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Wood Utilisation Research Centre

SEASONING 25mm MATURE JARRAH BOARDS USING A PROGRESSIVE TUNNEL KILN

G.K. Brennan and B.R. Glossop

May 1989
W.U.R.C. Technical Report
Limited Distribution

Weir Road Harvey WA 6220 (097) 29 1913
50 Hayman Road Como WA 6152 (097) 367 0333

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SUMMARY

The general concept of the progressive tunnel kiln is one of simple construction and low cost operation, and the overall feasibility has been demonstrated by the CSIRO in commercial practice. This study discusses research carried out in modified versions of the tunnel kiln.

Bundles of 75 x 25 mm mature jarrah (*Eucalyptus marginata* Donn ex Sm.) were seasoned to fibre saturation point by tunnel kilning, before high temperature drying to final moisture content. Initially the feed rate in the tunnel kilns was one bundle of green timber a week. This was increased to two bundles a week to try to reduce surface checking by increasing the amount of moisture in the kiln. Other methods tested to reduce checking were:

- transferring the timber to another kiln which recirculated moist air from the green to the dry end,
- applying a make shift "Coolgardie" safe for a short period,
- adding two steam humidifiers.

Timber dried under winter ambient conditions at the green end of either kiln had minimal surface checking. When the hot dry summer ambient conditions began, timber at the green ends of the kilns checked and warped. Adding two bundles a week was unsuccessful in the No. 1 kiln, but in the No. 2 kiln, which uses recirculated air, resulted in reduced checking. Both the Coolgardie safe and steam humidifiers reduced checking but use of the latter resulted in increased twist, bow and spring.

INTRODUCTION

In the early 1970's CSIRO developed a progressive tunnel kiln for drying timber, which operates on a simple principle. Ambient air is drawn into the kiln through a large inlet vent at the unloading or dry end, then directed with the aid of baffles through the stacks of timber to the wet or loading end where it is exhausted. By the time air has reached the wet end it is almost saturated, and under these conditions the tunnel kiln is very suitable for drying check-susceptible timber (Campbell, 1978). The timber is moved on trolleys against the counter flow of air to the unloading end, where it is removed.

The first CSIRO-designed progressive kiln has been operating successfully on a commercial scale at Leongatha, Victoria. This kiln has successfully dried a wide variety of species, ranging from ash-type eucalypts to radiata pine, and in timber thickness from 20 to 70mm (Fricke, 1983). This type of kiln is an effective way of pre-drying timber from green to fibre saturation point (f.s.p.), before drying to final moisture content. Subsequently commercial tunnel kilns have operated in Tasmania at Scottsdale and Smithton (Lembke, 1984).

Simplicity of the design and easy access to all equipment leads to low maintenance costs of the kiln, and except for loading and unloading operations the process requires no supervision except for routine moisture content measurements (Campbell, 1976).

Two research progressive kilns constructed by the Department of Conservation and Land Management are based on the CSIRO's design. The differences between the CSIRO's and the Department's kilns are:

(i) in the Department's kilns the drying source is a centrifugal fan which blows air instead of sucking air through the stacks.

(ii) the timber is stacked onto trolleys with its length perpendicular to the kiln length. The CSIRO's kiln operates by having the timber parallel to the kiln length.

(iii) the baffling system is different. The baffles in the Department's kiln are located between the sides of each stack and the kiln wall, allowing the air to flow straight through the stack instead of flowing on the sinuous path used in the CSIRO's kiln. The baffles stop the air rushing down the sides then out the back of the kiln.

The original Departmental kiln (No. 1 kiln) operates with ambient air blowing from the dry to the green or loading end. Baffles have been designed to direct air through the timber stacks. The second kiln (No. 2 kiln) also operates by drawing ambient air into the kiln, but a ducting system is included to recirculate the moist air from the green end back to the dry end. Vents at the green end can be used to exhaust moist air if the humidity becomes too high.

Both kilns are 12 m long, 2.4 m wide and 0.8 m high, and hold 10 small bundles of approximately 0.5 to 0.6 m^3 of timber. Wet and dry bulb temperature sensors located along the kiln at every third stack were connected to a "Chino" continuous chart recorder. When modifying the kilns, a pair of sensors was placed at the dry and green ends of each kiln.

A joint seasoning trial involving Millars (W.A.) Ltd. and the Department, using mature jarrah (*Eucalyptus marginata* Donn ex Sm.) started in March 1984. Timber was initially dried in the No. 1 kiln from March to December 1984, before being transferred to the No. 2 kiln in January 1985, remaining there until the trial was completed. Bunnings Ltd. continued the involvement when they acquired Millars, and the joint trial was completed in June 1986.

The aim of the trial was to assess the overall drying behaviour (degrade and moisture content changes) of 75 x 25 mm timber cut from mature jarrah logs, and to determine the optimum conditions for drying this material from green to f.s.p. by tunnel kilning.

