ACCELERATED BORON DIFFUSION TREATMENT
OF TIMBER

A. J. McQUIRE

Forest Research Institute, New Zealand Forest Service, Rotorua

and

K. A. GOUDIE

PTY Industries Ltd, Putaruru

ABSTRACT

Small-scale trials showed that the time required for treating freshly sawn radiata pine (**Pinus radiata** D. Don) timber with boron could be reduced greatly by using a hot and cold bath followed by diffusion at elevated temperatures. Results obtained were close to theoretical predictions and with 100 × 50 mm timber, the total treatment time required was 7-9 days compared with a normal treatment time of about 60-80 days for timber treated by momentary immersion plus diffusion. Subsequent trials with a commercial prototype plant confirmed these results and demonstrated that accelerated diffusion had many technical and economic advantages over the momentary immersion process.

INTRODUCTION

The commercial use of boron salts for the preservation of New Zealand building timbers dates back to 1949, and the circumstances responsible for its rapid acceptance were set out by Carr (1957) who states:

"Diffusion impregnation with boron compounds was commercially introduced to New Zealand in 1949-50 for treatment of the *Lyctus*-susceptible hardwood tawa.

However, this method of timber preservation was not accepted by building authorities and lending institutions until 1952, when the report of the Committee of Inquiry into the Treatment of Timber by the Borax-Boric-Acid Process was presented. As a result of this inquiry, diffusion impregnation of tawa with boron was established in 1952 as an approved process for flooring and furniture. Furthermore, the committee of inquiry recommended the enactment of appropriate legislation and the setting up of a Timber Preservation Authority to control and co-ordinate activities in relation to timber preservation, to control the approval of preservatives and preservative processes, and to undertake inspection servicing of commercial timber preservation. This authority came into being under the Timber Preservation Regulation 1955, but did not commence activities until 1956.

"The use of boron compounds and diffusion impregnation was closely examined and approved by the Timber Preservation Authority for all parts of a house in addition to flooring. The process is now established commercial practice for radiata pine and many other locally grown building-timber species, apart from tawa, and for the purpose of official approvals has an equal status with pressure treatments for building timber."

As an indication of the wide acceptance of the boron salts used in the diffusion impregnation of New Zealand building timber after the approval of the Timber Preservation Authority (TPA), the annual production rose from 16 500 m³ for the year ending 31 March 1955 to 165 000 m³ 5 yr later, and reached a peak of 350 000 m³ in the year ending 31 March 1965. Although there has been some reduction in the annual production since 1965, the boron diffusion process still accounts for more than half of the building treatments.

The popularity of boron salts and the diffusion impregnation process is undoubtedly due to:

1. The low cost to the user. The salt is comparatively cheap, and the process plant needed is simple and relatively inexpensive. No special operating skills are needed and the small operator can usually treat in competition with much bigger plants, thus often having some territorial advantage.

2. The diffusion process requires the wood to be green, the sap carrying preservative salts in solution deep into the wood. No pre-drying is needed, thus avoiding a substantial part of the cost of normal pressure treatment. The seasoning or drying of wood inevitably produces some stresses within the wood fibres, often resulting in "seasoning degrade". For finishing grades the avoidance of pre-treatment drying not only reduces the total cost of treatment, but can effect a marked reduction in the overall losses from degrade.

Although these virtues have combined to make boron diffusion pre-eminent among New Zealand building timber treatment, it has several features which cause production problems. The most important of these is the long diffusion period required to meet the core retentions* laid down by the Timber Preservation Authority; 4-6 weeks for 25 mm thicknesses and 8-12 weeks for 50 mm thicknesses. Thus, a producer of predominantly framing timber will have approximately one-fifth of his annual production currently immobilised in the diffusion stage. This unavoidable stock accumulation is

---

* The core is defined as the central ninth of the cross section.

usually aggravated by the need to hold treated stocks of the less common sizes to meet sales demands at fairly short notice.

It was this stock problem and the lengthy delay in filling special size orders that prompted PTY Industries to start investigations to see if the diffusion phenomenon could be accelerated to produce the necessary core loadings more quickly.

Field observation and some simple experiments made in 1958 indicated that diffusion rates increased at higher than ambient temperatures. These simple tests were made by heating the wood throughout in the hot diffusion dip tank and then wrapping insulating coverings around the bundles to retain the heat as long as possible. The progress of diffusion measured by spot-test indicators showed considerable improvement over similar pieces from the normal diffusion stocks. It also explained why material treated and diffused during the cold part of the year produced more defective samples than that treated in summer.

In 1961 the Forest Research Institute (FRI) carried out controlled laboratory experiments on momentarily dipped timber diffused at higher than ambient temperatures. Analysis of these timbers showed a marked improvement in the diffusion rate, but there was considerable variation in the cross-sectional loading between replicated samples.

In 1966 further work was done at PTY Industries, Putaruru, to test the assumption that a good initial loading would be obtained by means of a hot and cold bath, and that the whole process would be improved if this could be followed by heat-assisted diffusion. Several trials were made with improvised techniques, and spot-tests showed results of sufficient promise to warrant more elaborate trials.

In May 1966 the FRI and PTY Industries agreed to conduct controlled trials jointly. Treatment schedules, solution concentrations, and diffusion times, as calculated from purely theoretical considerations, were set out in a work plan prepared by the FRI. PTY Industries constructed the necessary plant, prepared the timber, and did the experimental work. