lb. of water will be 23,000 cub. ft. The question of circulation in a vacuum kiln therefore becomes a very serious problem, and this, together with the additional cost of construction consequent upon the difference in pressure between the inside and outside of the kiln, has up to the present militated against the commercial success of this type of kiln. Thus it is that proposals for the exploitation of vacuum kilns, which on paper and on an experimental scale appear such excellent propositions, usually become a sink for money when commercial operations are commenced.

It may be mentioned in passing that the difficulty of conducting heat to the timber can be overcome by operating a kiln partially under atmospheric pressure and partially under a vacuum. The timber is heated at atmospheric pressure, or sometimes above atmospheric pressure, and is dried until cool under a vacuum, the process being repeated until the timber is at the desired moisture content. Such kilns have proved scientifically successful although they have not survived commercially, but the process has a commercial practical application in the steaming and vacuum treatment which is given timber as a preliminary to pressure process of timber impregnation for preservation, although the treatment in this case is usually carried out for a different purpose.

While drying above atmospheric pressure also has undoubted advantages, these are offset, as in the case of drying below atmospheric pressure, by the cost of construction and operation, so that this type of kiln has not yet proved a commercial success. The only class of drying, to which further consideration will be given in this book, is drying with the atmosphere modified only as regards temperature and relative humidity.

CHAPTER 5.

THE TIMBER SEASONING KILN—TYPES AND CONSTRUCTION.

A timber seasoning kiln has been defined as a chamber, in which provision is made for the control of temperature, relative humidity, and circulation. According to the degree of control which can be exercised over these three essentials, so, in any kiln, will vary, the perfection with which the drying process can be carried out. In theory, complete control is desirable; in practice, it involves too high a cost of construction and operation, so that it is necessary to sacrifice delicacy of control of some or all of the essentials in order to bring kiln drying within the realm of commercial possibility. Differences in the manner in which and the extent to which this sacrifice is made result in the many different types of dry kilns. With more easily seasoned timbers, kilns of a comparatively crude type are possible, although often not the best commercial proposition; but with the more refractory timbers, a class to which the Eucalypts of this State belong, too great a sacrifice of delicacy of control to initial and operating cost will, by the low quality of the seasoned product, soon be proved a false economy.

Kilns may be divided into two main classes, the progressive and the compartment kiln. The former is really a long tunnel, in which conditions vary from a very moderate drying atmosphere at one end to severe drying atmosphere at the other. Conditions in the kiln as a whole, that is at any one point, remain approximately constant. The timber enters, in its green state at the moderate end, and is moved progressively through the kiln by a series of stages, into severer and severer conditions, until it ultimately emerges dry at the hottest and driest end of the kiln. Drying cannot be controlled as accurately as in a compartment kiln, so that this type is used for the more easily seasoned timbers. Recent innovations in the control of circulation by the inclusion of a multi-disc fan shaft have improved this type of kiln considerably, and it is possible that it would be capable of drying the less refractory Eucalypts.

The progressive kiln must be operated at full capacity for good results, and since the supply of timber must be approximately constant both as to cross sectional dimensions and length, it is certain that under present milling conditions in this State a sufficient quantity of timber would not be available for the successful operation of this type of drier, and as milling units are tending to decrease in size, further consideration of this type is not warranted.

In the compartment kiln the timber remains stationary, while the drying conditions are varied from time to time. Compartment kilns can be designed to take small or large quantities of timber; and for very large quantities, a battery of a number of kilns can be built. As the kilns can be designed to take specified lengths, or sufficiently long to take a stack made up of random lengths, they are suitable for Western Australian conditions. Control can be made more delicate than it is in progressive kilns, and they are therefore used for the more refractory hardwoods. For the best results, timber of the one species and thickness only should be included in the one charge, but under especial circumstances mixed charges are often practicable.

It is possible to differentiate modern types of compartment kilns into two main sections:—

(a) External circulation kilns.

(b) Internal circulation kilns.

In the former type, fresh air is taken from outside the kiln, it is heated and humidified if necessary, and after passing through the timber stacks to perform its drying duty, it is discharged again into the atmosphere. Often in order to reduce heat losses, and provide moisture to raise the humidity of the inlet air, some of the air which has passed through the stacks is returned and mixed with the fresh air entering the kiln. Sometimes the relative humidity of the inlet air is raised by injecting steam from a perforated pipe. In an external circulation kiln, the air movement may be the result of convection currents, in which case the kiln is termed a natural circulation or ventilated kiln, or a motive force may be supplied by means of a fan or blower situated either internally or externally with respect to the drying chamber, and in this case, the kiln is described as a Blower or Fan kiln, these types sometimes being grouped in the name of Forced Draught kiln.

In the case of the Internal Circulation kiln, the same air circulates continually inside the kiln, and its drying quality is controlled as required by a variety of devices. This type can also be divided according to the method of providing the circulation, into natural circulation, and forced draught kilns, although since some of the most important kilns are neither one nor the other but a mixture of the two, it is more usual to classify according to distinctive features of the various designs.

Classifications of kilns are not altogether practical, for some of the most important types of kilns either cover several classes, or else have little in common with others of the class to which they belong. The classification must therefore be regarded merely as giving an indication of the general lines along which kiln design has been developed. The number of different types of kilns, which are likely to prove of special value where local timbers are concerned, is comparatively small, and it will be more profitable to consider fully these types alone, than to study the whole range.

The Tiemann Water Spray Humidity Regulated Kiln.

This type is of particular interest in this State, for it was in experimental kilns of this design that rapid seasoning tests with a modern kiln were first commenced here in 1918. On account of the positive control, the kiln was used for experiments on the rapid drying of Jarrah, Karri, Tuart, and to a lesser extent of some of the minor timbers. Of the few commercial kilns at present being operated in Western Australia, all but one battery are of this type.

The general design of this kiln is shown from the diagramatic cross section, Fig. 5

TT are the stacks of timber in the kiln.

RR are the radiator pipes or heating coils for heating the circulating air.

SS are water sprays delivered from spray nozzles pointing down the spray chamber.

S to D are the spray chambers which are boarded off from the rest of the kiln.

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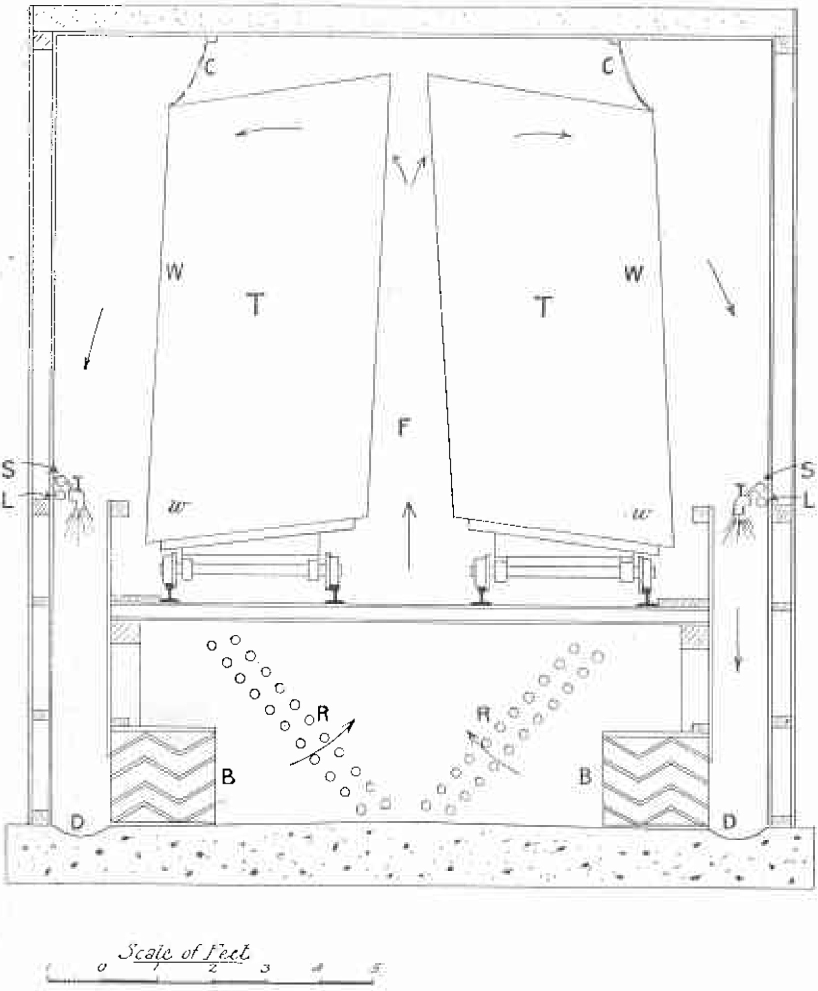
DD are drains at the foot of the spray chambers for removing water after it has passed through the sprays.

BB are baffles or eliminators which connect the bottom of the spray chamber with the rest of the kiln.



TIEMANN KILN

FIG. 5

LL are pipes for admitting live steam to the kiln; they are perforated with the holes pointing down the spray chamber.

F is a centre flue between the stacks.

CC are curtains which prevent air movement from the centre flue F to the spray chamber without passing through the stacks.

Air Circulation.

The air is heated by the steam coils R and passes upwards into the flue F. From F it passes downwards and outwards through the stacks, and then downwards into the spray chamber on either side. In moving down inside the spray chamber, the air is saturated with moisture by the sprays, which also materially assist the circulation. The air then passes from the bottom of the spray chamber in a generally horizontal direction through the baffles. These eliminate any fine drops of water, which in the form of a mist mixed with the air, might mean the equivalent of a super-saturated condition. The saturated air then passes upwards through the heating coils and commences another cycle.

It will be noted that—

(a) the same air is used continually and the kiln is therefore of the internal circulation type.

(b) the air circulation is a combination of natural and forced. The general disposition of the timber and the heating coils is such that the timber tends naturally to circulate as outlined above, while the sprays assist this tendency. Particular attention should be paid to the fact the timber is so stacked that in passing over the wood the circulation is downwards as well as outwards. Since air which is cooling so that it can supply the heat to absorb moisture, will become heavier, its natural tendency will be to move downwards. By sloping the stack, advantage of this property is taken to assist the natural circulation.

Temperature and Relative Humidity.

To measure the relative humidity of air, it is required to know its dry bulb temperature and either its wet bulb temperature or the temperature at which it is saturated. In the Tiemann kilns, since the air is saturated before it is heated by the radiators, the relative humidity can be found by taking the temperatures of the air leaving the baffles and the heating coils. Supposing, for example, the air upon leaving the baffles is saturated at 100deg. F. and upon leaving the heating coils the temperature is 110deg. F., then the relative humidity will be 74 per cent. (see Psychrometric Chart). The temperature at which the air emerges saturated from the baffles can be controlled by varying the temperature of the water delivered to the sprays, while the temperature to which the air is heated by the coils can be regulated by the amount of steam which is admitted to these heating elements. The temperature and relative humidity are, therefore, under the absolute control of the operator.

A normal feature of the design of the kiln is a series of two sets of condenser pipes along each side wall just above the spray chamber. (These are not shown in the diagram.) In the later stages of the run, accurate control of relative humidity and high circulation are not necessary, and by operating the condensers instead of sprays economy is effected. The kiln then becomes a condenser kiln, with a slower circulation, and consequent economy in heat consumption. Condensers have not been adopted in this State owing to the general shortage of cold water, but circulation is sometimes reduced towards the end of the run by reducing the pressure of the spray water.

Sometimes instead of being stacked on the slope, as shown in the diagram, the timber in a Tiemann kiln is stacked on the flat. In order to provide in this case for the downward circulation as the air proceeds through the stack, an edge to edge space of 1 to 2 inches, according to the width of the timber being dried, is left between boards. The air then passes outwards along a layer of timber downwards to the next layer, outwards again and then downwards until by this stepped path the spray side of the stack is reached. Whether stacking is on the slope or on the flat, the width of the stack is the same four feet, so that inclined stacking results in a slightly greater kiln capacity. Its disadvantage, of course, is in the handling of the timber, for where the loaded kiln truck has to be moved a considerable distance, deformation of the stack is likely. The stack slope should be made as great as possible, although 1 in 7 is usually the limiting figure if the stack is to be moved.

It will be noted that in this type of kiln the circulation is carefully arranged, while the temperature and relative humidity are under delicate control. It is not surprising to find, therefore, that drying in this kiln is more accurately controlled than in any other and that the kiln is suitable for the most refractory timbers.

Details of Construction of the Tiemann Kiln.

The kiln buildings can be made of wood, brick, concrete, or other material of construction, the desirable features being freedom from air leakage, and heat insulation. Wood frame construction has been adopted in Western Australia and has been found very satisfactory.

The cross sectional dimensions of the kiln are standard and the internal measurements of the chamber are 13ft. wide and 14ft. high. This makes provision for two stacks 4ft. wide and 8ft. high. The kiln can be made of any length, although under Western Australian conditions there is probably little advantage in exceeding 35 or 40 feet. If greater capacity is required than can be obtained by this length, the number of kilns can be increased and this then permits the drying of two or more sizes at once. In fixing the length of the kiln, it can either be made such as to take one or more specified lengths or else random lengths, according to the purpose for which it is intended.

The wall construction can consist of a framework of dry jarrah, 4 x 3 studs giving a substantial structure, while the inside wall sheathing can be 1in. T. and G. Jarrah, with 1in. T. and G. or weatherboard for the outside sheathing, the latter being used if cheaper construction is desirable. An excellent building can be made by lining both sides of the studs first with single-ply roofing felt. The felt then makes the kiln air-tight while the sheathing provides the heat insulation. In this case second quality timber can advantageously be used for both inside and outside sheathing, and since this class of material usually has a very low value compared with first quality at most kiln sites, the saving in timber sheathing may more than cover the cost of the felt lining. If desired, on exposed walls where T. and G. timber is used, the roofing felt may be placed outside the wooden sheathing instead of inside, in order to protect the wood from the weather. Narrow T. and G. is best for sheathing, and it must be thoroughly seasoned and double nailed. It is to be noted also that the ordinary building construction practice of using green timber for framing must be varied in favour of thoroughly seasoned Jarrah for this work. The ceiling is made of 1in. T. and G. on Jarrah joists, roofing felt being used under the same conditions as for the walls, and the ceiling is packed for 6 inches or to the top of the joists with sawdust. It may be mentioned that in cold countries steam-heated ceiling coils are used to prevent condensation on the ceiling, but if the ceiling is well insulated with sawdust such a precaution, here, is unnecessary.

With suitable drainage the floor can be made of rough but dry 1in. boards, covered with 2-ply felt. If, however, suitable drainage cannot be arranged, a concrete basement is necessary to prevent the upsetting of the humidity control by water leakage on to the floor of the kiln. The floor should be laid with ample slope towards the spray chamber drains which should be at least 3in. deep at the shallow end, full width of the spray chamber and laid with a fall of at least 1in. in 10ft. Spray chamber drains discharge to the outside of the kiln through a water seal to prevent air leaks. The baffles are made in sections of dressed 1in. Jarrah, fastened with brass screws. They should make reasonably air-tight joints with the spray chamber, but should not be fastened in place in order to be removable for cleaning and repair. In construction care should be taken that the trough portions are not watertight, as water is likely to collect here and reduce the efficiency of the baffles. It is advisable to raise the baffles about ½in. off the kiln floor to allow floor drainage to reach the spray chamber drains. The sheathing on either side of each spray chamber is T. and G. Jarrah laid vertically. This sheathing must be of *green* narrow T. and G. well nailed, or trouble will be experienced. In placing the storey posts to carry the rails, care must be taken that these do not interfere seriously with the circulation, or the disposition of the heating pipes. Well insulated air-tight inspection doors must be provided opposite each stack at one end of the kiln and in both side walls at the centre of the kiln. Loading doors of sufficient width and extending from the rail level to the ceiling are provided at one end of the kiln. Two wooden doors, well insulated, closing on a central removable stop stud are satisfactory, although more elaborate door systems are available and are perhaps warranted in a battery of kilns.

Heating Coils.

With steam at 60lbs. pressure, four sets of coils each of seven 1¼in. pipes are recommended, two sets to each side of the kiln. If the pressure of the steam is higher or lower, the number of pipes may be decreased or increased respectively. An equivalent number of 1in. pipes may be used for kilns 30ft. or less in length. The coils *must be of the continuous return bend type* and should be made of the best wrought iron steam pipe. The bends are preferably wrought iron double bends, although malleable cast double bends may have to be substituted in order to make the coils small enough for the kiln. The use of two elbows instead of a double bend must be avoided. In assembling the coils, all pipes should be freed of internal scale, rust, etc., and joints should be carefully made, preferably iron to iron, although red lead may be used with care. Precautions taken to secure well built coils are amply repaid, for once a leak develops its repair is often a costly matter owing to the construction and placement of the coils. Instead of four sets of seven-pipe coils, an arrangement giving, for example, a five-pipe and a nine-pipe coil on each side of the kiln can be made. The five-pipe coil would be the upper coil on each side. With this method, in the early stages of the run when the steam consumption is small, steam can be admitted to the two top five-pipe coils alone, with a consequent more even distribution of heat throughout the coil than would be the case with a larger coil.

Coils should be laid continuously to drain, and the drain end of each pair of coils, *i.e.*, the two upper and the two lower coils, should be provided with a globe valve connected with a steam trap. Where the number of pipes in the upper and lower pairs of coils is the same, both pairs may be drained through a single trap, but where it differs two traps are required to prevent starving of the larger coil. According to the type of trap, provision should be made for it to be a sufficient distance below the bottom of the coils to discharge properly. Although traps have usually a provision for discharging air when operation commences, a separate by-pass to air on the drain line, before the trap is reached, is recommended. This is an advantage, when freeing coils of water and air when they are being brought into use, or when cleaning them of extraneous matter.