MATERIALS AND METHODS

Bundles of select grade mature jarrah were initially placed in the No. 1 kiln at a rate of one bundle per week. Jarrah was cut at Bunning's Yarloop Mill, block stacked and wrapped in plastic (to prevent any drying before placing in the kiln), then transported to the Wood Utilisation Research Centre (WURC) at Harvey each Wednesday. At Harvey the timber was strip stacked, sampled and placed in the kiln. Initially four random samples were selected from each bundle and weight, moisture content, width, thickness and timber defects were recorded. Inspection indicated a larger sample was needed for degrade assessment. The sample size was increased subsequently to 20 boards for timber degrade assessment only, and the original four boards for both moisture variation and degrade assessment.

Degrade and moisture content assessments were done after two days, one week, two weeks and 10 weeks. Prior to the bundle entering the tunnel kiln all timber defects were recorded eg. sapwood, knots, wane, want, mechanical and borer damage, bow, spring, cup, twist and checks.. After this initial inspection only seasoning degrade was recorded. Sample size was also increased during the trial to obtain data for drying rate and surface checking equations.

Drying conditions were measured along the tunnel kiln. Selected bundles had drying conditions in the first week analysed, by reading off wet and dry temperatures from the 'Chino' recording chart, calculating the wet bulb depression, then reading the relative humidity from a psychrometric chart. Vapour pressure deficit (V.P.D.) was calculated from tables in Fritschen and Gay (1979).

When the hot dry summer ambient conditions began, surface checking became a problem so changes were implemented to attempt to reduce checking. These changes were:-

(i) adding two bundles per week to increase the moisture in the kiln,
(ii) transferring some timber from the No. 1 to No. 2 kiln which re-circulates the moist air,
(iii) applying a make shift "Coolgardie" safe for a short period,
(iv) adding two steam humidifiers in summer 1985/86.

Following modifications to the No. 2 kiln, air velocities were measured with an anemometer before and after sealing.

The wet and dry bulb temperature sensors used in this trial were not initially calibrated, so a calibration exercise using three humidity and temperature instruments was conducted for one week. These instruments were a psychrometer, hair thermohydrograph and a direct relative humidity sensor.

RESULTS

A complete history of the trial is given in Appendix 1.

Air Velocity

A mean air velocity in the No. 1 kiln of 1 m/s was recorded at the green end before the kiln was sealed.

Air velocity was measured with an anemometer before and after sealing the No. 2 kiln. The results were:-

	Before Sealing	After Sealing
Green end:	0.4 m/s	0.5 m/s
Centre (6 m):	0.8 m/s	0.7 m/s
Dry end:	1.2 m/s	2.6 m/s

Temperature, relative humidity (RH) and vapour pressure deficit (V.P.D.)

The drying histories during the first week of drying of selected bundles are listed in Tables 1 to 4. Wet and dry bulb temperatures were extracted from the temperature charts at 0300 and 1500 hours, then a mean temperature, R.H. and V.P.D. were calculated. These results are given below:

Table 1 **Drying conditions in the first week during mild winter/spring conditions (No. 1 kiln).**

Bundle No.	Date into kiln	Temperature °C 0300 hrs	1500 hrs	mean	Rel. humidity (%) 0300 hrs	1500 hrs	mean	Vapour pressure (mb) 0300 hrs	1500 hrs	mean	Initial M.C. (%)	Weekly Drying rate (%/day)	No. of pieces with surface checking after 1st week (%)*
19	25/7/84	13.4	16.8	15.1	85.1	84.9	85.0	2.29	2.88	2.59	70	2.3	Not recorded
20	1/8/84	10.5	14.9	12.7	81.7	77.1	79.4	2.32	3.87	3.10	73	2.4	Not recorded
21	8/8/84	10.6	15.5	13.0	82.3	80.0	81.2	2.27	3.52	2.89	71	2.8	Not recorded
22	15/8/84	10.8	15.2	13.0	86.7	82.7	84.7	1.72	2.98	2.35	81	2.5	Not recorded
23	22/8/84	12.4	16.1	14.2	82.9	79.9	81.4	2.46	3.68	3.07	78	3.4	Not recorded
24	29/8/84	12.3	15.7	14.0	82.1	81.7	81.9	2.56	3.26	2.91	78	2.8	Not recorded
25	5/9/84	10.5	15.6	13.0	81.4	80.6	81.0	2.36	3.43	2.90	76	3.1	Not recorded
26	12/9/84	12.3	17.0	14.6	84.4	79.4	81.9	2.23	3.98	3.10	80	3.2	25 *
Mean		11.6	15.9	13.8	83.3	80.9	82.1	2.28	3.45	2.87	76	2.8	

NOTE: : In the early stages of the experiment no degrade was recorded.

