Design and construction of a small, low cost, low temperature, timber-drying kiln

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Abstract

*A timber-drying kiln of 4 m³ capacity was constructed off-site and installed at a sawmill near Queenstown on Tasmania's west coast to dry Huon pine (*Lagarostrobos franklinii*). The kiln was designed to be low cost and simple to construct, use and maintain. The only site requirements were for three-phase power, mains water supply and a flat, concrete base approximately 8.0 m × 2.4 m. The kiln is currently used for drying boards sawn from stored logs and will also be used to dry thick veneer sawn from stored logs. It proved to be able to maintain set points very closely, with variation over time in temperature of ± 0.1°C and relative humidity of ± 0.5%, variation in temperature and relative humidity across the rack face of 0.7°C and 2.4% respectively, and air velocity across the rack face ranging from 0.40 to 0.73 m/s. Maximum moisture content variation within a rack of dried timber was generally ± 1%. The kiln would be suitable for final drying of other species, and minor modifications could make a kiln based on this design suitable for drying green timber. The majority of the kiln can be constructed with basic tools and partially skilled labour.*

Introduction

All Huon pine timber is presently cut from logs that have been in storage for several years and so have much lower moisture content than the living tree. Previously, Tasmanian Special Timbers Pty Ltd (TST) air-dried their boards to approximately 18–20% moisture content over a period of several months, then dried these to the final moisture content of 10% in a large shed with a heated floor. Production of thick veneer from their deep cut, thin-kerf, horizontal bandsaw had not reached commercial volumes due to difficulties in drying the material flat. In March 2004, the Tasmanian Forests and Forest Industries Council (FFIC) and TST engaged the Timber Research Unit (TRU) of the University of Tasmania to design, construct, install and commission a low temperature, conventional drying kiln for TST, to be situated at their sawmill at Lynchford, near Queenstown, Tasmania, in an attempt to address the problem. The kiln was to replace the heated shed for the final drying of Huon pine, both in board and thick veneer form. The kiln was developed from the design of an existing kiln at the TRU.

Specifications

The new kiln needed to accommodate a stack of timber 1.5 m wide, 1.1 m high and 3.5 m long, with a maximum temperature of 50°C and maximum relative humidity (RH) of 90%. Air velocity through the stack was to cover the range 0.5–1.5 m/s. Reversible airflow was not required due to the narrow width of the timber stack. The kiln was to be housed in a fully sheltered environment, with a flat base to be used as the kiln floor.

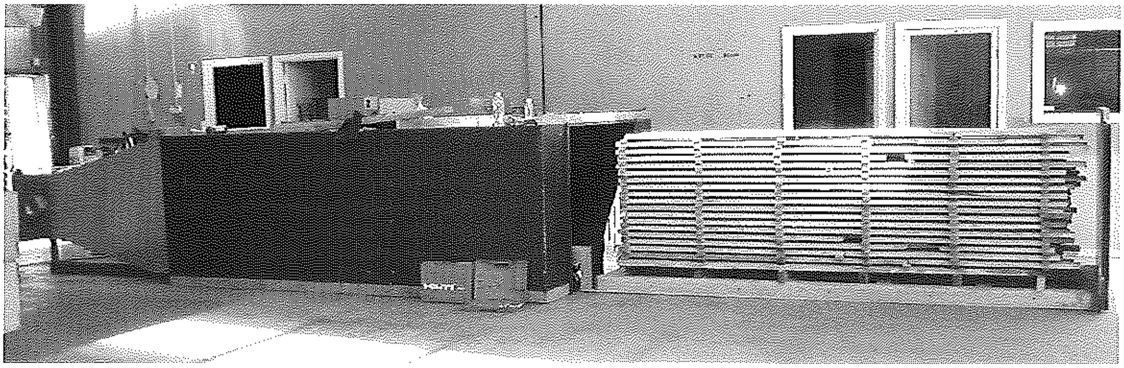

Photo 1. Completed kiln, ready for loading. In practice, the gap at the right between the rack and the kiln door is baffled.