The upper and lower pairs of coils are provided with globe valves at the supply end, and these are fed from a single pipe controlled by a temperature regulating valve, which is preceded on the supply side by a globe valve as a stop valve. Bends are, where possible, preferable to elbows, and ample provision should be made by unions for the removal of defective valves and other fittings.

Steam Jets.

At the top of the spray chambers, pipes, which are for steaming the timber to heat up at the beginning of the run, and for removing casehardening during and at the end of the run, are wrought iron steam pipes perforated with ⅛in. holes about every eight or nine inches. 1in. pipe is used for kilns up to 30 feet, and 1¼in. pipe over this. The steaming pipes are fed from one end, the other end being capped. The supply lines to the two pipes are led through a single valve which is connected on the supply side of the temperature regulating valve. If exhaust or low pressure steam is used for the heating coils, a direct high pressure line from the boiler is necessary for the steam jet. Lower pressure steam can in emergency be used if provision is made for its proper introduction into the kiln.

Water Spray System.

The sprays are placed every 12 inches along the top of the spray chamber. The spray heads used in experimental work in this State have been the all brass "Vermorel" type of horticultural spray. While these have been satisfactory, their somewhat complicated construction makes the cost of maintenance comparatively high, when corrosion is at all prevalent. In Victoria, a much simpler type of spray has been found more satisfactory. It consists of a small vortex chamber tangentially fed, the spray outlet being at right angles to the inlet and at the centre of the vortex. The spray is all brass and can either be cleaned through the outlet by means of a pin, or in cases of bad blockage by removing the top of the vortex chamber. There are many other types of sprays which give satisfactory results, but owing to the absence of test data to show the relative efficiency of the various types, the spray mentioned above as being used in Victoria is recommended.

The spray heads are connected to ¼in. brass or copper bends, and these are connected to the spray feed line by ½in. to ¼in. iron bushings, tees reducing to ½in. being used on the feed line. It has been found that in the spray system corrosion of the iron is most serious at the junction of brass and iron. By using a brass bend and an iron bushing, the loss through corrosion is small, for the part destroyed, the bushing, is of small cost and can be replaced with ease. The spray heads should point vertically down and should be aligned along the centre of the spray chamber. The pressure of spray water should be 50 or 60 lbs. per square inch and at this pressure each spray will deliver 3 or 4 lbs. of water per minute when new. It is advisable, however, in determining pump and pipe sizes to allow 5lbs. of water per minute per spray head as the orifices and working parts of these become worn and deliver an increasing quantity of water.

Owing to the difficulty of keeping the spray water clean of all extraneous matter, sprays from time to time become choked and it is necessary to make provision for their inspection and cleaning. One method is to inspect the sprays from small inspection windows in the ends of the kilns while a light is shined along the top of the spray chamber. Defective sprays are attended by entering the kiln and removing the obstruction, or if this cannot readily be accomplished, by replacing the spray head with a spare, a number of which should be kept in stock. With this method, easily opened but air-tight inspection doors must be provided, and these must be fastened with a latch which can be operated from the inside, so that attendants cannot be locked in. In addition to external visual inspection, spray heads should be inspected from inside the kiln at least once every day.

As conditions inside the kiln are unpleasant from the standpoint of bodily comfort, it is considered by some to be more satisfactory to provide for kiln inspection without entering the kiln. This is done by building small ports at regular intervals along the sides of the kiln just above the spray chamber, so that a hand can be inserted to detect by the feel of the spray delivery whether each spray head is operating and free, or remove and replace defective heads. In a battery of kilns, this necessitates the duplication of party walls to provide the inspection passage between kilns. Whichever method is used, it is advisable to have a quarter-inch pipe supplied by a valve from a spray water main, at some convenient position outside the kiln, in order that spray heads may be tested before installation.

In calculating the size of the spray pipe line, full allowance should be made for the friction effect of the numerous spray supply reducing tees. The pipe line should be centre fed, and for a kiln up to 30 or 35 ft. in length 1¼in. pipe is suitable, but above this 1½in. pipe should be used. Instead of being plugged at each end, the spray lines are continued through the two ends of the kiln, turned down and provided with blow-off cocks. By opening these in turn about once in every 24 hours the spray pipes can be flushed out to remove extraneous matter.

Where one kiln alone is to be considered the temperature of the spray water can be controlled by means of a sump or well provided with return water inlet from the spray chambers, cold water inlet, and a steam heating pipe. The water, after leaving the sprays, falls to the bottom of the spray chamber and returns to the sump. If the temperature of the return water is too low, it is all returned to the sump and reheated. If it is too high, some of the water is bypassed to waste or cooling tower, that returned being cooled in the sump by the addition of cold water and recirculated. As a large quantity of cold water is usually difficult to obtain on Western Australian mills, a cooling tower will probably be needed in most plants. Where a battery of kilns is to be supplied, it is advisable to instal a two-main or three-main system.

In the two-main system, the supply for each kiln is obtained through an automatic mixing valve fed by cold water and recirculating water main. The mixing valve should be installed between unions and bypassed by each main so that it can be removed if necessary. Either main should be of such a size that alone it can provide the full water supply, while inlets and discharge for the water mixer should be full size of the spray line supply. The three-main system is similar to the two-main system, with the exception that a third main is added supplying hot water. Under W.A. conditions this third main is scarcely warranted, as in cases where it might be required the baffle temperature can be increased by supplying a small amount of live steam through the steam jets.

In Western Australia a modified single-main system has been used with success for a battery of kilns. The method employed for heating up the spray water is to use a steam jacket on the supply to each kiln, the temperature being controlled by the amount of steam admitted to the jacket. Such a method in conjunction with a two-main system would be much more economical and should give results as good as a three-main system at lower cost.

All water circulating pumps should be fitted with cleansable strainers on the delivery side; the recirculation water sump should be divided by three hessian screens placed in removable frames, between the return drain from the kiln and the pump intake. From some of the Western Australian timbers an appreciable quantity of acid is distilled, particularly during the early stages of kiln drying. This acid is taken into solution by the spray water, and with recirculation the acidity of the water increases to a marked degree. To prevent serious corrosion of pipes and fittings it is therefore advisable to add soda to the sump at intervals in sufficient quantities to give a slightly alkaline reaction.

For dry kiln operation, pumps of the steam-driven duplex double acting type used for boiler feed are used, and these should be provided with water pressure regulators. If an oil separator and a pressure relief valve is installed, the pump exhaust can, if desired, be used for supplying a low pressure heating coil, or it can be used for heating recirculating water. Each pump should have an air chamber located as near the delivery valves as is possible, and it is advisable to provide a small air cock on the suction to prevent filling of the chamber with water. As the supply taken by the water mixers from any one pump may become very low, relief valves must be provided on pump deliveries, where a multi-main system is used.

Cost of Drying.

The cost of construction of Tiemann kilns varies between rather wide limits according to the type of construction, number of kilns, and quantity of equipment. For a battery of six kilns with a total capacity of 70,000 s. ft. and an annual output of 700,000 to 800,000 s. ft. of 1in. jarrah, the capital cost would be between £5,000 and £6,000. This would provide for kiln buildings of suitable timber construction, all heating, water and control equipment, boilers, and trucks and rails for handling the timber throughout the drying process. With material thicker than 1in. the charge capacity of any kiln in the battery will increase owing to the increased ratio of thickness of timber to thickness of strips. The annual capacity will, nevertheless, decrease owing to the greater rate of increase in the drying time with thicker material. Because of these variations, the figures of charge and annual capacity of the battery above are given with reference to 1in. timber, although it is recognised that a plant of this size to dry other than mixed sizes is not a practical proposition in this State.

A fair estimate of the cost of drying of 1in. wide jarrah boards in conjunction with other thicknesses in a plant of this size would be 1d. per super. foot. This includes all overhead, fuel, handling, and attendance costs from green delivery at the kiln site to immediate delivery kiln dry. If timber cannot be railed, or machined, as it completes the drying process, additional provision will have to be made for the expense of erecting and operating a dry storage shed. With very favourable conditions of fuel and water supply and attendance, a figure considerably below 1d. per super. foot should be obtainable.

The rate of drying of thicker jarrah up to 3in. thick can be roughly fixed by allowing 1d. per super. foot for the first inch and 0.7d. per inch or part of an inch in thickness above this. Thus 1½in. material would cost 1d. and 0.35d., or 1.35d. per super foot.

Plates 1 and 2 are views of a commercial plant of four Tiemann kilns operated at Yarloop by Millars' Timber and Trading Company.

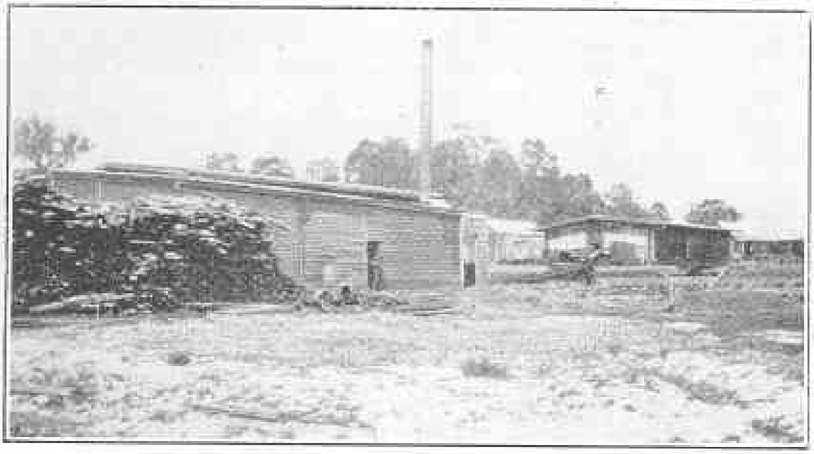


Plate 1.

General View of Battery of four Tiemann Kilns (Millars' Timber and Trading Co. Ltd., Yarloop).

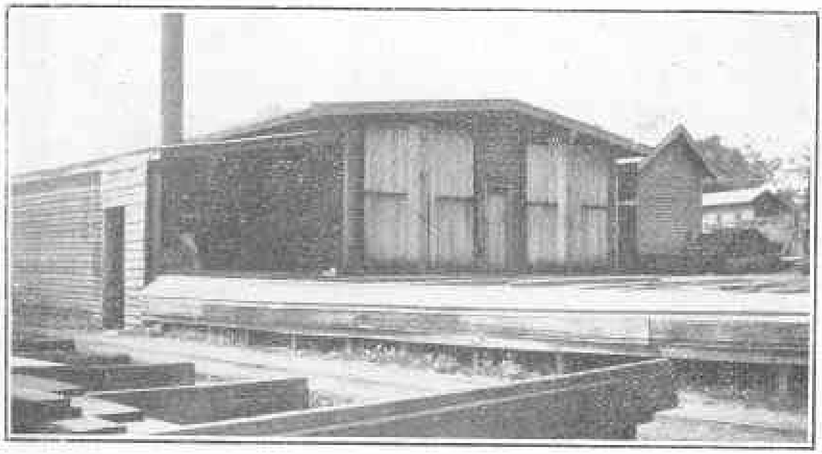


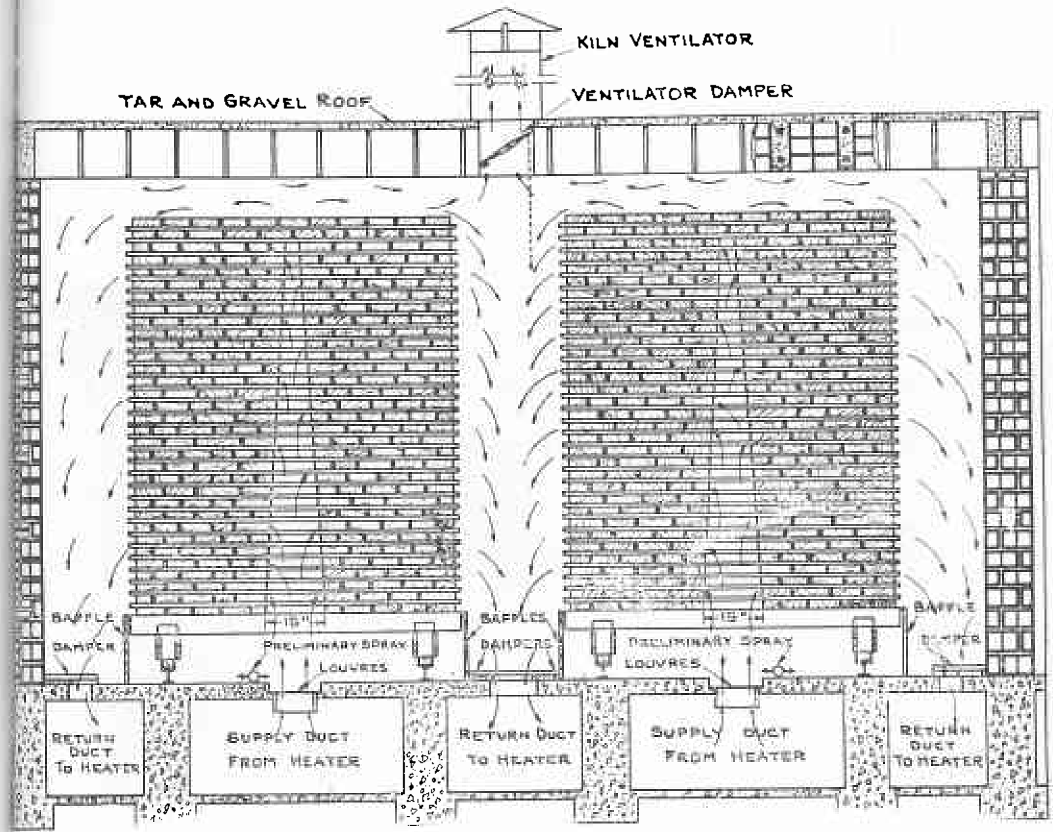
Plate 2.

Loading End of Tiemann Kilns (Millars' Timber & Trading Co. Ltd., Yarloop).

Blower Kilns.

The cross section of a modern type of blower kiln is shown in Fig. 6. The air enters the kiln through the two supply ducts, rises up through the louvres into the internal flue of each stack, and moves through the stack between the rows of boards. A small percentage of the air then passes out through the kiln ventilator in the roof, which is controlled by a damper, and the remainder of the air falls to the three return ducts, along which it is drawn back to the fan. The suction of the fan also draws in a small quantity of fresh air through an inlet damper, to replace that ejected through the vent in the roof of the kiln, and the return air and the fresh air are then passed through a heater and a humidifier which liberates live steam to increase the relative humidity. The treated air is drawn into the fan and delivered back into the supply ducts to commence another cycle.

The temperature is controlled by a temperature regulating valve which operates on the steam supply to the heater in the air circulation system. Temperature can therefore be accurately controlled. The relative humidity is regulated by the amount of fresh air drawn into the suction, and by the amount of steam supplied to the humidifier. With regard to circulation it will be noted, firstly that the maximum travel of air over timbers before it is returned to the heater to



(Through the courtesy of H. P. Gregory & Co., Sydney.) (From Cat. 282, B. F. Sturtevant Co.)

Fig. 6.—Blower Kiln: Cross Section of End Elevation.

be reconditioned is very small (not exceeding 3ft. 6in. in this particular kiln). This prevents a large difference in the drying rate between the entering and leaving air portions of the stacks. The second point is that the air to pass from the supply to the return duct must move through the stack, while thirdly, by means of dampers on the outlets and inlets of the supply and return ducts respectively, adjusted when the kiln is first constructed, a reasonable uniformity of air supply throughout the lengths of the kiln is obtained. This type of kiln while, strictly speaking, of the external circulation type, has more in common with an internal circulation kiln. For instance, if instead of removing the evaporated moisture by discharging a small quantity of the used air and replacing it by fresh air, this moisture were removed by means of a condenser preceding the heater in the circulation system, the kiln would be of the internal circulation type. Reference may be made, in this connection, to a type of blower kiln in which the evaporated moisture is removed by a somewhat unique means. The used air with the moisture evaporated from the timber is passed along one side of a thin porous wall. On the other side of this wall is passed ordinary air, the motive power to make this air circulate naturally being supplied by heat transmitted through the porous wall. This outside air absorbs some of the moisture from the air inside the kiln and the amount absorbed can be controlled by dampers which vary the amount of outside air supplied. The thin porous wall thus acts as a condenser, and with a comparatively low expenditure of energy the kiln is made a true internal circulation kiln with such advantages as are possessed by that type.

Construction of Blower Kilns.

The patents covering the various types of blower kilns are usually held by firms who sell the complete equipment for the circulation, and temperature and humidity control of the air. A firm will supply full particulars of kiln buildings, and particularly in cases where guarantees covering successful kiln operation are given may specify definitely the types of construction which may be used. A detailed description of construction and operation is not, therefore, necessary here. It may be mentioned, however, that for Western Australian conditions, Jarrah frame structures sheathed with T. & G. material, and roofing felt, should be quite suitable, although the use of the roofing felt must be regarded as compulsory rather than optional if good results are to be expected.

Suitability of Blower Kilns for W.A. Eucalypts.