: Only four sample boards were assessed.

: All bundles received mild winter conditions during the first week of drying.

* Four sample boards per bundle.

Table 2 **Drying conditions in the first week during hot-dry summer conditions (No. 1 kiln).**

Bundle No.	Date into kiln	Temperature °C 0300 hrs	1500 hrs	mean	Rel. humidity (%) 0300 hrs	1500 hrs	mean	Vapour pressure (mb) 0300 hrs	1500 hrs	mean	Initial M.C. (%)	Weekly Drying rate (%/day)	No. of pieces with surface checking after 1st week (%)*
32	24/10/84	12.2	19.6	15.9	79.0	71.0	75.0	2.98	6.59	4.78	72	3.4	75
33	31/10/84	14.1	19.0	16.7	79.0	75.0	77.0	3.38	5.48	4.43	77	4.0	25
34+35	7/11/84	15.2	21.7	18.4	79.0	73.6	76.0	3.62	6.82	5.22	76	4.2	50
36+37	14/11/84	15.1	19.8	17.4	74.3	71.0	72.6	4.40	6.67	5.54	69	3.5	50
38+39	22/11/84	12.8	19.2	16.0	78.8	73.5	76.2	3.13	5.88	4.50	76	3.6	38
40+41	28/11/84	15.4	22.3	18.8	69.8	63.8	66.8	5.27	9.70	7.48	71	4.0	38
42+43	5/12/84	13.5	19.3	16.4	74.3	66.4	70.4	3.97	7.50	5.73	70	3.6	38
44+45	12/12/84	13.9	20.4	17.2	73.8	69.0	71.4	4.16	7.40	5.78	65	3.3	38
Mean		14.0	20.2	17.1	76.0	70.4	73.2	3.86	7.01	5.44	72	3.7	44

NOTE: : After bundle 33, two bundles were added every week (at the same time).

: Despite having four samples for degrade assessment, it was observed that some boards on top layers of the bundles were surface checking after 1 weeks drying.

: All bundles received hot summer conditions during the first week of drying.

* Four sample boards per bundle.

Table 3 **Drying conditions in the first week during hot-dry summer/autumn conditions (No. 2 kiln).**

Bundle No.	Date into kiln	Temperature °C 0300 hrs	1500 hrs	mean	Rel. humidity (%) 0300 hrs	1500 hrs	mean	Vapour pressure (mb) 0300 hrs	1500 hrs	mean	Initial M.C. (%)	Weekly Drying rate (%/day)	No. of pieces with surface checking after 1st week (%)*
62+63	27/2/85	Coolgardie Safe Operating - no data extracted for this period									72.4	2.2	
66+67	13/3/85	21.1	23.5	22.3	90.9	95.0	93.0	2.26	1.44	1.85	75.6	1.6	
68+69	20/3/85	17.8	20.3	19.0	85.6	85.2	85.4	2.92	3.51	3.22	73.0	2.6	10
70+71	27/3/85	16.5	20.1	18.3	75.3	76.2	75.8	4.62	5.57	5.09	84.7	3.8	20
72+73	3/4/85	15.4	18.5	17.0	79.5	82.2	80.8	3.58	3.77	3.68	74.0	2.4	0
74	10/4/85	12.8	17.6	15.2	83.0	74.0	78.5	2.52	5.23	3.87	75.8	2.0	10
76	17/4/85	13.9	17.6	15.8	82.0	78.7	80.4	2.86	4.28	3.57	77.6	3.2	20
78	24/4/85	13.9	17.3	15.6	89.0	90.0	89.5	1.75	1.97	1.86	73.9	1.5	5
80	1/5/85	10.4	13.4	11.9	86.3	87.9	87.1	1.72	1.86	1.79	70.0	1.7	10
Mean		15.2	18.5	16.9	84.0	83.6	83.8	2.78	3.45	3.12	75.2	2.3	11

NOTE: : When the cooler ambient conditions started only one bundle was added per week.

: Coolgarde safe was added for one week. This stopped because it changed the drying schedule and interrupted the data collection.

* Twenty sample boards per bundle.

Table 4 **Drying conditions in the first week during mild winter conditions (No. 2 kiln).**

Bundle No.	Date into kiln	Temperature °C			Rel. humidity (%)			Vapour Pressure (mb)			Initial M.C. (%)	Weekly Drying rate (%/day)	No. of pieces with surface checking after 1st week (%)*
		0300 hrs	1500 hrs	mean	0300 hrs	1500 hrs	mean	0300 hrs	1500 hrs	mean			
93	19/6/85	12.8	14.6	13.7	90.0	89.4	89.7	1.48	1.76	1.62	69.8	0.7	4
94	26/6/85	15.8	16.8	16.0	91.0	89.4	90.2	1.56	2.02	1.79	71.2	1.1	0
95	3/7/85	11.8	14.3	13.0	87.1	86.4	86.8	1.78	2.21	2.00	75.8	1.6	4
96	10/7/85	11.1	13.4	12.2	88.3	87.4	87.8	1.54	1.93	1.74	67.6	0.7	4
97	17/7/85	9.8	11.9	10.8	90.0	88.7	89.4	1.21	1.57	1.39	76.0	0.6	0
98	24/7/85	9.6	12.8	11.2	88.6	88.6	88.6	1.36	1.68	1.52	75.6	1.2	0
99	31/7/85	10.3	13.1	11.7	89.6	87.4	88.5	1.30	1.89	1.60	66.1	1.3	4
100	7/8/85	10.0	12.9	11.4	87.7	86.3	87.0	1.51	2.04	1.77	75.7	1.4	0
101	14/8/85	9.8	13.1	11.4	88.4	83.7	86.0	1.40	2.45	1.93	73.8	1.0	0
102	21/8/85	11.3	13.9	12.6	87.4	88.7	88.8	1.69	1.79	1.74	74.9	0.8	0
103	28/8/85	10.8	13.5	12.2	87.1	84.6	85.8	1.67	2.38	2.03	70.5	1.2	0
104	4/9/85	12.2	16.2	14.2	85.7	83.0	84.4	2.03	3.12	2.58	71.9	1.6	4
Mean		11.3	13.9	12.6	88.4	87.0	87.7	1.54	2.07	1.81	72.4	1.1	1.8

NOTE: : All bundles received mild winter drying conditions during the first week

* Twenty-four sample boards per bundle.

Bundles	Mean Temperature (^{0}C)	Mean R.H. (%)	Mean V.P.D. (mb)
19 to 26 (No. 1 kiln)	13.8	82.1	2.87
32 to 45 (No. 1 kiln)	17.1	73.2	5.44
62 to 80 (No. 2 kiln)	16.7	83.8	3.12
93 to 104 (No. 2 kiln)	12.6	87.7	1.81

The table indicates the differences in conditions between the No. 1 and No. 2 kiln. The recycling No. 2 kiln was used when it became obvious that checking was inevitable in timber in the No. 1 kiln under ambient conditions in summer.

Drying rates and initial moisture content (I.M.C.)

The I.M.C. of selected bundles did not vary much, ranging from 65.0 per cent to 84.7 per cent with a mean of 73.9 per cent (Tables 1 to 4). The mean drying rate during the first week for the No. 1 kiln during winter/spring was about 2.8 per cent/day and for the summer 3.7 per cent/day. This increase in drying rate caused a large number of boards to surface check. In comparison, the No. 2 kiln's mean drying rates during the first week were 1.1 per cent/day in the winter and 2.3 per cent/day in the summer/autumn.

Timber degrade (particularly surface checking)

When this trial commenced, timber degrade was not expected because results from the CSIRO's trials had indicated that moisture generated from the green timber would provide a suitable drying environment. Therefore only four sample boards were assessed for moisture loss and to indicate their drying behaviour. Seasoning degrade was recorded at every inspection but only surface checking, the major defect, is addressed in this report. Checking became evident when the hot dry conditions began, and many boards checked in addition to the sample boards.

Tables 2 and 3 indicate surface checking was a problem when hot dry summer conditions prevailed and the kiln air was at ambient temperature, but under winter ambient conditions checking was not a problem.

Instrument calibration exercise

The instrument calibration exercise produced the following results for R.H. and dry bulb temperature (Figures 1 and 2). The R.H. readings generally followed the same trend, with the direct sensor being consistently high (90 to 94 per cent), hair thermohydrograph consistently low (75 to 82 per cent) and the psychrometer and experimental sensors with very similar readings between the other two sets of readings (84 to 90 per cent). For temperature, all instruments showed the same trend, with the psychrometer consistently reading 0.5 to 1.5°C higher than the experimental sensors. This exercise was done for a week, and the data indicated that all instruments followed the same trend in recording R.H. and temperature.-7-

Regression analysis

The data for V.P.D. and I.M.C. for 75 x 25 mm mature jarrah during the first week of drying were used to develop multiple regression equations for drying rates in each kiln (16 bundles or 8 weeks of results were used). The regressions were:

No. 1 kiln

Drying rate = 0.406 (V.P.D. mean) + 0.068 I.M.C. - 3.44 1
$r^2 = 0.73$ S.E. = 0.30%Drying rate = per cent/day
V.P.D. mean = mean vapour pressure deficit (mb)
I.M.C. = initial moisture content (%).

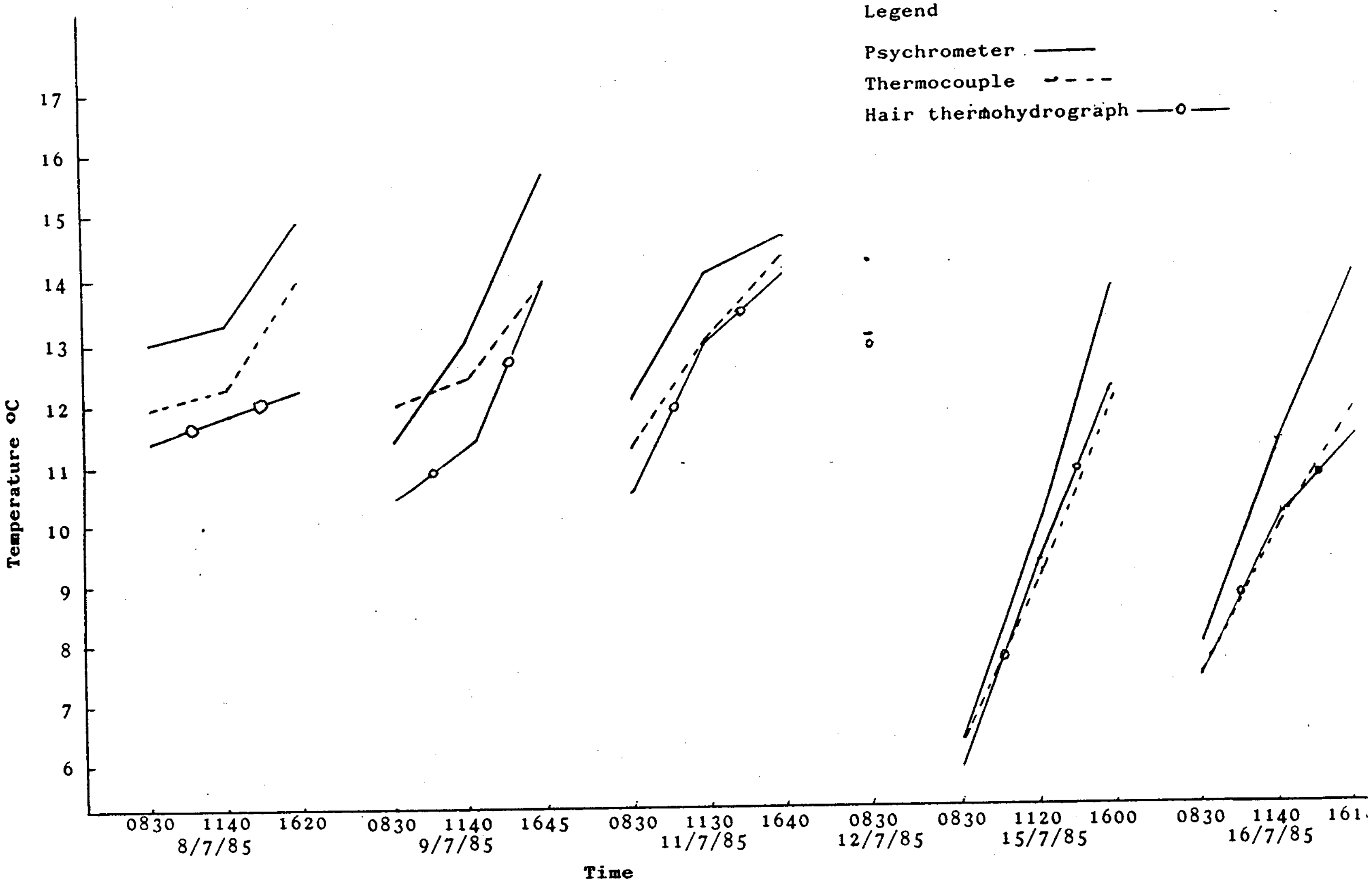
No. 2 kiln

Drying rate = 0.417 (V.P.D. mean) + 0.0696 (I.M.C.) - 4.22 2
$r^2 = 0.67$ S.E. = 0.50%
V.P.D. was the major predictor of drying rate in both kilns.

An equation to predict the percentage of boards that would surface check was developed, but was considered unreliable because of the low coefficient of determination and high standard error.

Figure 2

Calibration of dry bulb temperature



DISCUSSION

Drying conditions

Results from this seasoning trial show 75 x 25 mm mature jarrah could be successfully dried under mild winter conditions, drying timber from 70 per cent I.M.C. to below f.s.p. in six to eight weeks. At this time R.H. at the green end of the kilns was in the 85 to 90 per cent range, temperature was 12°C to 17°C and V.P.D. 2.5 mb to 3.0 mb. When the drier spring/summer conditions occurred the timber began to surface check, bow and twist. This was caused by an increase in temperature at the kiln's green end to between 18°C to 22°C, R.H. falling to between 64 to 75 per cent and V.P.D. increasing to between 3.3 mb to 4.0 mb.