Design

The general layout is for an end-loaded kiln, with the fan mounted beyond the timber (Photo 1). The design is an expansion of an existing TRU research kiln, which has a working section 2.4 m long. Heating is by an electrical element, with humidification by a spray of cold water, and vents are used to intake fresh air and exhaust high humidity.

Air is blown by the fan around a 90° bend, through a vaned diffuser into the intake plenum. This produces a volume of slow-moving air at pressure above atmospheric that helps to ensure a uniform flow through the timber stack (Photos 2, 3). The fan is expected to have excess capacity for this application, so turning vanes have not been used to decrease the pressure drop around the bend. Eight vanes are used in the intake diffuser to improve vertical air velocity distribution in the kiln by reducing flow separation, with included angle between vanes of 8° (Vennard and Street 1982).

The diffuser exit attaches to an intake plenum of approximately the same width and height, which runs the full length of the kiln working section. A slotted aluminium screen with 20% open area on the timber side of the intake plenum assists in ensuring uniform airflow across the rack face. After passing through the timber stack, the air is returned to the fan via a plain return duct. Holes at the lowest point of the two diffuser sections drain away condensate.

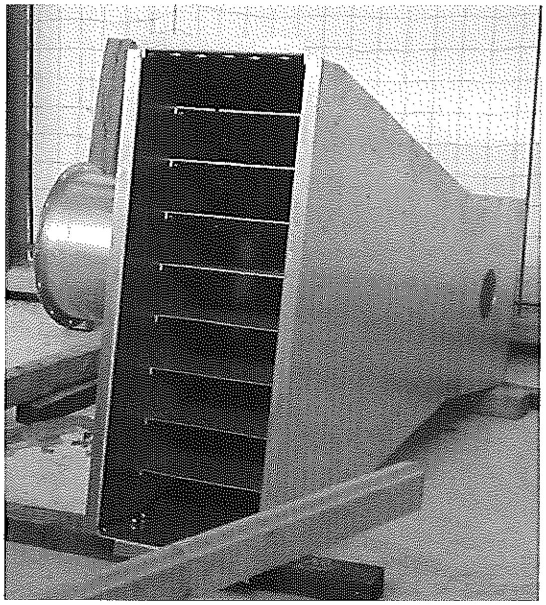

Photo 2. Fan (at rear), 90° bend and vaned inlet diffuser.

Components

Fan

The kiln uses a 500 mm diameter axial flow fan incorporating a sealed 1.5 kW three-phase motor (model number A3504AL, supplied by Dry Air Systems), specified to supply 2500 l/s at 175 Pa. The motor is controlled by a Lenze variable speed drive (VSD) with a digital readout, and is wired to a potentiometer, giving simply controlled, infinitely variable air speed.

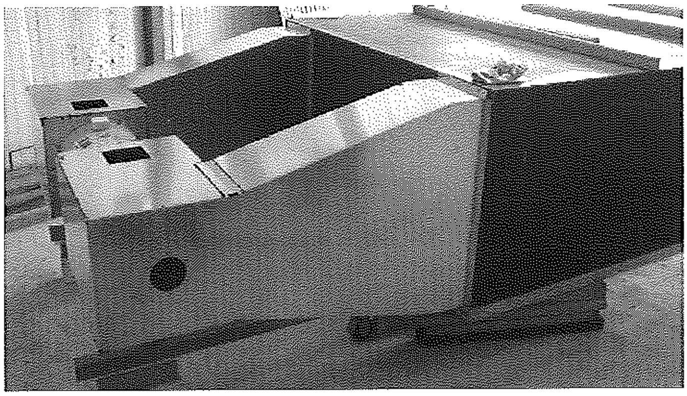

Photo 3. The partially constructed kiln showing the aluminium end section with the fan attached to the plywood working section. The round hole is for an inlet vent; the exhaust vent is directly in line on the far side. The square hole on the far side houses water sprays.