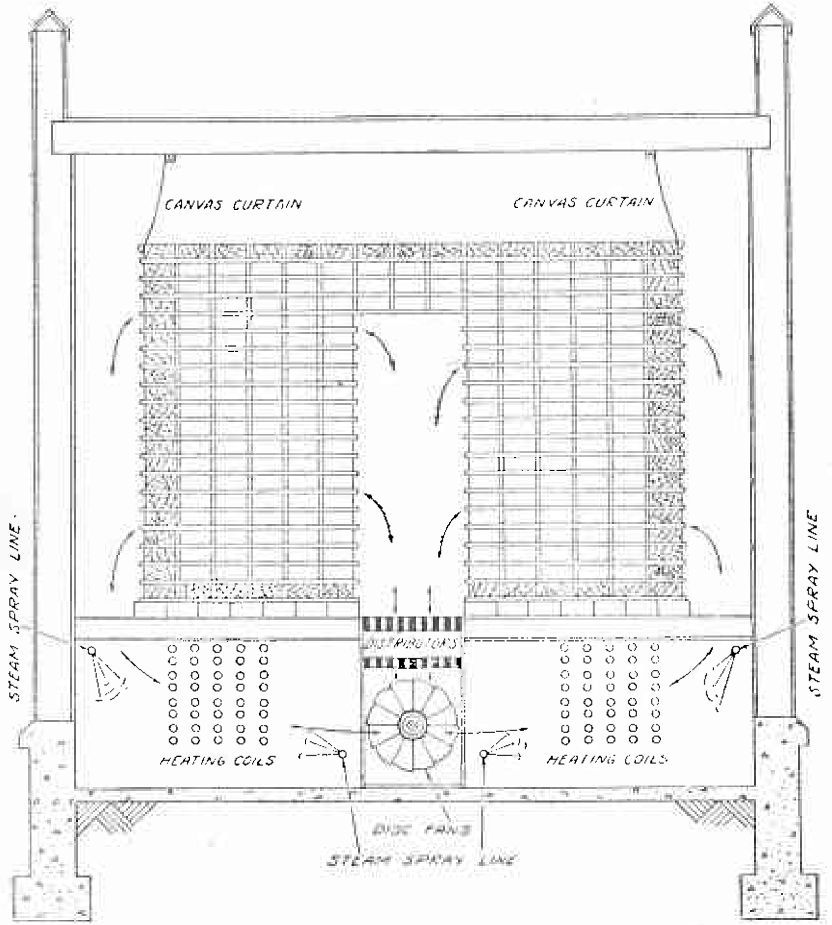
Although there are no blower kilns operating in Western Australia, sufficient data has been obtained to show that they are capable of drying Western Australian timbers. Apart from a study of the delicacy of control, which indicates that with material at least up to 1½in. thick, these kilns are quite suitable for Western Australian Eucalypts, there are the results of practical tests. In South Africa, immature Eucalypts up to 1½in. thick and including 1in. Karri have been dried out in a blower kiln with excellent results. Samples of Karri and Jarrah were forwarded from this State to U.S.A. with special precautions to prevent drying, and these samples were converted into 6 x 1 boards and dried out in a blower kiln by the B. F. Sturtevant Company. It is stated that apart from a tendency to caseharden, which was alleviated by steaming, there was no difficulty in drying.

Cost of Drying.

Owing to the high cost of mechanical equipment in this State, the capital cost of a blower kiln is slightly higher than that of a Tiemann of the same capacity. On the other hand, the blower kiln has the advantage of requiring but a small water supply, and less attention by kiln attendants. It is generally considered also, that the drying time is less with a blower kiln owing to the advantage of increased circulation during the early stages of the run, and providing that the air circulation is distributed with reasonable uniformity throughout the height and length of the timber stack, this must undoubtedly be the case. As against these advantages, however, the Tiemann kiln has absolute uniformity of circulation throughout the length of the kiln and delicacy of humidity control. It may be stated that for W.A. Eucalypts up to 1½in. thick, the blower kiln will in the majority of cases prove the more attractive proposition, but where drying of timber above this thickness is to be considered, the circumstances of the case will need very careful consideration before a decision is made.

The Internal Fan Kiln.

A type of kiln which has lately been developed and which has given very promising results is the reversible internal fan kiln shown in Fig. 7. The kiln was developed by the United States Forest Service for the seasoning of Douglas fir, common grades of boards and scantlings. As the main object of seasoning was reduction in weight to reduce freight costs, the expense of drying had to be low. The control of the drying essentials in the kiln is such, however, that it would appear to be suitable for the seasoning of W.A. timbers.



(From Bulletin 1136, U.S.A. Department of Agriculture.)

Cross Section of Internal Fan Kiln. A number of disc fans are mounted at intervals upon a shaft extending the full length of the kiln.

Fig. 7.

It will be seen that the kiln is very similar in operation to a blower kiln except that instead of taking the air out of the kiln for reconditioning, reheating and humidifying is effected in the kiln itself. From the fan, the air passes upwards into the centre flue of the stack, the two gratings being merely to build up a slight static pressure and so distribute the air more evenly. The air then moves outwards through the timber stacks, and some of it passes out through the roof vent. The majority moves downwards along the side walls, and is humidified by the steam spray and reheated by the coils below the stacks. It is then drawn into the fan and recirculated. The fresh air required is brought in through the fresh air intake ducts. The direction of circulation can be reversed by reversing the fans. Two pairs of steam jets are provided for humidifying, these being so placed that the pair being used assists the circulation. The fans are of the disc type and are placed at about 7ft. centres on a common shaft running the length of the kiln. The advantages of using the internal fan are stated to be greater accuracy of control, and ability to reverse the direction of circulation, and so prevent any difference in the rate of drying between boards on the central air flue and those on the outside of the stack. Also the power consumption for fan operation is low.

Precise details as to the operation of this type of kiln in W.A. are of course not available, but it would appear that the kiln is comparable in cost of construction with the blower kiln, but somewhat cheaper in operation, and it is quite probable that it would be suitable for the drying of all thicknesses of W.A. Eucalypts for higher grade work.

The Clarke Kiln.

Up to the present there have been considered types of kilns suitable for drying high grade material green from the saw. It has been pointed out when studying the drying of a piece of wood that after most of the free water has been removed, drying does not require such delicate control of temperature and humidity, nor, owing to the lower humidities and slower drying rates, does it require such a large circulation of air. Where timber can be obtained in a partially seasoned condition, therefore, the completion of the drying is a comparatively simple matter. In Western Australia climatic conditions are such that some classes of timber can be air-dried without serious degrade from cracking and warping. Amongst these classes, greatest prominence must be given to flooring boards, for far more Jarrah and Karri are seasoned for this purpose than for all the rest of the uses together. The air seasoning of flooring boards has certain disadvantages, the chief of which are the slow drying rate, particularly in the later stages, seasonal variations in moisture condition, and the comparatively high final moisture content. The possibility of combining air and kiln seasoning of Jarrah and Karri flooring has, therefore, been considered and has led to the design of a kiln for this purpose.

A diagrammatic cross section of this kiln is shown in Fig. 8. Air from the atmosphere passes into the entering air flue E below the floor of the kiln, and from thence past the damper LD into the kiln proper. Here it is heated by the heating coils L and passing up through the left half of the timber which is strip stacked on edge, reaches the space above the timber S, and then passes down again through the right half of the timber, through the heating coils R which are cold and past the damper RD into the hollow wall flue F, and from thence ultimately into the atmosphere. Periodically the oscillating dampers LD and RD are reversed, and the steam is shut off from coils L and admitted to coils R. The direction of air circulation is then reversed. Short circuiting of

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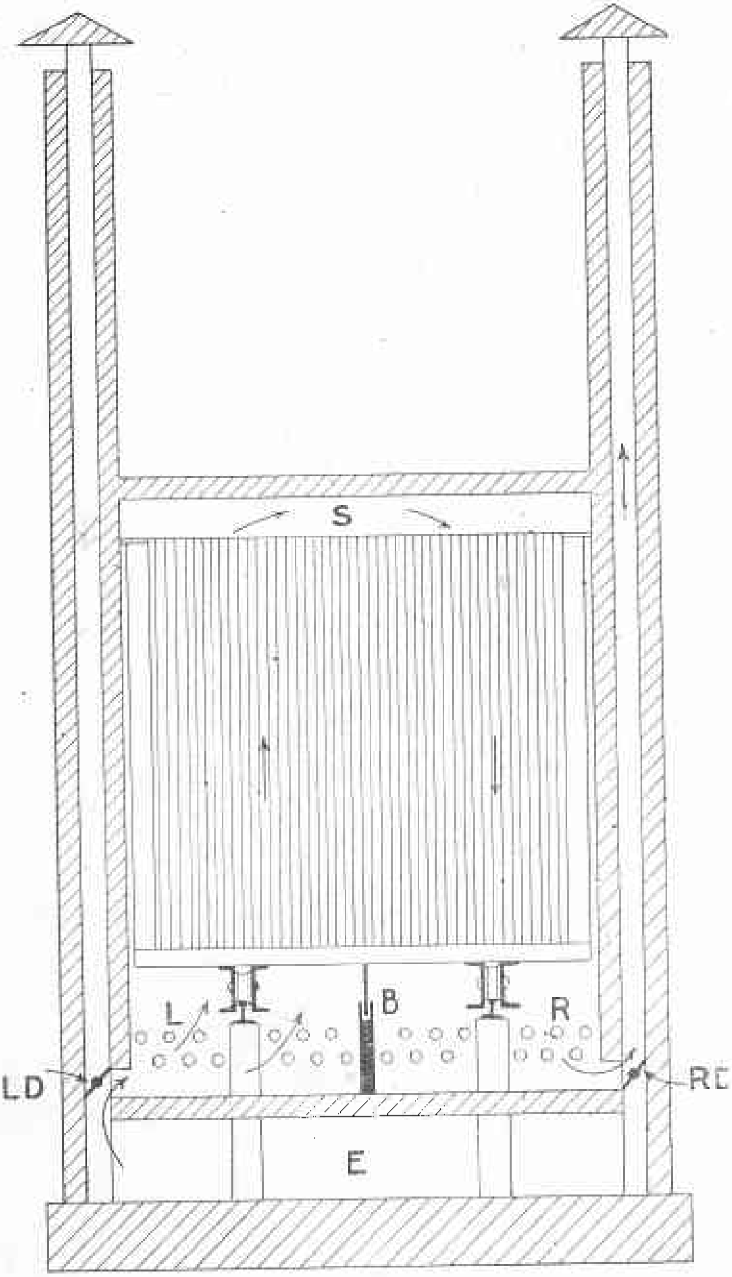

THE CLARKE KILN

FIG. 8

the circulation by passing directly along the bottom of the kiln from entering to exit damper is prevented by the central baffle B which divides the lower portion of the kiln chamber into two parts. The oscillating dampers and the wall flues run the full length of the kiln, so that circulation is uniform throughout the length of the kiln. The distribution of the steam heating pipes throughout the width of the kiln ensures even circulation throughout the width of the stack.

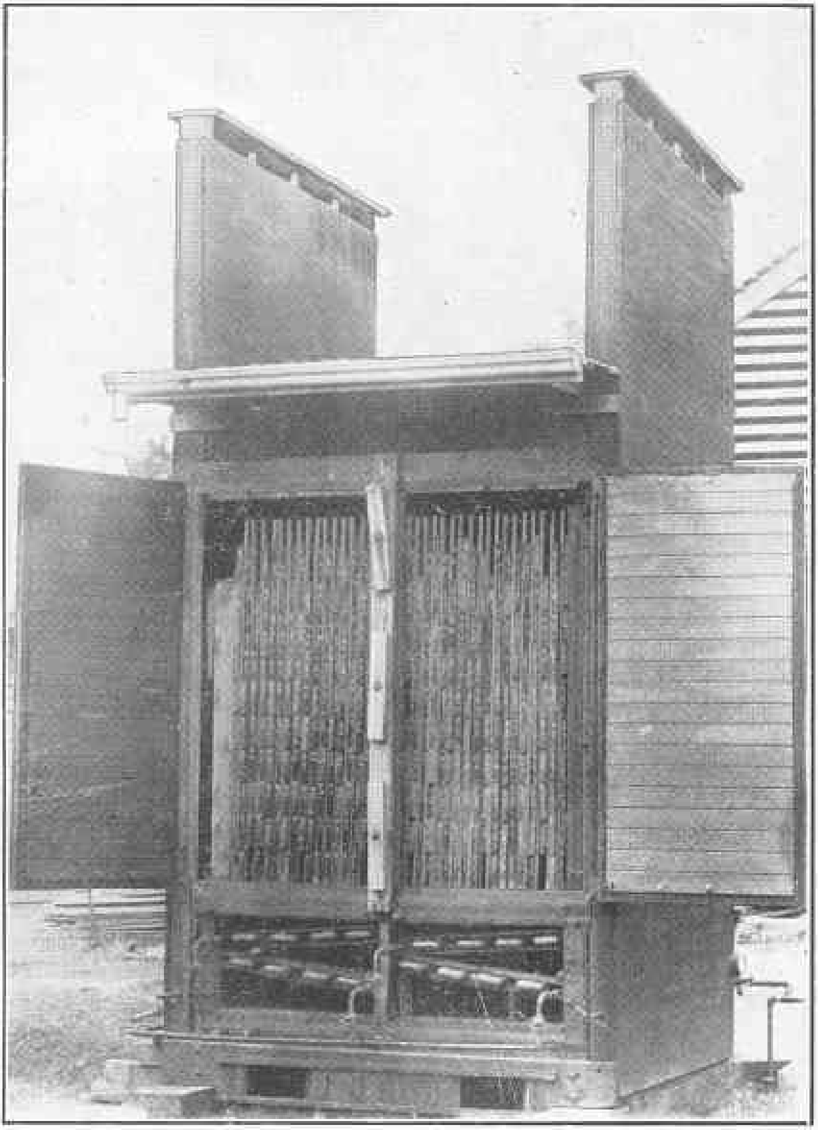

Plate 3.

Experimental Clarke Kiln at the Engineering School, University of Western Australia, Crawley. Portion of back has been removed to show heating coils.

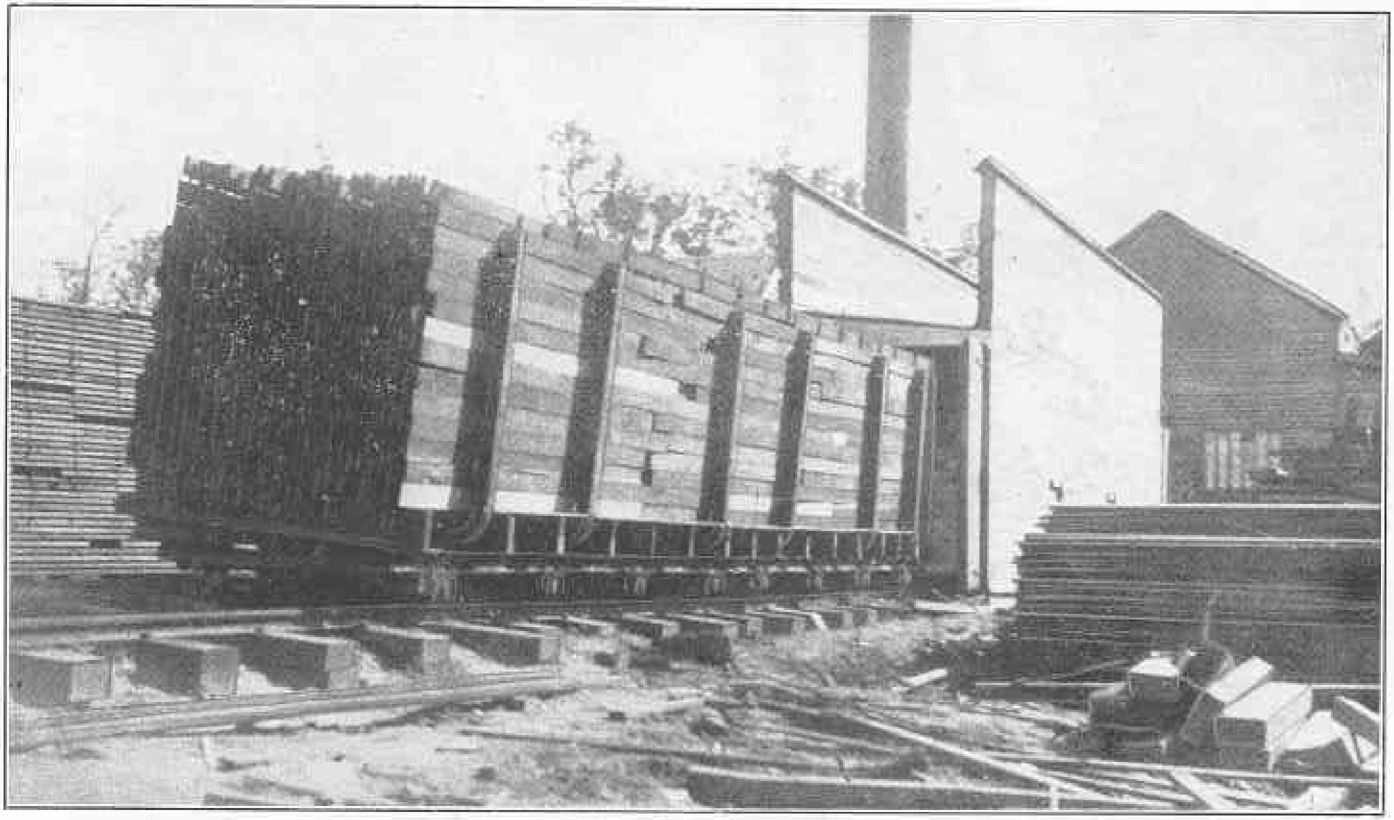

Plate 4.—A Commercial Clarke Kiln operated by the WA. Jarrah Forests Ltd. at Pilgrim's Mill. The charge of 1in boards is being removed from the kiln after drying.

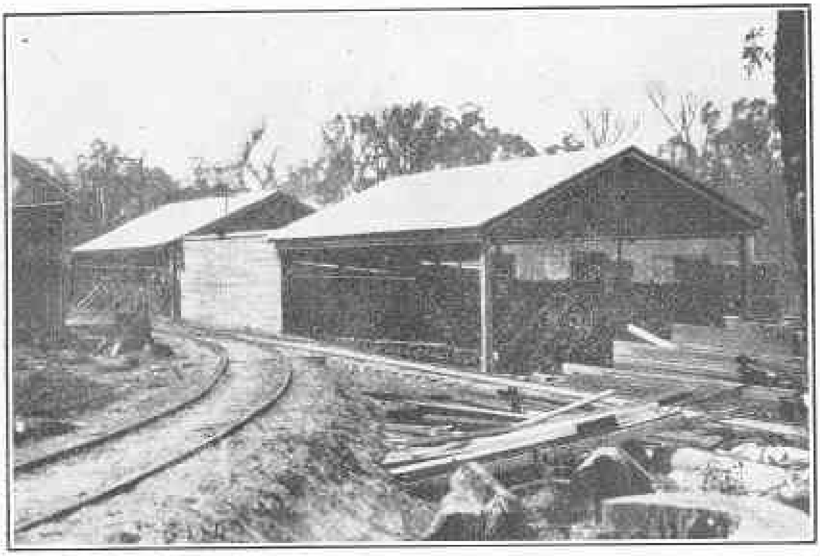

Plate 5.
Extended Commercial Plant of four Clarke Kilns at Pilgrim's Mill.