Timber in the No. 2 kiln did not provide enough moisture to the system as spring/summer drying rates are greater than winter rates, and can be greater than 2.5 per cent/day. Campbell (1978) believed there was sufficient green timber in the larger CSIRO tunnel kiln to provide the necessary moisture, but with the Department kiln the timber did not produce enough moisture, which had to be added artificially. The CSIRO's kiln has the timber lengths parallel to the kiln wall, baffles are designed for a sinuous air movement to give a longer air flow, and air is sucked into the kiln instead of blown. The different design and drying conditions must be taken into consideration when comparing the results from their kiln and the Department's kilns.

Regression analysis

The regression equations for the No. 1 and No. 2 kilns had similarities and discrepancies. The coefficients for V.P.D. and I.M.C. were similar, implying that the drying proceeded similarly in each kiln, but the constants differed markedly, indicating timber in the No. 2 recycling kiln was drying 0.6 per cent/day slower than timber in the No. 1 kiln. A reasonable explanation is that variation in air velocity was influencing the system. The mean air velocity at the green end of the No. 2 kiln was 0.5 m/s to 0.6 m/s, whereas the mean velocity at the green end of the No. 1 kiln (before sealing) was 1 m/s. Sensors, recording apparatus and the radiation effect were very similar in the two kilns, and were unlikely to contribute to the discrepancy. The sample material was also similar.

After sealing, the No. 2 kiln the mean air velocity at the green end increased from 0.4 m/s to 0.5 m/s, and at the dry end increased from 1.2 m/s to 2.6 m/s. The decrease in the centre of the kiln from 0.8 to 0.7 m/s is presumably due to experimental error.

Reducing drying rate during the initial stages to 1.0 per cent/day would minimise drying degrade. The multiple regressions indicated that to achieve this rate a R.H. of 97 per cent at 20°C or 93 per cent at 10°C were needed, but these relative humidities are higher than most autumn and winter ambient conditions. To achieve these conditions, humidification and kiln controls to manipulate humidity and temperature are required.

Measurement of wet and dry bulb temperatures

The comparison of temperature and R.H. instruments indicated that the experimental sensors used to measure wet and dry bulb temperatures gave readings which could possibly be both inaccurate and imprecise. An instrument of known accuracy was required to calibrate sensors and to accurately assess drying conditions in the kilns.

Fritschen and Gay (1979) described sources of errors that can arise with wet and dry bulb sensors. These include unmatched thermometers, atmospheric pressure changes, radiation and conduction effects, inadequate ventilation and impure water. Any errors in assessing wet bulb depression can generate large errors in relative humidity estimates.

Errors associated with radiation, conduction and impure water tend to raise the wet bulb temperature, which results in an over-estimation of true vapour content. Radiation error could affect both dry and wet bulb readings, but it usually warms the wet bulb more and results in a vapour pressure estimate higher than the true value. Care should be taken to ensure adequate radiation shielding of the temperature sensors eg. shielding the sensor with polished metal tubes.

Conduction of heat to the temperature sensors can affect their performance, and this is more pronounced on a wet bulb sensor which differs considerably from the temperature of the air. This error will be minimized if the wet bulb wicking extends for at least 1 cm on either side of the sensing tip.

The wet bulb temperature is affected by wind movement, especially at lower velocities. The ventilation requirement decreases with decreasing size of the wet bulb sensor, but the maximum depression is achieved at velocities in excess of 3 m/sec. Air velocity in both kilns was below 3 m/sec and this would affect the wet bulb readings. In addition the thick sponge wicks used on the wet bulb sensors would prevent the air moving freely over the sensor and affect wet bulb temperatures. Impurities in the water tend to cause increases in wet bulb temperatures, and it is known that during this trial the water baths occasionally became contaminated.

Another possible source of error was by manually reading the temperatures from the Chino recording charts. The thick pen traces combined with the small graduations on the charts made it difficult to accurately read wet and dry bulb temperatures. The accuracy an operator could achieve would be $\pm$ 0.5°C. In addition the experimental sensors were not re-calibrated after the manufacturer supplied them, so their accuracy was not established.

Behaviour in the remainder of the kiln

Few data after those for the first week of drying have been analysed, because of time constraints in reading the temperature charts, and the latter should be used as an indication only. The drying behaviour in the first few weeks is critical in avoiding degrade, and affects the drying conditions in the remainder of the seasoning process. Consequently, understanding the drying behaviour during the first few weeks will allow control of the drying rate, because after those first weeks the likelihood of degradation decreases. Following the completion of the joint trial between Bunnings and the Department, an improved system was set up to achieve greater control of the drying process. Details are given in Appendix 2.