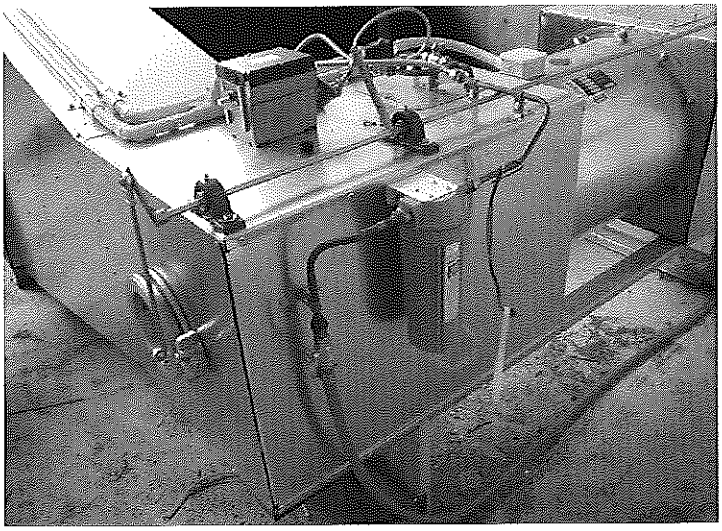

Photo 4. Fan, 90° bend, inlet diffuser (rivets hold vanes), water filter in line to sprays, and exhaust vent with servo motor and linkage (also driving the inlet vent).

Control elements

Three Shinko micro-temperature controllers are used to control the kiln (model JCS-33A, with either a relay output for the sprays or a 4–20 mA output for the temperature and vent control). Input is from a single Vaisala HMP230 temperature and RH probe. The probe is mounted at the mid length of the intake plenum, approximately 150 mm below the top of the kiln and 175 mm upstream of the slotted screen. A serial port is provided for logging of kiln conditions by computer if required.

Inlet and outlet vents (KromSchroder 150 mm butterfly valves) are situated directly in line with the fan axis. They are driven by a KromSchroder GT 50E modulating servo motor via a single crank shaft and adjustable rose-jointed connecting rods (Photo 4).

Two water sprays are used (Bex model CC 1.9), supplied with mains pressure cold water through a 1 μm cartridge filter. They spray into the airflow directly downstream of the fan, and are installed on a removable panel via flexible hose to facilitate servicing (Photo 4).

Heating elements are mounted in the aluminium ducting adjacent to its attachment to the plywood working section on both inlet and outlet sides. Elements are

1.8 kW 'U' style (Stokes Synertec 2216-U). Three elements are installed each side, giving a total heat capacity of 10.8 kW.

The output of the Vaisala probe is set to 4–20 mA for both temperature and RH channels. The temperature output is wired to one of the Shinko controllers. The output from this controller is fed to two series-wired Fastron phase angle controllers (F–312–2-VA) which, in turn, drive two Fastron solid state relays (model HPF240D30R). These are 30 A units, and are wired off separate phases and protected by semiconductor fuses. Though slightly more expensive, the use of a single three-phase silicon controlled rectifier would be recommended if more heat input is required.

The RH output from the probe is wired in series to the two remaining controllers. The first of these is a relay controller, which supplies a simple on–off control to the water sprays. The second controller has a 4–20 mA output and is wired directly to the modulating motor controlling the vents. Two separate controllers are used for RH control of the spray and vent operations rather than a single controller with a 'heat/cool' output, as the tuning of these two functions can be vastly different.

The electrical control equipment is installed in a custom-built switchboard manufactured by Pierce and Parkinson. The switchboard is divided into two sections, with the lower half having a screwed front panel and a DIN rail for installation of the various circuit breakers. The top half has a hinged front panel and contains the various control devices. This section is also fitted with a small extraction fan, drawing cooling air through a vent located in the bottom of the switchboard. A transformer is installed to provide 24 V AC power for the spray solenoids and the Vaisala probe. The entire electrical system is protected with a three-phase residual current device.

All wiring external to the switchboard is enclosed in 25 mm electrical conduit. A heavy duty metal junction box is used to enclose the connections to the heating elements on either side of the kiln. Each trio of elements is wired with a manual reset over-temperature switch. A red indicator light is installed on the outside of each junction box to provide a simple indication of correct function.

Loading

The kiln is designed for end-loading by a trolley (Photo 1). The trolley has two cast-iron wheels at the fan end (Richmond Castor model R691, 1500 kg capacity), which sit outside the kiln working section to prolong their life and allow the maximum room for timber in the working section. They roll in galvanised 100 mm channels attached to the floor with concrete screws. These channel sections are also used as stiffeners during transport by bolting them along the bottom of the kiln. A forklift is used to lift the outer end of the trolley and move it in and out, while the timber stack is generally pre-built and loaded onto the trolley by a forklift.

The trolley itself consists of two longitudinal 125 mm channel sections on edge, joined by two 125 mm channel sections on their flat at either end and three intermediate 100 mm channel sections also on their flat. Wheels are attached beneath an elevated end section. The trolley is fully welded and galvanised. The kiln door is built of 17 mm form ply supported by two 100 mm channel sections bolted to the end of the trolley. Small doors attached to the trolley seal the door cut-outs in the fan end of the working section (Photo 5). All channel sections are mild steel.

When in position, the trolley blocks airflow from diverting beneath the timber stack. Baffling at the ends of the rack, or building square-ended racks by top-and-tailing boards less than the full length of the kiln, improves airflow uniformity through the timber rack. Racks will generally be the full height of the kiln working space, avoiding the need for baffling above the rack.

Control strategy

Temperature of the air going into the timber stack is controlled by a Shinko controller, based on measurement from the Vaisala temperature/humidity probe. The controller auto-tuning function is used to select appropriate proportional, integral and derivative (PID) control parameters. The auto-tuning operates by cycling the temperature and selecting appropriate PID parameters based on the kiln's response. The parameters can also be altered manually. When using the auto-tuning, consideration has to be given to the status of the other inputs and also to the load in the kiln. Best results are obtained by auto-tuning all three controllers, then repeating the process once the kiln is operating close to the set point. The behaviour of the sprays, and to a lesser extent the vents, has considerable impact on the performance of the heating elements.

Humidity is controlled by two Shinko controllers operating vents and water sprays separately, based on measurement from the Vaisala temperature/humidity probe. Controlling humidity on the basis of RH rather than on wet-bulb temperature improves control markedly as fluctuations in temperature do not affect the RH reading as much as they do wet-bulb temperature.

Vents are used to decrease humidity, and sprays to increase it. Each is controlled by separate PID loops. In practice, an effective 'deadband', achieved by setting the spray RH set point 0.5% lower than the vent RH set point, results in smoother control, along with lower spray and vent settings. The sprays use a simple on-off control system, in which the on-off cycle is completely controlled by the PID settings in the controller, with no specific time base. The vents are controlled approximately linearly with the controller output, with 100% controller output corresponding to a vent opening of approximately 45°. The various crank arms between the modulating motor and vents are provided with additional holes to allow for variation to this relationship.

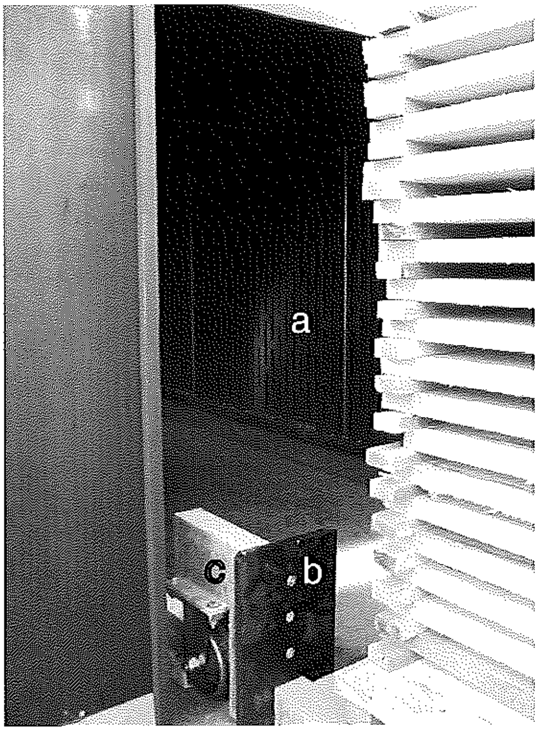

Photo 5. Timber on the trolley ready for loading into the kiln. Note the slotted screen on the intake plenum (a) and the small door (metal plate; b) attached to the trolley; the elevated end section with the wheel (c) is external to the kiln at the far end when the kiln is operating.

Construction

The working section of the kiln is constructed from standard 17 mm thick concrete formwork plywood. Two lengths of copper-chrome-arsenic (CCA) treated pine (107 mm × 45 mm) are installed along the length of the kiln underneath the inner edges of the plenums; a 17 mm deep rebate along the top of each locates the plywood, and the pine lengths also support the fan. CCA treated pine (90 mm × 45 mm) is used to complete a box underneath the plywood floor of both plenums; this rests on the concrete underneath. Plywood edge joins are all rebated, sealed with Sikaflex 11FC adhesive sealant and screwed with 50 mm × 12 ga stainless steel screws. Butt joints across the top of the kiln are reinforced by 100 mm × 50 mm Tasmanian Oak. All internal bare timber and plywood edges are coated with Ormonoid bitumen coating but the melamine coating on the form ply is left bare.

Plans of the aluminium end section of the kiln were drawn by Tas-Fab Laser Services from working sketches by the TRU. Tas-Fab laser-cut, folded and riveted the sections from 3 mm thick aluminium sheet. Vanes were riveted into the inlet diffuser. All joints have been sealed with Sikaflex 11FC.

An aluminium screen with 20% open area was designed by the TRU and Tas-Fab, who laser-cut the screen from three sheets. The screen is screwed to the shell of the working section across the timber side of the inlet plenum (Photo 5).

The kiln was built at the TRU's Launceston laboratories, then delivered, installed and commissioned in two days.

Performance

Kiln performance was monitored with a rack of timber in place near the end of a drying cycle. Set points were 35°C, 50% RH and 0.5 m/s airflow.

Air velocity

Air velocity was measured on a grid of 35 points over the rack entry face using a TSI hot-wire anemometer. Measurements were taken between the plenum screen and timber rack, 300 mm from each end of the kiln and every 500 mm along it, and every 200 mm vertically. Results are shown in Table 1. The maximum velocity was 0.73 m/s; the minimum was 0.40 m/s. Lower readings tended to be near the rack edges. This degree of variation over the rack entry face is approximately half that typically measured at this low velocity in commercial timber-drying kilns.

Control over time

A Vaisala HMP233 temperature and RH sensor was placed at the centre of the timber rack entry face and read every five seconds for approximately one hour using an Onset HOBO U12 datalogger. Relative humidity remained within ± 0.5% of the set point while the maximum temperature fluctuation was ± 0.1°C.

Uniformity of conditions over the rack face

Temperature and RH were monitored over the same grid of points as air velocity. At each point, the portable Vaisala probe was logged every five seconds for 30 seconds. Relative humidity at the top of the kiln was approximately 1% higher than that at the bottom for each vertical set of measurements. Temperature at the top was approximately 0.3°C lower than that at the bottom for each vertical set of measurements. This is probably due to the 'U' shaped heating elements putting more heat into the airflow at the bottom of the kiln than at the top.

Conditions at the door end of the kiln were approximately 0.7°C cooler and 2.4% higher RH than at the fan end. Mean absolute humidity was only 0.1 g water per kilogram of air higher at the door end than at the fan end, which is one-third of the variation observed from top to bottom. The difference in drying conditions over the rack face was therefore negligible.

Usage

When using high humidity set points and kiln temperatures above ambient, condensation inevitably occurs as the aluminium section is not insulated. The kiln required a well-drained area to run the condensed water away from the timber stack. TST plan to enclose the section to decrease condensation and energy consumption. Extended use of high humidity conditions could be expected to shorten the life of the plywood working section.

The schedule currently in use for 28 mm thick Huon pine boards is shown in Table 2. The heat-up part of the schedule will vary

Table 1. Air velocity (m/s) measured on a grid of points over the rack air-entry face.