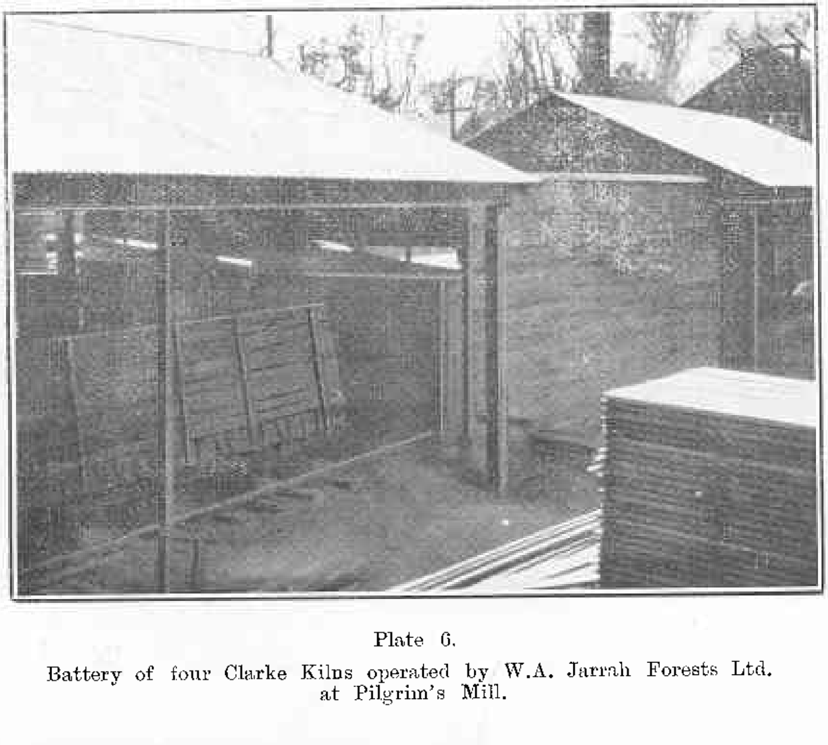

Plate 6.
Battery of four Clarke Kilns operated by W.A. Jarrah Forests Ltd. at Pilgrim's Mill.

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Temperature can be regulated if desired by varying the quantity of steam admitted to the heating coils, but no temperature regulating valve is necessary. Steaming for the removal of casehardening is effected by means of two steam spray pipes, located underneath the stack, one each side of the centre baffle. Plate 3 is from a photograph of the experimental kiln loaded with 6in. x 1in. boards. Portion of the back has been removed to show the heating coils. Plate 4 shows a charge of boards removed from the first commercial kiln built at Pilgrim's Mill.

Plates 5 and 6 are views of the plant operated by W.A. Jarrah Forests, Limited, at Pilgrim's Mill, extended to a battery of four kilns. Provision has been made for protection of the seasoned timber by sheds at either end of the kiln battery.

The kiln has been designed primarily to provide even circulation throughout the stack, not to give good control of temperature and humidity. It will be noted, however, that the boards at the bottom of the stack, which at one time receive very dry hot air, upon reversal receive air which is comparatively moist and cool. This has the effect of tending to reduce casehardening and makes possible the use of very dry air without detriment to the timber. The kiln has been operated successfully with 1in. Jarrah, Blackbutt and Karri boards at 30-40 per cent. moisture, the drying time for Jarrah and Blackbutt being about ten days, and for Karri twelve days.

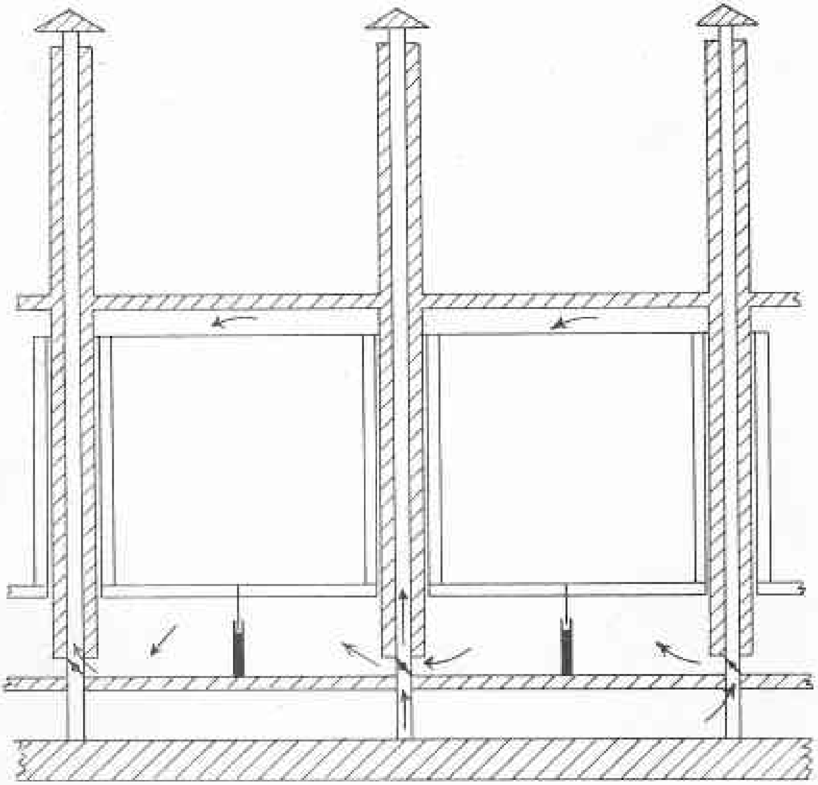
Details of Construction.

One of the advantages of this type of kiln is the simplicity and low cost of construction per unit of capacity. The ratio of stack volume to kiln volume is very high, and as comparatively thin stickers are used, the effect of this is increased. The cross section of the kiln is approximately standard, the kiln chamber being about 6ft. wide and 7½ft. high, the walls being extended about 1ft. below the floor and about 5ft. above the ceiling to provide space for the inlet flue and to make the outlet flues respectively. The capacity of the kiln is varied by varying the length, which may be anything convenient. A length between 30ft. and 40ft. is likely to be most suitable from the standpoint of stacking lengths.

The materials of construction can be timber, concrete, brick, etc. Jarrah frame construction and sheathing, as suggested for the Tiemann kiln, has been found satisfactory, and the use of roofing felt in this connection is strongly recommended. The ceiling is sawdust packed, and the floor can be built as described for the Tiemann kiln, though drainage slope on the floor is not essential. Except where water lies, no floor to the inlet flue below the kiln floor proper is necessary. When building a number of kilns side by side, party walls can also act as party flues as shown in Fig 9. A roof of G.C. iron or roofing felt can be provided between the party walls at such a distance above the ceiling as will allow sufficient air circulation to prevent stagnation.

The oscillating dampers are made of two small sheets of 20-gauge iron painted, of such a length as to fit between the wall studs. The sheets are clamped together with bolts on strips of saddle felt which project about ½in. around all edges to make tight joints with the studs and sheathing of the kiln walls. These sheets are fastened by clamping bolts to a bar, which runs the full length of each kiln wall, and which is provided with handles at either end so that the dampers can be moved to reverse the circulation. Care should be taken when assembling dampers that they do not fit too tightly between studs, or difficulty will be experienced in moving them as required.

The coils are of the return bend type and conform to the same specification as those of the Tiemann kiln. With steam at 60lbs. a coil of fourteen 1in., or ten 1¼in. pipes on each side of the kiln is required. If the boiler pressure is reasonably constant, the kiln coils can be designed for this pressure and connected with the boiler. If the boiler pressure fluctuates greatly it is better to include a reducing valve in the equipment and design, and operate the kiln at some pressure sufficiently below that of the boiler to give a moderately constant pressure. Fluctuations in pressure do not endanger the timber being dried if the coils are designed for the maximum pressure, but they tend to reduce the drying rate by introducing slow drying or non-drying periods when the steam pressure and hence the kiln temperature is low. Each kiln coil is provided with a globe valve on the drain end and connected to a common steam trap with a valve-controlled by-pass to air. Care should be taken in setting the trap that sufficient fall from the lowest portion of the coils is given for the type of trap selected. If desired, a return trap system may be installed to return the water of condensation to the boiler. This is a distinct advantage in this and other types of kilns which are worked for a period at night on banked boilers.



CLARKE KILN (PARTY FLUES)

FIG. 9

The steam spray pipes are similar to those in the Tiemann kiln, being 1in. pipes for kilns up to 30ft. and 1¼in pipes over this, perforated with ⅛in. holes every 8 or 9 inches and fed from a high pressure steam main.

As the timber is stacked on edge, stanchions are required to keep the stack in position; ½in. to ⅝in. stacking strips are used, and except where the moisture content of the timber is comparatively low, or where special equipment is provided to take up the slackness caused by shrinkage, it is advisable to place the strips at shorter centres than is usual, reduction to as low as 1ft. centres in many cases proving an advantage.

Perhaps the most desirable feature of this kiln is the small amount of attention necessary for operation. Apart from determining the moisture content of the charge every day or two, the operator has only, every 12 or 24 hours according to the moisture content of the timber, to change the steam supply from one side coil to the other and change also at the same time the oscillating dampers. Alteration of the kiln temperature from day to day is not necessary, although in some cases it is a desirable refinement. With the exception of these duties, the kiln requires no attention upon the part of operators or attendants.

Cost of Construction and Operation.

The capital cost of a kiln 36ft. long to hold 10 loads of timber will be £250 to £300, including buildings, dampers, rails, steaming and heating pipes coupled through a reducing valve to an existing boiler, but excluding kiln trucks, external kiln rails, and other handling equipment. If two or more kilns are built side by side with party walls, the saving per kiln wall eliminated will be about £50, *i.e.,* every kiln after the first will cost £50 less than the amount stated above. The steam consumption is very low, being about 4 h.p. for heating with a kiln as above, although during the 6 to 8 hours' steaming period at the end of each run a much higher consumption occurs.

The duties of operation are very light and, except when a large number of kilns are used, can, where kilns are operated at a mill or stacking yard, usually be performed by members of existing staff without serious encroachment upon their time. The greatest cost is in the handling of the timber, for this has to be stacked to air season on the flat and then stacked on edge on the kiln truck for kiln seasoning. For a single kiln this cost is not excessive provided that care is taken in reducing handling to a minimum by suitable placement of seasoning stacks and the kiln truck. For a number of kilns, handling costs can be greatly reduced by the provision of a mechanical system for the handling of a stack as a whole, without restacking, through the air and kiln seasoning treatments.

Although the kiln was designed for the drying of semi-dry boards, preliminary tests with material green from the saw have indicated that with the provision of proper facilities for taking up the slackness caused by shrinkage, there is a good possibility of eliminating the preliminary air seasoning and of yet producing a product well suited for flooring. Should this prove to be the case, drying green from the saw would in the majority of cases probably prove the more economical proposition. The patent covering this design is held by the Conservator of Forests, to whom any inquiries for further information should be directed.

It is not contended that this type of kiln is the only one suitable for the combined seasoning process with flooring. There are many types of kilns designed for this class of work, but as this type is in operation in this State, and has been designed particularly with reference to local conditions, it has been selected as a representative of this kind of drier.

Dry Kiln Instruments.

Temperature Recorders.—The automatic temperature recorder used is of the long distance type, and consists of a bulb filled with a volatile liquid and its vapour, connected by a long flexible tube filled with the liquid, to the recording apparatus. An increase in temperature raises the vapour pressure of the liquid, and this increase in pressure is transmitted by the liquid in the tube to an ordinary pressure gauge in the recorder case. This pressure gauge moves a needle which denotes, instead of pressure, the temperature appropriate to the pressure produced. On the end of the needle is a pen, and this traces on a chart a continuous record of temperature. Charts are usually for 24 hours' or 7 days' periods.

It should be noted that, as the instrument works on the principle of the vapour pressure of a volatile liquid, the temperature recorded will be the maximum occurring anywhere in the vapour and liquid system. It is essential, therefore, in installing these instruments, to be careful that no part of the apparatus can become exposed to a temperature higher than that of the bulb when the kiln is running. The bulb of the thermometer should be so placed that it is not influenced to any appreciable extent by radiation, from the cold wood stacks, or the hot steam pipes. When necessarily placed near either of these, it should have a small shield so placed as to keep off most of the radiation, without preventing a free circulation of air. It is to be noted, in this connection, that screening from radiator pipes is the more important.

The thermometer bulb recording the maximum temperature is placed in a convenient position in the central air column of the kiln. A bulb recording the baffle or saturation temperature in the Tiemann kiln is placed inside the baffle boxes. Both bulbs should be carried as far from the end of kiln as the length of flexible tubing will permit, and this distance from the end should be at least 10 feet.

Other types of recorders operating on the expansion, with rise in temperature, of a liquid or gas are available, but the vapour pressure type is recommended. The temperature range to be specified when ordering recorders should be 60° to 160° F. Care must be taken during the steaming of timber that the temperature does not exceed this maximum while the bulb is in the kiln, as damage to the instrument might result.

Recording Hygrometer.—The air in the Tiemann water spray kiln is saturated before being reheated. This makes the determination of the relative humidity a simple matter, as the maximum temperature and the saturation temperature, or dew point, can be read with ordinary thermometers. In blower or fan kilns the air is heated without presaturation, the humidity being adjusted by adding moisture by means of a steam jet. It is, therefore, necessary to employ wet and dry bulb thermometers (psychrometers or hygrometers as they are sometimes called) to give readings from which the humidity can be determined. The recording hygrometer is similar to a two-bulb recording thermometer, except that one of the bulbs is covered with a thin absorbent sheath which is kept supplied with water from a reservoir. Great care must be exercised in the use of the recording or simple wet bulb thermometer. Distilled or clean rain water only should be used for wetting the absorbent material. This should be examined from time to time to see that it still soaks up water readily, and should be renewed about once a month. Special bulb coverings are sometimes supplied; but if these are not available a fairly fine cotton material may be used. It is very necessary that the bulb should be in a free current of air. Low air velocity or stagnation gives incorrect (high) readings of the wet bulb, as the air which comes in contact with the bulb does not, before being raised to a high humidity, cause sufficient evaporation to cool the bulb to the requisite temperature.

Chemical Thermometers.—It is advisable to have some check on the operations of recording thermometers, and this can be done by hanging ordinary mercury-in-glass thermometers in the vicinity of the recorder bulbs. A useful idea is to provide the thermometer with an enlarged metal scale so that it can be read from a distance. By lighting the thermometer from a suitable angle it is then possible to read temperatures without entering the kiln. Wet bulb thermometers should not be of the metal frame type, but are preferably made from chemical thermometers in order to secure a maximum circulation around the bulb. Although chemical thermometers fastened to a piece of wire can often be suitably arranged for indicating baffle temperatures in the Tiemann kiln, maximum thermometers of the clinical or similar type are more convenient. These can also profitably form part of the kiln equipment for detecting the temperatures of inaccessible places.

It should be noted that, when a cold thermometer is first inserted in a kiln, water may condense on it, and the thermometer will then register the wet bulb temperature. Sometimes it is quite an appreciable time before this water evaporates, and, until this occurs, care should be taken that the thermometer reading is not mistaken for the dry bulb temperature. In selecting thermometers, those with the graduations etched on the glass or with a glass case enclosing the scale should be chosen, and unless evidence is available that the thermometers have been checked after manufacture, it is advisable to carry out a rapid test against a standard thermometer over the temperature range for which they are required.

Automatic Temperature Controllers.

These instruments have a thin flexible tube ending in a bulb similar to that of a temperature recorder, and the expansion and contraction of the liquid in the bulb acts directly or through an auxiliary system, on a throttling valve on the steam supply pipe. The direct acting type has the advantage of simplicity and low initial cost, but the greater accuracy of the auxiliary type is an offset to the high initial cost of the compressed air auxiliary mechanism. The throttle valves of controllers should be examined at intervals, as the valve seating is frequently subject to considerable wear. Controllers should be by-passed, so that, in the case of failure, operation can continue with hand control of an ordinary globe valve.

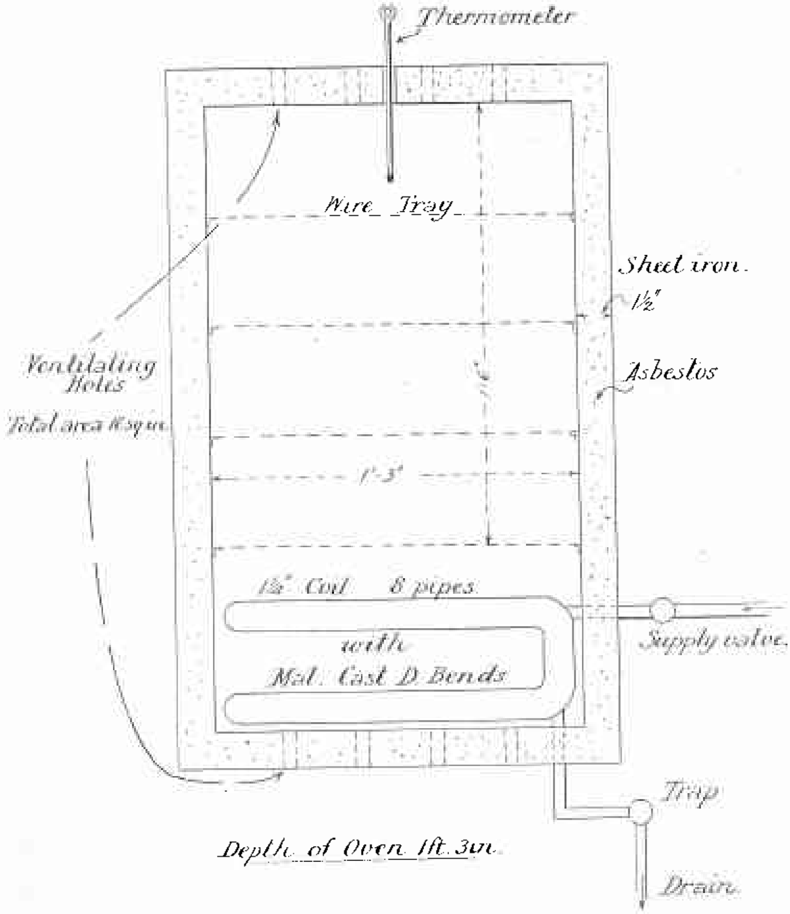
The instruments are used for the regulation of the steam supply to kiln heating coils in order that the maximum drying temperature may be controlled. The actuating bulb is located in a position similar to that of the maximum temperature recorder bulb of the kiln. Where the kiln coils, as in the Tiemann, are made up of two sets separately valved, the controller can be placed upon the upper set only. This permits of the use of a smaller controller, and gives greater satisfaction as the variation in demand on the valve is reduced. Where a steam jacket or a single main system is used, a controller is a valuable addition in maintaining the spray water at a constant temperature.

Thermostatic Water Mixers.

These mixing valves which are used to control the temperature of spray water in the Tiemann kiln are self-contained and are fed by hot and cold mains, sufficient water being taken from each to deliver the mixture at a predetermined temperature. The operation of the valve is controlled by a thermostatic element which can be adjusted to operate at any temperature within the range of the instrument, but for satisfactory results it is necessary to have the hot and cold water supplies at approximately the same pressure. When ordering, a range of 60deg. F. to at least 140deg. F. should be specified.

Pump Regulators.

Pressure regulators for pumps consist of a throttle valve controlled by the pressure of the delivery water. The water connection to the regulator should be taken from the delivery side of the air cushion. A pressure gauge of the Bourdon type should be provided on the pump delivery.



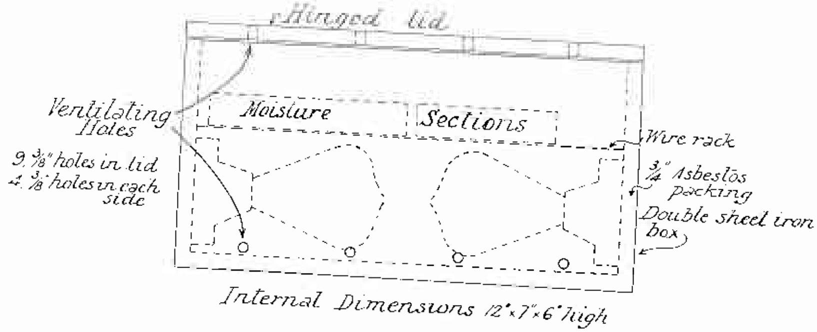
STEAM DRYING OVEN

FIG. 10

Drying Ovens.

Ovens for the drying out of moisture content samples can be heated conveniently by steam or electricity. For kiln drying installations, where steam is continuously available, a suitable type is shown in Fig. 10. This consists simply of a double sheet iron box packed with loose asbestos and provided with inlet and exit ventilating holes, wire racks for holding sections, and a steam heating coil. The temperature in the oven, which should be between 212deg. F. and 220deg. F., is controlled by a globe valve on the supply line, and the pressure is maintained inside the coil by a trap on the drain, or a small valve, opened sufficiently to permit of the escape of the condensed water.

For occasional tests the portable electric drier is useful (Fig. 11). A double sheet iron box is again employed packed with asbestos. This has a hinged lid provided with exit ventilation holes, inlet holes being provided in the sides of the box. Heat is provided from four 32 C.P. (90 watt) carbon globes, two each end of the oven. The two globes at each end are wired in series, the two ends being in parallel. The total consumption of the oven is, therefore, only 90 watts. This oven scorches specimens slightly on the under side, but will be found quite accurate enough for all ordinary moisture determinations.



ELECTRIC OVEN
FIG. 11

Gas heated hot air ovens, and boiling water or steam jacketted ovens at atmospheric pressure are sometimes employed, but these are not recommended, the former on account of the difficulty of control, the latter because the oven temperature is below 212deg. F. and complete drying of the sample rarely occurs.

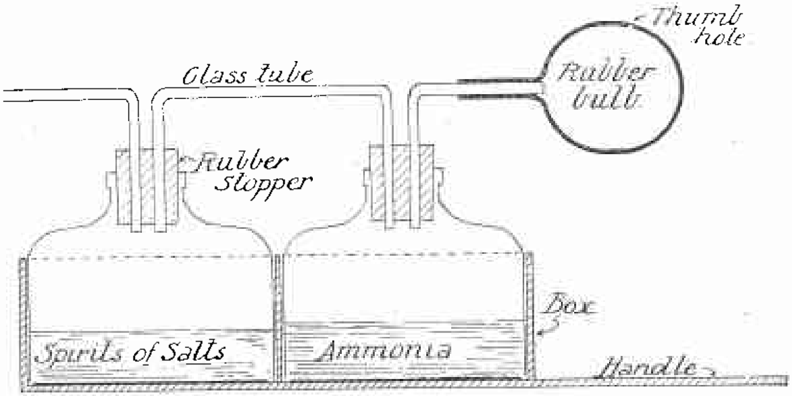
A simple but effective drier can be made from a small tin of 6in. or 8in. diameter. This is coated on the sides and top with about an inch of asbestos, and a few small holes are drilled through the top. An area on the upper part of the shell of a high pressure boiler is bared and in this area are placed the moisture samples, which are kept just above the boiler plate by netting or gauze. The prepared tin is placed as a cover over the moisture content sections, so that it makes a close joint with the boiler insulation. This oven should give a temperature of about 215deg. F., and specimens after 48 hours will be dried to ½ per cent. moisture or less.

Sample Board Scales.

Special scales for sample boards can be procured, but ordinary platform scales or retailing scales of the centre balanced beam type with superimposed platforms are quite suitable. In the last mentioned type it is very convenient to provide two weights each of 0.2 and 0.02 of a lb. and one each of 0.5, 0.1, 0.05 and 0.01 of a lb. Weighing can then be conveniently carried out in hundredths of a lb. For a kiln plant drying boards, scales weighing up to 10lbs. are of ample capacity, but if thicker stock is to be dried a greater range will be necessary.

Smoke Tests of Air Circulation.

For successful operation, it is essential that the air circulation throughout the length and the breadth or height of a kiln should be reasonably uniform. Where doubt exists as to uniformity, specimen boards may give an indication of irregularities, but rarely do they show the cause. It is convenient, therefore, to be able to trace the air movement by means of smoke, so that necessary alterations can be effected. When studying the general circulation inside a kiln, the burning of turpentine will give a dense black smoke which persists for a considerable time. If, however, it is desired to obtain a more accurate indication of the rate and direction of air movement at any particular point, punk sticks, such as are used to discourage mosquitoes, can be burnt. The advantage of the punk stick is that it will provide a little cloud of smoke, and the manner in which this cloud moves can be noted. In some cases, however, the heat of the burnng stick will cause convection currents sufficient to give an erroneous impression, and where this is likely a cold chemical smoke can be employed. An apparatus for producing ammonium chloride smoke is shown in Fig. 12. The sketch is self-explanatory for the apparatus is merely a means of mixing ammonia and hydrochloric acid gases and discharging them into the air. For most kiln drying work the use of punk sticks will be found quite satisfactory.



SMOKE PRODUCER

FIG 12

CHAPTER 6.

THE TIMBER SEASONING KILN—OPERATION.

Stacking of Timber in the Kiln.

When considering the loading of a kiln, the first factor is the quality of the timber to be dried. It must be remembered that seasoning adds to the value of only such timber as is reasonably free from blemishes. Low grade material which has faults resulting from knots, irregularity of grain, or from cutting too near the heart will depreciate in usefulness and in value, while the drying of timber badly affected by gum veins and pockets is of no advantage, for any slight increase in value resulting will be far below the cost of treatment. The futility of drying low grade material will be more pronounced when a kiln is employed, for in many cases the drying conditions are such that the faults will be accentuated. It is, therefore, essential, when operating a kiln or battery of kilns, to arrange that material of good quality only is supplied.

Jarrah, on account of its hardness and durability, has been found very suitable for spacing strips in kiln stacking. It is usual to make the width of the strip equal to its thickness with the proviso of a minimum width of 1in. In the Tiemann kiln 1in. strips should be used with timber up to 1½in. thick, and 1½in. strips should be used above this. If the circulation is very good, the use of 1in. strips with timber up to 1¾in. and perhaps 2in., may prove economical owing to the greater kiln capacity secured. In forced draught kilns, 1in. strips are often used for all thicknesses of stock, and any variation from this which is desirable is usually indicated by the supplier of the kiln equipment. In the Clarke kiln, strips are ½in. or ⅝in. in thickness, and with any other kiln, vertically stacked with a similar distribution of heating pipes, these thin strips would probably also be satisfactory. Care must be taken when providing spacing strips that they be of an even thickness throughout. If the strips vary, it is impossible to produce straight dry timber.

Spacing strips should not be more than 18in. or 2ft. apart and should be vertically above one another. With vertical stacking, better results have been obtained by placing the strips closer together and a spacing of 1ft. is recommended, unless special provision be made for preventing the looseness caused by shrinkage.

It is sometimes economical to use special short length material as spacing strips, but this is not advisable if pieces are more than 3 or 4 inches wide.

After the stack has been placed in kiln, before starting up, care should be taken to see that the only path for air to take from entering to leaving sides is through the stack itself. In this connection ends of kilns should be given particular attention. It will be noted that where stacking is flat or slightly inclined the central air flue is tapered. This is to distribute the air evenly throughout the height of kiln as, sometimes, when central flues are not tapered, the air tends to rise rapidly to the top and pass through only the top layers. Care should be taken to build the taper evenly, and for this purpose a stacking frame is recommended.

Unless the velocity is comparatively high, there is an appreciable lag between boards on the entering and leaving air sides of the stack. This is most pronounced in naturally-ventilated or assisted naturally-ventilated kilns. If in addition the air circulation is not perfectly even throughout the height of the stack this lag is increased in certain portions of the leaving air side of the stack. These areas are known as wet pockets and a position in which they are sometimes found when drying Jarrah is shown at WW in Fig. 5. The cure is to increase the air supply to the affected portions of the stack, and this is done by "opening up" the stack in these locations. In other words in slope-stacked timber an edge to edge space is left in and around the places likely to become wet pockets, while in flat-stacked timber the opening up is effected by increasing the normal edge to edge space.

Sometimes also the inductive effect of the air velocity up the central flue causes a reversal of circulation in the lower layers of the stack and, in these, air which has already passed from the entering to the leaving air side passes back through the stack to the central entering air stream. Naturally under these conditions a wet pocket develops in the bottom of the stack (ww in Fig. 5.) Prevention again lies in opening up the bottom layers of the stack so that some of the air from the central air column can pass up through these layers from the bottom of the stack. In severe cases the kiln floor at the rail level has sometimes to be laid with rough boards with an edge to edge space of ½in. to ¾in.

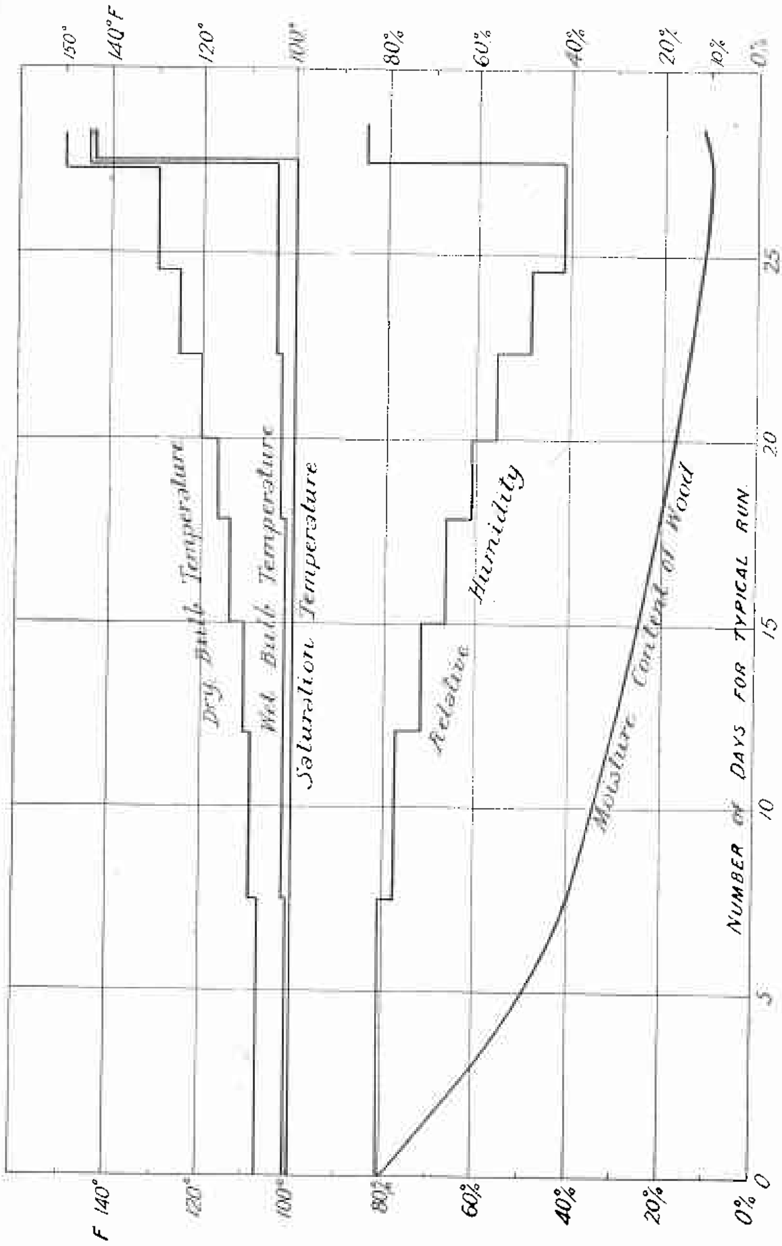
It might be considered that because mention of these faults is made in connection with the Tiemann kiln that the circulation in this type is vastly inferior. It must be remembered, however, that with the exception of the Clarke kiln, in which one of the reasons for adopting vertical stacking was the prevention of wet pockets, there are no other types of kilns operating in this State, and these may to a greater or less extent be affected by similar faults. The cure in any such possibility will result from the application of the principles of air circulation and should the cure be only a partial one, the most detrimental effect need merely be an increase in the drying time owing to the slower drying rate of the lagging portion.

DRYING SCHEDULES. (TIMBER GREEN FROM THE SAW).

The question now to be studied is "What are the desirable conditions to be maintained in a kiln?" These conditions are found as a result of experiment and are stated as relationships between the temperature and relative humidity of the air on the one hand and the moisture content of the wood on the other. Such a relationship or series of relationships is called a drying schedule, and schedules may either be tabular or graphical. In a graphical schedule, strictly, the curves should be obtained by plotting temperatures and relative humidities against moisture content. As it is desired, however, that the graph should give a picture of what is happening, it is more convenient to plot temperatures, relative humidities and moisture contents all against typical drying times in days. Nevertheless it must be realised that drying times are not essential to the schedule, for the whole purpose of it is to fix the relationship between the moisture content of the timber being dried and the atmospheric conditions in the kiln. No precise data as to the rate of air circulation is given in a schedule. This is rather a matter of kiln design, and it is assumed that the velocity of air movement over the timber is sufficient for drying to proceed satisfactorily.

In Fig. 13, the standard drying schedule for 1in. Jarrah is given in the graphic form, while in Table 1 the same schedule is given in tabular form. The schedules for other sizes and species are also given in tabular form in Tables

2 to 6. The curves illustrate the rapid loss of moisture when the timber is very green, owing to the high rate of transmission through green timber, and they show also the slow drying in the final stages, when the timber is in a fairly dry condition and has a very low rate of transmission. Another cause of the slowing up in the drying is that at the beginning of the run a high moisture gradient is built up, but as the run proceeds the difference between the moisture content of the inside and outside becomes less and less. It should be realised that the dry-



1" JARRAH STANDARD DRYING SCHEDULE

FIG. 13

ing curve shown indicates the average moisture content of a piece of timber at any stage in the drying. The centre of the piece will be above this average, while the outside layers will be lower and practically in a state of balance with the temperature and relative humidity of the air.

TABLE 1.

DRYING SCHEDULE FOR 1IN. JARRAH.

Moisture Content.	Dry Bulb Temperature.	Wet Bulb Temperature.	Saturation Temperature.	Relative Humidity	Remarks.
per cent.	F°	F°	F°	per cent.	
green	107	101	100	81	
40	109	102	100	77	
30	111	102	100	72	
25	114	102	100	66	
20	117	103	100	61	
17	120	103	100	56	
14	125	104	100	49	
12	130	104	100	42	
10	150	144	144	85	High humidity treatment.

TABLE 2.

DRYING SCHEDULE FOR $1\frac{1}{2}$IN. JARRAH.

Moisture Content.	Dry Bulb Temperature.	Wet Bulb Temperature.	Saturation Temperature.	Relative Humidity.	Remarks.
per cent.	F°	F°	F°	per cent.	
green	106	101	100	84	
40	108	101	100	79	
30	110	102	100	75	
25	113	102	100	69	
20	117	103	100	61	
17	120	103	100	56	
14	125	104	100	49	
12	130	104	100	42	
10	150	144	144	85	High humidity treatment.