Changes implemented to stop surface checking

With winter ambient conditions, there was no checking, and bundles dried to below f.s.p. by 10 weeks, with one bundle per week added to the kiln. When the hot dry summer ambient conditions prevailed, checking occurred, and two bundles a week were added to the No. 1 kiln because the timber could not produce adequate moisture to increase the R.H. into the 90 to 95 per cent range. Air leaking from the kiln aggravated the drying conditions. Using the No. 2 kiln and adding two bundles a week reduced surface checking, but could not prevent it under severe drying conditions. As this kiln was leaking also, it was turned off for one week in March 1985 to seal leaks.

The steam humidifiers and Coolgardie safe both increased the No. 2 kiln's humidity. While the humidifiers were operating surface checking was reduced but twist, bow and spring increased. High humidities were achieved when both humidifiers were operating and the air vents were closed, but temperatures higher than winter ambient temperatures occurred, making control over both R.H. and temperature difficult. Due to the short experimental time, when one or both humidifiers were operating, the best combination or humidity, temperature and venting to suit a desirable drying rate could not be evaluated.

For the short time the Coolgardie safe was operating promising results were achieved, but the air velocity was drastically reduced, and this made it impossible to compare drying behaviour under winter and summer ambient conditions.

In summary the general concept of the tunnel kiln is one of simple construction and operation and the overall feasibility has been demonstrated by the CSIRO in commercial practice. The Department's experimental progressive tunnel kilns have shown that select grade 75 x 25 mm mature jarrah can be successfully pre-dried by tunnel kilning under winter and early spring ambient conditions. When the hot dry summer conditions prevail the green timber in the tunnel kiln will surface check, bow and twist under ambient conditions. The results of this trial indicated that winter drying condition must be reproduced by artificial means during the summer months to prevent severe timber degradation. This requires relative humidities as high as 95 per cent and temperatures between 12°C and 15°C. This can be achieved by controlling temperature, humidity, air velocity and ventilation.

The accuracy and precision of the wet and dry bulb temperature sensors used in this trial were questionable. The new system described in Appendix 2, with accurate RTD sensors, computer control and data logging facilities will enable a better understanding of the kiln drying conditions and the timber's drying behaviour.

ACKNOWLEDGEMENTS

We would like to thank Bunning Bros staff for their involvement in the trial, and for supplying the select grade timber and two electric humidifiers. The staff and employees at the Wood Utilisation Research Centre are acknowledged for the time spent recharging the tunnel kilns and collecting data.

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APPENDIX 1

History of the 75 x 25 mm mature jarrah tunnel kiln seasoning trial

A joint tunnel kiln seasoning trial between Millars (W.A.) Ltd, and the Forests Department (now CALM) began in March 1984. Bunnings Ltd subsequently took over Millars and continued with the trial. The history of events is as follows:

21st March, 1984: The first bundle of 75 x 25 mm mature jarrah was placed into the kiln. Over the next 10 weeks one bundle per week was added until the kiln was full.

June/July 1984: Sampling the bundles of timber for degrade and moisture variation began. Only four samples per bundle were used and approximately every second bundle along the tunnel was assessed. Over the winter/early spring period, no severe timber degrade was observed.

29th September, 1984: Severe timber degrade was noticed (particularly surface checking) due to the rapid drying rates of the timber and the loss of moisture from them kiln through air leaks.

7th November, 1984: Two bundles per week were added (both at the same time) to increase the feed rate and hopefully reduce the surface checking.

16th January, 1985: The air recycling kiln (kiln No. 2) was completed and the mature jarrah bundles moved to this kiln.

4th February, 1985: A "Coolgardie" safe was attached to the end of the fan housing outside the No. 2 kiln. The air movement through the kiln was affected by the Coolgardie safe so it was removed after one week.

22nd February, 1985: The sample size was increased when bundles 60 and 61 were placed in the kiln. This technique involved random sampling of 20 boards for timber degrade assessment and four boards for moisture variation and degrade assessment. Assessment was done every Wednesday and Friday.

5th March, 1985:	The kiln was turned off for one week for sealing to minimise air leaks.
12th March, 1985:	The kiln was restarted.
29th May to 12th June, 1985:	Air was exhausted through the vents to increase the drying rate.
12th June, 1985:	Vents were closed and only one bundle per week added.
8th July to 16th July, 1985:	An instrument calibration exercise was done using a hair hygrograph, an Aircraft Industrial Marine Services (AIMS) direct sensor, a psychrometer and experimental sensors.
7th August, 1985:	The 25mm regrowth jarrah seasoning trial began in the No. 1 kiln.
18th September, 1985:	Selection and assessment of the 20 samples per bundle for I.M.C. (required for data for calculating the multiple regressions) ceased.
10th October, 1985:	Two steam humidifiers were placed in the fan housing of the No. 2 kiln with one operating at maximum setting.
16th October, 1985:	The air recycling tube was removed to exhaust air and increase the drying rate, but this resulted in severe checking.
21st October, 1985:	Both humidifiers were operating at maximum setting.
6th November, 1985:	The recycling tube and humidifiers were operating.
9th December, 1985:	Very hot ambient conditions were recorded.
8th January, 1986:	The air inlet was covered with plastic, which resulted in saturated conditions in both the tunnel and recycling tube.