	Door						Fan
Top	0.51	0.53	0.48	0.55	0.55	0.58	0.40
	0.73	0.64	0.66	0.52	0.47	0.60	0.40
	0.60	0.60	0.63	0.50	0.45	0.56	0.43
	0.54	0.65	0.70	0.55	0.60	0.70	0.55
Bottom	0.49	0.45	0.45	0.47	0.58	0.68	0.43

depending on ambient temperature; it is expected to take much longer in winter, when timber will enter the kiln below 10°C. Drying time can probably be decreased below 15 days with further tuning of the schedule. TST use a hand-held dielectric meter to determine timber moisture content, and maximum variation across a dried kiln charge is typically about 1%. No effect of board position in the stack on dried moisture content has been observed.

The kiln was assessed after continuous operation for three months and TST were satisfied with its performance, with high quality dried timber being achieved in a short drying time. The majority of timber will now be dried directly after sawing (with no air pre-drying) in about 15 days. Loss to drying degrade, mostly surface checking, has decreased from approximately 10% in the heated shed to 5% in the kiln. Power usage has decreased to approximately $80 per rack, about 13% of that previously required to final dry the timber in a heated shed. The kiln is estimated to be capable of processing approximately 80–100 m^3 of sawn Huon pine boards per annum.

Table 2. Drying schedule for 28 mm thick Huon pine boards initially at 18–20% moisture content.

Time (days)	Temperature (°C)	Relative humidity (%)
0	20	73
0.5	22	73
1	26	70
2	30	70
3	35	70
4	35	65
5	35	62.5
6	35	60
7	35	59
8	35	58
9	35	57
10	35	56
11	35	55
12	35	54
13	35	53
14	35	51.5
15	35	50
Finish		

Veneer drying

To date, the kiln has not been used for drying thick veneer. It is planned for stacks of veneer to be dried using a mesh racking system based on that of Shedley (2002), beginning in winter 2005. Shedley had mesh sheets custom-made with cross wires (parallel to the airflow) every 50 mm and three longitudinal wires per sheet. Veneer sections were laid on the cross wires, between the longitudinal wires. Thus, layers of veneers were separated only by the cross wires, which provide regular support and restraint to the sheets of veneer and uniform airflow over their faces. Due to the cost of custom mesh, TST is likely to use sheets of conventional mesh, with two sheets laid back-to-back separating layers of veneer, and the wires on the top and bottom of the doubled mesh running parallel to the airflow. There will then be no restriction on the width of veneer (up to the full stack width), with few disadvantages other than a lower packing density of timber veneer in the stack. The softness of Huon pine may necessitate construction of a supporting structure to prevent indentation of sheets of veneer lower in the rack. Potential throughput of thick veneer is difficult to estimate at this stage.

Table 3. Cost breakdown of parts, including 10% GST, $AUD, and 2004 prices. Only labour for ducting and trolley design and fabrication is included.

Part	Details	Cost ($)
Fan	including variable speed drive	3 200
	all components, including heaters, sprays, vents, plumbing and wiring	7 300
Working section	plywood, timber, fasteners and sealant	1 500
Trolley	including guide rails, fabrication and galvanising	1 900
Ducting	aluminium end section, including slotted plenum screen, drawing, laser cutting, folding and riveting	3 600
Total parts		17 500

Conclusions

The kiln's performance exceeded expectations. Control over time and uniformity across the rack face of temperature, humidity and airflow are excellent. The kiln is meeting the requirements of TST in terms of drying time and dried timber quality.

Overall cost of the kiln, including fabrication of the trolley and aluminium ducting but not including labour for design, assembly and installation of the kiln, was approximately $17 500 (Table 3). Off-the-shelf parts have been used wherever possible to simplify fault rectification or replication of the kiln. Drying of timber from green will probably necessitate regular replacement of the working section or construction from other materials to cope with extended periods of high humidity. The kiln could be easily adapted to drying other species.

The design could be modified to allow the possibility of steam reconditioning in the unit for species prone to collapse, and final drying at higher temperature. The heat source could be changed to other sources such as steam or a hot water heat exchanger for sites with a steam supply or lower cost gas. Construction is comparatively simple, requiring only basic tools and materials (other than for construction of the aluminium section) and an electrician.

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