TABLE 3.

DRYING SCHEDULE FOR 1IN. KARRI.

Moisture Content.	Dry Bulb Temperature.	Wet Bulb Temperature.	Saturation Temperature.	Relative Humidity.	Remarks.
per cent.	F°	F°	F°	per cent.	
green	104	101	100	89	
35	106	101	100	84	
25	108	101	100	79	
20	111	102	100	72	
17	115	103	100	64	
15	120	103	100	56	
13	125	104	100	49	
12	130	104	100	42	
11	135	105	100	37	
10	150	144	144	85	High humidity treatment.

TABLE 4.

DRYING SCHEDULE FOR 1½IN. KARRI.

Moisture Content.	Dry Bulb Temperature.	Wet Bulb Temperature.	Saturation Temperature.	Relative Humidity.	Remarks.
	F°	F°	F°	per cent.	
green	99	96	95	89	
35	101	96	95	84	
25	103	96	95	79	
20	106	97	95	72	
17	110	97	95	64	
15	115	98	95	55	
13	120	99	95	48	
12	125	100	95	42	
11	130	101	95	37	
10	150	144	144	85	High humidity treatment.

TABLE 5.

DRYING SCHEDULE FOR KARRI 2IN. THICK AND THICKER.

Moisture Content.	Dry Bulb Temperature.	Wet Bulb Temperature.	Saturation Temperature.	Relative Humidity.	Remarks.
per cent.	F°	F°	F°	per cent.	
green	94	91	90	88	
35	96	91	90	83	
25	98	92	90	78	
20	101	92	90	72	
17	105	93	90	63	
15	110	94	90	55	
13	115	95	90	47	
12	120	96	90	41	
11	125	96	90	36	
10	150	144	144	85	High humidity treatment.

TABLE 6.

DRYING SCHEDULE FOR 1IN. TUART.

Moisture Content.	Dry Bulb Temperature.	Wet Bulb Temperature.	Saturation Temperature.	Relative Humidity.	Remarks.
per cent.	F°	F°	F°	per cent.	
green	105	101	100	86	
40	107	101	100	81	
30	109	102	100	77	
25	111	102	100	72	
20	114	102	100	66	
17	118	103	100	59	
14	124	104	100	50	
12	131	105	100	42	
11	130	106	100	33	
10	155	150	150	88	High humidity treatment.

In an ideal schedule, the temperature would gradually be increased and the relative humidity gradually lowered in the form of smooth curves. In practice it is more convenient to make the change in a series of steps, these steps being made as large as possible in order to reduce the number of resettings of the control intsruments. The drying curve shown is, of course, ideal, and would actually be somewhat irregular as a consequence of the step changing of the atmospheric conditions. At the end of the drying run is shown a period of high temperature and high relative humidity during which the timber absorbs moisture. This treatment is for the removal of casehardening, and can be used instead of the steaming treatment. One of the disadvantages of the steaming treatment is that when the timber is severely casehardened, the saturated atmosphere of steaming has to be continued for such a long time that excessive reabsorption of moisture by the timber takes place. When this moisture is redried out, tensile stresses are set up in the surface layers owing to reshrinkage and a condition known as reversed stress or oversteaming is caused. This condition, if the stresses are severe, is as deleterious as casehardening, with the additional disadvantage that it is far more difficult to remove. By using a high temperature treatment with the relative humidity below saturation, the possibility of excessive reabsorption is practically removed. The process has, unfortunately, the disadvantage that it takes much longer. The decision as to which treatment is to be used must rest with the individual operator. When high humidity treatment is to be employed it is a considerable economy in time to remove casehardening by a steaming treatment when the timber is at 14 or 15 per cent. If drying below this figure is carefully carried out, the extent of casehardening at the end of the run should not be great, and the period of treatment will be comparatively small.

For steaming and high humidity treatments to be effective, a certain amount of reabsorption of moisture by the wood is necessary. These treatments must, therefore, be carried out at temperature 10° F., or preferably 15° F. or more, higher than the drying temperature previous to the commencement of the treatment, in order that reabsorption will occur. The reason why the temperature of the timber must be less than that of the surrounding humid atmosphere will be apparent upon further consideration of the laws relating to evaporation and condensation.

That it is necessary to supply about 1,000 British Thermal Units to vaporise 1 lb. of water in wood has already been mentioned. In other words, the water in the state in which it exists in wood has no latent heat of vaporisation. Supposing a piece of dry wood be placed in a saturated atmosphere the temperature of which is slightly higher than that of wood, then, since the moisture content of the wood is below the balance point for these conditions, absorption of moisture by the wood from the air will take place. For every pound of water absorbed, latent heat will be liberated to the amount of about 1,000 B.Th.U., owing to the passage of moisture from the gaseous state in the air to the equivalent of the liquid state in the wood. This liberated latent heat can only be disposed of by transmission to some material at a lower temperature, in this case, the wood. As soon as the temperature of the wood rises to that of the surrounding air, absorption of moisture by the timber must cease, for there is no provision for the absorption of the latent heat. This temperature action is likely to be more pronounced with high humidity than with steaming treatment, for when steam is liberated into a kiln the atmosphere becomes filled with a fog of minute drops of water, and these can be absorbed by the wood without temperature change.

It is impossible to lay down empirical rules for the duration of treatments for the removal of casehardening. With 1in. timber, severe casehardening at the end of a run may require six hours, or even a longer period of steaming, while with thicker timber this figure may have to be doubled. High humidity treatment may require up to 24 hours for 1in. timber.

Sometimes during the run, particularly in the case of thick stock, cracks will be noticed in the early stages. This is, of course, an indication of too severe drying conditions, and may be caused by too severe a schedule or by inability to operate the kiln accurately to the schedule. In the former case, the relative humidity must be increased so that drying from the surface proceeds at a reduced rate. In the latter case, it is often advisable to drop the dry bulb temperature of the schedule 5° F., or in bad cases 10° F., the relative humidity remaining the same or perhaps being slightly increased. At lower temperatures control of the kiln is more easily effected, so that by this means the faulty conditions can be corrected. Cracked timber must be watched carefully, and if the cracks nip in at the surface it is an indication that the timber is casehardening. The condition is corrected by a steaming treatment of two or three hours, at, say, 20° F. above the drying temperature. Care must be taken at the completion of steaming that the timber is reduced to the schedule drying temperature in an atmosphere at or near saturation, for the heat available in the timber is capable, with fairly dry air, or hardening the surface in a very short time. Repetition of the nipping of the cracks must be countered again by a steaming treatment, for it will be found that unless this nipping condition is remedied, upon the completion of drying, the timber, although appearing sound from observation of the surface, will have internal cavities in the locations of the original cracks, and these cavities will become all too apparent upon removal of the outer layers of the timber during machining. Where cracking is not present, the existence of casehardening is often indicated by an excessive reduction in the drying rate, and here again the cure is short-period steaming, which may have to be repeated periodically throughout the run. It should be remembered that steaming is a treatment for the softening of wood cells below fibre saturation point. Wood cells which are above fibre saturation cannot be hardened, and therefore require no treatment; in fact, steaming of these cells in some cases may have deleterious results. If steaming is necessary when the inside cells are still above fibre saturation point, it should always be of comparatively short duration, so that only the surface cells are affected.

The 1in. Jarrah schedule given is a conservative schedule for the rapid seasoning of wide backcut boards for higher grade purposes. Narrow Jarrah boards are not so likely to warp and crack, and for these the schedule can be increased in severity. Quarter cut Jarrah has not the tendency to crack and warp that backcut material has, but the rate of drying under similar conditions is appreciably slower. For narrow boards and for quarter cut boards, therefore, the temperature of the schedule can be increased throughout 10° F., the relative humidity remaining the same, or being slightly lowered. Schedules for the drying of thicker sizes of Jarrah for higher grade uses are included in the tabular form. For 1½in. Jarrah, Table 2, and for 2in. Jarrah, Table 6, respectively, are used, while for Jarrah thicker than 2in. Table 4 can be followed. The 1in. schedule should be used for material less than 1in. thick. The time of drying of 1in. Jarrah has been given as 28 days. With a spray press of 50 or 60 lbs. in the early stages of the run, and elimination of any wet pockets, this time could probably be reduced in the Tiemann kiln to 26 days or even less. With a blower or internal fan kiln, the time would probably be 24 or 25 days. Half-inch timber would probably dry in about one-third of the time required for 1in. timber, but for timber over 1in. thick the time of drying will vary as the thickness; for example, 2in. timber will take twice as long as 1in.

It has been mentioned that a board on the leaving air side of the stack tends to dry more slowly than one on the entering air side. In the schedule given, it is the moisture content of entering air side timber which must decide the temperature and relative humidity conditions of the kiln. In some cases, however, the lag of the spray side is so great in the early stages, that at some later stage the rate of drying here becomes excessive. In this case, the severity of drying conditions must be reduced at the expense of a slowing up of the drying rate on the entering air side. Sometimes also in the later stages of the run, a lag occurs in a portion of the stack although the circulation there is known to be satisfactory. This is an indication that at some period drying in this area has taken place at an excessive rate and the timber is severely casehardened. The cure lies in a steaming treatment.

Karri.

The standard schedule of 1in. Karri is for narrow and wide back cut boards which are required seasoned in a perfect condition. The outstanding features in the drying of Karri are the readiness with which checking takes place, and the tendency to caseharden owing to the low rate of moisture transmission. The former feature necessitates very careful operation in the early stages of the run; the latter, periodical steaming for the removal of casehardening. As a comparatively small departure from scheduled conditions for a few hours may, in the early stages of a Karri run, cause serious checking, both kilns and equipment for this timber must be of the best quality. In construction, roofing felt must be included in the specification of wooden walls, and every care must be taken to secure a well insulated, reasonably air-tight building, while in operation particular attention must be given to the maintenance, setting, and calibration of all control equipment. Quarter cut Karri dries more slowly than back cut, and although it does not check as easily, yet it has an appreciable tendency to form fine cracks in the direction of the annual rings. Quarter cut boards should be dried to a schedule 5° F. higher than the standard, with the same relative humidity.

The standard schedules for greater thicknesses are given. Table 4 is used for 1½in. Karri and Table 5 for Karri 2in. thick and over. For thicknesses below 1in., the 1in. schedule should be used. It is recommended that an operator should not attempt to dry Karri greater than 1in. thick until he has seasoned at least one charge of 1in. Karri in the kiln to be used, or in the case of a battery of kilns, in one of the kilns to be used. Steaming treatments, etc., for Karri follow the same rules as those for Jarrah, the only difference being that slightly longer periods are necessary throughout.

The time of drying of 1in. Karri in a Tiemann kiln has been estimated at 39 days. As this was computed from the results of experiments with a kiln hand controlled, it is very probably considerably high. Immature Karri 1in. boards from logs 2ft. diameter at breast height, grown in South Africa, were dried there to 7 per cent. moisture in 31 days, including two days' final humidity treatment. This test was carried out in a blower kiln. It was considered that the schedule was conservative and could be accelerated. Similar timber 1¾in. thick was dried in a Water Spray kiln to 10 per cent. moisture content in 49 days, although in this case control was not considered to be satisfactory and the spray pressure averaged only 44 lbs.

Tuart.

The schedules for Tuart are only provisional, as they are based on insufficient data. The schedules are conservative, and it will probably be found that after one or two runs they can be made more severe, with consequent reduction in drying time. Tuart, which is a denser timber than Karri or Jarrah, has, like Karri, a lower rate of moisture transmission than Jarrah, but, although worse than Jarrah as far as cracking is concerned, it is not so subject to this fault as Karri. Periodical steamings below 30 per cent moisture content will be found to be advantageous. Table 6 is used for 1in. Tuart, Table 3 for 1½in., Table 4 for 2in., and Table 5 for thicker timber.

Minor Timbers.

Little information is available on the physical properties of the minor timbers of the State, and the following information should be regarded as an indication rather than as a definite pronouncement.

Blackbutt.

This timber probably has a rate of moisture transmission as great, if not greater, than Jarrah, but it has a greater tendency to check. Tentatively the Karri schedules are recommended, but it may ultimately be found that the Jarrah schedules may be approached, or even adopted. Steaming treatments will probably approximate those of Jarrah. The drying time will be much less than that of Karri.

Marri.

The Jarrah schedule can be adopted, but this will possibly be found to be somewhat conservative.

Red Tingle Tingle.

The Jarrah schedules should give perfect material with a higher drying rate. Collapse is likely to be a feature when kiln drying this timber. If it is encountered with the 1in. schedule, the temperature should be reduced 10° F. throughout. If it is considered that the Jarrah schedules can be made more severe, this should be done by reducing the relative humidity throughout, not by increasing the temperature, as this latter course is likely to result in a serious increase in the tendency to collapse.

Yellow Tingle Tingle.

The Karri schedules are recommended initially, although the Tuart schedules may ultimately prove more suitable.

Wandoo.

Wandoo has a very low initial moisture content, probably between 30 and 35 per cent. The Karri schedules below 35 per cent. are recommended. Drying times will probably be considerably longer than for Karri.

Salmon Gum, Morrel, York Gum, Yate.

These are dense timbers of low initial moisture content. The recommendation with regard to Wandoo is applicable to these woods.

Banksia, Sheoak, and Native Pear.

The Jarrah schedules should not be too severe. In the case of Banksia, the temperatures could probably be increased 20° F. or more throughout with safety. The drying rate of this timber would probably be very rapid.

Schedules for Semi Air Dried Timber.

Where the seasoning of material which has previously been air dried to a greater or lesser extent is to be completed in the kiln, timber required for higher grade uses should be given the schedules above, commencing at the temperature and relative humidity corresponding to the moisture content of the charge in question. If, before kiln drying, tests disclose casehardening, the timber should be heated up in a saturated atmosphere to the temperature of the commencement of the run, or, in cases of severe casehardening, to a higher temperature, and it should be maintained at this until casehardening has been removed. This treatment may cause a considerable deposition of moisture on the surface of the timber, and this will have to be removed before drying of the wood commences. Where casehardening is absent, therefore, it is more economical to heat up in an atmosphere of a relative humidity, approximately that specified for the commencement of the run

Schedules for the Clarke Kiln.

The drying schedule for partially air dried 1in. Jarrah flooring board stock below 40 per cent. moisture is to maintain the entering air temperature at about 120° F.-130° F., reversal of circulation taking place every 24 hours. If existing checks open up more, or fresh checking occurs, reverse every 12 hours until 25 per cent. moisture content is reached. It will probably be found that the temperature increases somewhat towards the end of the run. This is not deleterious. For drying green Jarrah, 120° F. should not be exceeded until 40 per cent. moisture content is passed, and until 30 per cent. moisture content is reached reversal should take place every 12 hours. In some cases a steaming period of two hours at 160° F., when 20 per cent. moisture content is reached, will decrease the drying time. For final steaming six hours, rising to 200° F., is recommended.

In drying Karri below 30 per cent. moisture content, commence with a temperature of 120° F. Steam for two hours at 160° F. when 18 per cent. moisture content is reached. The capabilities of the kiln in drying Karri above 30 per cent. moisture content are not known. Final steaming will be six hours, rising to 200° F.

Blackbutt drying conditions are the same as those specified for Jarrah.

Economy of steam consumption can be effected when steaming by bringing both oscillating dampers to the inlet position, and closing the outlets to air of the inlet flue beneath the floor. A separate steaming kiln can be provided if desired.

After final steaming, dampers should be returned to their normal positions, the inlet flue reopened, and the direction of air circulation reversed at lengthening intervals. By about 12 hours, or perhaps less, after the completion of steaming, most of the moisture absorbed from the steam will be found to have evaporated. Slight reversal of casehardening stress may be present in some cases, but this will not be sufficient to be deleterious.

The high temperature final steaming causes a slight brittleness in the timber, but this is not sufficient to cause a reduction in value, and is more than offset by the softness of the final product. This softening results in improved machining with a reduced blunting effect upon the knives.

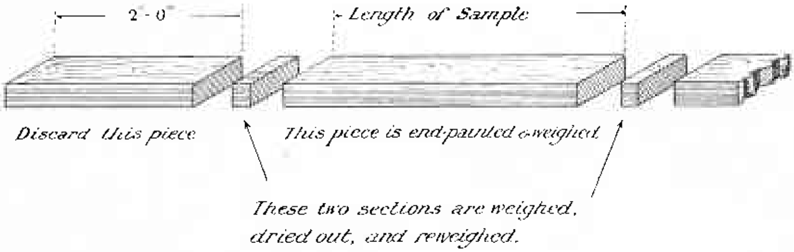
The possibility of using high temperature steaming when drying timber for joinery and similar purposes is worthy of consideration, particularly in cases where much of the working has to be done by hand.

Specimen Boards.

Since the drying conditions of the kiln atmosphere are governed by the state of seasoning of the charge, it becomes necessary to have some method of determining the moisture content of the timber at any instant. This determination could be made by withdrawing pieces of timber from the kiln and making on them direct tests for moisture content. If many determinations were required, this method in addition to its inconvenience would become somewhat costly, owing to the amount of timber destroyed in testing. Direct tests are, therefore, reserved for special occasions. It is far more convenient to place in the stack a number of specially prepared samples or specimen boards, the moisture contents of which have been determined prior to their inclusion in the stack. These samples are so placed that they can readily be removed to be inspected, and also to be weighed, for, from their weights at any time the moisture contents of the boards can be computed.

Placement.—The first essential of a specimen board is that throughout the run it must be truly representative of the timber adjacent to it; the second is that its original moisture content and weight must be accurately determined at the time of preparation of the sample; the third essential is that it must be placed so that it can be removed at any time from the stack, conveniently and rapidly, in order that by weighing it a determination of moisture content can be made.