10th January, 1986:	Holes were cut in the plastic covering the air inlet to reduce the humidity from full saturation to between 90 per cent and 95 per cent, which took two to three hours. An electricity meter was fitted to the power supply for the No. 2 kiln to monitor the electricity consumed by the humidifiers.
15th January, 1986:	The humidifiers were turned down to reduce drying rates.
16th January, 1986:	The vents were opened slightly to reduce humidity.
22nd to 29th January, 1986:	Very hot ambient conditions were recorded.
5th to 7th February, 1986:	The humidifiers were set to maximum to counter the hot ambient conditions, resulting in a saturated chamber.
7th February, 1986:	Humidifiers were turned down to reduce humidity.
26th March, 1986:	The last 75 x 25 mm mature jarrah bundle was placed in the kiln.
4th June, 1986:	All the mature jarrah was removed from the No. 2 kiln.

APPENDIX 2

Acquisition of new data collection and control equipment

In choosing the equipment to control the kiln and record data, the following were required for the system.

(a) a high standard of accuracy
(b) flexibility and expandability
(c) ease of installation and training
(d) reasonable time for installation and commissioning
(e) local technical expertise (either Departmental or external)
(f) local repair available
(g) suitable for an industrial environment.

The computer system would allow:

(a) accurate and rapid assessment of the timber's environment (temperature, relative humidity and air velocity), then if required altering the environment by automatic control of air vents and humidifiers to prevent timber degradation
(b) storing of large amounts of data of the kiln operating conditions to develop a detailed and practical knowledge of the drying process.

Preliminary work indicated the following were required:

	Accuracy	Range
Temperature	$\pm$ 0.2°C	0-185°C
Relative humidity	$\pm$ 2%	20-98%
Weight loss (load cell)	$\pm$ 0.1kg	up to 1500kg

The equipment chosen to accurately control and record information from the kiln was:

(a) Olivetti M24 micro-computer with 30 megabyte hard disk
(b) computer software package Dbase III and Micro-mac software modules
(c) Micro-mac 5000 for interfacing the computer with the temperature sensors and kiln controls
(d) four wire 100 Ohm platinum resistance temperature devices (RTD's).

This system will convert the signal (eg. mV) from the temperature sensors into meaningful units (eg. °C) so that controls can be activated to change the drying conditions. This system will also store the history of the kiln's drying conditions at regular interval.

GLOSSARY

Ambient temperature. Referring to the natural temperature conditions at a given place and time.

Charge. The quantity of timber required to fill a timber seasoning kiln.

Coolgardie safe. The Coolgardie safe was constructed with a hessian bag which remained continuously wet. When ambient air was blown through the bag it was cooled.

Defect. An irregularity in timber that reduces its strength, durability, appearance or utility.

Dry bulb temperature. The temperature of an air stream.

End point moisture content. The final moisture content required in a charge of timber being kiln dried.

Fibre saturation point (f.s.p.). The moisture content at which all free moisture in wood has been removed but at which the cell walls are still saturated.

Green timber. Timber still containing free moisture in its cell cavities.

High temperature kiln. Kilns which use temperatures in excess of 100^{o}C.

Initial moisture content (i.m.c.). The moisture content of a piece of timber immediately after it is sawn.

Mature hardwoods. Timber from the original forest.

Progressive tunnel kiln. A long chamber holding a succession of timber stacks ranging from green at one end to dry at the other. Air is drawn in at the dry end and expelled from the green end. As the air moves through the kiln moisture is collected from the timber and the temperature drops. As a stack is removed from the dry end all remaining stacks are moved along and a green one is placed in the green end, thus maintaining a full chamber at all times.

Regrowth hardwoods. Immature hardwoods naturally or artificially regenerated.

Relative humidity. The ratio of actual water vapour pressure in the air to the water vapour pressure in saturated air at the same temperature and pressure.

Seasoning. Drying timber to a moisture range appropriate to its end use requirements.

Stripping. Stacking of timber for seasoning in layers separated by small pieces of sawn or dressed timber of rectangular or square cross section.

Surface checking. A split in the surface of timber which is the separation of the fibres along the grain forming a fissure in the timber but not extending through the piece from one surface to another. It generally results from stresses set up in the timber during seasoning.

Vapour pressure deficit (V.P.D.). The difference between the saturation and actual vapour pressure at the same temperature and pressure.

Wet bulb temperature. The minimum temperature reached by a wetted thermometer in an air stream. The humidity measurement is derived by comparing the wet bulb temperature to the ambient or dry bulb temperature on a psychometric chart.