The third essential limits the length of the specimen board, usually to about 2ft. or even less, for it can most readily be removed if it is placed between spacing strips. Sometimes where strips are very close together it may be necessary to increase the length to nearly twice the spacing of strips, and allow one strip to bear on the board in its centre. If this strip is likely to bind the sample, the portion of it above the board should be removed. In order that the first essential may be complied with, it is necessary to see that in the placement of samples, there is no interference with the circulation, nor are there in the vicinity of the sample, spaces, or blanks in the stack of any kinds likely to give an excessive supply of air to the surfaces of the board. The placement of specimen boards in the sides and ends of a stack is shown in Fig. 14B. Where back cut wide boards are being dried it is not usually practicable to make the samples of full width, for these being unrestrained often warp and either bind on the strips or else interfere wtih the circulation. The sample is therefore made six or eight inches wide, and in placing it in the stack the full width is made up by a filler piece adjacent to it.

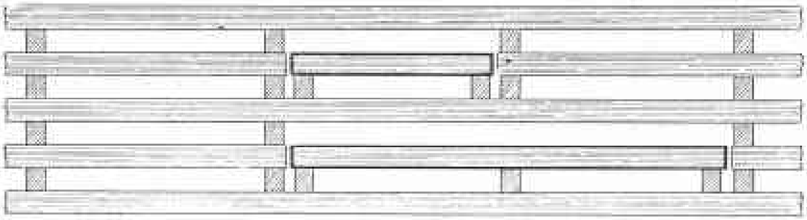


CUTTING *of* SAMPLE BOARD.

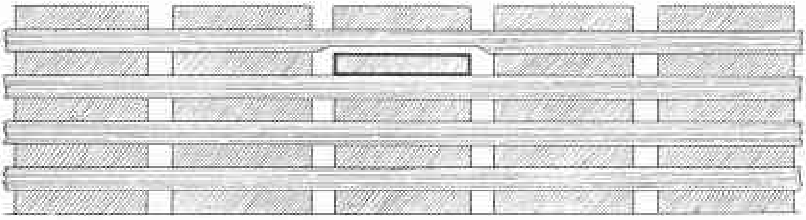
FIG. 14A

Preparation.—To prepare a sample a piece of timber is taken, and from it is docked a length slightly greater than that required in the sample. From each end of this is cut a moisture content section upon which a moisture content determination is made, and the sample board left is suitably marked for identification.

and weighed. The first precaution to be taken is due to the fact that timber dries much more rapidly through the ends than through the sides. The result is that the end foot or two of a piece of timber is not representative of the condition of the board. When cutting a specimen board, therefore, about 18in. or 2ft. are first discarded and then the length for the sample is docked. This comparatively rapid end drying also makes it essential that moisture content sections cut from the ends of the sample must be weighed *immediately* after cutting. Before weighing sections, however, it is necessary to scrape off loose fibres, as these become brittle in the drying oven, and fall or are brushed off, with consequent inaccuracies. As soon as possible also the ends of the sample board must be coated with end-paint in order that end drying may not occur here, and the sample board must then be weighed. The order of procedure is, therefore, dock the discard, dock the sample length, cut the moisture content sections, weigh the sections, paint the ends of the sample, and finally weigh the sample. All these operations must be concluded in the shortest possible time. In very hot dry weather it is sometimes advisable to cut a moisture section from one end and weigh it, and then cut a ½in. discard before cutting the moisture section from the other end of the sample. The necessary qualities in the end paint are that it will be impervious to moisture, that it will stick to the end of the timber, and that it will withstand the kiln temperatures. Suitable end paints are:—lampblack and resin or tar mixture; pitch or bitumen and tar mixture; bituminous paints with the volatile constituents expelled. The end paint must be hot and is best applied by dipping the end, although careful brushing is satisfactory. A thick coat adhering well and completely covering the end should be given, while care should be taken that the paint does not boil. The preparation of a sample board is shown diagrammatically in Fig. 14A. Care must be taken that samples are prevented from drying until they can be placed in position in the stack.



Side of Stack



End of Stack

PLACEMENT of SAMPLE BOARDS.
FIG. 14B

The number of samples to be included in a kiln run may vary from two to a dozen or more, according to circumstances. In the initial run of a kiln, or when modifications have been carried out, it is advisable to include the maximum number, but reduction can be made as the behaviour of the kiln becomes known. Where a kiln is in use continually for the drying of the same class of material, from two to four samples would probably be sufficient. In placing specimen boards for an initial run, it should be remembered that conditions are usually most severe at the top of the stack on the entering air side, and at least one sample should be located there. Portions of the stack where the circulation is likely to be below normal should also receive samples, as these will probably be the slowest drying areas. Where a large number of samples are included in the charge several samples can advantageously be cut from the one piece of wood, if it is of sufficient length. Where the number of samples is four or less it is advisable to cut each sample from a separate piece of wood. When selecting pieces of wood for sample board material, care should be taken to select timber which appears to be of the highest moisture content. If a back cut charge includes material cut other than on the tangent, a piece of this should be chosen for one of the samples to be located in the slower drying areas.

It is often convenient when cutting specimen boards to cut also a few pieces about two or three feet long, paint the ends and include these in the stack alongside specimen boards. When pieces are required for casehardening tests these short lengths can easily be removed to provide the necessary material, and it is thus not necessary to deplete the number of sample boards. If there is any doubt as to the reliability of sample boards it is advisable to withdraw a board or two from the kiln for direct test, before the timber is removed from the kiln. In any case it is advisable when unloading a kiln charge to select a number of representative pieces and test these for moisture content, moisture distribution, and drying stresses.

A typical series of calculations from the preparation of a sample board would be as follows:—

First Section—

Weight as cut	91·4 gms.
Weight after oven drying	50·9 gms.
Loss of weight	40·5 gms.

$$\text{Moisture content } \% = \frac{\text{loss of weight}}{\text{oven dry weight of section}} \times \frac{100}{1}$$

$$\frac{40\cdot5}{50\cdot9} \times \frac{100}{1} = 79\cdot5\ \%$$

Second Section—

Weight as cut	89·8 gms.
Weight after oven drying	50·3 gms.
Loss of weight	39·5 gms.

$$\text{Moisture content } \% = \frac{39\cdot5}{50\cdot3} \times \frac{100}{1} = 78\cdot5\ \%$$

Average moisture content of sections 1 and 2 = 79%.

This is assumed to be the average moisture content of the sample.

Moisture content of sample when cut ... ... = 79 %

Weight of sample when cut ... ... = 6·55lbs.

Dry weight of sample ... ... $\dfrac{\text{Weight of sample}}{\text{Moisture percentage plus 100}} \times \dfrac{100}{1}$

$$= \frac{6{\cdot}55}{179} \times \frac{100}{1} = 3{\cdot}66\text{lbs.}$$

A typical record of the drying of this sample is shown in Table 7.

TABLE 7.

SAMPLE BOARD DRYING RECORD.

Date.	No. of days.	Weight at date.	Dry Weight.	Moisture content.	Moisture content.	Remarks.
				lbs.	%	
1–6–27	...	6·55	3·66	2·89	79	When cut.
2–6–27	1	6·30	3·66	2·64	72	
3–6–27	2	6·07	3·66	2·41	66	
4–6–27	3	5·85	3·66	2·19	60	
5–6–27	4	5·64	3·66	1·98	54	
19 days }	...	...	...	...	...	
25–6–27	24	4·10	3·66	0·44	12·0	
26–6–27	25	4·06	3·66	0·40	11·0	
27–6–27	26	4·04	3·66	0·38	10·3	
28–6–27	27	4·03	3·66	0·37	10·0	Drying completed.
29–6–27	28	4·03	3·66	0·42	11·5	After high humidity treatment.

CHAPTER 7.

AIR SEASONING.

The term air seasoning covers a very wide range of drying practice, from the crudest to the most expensive of processes. At the bottom of the scale in this State, there are stacks of timber without any deliberated provision for separating the surfaces of the boards, and in these that drying which occurs is due to air movement through spaces caused by careless stacking, and irregularities of cutting and shrinkage. Where seasoning and not storage is the object, such methods are fortunately confined to sleepers. Next comes the practice of strip stacking timber in the open air with more or less protection from sun and rain. Where strict attention is paid to stacking conditions, good results are often obtained with certain classes of timber, but climatic conditions introduce factors of enormous importance, which unfortunately are rarely recognised. The highest form of air seasoning is that carried out under cover, and in this method there is sometimes the refinement of provision for shutting off excessive air movement when the atmosphere is so dry as to be deleterous, or in other words of stacking the timber in a closed room. Providing sufficient precautions are taken, the most refractory timbers can be air seasoned by this method. It should be recognised, however, that if, as is sometimes done, a fan, a heating source such as a radiator, or a combination of these is included for assisting the drying in the later stages, the room virtually becomes a kiln used with a combined air drying, kiln drying system.

Since seasoning in the open air is the only method adopted to any appreciable extent for the seasoning of local Eucalypts, it is not surprising to find that the larger proportion by far of the product consists of narrow boards for flooring. This is due to a certain extent, to the lack of appreciation of the principles underlying air seasoning, a deficiency which has led to the belief that these Eucalypts cannot be thoroughly air seasoned or for that matter kiln seasoned. It has already been proved that Jarrah, Karri, and their fellow timbers can be thoroughly kiln seasoned, and it may be definitely stated that they can be thoroughly air seasoned.

It has been mentioned that narrow boards constitute the bulk of the Jarrah and Karri which is used in the seasoned form. Recent tests, which are still proceeding, on the air seasoning of Jarrah flooring stock, have provided some interesting data which indicate the limitations of present practice, and the improvements desirable to elevate the existing standard of this product.

Stacking is usually carried out in yards with several sets of more or less parallel railway lines, the length of the stacks being at right angles to the direction of the lines. With the exception of short pieces such as verandah boards about 8ft. and under in length, random lengths are stacked and hence stacks are usually long, 60 or 70 feet being common. The width of stacks varies from 4 to 7 feet, while the height at times is as great as 12 or 15 feet or as high as the stackers can lift in one handling. The thickness of strips varies usually from three-eighths to one inch, the width from one to three inches. The tops of stacks are covered with rough boards as a protection from the sun. No attempt is made to protect from rain.

The care with which stacking is carried out varies between wide limits. In some yards clean conditions generally, good foundations, vertical lines of strips directly over foundations, not more than 2 feet or 3 feet apart, a spacing of not less than three or four feet between stacks, and no overhanging boards at the end of the stacks, contrast with the poor foundations, irregular and insufficient stripping, overhanging ends, and heaps of strips and low grade timber blocking the circulation around and between stacks, all of which, particularly in the smaller yards, are far too common. The former careful practice, especially when accompanied by open spacing of the boards with the openings vertically above one another to facilitate air circulation downwards through the stack, and where docking of blemished material before stacking is employed, results in faster and more even drying with a minimum of deterioration owing to seasoning faults. Virtue in this case brings its own reward, for it has been found that where stacking methods are the best, the convenient half-inch strip is sufficiently thick and during summer stacking is even preferable to the thicker strips, which are necessary for satisfactory drying in less carefully conducted yards.

The sites of stacking yards are unfortunately often fixed by the locations of mills and railway sidings, but where choice exists, exposed areas well drained or with moisture absorbing soils should be secured. Where conditions from this standpoint in existing yards or on the best sites available, are bad, the provision of suitable drainage must be regarded as a profitable investment.

The biggest difficulty of open air seasoning has been shown to be seasonal variation in moisture content. As soon as winter rains commence the moisture content of stacks rises, due to water which falls directly on or leaks through to boards being absorbed. The result is that during winter months and during summer months, until this moisture has been dried off, no seasoned timber is available in open air stacks.

Unfortunately except in those yards, where stacking conditions are the best, the high reabsorption during winter, combined with the small amount of summer rain is sufficient during some summers to prevent the timber from ever reaching a thoroughly air seasoned state. Thus, where stacking conditions are bad, most of the stacks which leave the yard during the summer have an average moisture content approaching 15 per cent. or 16 per cent., although boards of 18 per cent. moisture content, or even higher, are not infrequent. On the other hand in the best yards the loss of the moisture reabsorbed during the winter and during occasional summer rains is comparatively rapid, so that for most of the summer months stacks are available of an even moisture content of 12 to 14 per cent.

If dry boards are to be available during the winter months, one of two courses must be adopted. Either stacks must be provided with an efficient rain covering, or else timber required during the winter months must be unstacked during the summer and placed under cover. It seems probable that the former alternative would prove the more economical, if some method such as sloping stacks in the width towards the weather about half-inch per foot to reduce the penetration of rain into the stacks and to prevent moisture from lying on the boards were combined with the provision of cheap but watertight sloping roofs made up in sections for convenient handling. Tests have shown that not only is the rate of reabsorption of moisture by the surface of timber comparatively slow, but also that even after a few days in contact with water the surface layers only of a dry board are affected. If, therefore, water can be prevented from lying on the surface of boards, slight wettings will not be very serious, for the moisture absorbed will be reduced before it has an opportunity to penetrate deeply.

At present the panacea for all evils attendant upon the use of improperly seasoned flooring is to machine the timber some time before it is required, and then stack for further seasoning, either in the vicinity of the machine, or near the building in which it is to be used. In neither case is the material usually properly stripped to provide even drying, and in some cases it is stalled or flat stacked without any deliberate provision for air circulation. Sometimes also the wood is stacked out of doors with little or no protection during the wet months, when there is a shortage of space.

The prime object in stacking timber after machining is to permit further shrinkage to take place. Unfortunately, flooring boards which have been improperly seasoned practically always have a considerable variation in moisture content from board to board, and throughout the same board. After machining all boards are of exactly the same width, but if further seasoning to a constant moisture content is permitted the original variation in moisture content will result in different amounts of shrinkage. If to this effect are added variations due to the wide difference in total shrinkage between different Jarrah and Karri boards, and sometimes variations due to the irregular methods usually employed in this secondary seasoning, the total effect upon the variation in width of the boards, when they are ready to be laid, will be considerable. While, therefore, stacking after machining prevents to a variable extent the opening up of floors along the joints, it is often impossible to lay a good floor with such boards as they are infrequently of exactly the same width.

With thorough seasoning in the stack, seasoning after machining is not, except in special cases, necessary. It is thus far more economical to season properly in the first place than to incur the expense of attempting to cure conditions which need never occur.

Lack of appreciation of the evils of careless practice in the past has built up to a large extent the belief that with the Jarrah and Karri flooring a certain amount of opening up and of attendant faults is inevitable. This is certainly not the case, for these timbers can be thoroughly air seasoned, and when they are used in this State they will give entire satisfaction.

On the air seasoning of Karri and Jarrah, thicker than flooring, few experiments have been made. Jarrah is strip stacked for air seasoning in the open, and in sheds for joinery material. That in some respects seasoning is not thorough, is shown in one large yard by the practice of seasoning joinery for several months after it has been manufactured, before it is finally glued, wedged, and finished. This procedure is also not an uncommon feature of specifications. Such methods are expensive and far from satisfactory, and they indicate that investigation into the seasoning of this class of material is long overdue. Scarcity of seasoned local timbers, in the thicker sizes, is often prevalent, and frequently results in the use of semi-dry material with consequent dissatisfaction. This is an additional cause of the erroneous belief that it is impossible to obtain proper service from local timbers in the seasoned state.

One test of note may be mentioned, in which Jarrah door stock was submitted to the combined seasoning process. The material was stacked in the spring with 1in. strips, under cover, to air season for 58 days and was then loaded into a kiln and dried for 21 days. The original moisture content varied from 75 per cent. to 68 per cent.; after air drying it was 27 per cent. to 18 per cent., while the final kiln moisture content was 9 per cent. The total drying time was only 79 days, whereas if the material had been dried throughout in a kiln, the period would have been 45 or 50 days. As the quality of the dried timber was good, the test indicates a profitable line of investigation.

The desirable conditions for the stacking of timber for air seasoning may be summarised as follows:—

Foundations elevating the bottom layer of the stack well above the ground and sloping slightly in the width towards the weather side.

Strips ½in. thick and 1½in. wide spaced at 2ft. 6 centres in vertical lines directly over the foundations. Boards open spaced with openings vertically above one another.

The spaces between stacks unobstructed and at least 4ft. wide.

Stacks to be protected with rainproof covering, sloping in the direction of the width of the stacks towards the weather.

While the desirability of these conditions has been determined from the results of investigations on flooring boards, they form a valuable indication as to the best procedure for seasoning thicker timber.

CHAPTER 8.

FEATURES OF SEASONING PRACTICE.

The Moisture Content of Seasoned Timber.

The simplest method to test if a piece of wood is thoroughly seasoned is to test for moisture content, moisture distribution, and presence of drying stresses. But it is necessary before a pronouncement can be made to know what moisture content can be regarded as a measure of thorough seasoning. The moisture content at which the surface of a piece of wood must be to balance the temperature and relative humidity of the air will be continually changing from day to day, and throughout the same day. This change in moisture content of the wood will affect only the surface layers to any appreciable extent. The bulk of the wood, owing to the slow rate of moisture transmission through dry wood, will not be able to keep pace with these changes, but will remain in an average condition, the moisture content of which will depend on the relative duration of the various temperature and humidity periods. A thin piece of wood will, of course, have a greater variation in average moisture content than a thick piece, while if the surfaces of a piece of wood are coated with some material which resists the transmission of moisture through it, the average moisture content of a piece can be kept approximately constant throughout the year. From incidental data obtained during other investigations, it would appear that local hardwoods about 1in. thick, if untreated in any way, but stacked under cover in the vicinity of Perth, will vary from a moisture content of about 13 per cent in winter to 10 per cent. in summer, providing that there is a free circulation of air over the faces of the boards. As most timber which is used for interior trim, furniture, etc., receives a coating of paint, varnish, or some such material, the average moisture content under these conditions is that to which, in the majority of cases, timber should be dried. As far as Perth is concerned, experience has shown that timber at an even state of 11 per cent. or 12 per cent. moisture content gives very satisfactory service when painted, polished or varnished. A moisture content of 11 or 12 per cent. can be regarded, therefore, as the desirable moisture content to which timber should be dried if it is to be used for panelling, furniture, furnishings, or for similar interior purposes. In the case of timber which is wholly or partially exposed to the weather, unless the moisture proof coating is very efficient, the variation in moisture content is likely to be considerably greater than is the case with material under cover; but as to the ultimate effect this will have upon the average moisture content of the timber, there is no precise information. Tentatively, it may be assumed that it is desirable to dry to the same moisture content as in the case of timber to be used under cover, namely, 11 per cent. or 12 per cent.

Although definite information is not available, it is very probable that for the higher rainfall agricultural areas timber should be dried to about 10 per cent., while for the lower rainfall areas a moisture content of 8 per cent., or perhaps even 6 per cent. in the case of the driest portions of the State, would be desirable. The figures given for Perth, viz., 11 per cent. or 12 per cent., would probably prove suitable for the coastal areas from Geraldton southwards; but these could safely be increased by at least 1 per cent. when timber is to be used in the comparatively wet climate of the Karri forest country and its environs.

Timber is normally at a lower moisture content in summer than in winter, but under artificial atmospheric conditions the position may be reversed. When the weather is cold and a room is heated, either by a fire or a radiator, cold air enters the room and is heated to a sufficiently high temperature for comfort. Unless a humidifying apparatus is installed when this air is heated, its relative humidity decreases to a considerable extent. The air changes, therefore, from a cold moist condition to a warm dry one, and in this latter state its balance moisture content with wood is very low. Timber in such a room may in winter tend to dry to a lower moisture content than in summer. Whilst in cold countries where artificial heating is more or less continuous throughout the winter months, this effect is likely to be more important than in the temperate climate of the South-West of this State, there are factors which here make it still worthy of consideration. As during the winter months artificial heating is required in a room only for periods usually less than one-third of the day, the convection heating systems of colder countries are not warranted, and warming is usually effected largely by heat radiation from a fire or from an electric radiator. Such radiated heat warms the air in a room indirectly for it is first absorbed at the surface of objects in the room, and as a result of the increase in temperature of these surfaces the air throughout the room is heated by conduction and convection. Heat which is available at the surface of wood is eminently suited for the promotion of drying of the timber, so that the comparatively short duration of the drying conditions is partially discounted.

It is not generally necessary to make provision against the effects of artificial winter drying in this State, but in special cases where timber is required for a room which will be heated throughout the winter it would be advantageous to obtain material at 10 per cent. moisture content. More common applications of this knowledge would be the selection of the driest timber for locations in the vicinity of a fire or heating point, and the paying of particular care to the efficiency of moisture proof coatings on wood in rooms which are to be heated.

Consideration should also be given in arranging the interior of a room to the fact that moisture movement takes places more readily along the grain of timber, and the ends of timber should therefore be exposed as little as possible to direct radiations from the heating source.

The Behaviour of Seasoned Timber.

It is sometimes stated that the absorption and loss of moisture by seasoned timber with accompanying swelling and shrinkage are properties peculiar to the local timbers. This characteristic which is usually known as the "work" of the timber is common to all timbers, and cannot be entirely eliminated unless the timber is enclosed in an absolutely air-tight case or exists in unchanging air conditions. A further idea is that the "work" of the timber decreases as the age of the timber increases, but experiments in other countries have indicated that such an effect, if it does occur, is not appreciable. The misconception is probably the result of mistaking for "work" alone what is really a mixture of a constant amount of "work" and a decreasing amount of initial shrinkage owing to the slow loss of moisture from the central portion of imperfectly seasoned timber.

Perhaps the most common fallacy is that the best way to season Western Australian Eucalypts is by drying after a preliminary soaking in water. A test carried out on four boards of one inch Karri showed that in portions of the same board there was no appreciable difference as far as shrinkage, rate of seasoning, the extent to which surface cracking occurred and subsequent "work" were concerned, whether it was simply air seasoned or given a preliminary treatment of four months soaking in fresh water. While in some timbers it is possible that soaking may result in the breaking down and leaching out of constituents which affect seasoning properties, it is certain that in the case of the local Eucalypts the period required would be so long that it places the method without the realms of feasibility. For similar reasons the notion that air seasoning without rain protection is superior, because the rain washes the sap out of the timber may also be discarded. While a certain amount of leaching of the constituents of the surface cells does occur, there is evidence to show that the low rate of moisture transmission limits the action to a shallow depth unless the time is inordinately long.

Improvement in the rate of seasoning and in the behaviour of the seasoned timber is, by some, thought to be possible by ringbarking the tree for some time before felling. In an investigation not yet completed, a jarrah tree was girdled 12 months before felling with cuts completely removing a section of the bark and sapwood. When converted some four months ago this tree produced timber as green as freshly felled untreated logs, and as far as the test has proceeded there is nothing to indicate that the rate of drying has been in any way affected. While at the present stage of this investigation more definite pronouncement is impossible, it would certainly appear that ringbarking Jarrah trees 12 months before felling would accomplish no useful object.

The question may arise "Do the moisture content, moisture distribution, and casehardening tests give a complete indication of the seasoned state of the timber?'' In other words if a piece of timber is seasoned, for example in a kiln, and if it is produced at the end of the process, free from stress, and at the moisture content desired throughout its thickness, will this piece of wood give as satisfactory service if used immediately, as it would if it were stored for a few years before use? The swelling and shrinkage in recently dried timber might be expected to be greater than that which would result from atmospheric changes in the case of timber which has been left for a considerable period after seasoning. Such greater variation in size would be explained by a rearrangement of the wood material in the timber which has just been seasoned. It is known that timber which is casehardened will gradually improve owing to the wood material yielding to the stress; and as timber in drying is subjected to stresses which ultimately leave different portions of the timber in conditions varying to a considerable extent from that of wood material totally unrestrained in drying, it might be thought that there might, to a certain extent, be a tendency towards rearrangement of the wood material in an effort on the part of timber to reduce this variation from normal. A study of Jarrah and Karri pronged sections which have been allowed to stand for four or five years shows that casehardened prongs after a time lose to a large extent their tendency to bind on one another, but do not change in shape, and oversteamed prongs show no change in condition. Thus, where stress exists there is a yielding which produces alleviation, but after this stress has been alleviated, or where it does not exist, there is no evidence of visible change of condition. It appears, therefore, very probable that once timber has been obtained in the desired condition with regard to moisture and freedom from stress there is no appreciable advantage to be gained by prolonging the period of seasoning, and the three seasoning tests are therefore a reliable indication of the suitability of the timber for its purpose.

The Care of Seasoned Timber.

A frequent cause of the unsatisfactory behaviour in some cases of seasoned wood is the lack of appreciation for the necessity of exercising due precautions after the material has been seasoned. In this connection attention might be drawn to the fact that there is far too great a tendency to exaggerate the importance of the age of a piece of timber since it was cut from the tree as being a factor in its state of seasoning. This period only becomes a feature of importance if the material is stored under satisfactory conditions. For example, if a stack of flooring boards is put down at the end of winter without efficient rain proof covering, this timber will be far more fit for use in five or six months' time than it will be if unstacked towards the end of winter ten or twenty years later. Thus, seasoned timber, if it is to remain seasoned, must be safeguarded.

Practically, contact with water, or exposure to a saturated or very moist atmosphere, are the features of the storage of seasoned timber most to be avoided. Of these, the former is, of course, the more serious, although in the case of the latter, if exposure is prolonged, the moisture content of the timber will become far too high for satisfactory behaviour after manufacture. Seasoned timber must be stacked under cover, and it is desirable that the building should be provided with sides to prevent the entry of driving rain. With efficient cover, seasoned timber can be block stacked, but it is essential that the bottom layers of the stack should be raised a few inches from the ground. In fact, it is desirable even where buildings are floored to place seasoned material on foundation cross pieces a few inches thick, in order that there may be a free circulation beneath piles, and that the formation of pockets of stagnant air, which are often associated with high humidities, may be avoided.

Moisture-proof Coatings.

Paints, polishes, and varnishes are usually considered only from the appearance standpoint, but it must not be forgotten that they have at least one other very important property. By retarding change in moisture content, they have the very beneficial effect of reducing the "work" of the timber. With varying atmospheric conditions, it is impossible to prevent entirely moisture change in timber, unless the piece of wood is hermetically sealed in an air and water-tight case. Some coatings are very efficient in this respect, but, on the other hand, many finishes, generally considered to be effective, have a comparatively low value. As no tests on moisture proofing have been carried out in this State, the data below has been extracted from Technical Note 181 of the United States Forest Products Laboratory.

It will be noted that linseed oil has a comparatively low value as a moisture resistant coating, and that white lead paint is also very inefficient.

"The following table gives the results of moisture absorption tests on panels coated with the different preparations. The percentages are based on average amounts of moisture absorbed per unit surface area by coated and uncoated panels subjected to a humidity of 95-100 per cent. for 14 days."

	Percentage efficiency.
Aluminum-leaf process—asphalt paint base	98
Three coats spar varnish coated with vaseline	98
Three coats of asphalt paint	96
Aluminum-leaf process—spar varnish base	95
Aluminum-leaf process—cellulose lacquer base	94
Aluminum-leaf process—oil paint base	93
Three coats of aluminum bronze (quick drying)	92
Heavy coating of paraffine	91
Three coats of rubbing varnish	89
Three coats of enamel	88
Three coats of orange shellac	87
Three coats of cellulose lacquer	73
Sheet pyralin 5/1000ths inch thick glued to wood	68
Three coats of graphite paint	61
Three coats of spar varnish	60
Three coats of white lead oil	54
Five coats of linseed oil applied hot, and two coats of wax	38
No coating	00

A very unsatisfactory feature of timber utilisation which is due to the lack of appreciation of the importance of finishes in resisting moisture change, is the tendency to treat only surfaces which are to be seen. It is not uncommon, as a case in question, to find the upper side of a table top effectively treated against moisture change, while the under side is naked wood, or at most has been given a single coat of polish or oil. Under these conditions, if the atmosphere of the room is such that the wood in the table top absorbs moisture, the under side will absorb far more than the upper, and, in addition to swelling, the tendency will be for the top to cup. If, on the other hand, drying takes place, the top will shrink and arch. It is essential, therefore, that the hidden surfaces of timber should be treated so that they are equally as moisture resistant as the exposed ones, although it is not necessary in the case of the former to involve expense by attention to appearance.

Particular attention is necessary in the case of panelling and interior trim generally, for these are often placed in position before walls have become thoroughly dry. In addition, it must be remembered that here again the ends of pieces of timber are to be regarded as places at which moisture change is very likely to occur, and they must be safeguarded accordingly.

Incidentally it may be mentioned, in connection with timber coatings, that trouble is often experienced in obtaining transparent coatings for Jarrah which will withstand the local climatic conditions and maintain a good appearance. Recent tests have shown that where timber is exposed to the weather, drying oils are far more satisfactory than non-drying oils, while hardwood finishes of the varnish type give the best service of all.

Continued Shrinkage.

It has been already pointed out that the extent of shrinkage of a piece of timber in seasoning, besides depending on the properties of the piece in question, is also influenced to a great degree by the treatment during drying. In other words if a length of timber were cut into two pieces of the same dimensions, and these were dried under different conditions, it would be quite possible when the two pieces finally reached 10 per cent. moisture content, for them to vary considerably from one another in size. It is not surprising therefore to find that by suitable treatment, and without decreasing its moisture content, further shrinkage of a seasoned piece of wood can be induced.

Supposing that a green board 12 inches wide is taken and that it is seasoned, in drying it will shrink to some lesser width, for example, 11 inches. The seasoned board is now placed in a very strong metal frame 11 inches wide and is resoaked with water. If the frame is strong enough to prevent swelling the board will return to its green condition as far as moisture content is concerned, but will be only 11 inches wide.

Upon redrying, this resoaked piece 11 inches wide will suffer further shrinkage, and will decrease in width to some dimension between 11 and 10 inches. Similarly by repeating the treatment with the same board, but another metal frame between 11 and 10 inches wide, the total extent of shrinkage can be further increased although the amount of shrinkage following each redrying will become successively less and less.

The reason for the shrinkage is that when the timber is being soaked the cells tend to expand but are prevented by the iron frame. Compressive stress is therefore present in the wood. After the moisture content has risen above fibre saturation point, the timber regains that softness and plasticity typical of green wood, and much of the compressive stress is relieved by yielding of the material of which the cells are composed. In this condition the timber has practically become a new piece of green timber of greater density than the original piece, and on drying it exhibits shrinkage.

Many joints in timber are so constructed as in the case of a wedged mortice and tenon joint, that they will resist a stress tending to force the members apart. Such joints, if exposed to the weather, often lose their tightness. This is usually taken as an indication that the timber was not thoroughly seasoned before use, but it is very probable that in many cases the timber has undergone further shrinkage due to increase in moisture content under restraint, together with subsequent redrying. Thus it denotes not faulty material supplied by the seller, but failure on the part of the purchaser to take proper care of timber which with due precautions could give every satisfaction. Continued shrinkage is also a factor in some of the cases in which timber which is exposed develops a deformation out of all proportion to the normal stresses produced by its load.

During drying of a piece of green timber this yielding of green wood to compressive stress is undoubtedly a factor in the production ultimately of the condition of stress known as casehardening, and in the extent to which shrinkage occurs. For example, at the stage when the outside is below fibre saturation point and the inside above, the outside is tending to shrink more than the centre with the result that the outside is in tension and the inside is in compression.

The extent of the crushing stresses in the central portions can be gauged to a certain extent by the fact that the tensile stresses of the surface layers which they balance are often sufficiently great to produce rupture of the timber with the formation of surface checks. Although this indication must not be taken altogether at its face value since surface checks are not formed instantaneously for their full depth but gradually develop, offsetting features are that many timbers are appreciably weaker in compression than in tension, and that under prolonged loading timber yields to stresses far below those causing rupture when the load is applied at a rapid rate.

While during the early stages of the drying of green wood, compacting of the central portions tends to take place, with the resoaking of dry wood conditions are reversed. The outside of the timber soon reaches a much higher moisture content than the centre, and hence tends to swell more. In this it is prevented to a large extent by the centre which, being at a lower moisture content, is stiffer and less easily deformed. Compressive stress is therefore present on the outside of the piece of wood. When the moisture content of the outside layers has risen above fibre saturation point the outside cells become more plastic and tend to yield to the compressive stress. This produces a denser timber in the case of the piece of wood. If resoaking is due to exposure to weather during the winter months, the process of reabsorption of water very often ceases before the central portion has exceeded the fibre saturation point. Hence upon redrying this outside layer tends to shrink below its original dimension. In many cases exposure to the weather only takes place on one side of the timber. The result of soaking and redrying in this instance is to cause shrinkage of the exposed face and a tendency of the board to become concave outwards. A common example of this is the curling up of exposed verandah boards. The tensile stresses produced by this continued shrinkage of the surface resulting from exposure are often sufficient to cause ruptures of the outside layers of the timber with the formation of what might be called "weathering checks" to distinguish them from seasoning checks. On the other hand it should be noted that if seasoned timber is protected from the weather, although its moisture content will vary throughout the year, this change will be far too small to bring the surface layers above fibre saturation point, and so introduce the factor of continued shrinkage.

MAP
OF
PART OF THE SOUTH-WEST DIVISION
OF
WESTERN AUSTRALIA,
SHOWING FOREST ZONES.

Red hatching indicates approximately the position of prime merchantable forest.

SCALE: 15 MILES TO AN INCH.

TUART ZONE.

Tuart	*(Eucalyptus gomphocephala).*
Coastal White Gum	*(Eucalyptus decipiens).*
Peppermint	*(Agonis flexuosa).*

JARRAH ZONE.

Jarrah	*(Eucalyptus marginata).*
Marri	*(Eucalyptus calophylla).*
Blackbutt	*(Eucalyptus patens).*
Flooded Gum	*(Eucalyptus rudis).*
Wandoo	*(Eucalyptus redunca, var. elata).*
Powder-bark Wandoo	*(Eucalyptus accedens).*
River Banksia	*(Banksia verticillata).*
Sheoak	*(Casuarina Fraseriana).*

WANDOO ZONE.

Wandoo	*(Eucalyptus redunca, var. elata).*
Powder-bark Wandoo	*(Eucalyptus accedens).*
Jarrah	*(Eucalyptus marginata).*
Marri	*(Eucalyptus calophylla).*
Salmon Gum	*(Eucalyptus salmonophloia).*
Red Morrel	*(Eucalyptus longicornis).*
York Gum	*(Eucalyptus foecunda, var. loxophleba).*
Jam	*(Acacia acuminata).*
Sheoak	*(Casuarina Huegeliana).*
Sandalwood	*(Santalum spicatum).*

KARRI ZONE.

Karri	*(Eucalyptus diversicolor).*
Red Tingle	*(Eucalyptus Jacksoni).*
Yellow Tingle	*(Eucalyptus Guilfoylei).*
Marri	*(Eucalyptus calophylla).*
Bullich	*(Eucalyptus megacarpa).*
Karri Sheoak	*(Casuarina decussata).*
Cedar	*(Agonis juniperina).*
River Banksia	*(Banksia verticillata).*

SALMON GUM ZONE.

Salmon Gum	*(Eucalyptus salmonophloia).*
Red Morrel	*(Eucalyptus longicornis).*
Yorrell	*(Eucalyptus gracilis).*
Gimlet	*(Eucalyptus salubris).*
York Gum	*(Eucalyptus foecunda, var. loxophleba).*
Wandoo	*(Eucalyptus redunca, var. elata).*
Jam	*(Acacia acuminata).*
Brown Mallet	*(Eucalyptus astringens).*
Blue Mallet	*(Eucalyptus Gardneri).*
Merrit	*(Eucalyptus Flocktoniae).*
Sandalwood	*(Santalum spicatum).*

COASTAL PLAIN.

Holly-leaved Banksia	*(Banksia ilicifolia).*
Narrow-leaved Banksia	*(Banksia attenuata).*
Firewood Banksia	*(Banksia Menziesii).*

SAND PLAIN ZONE.

Various small shrubs of several families. All of low stature.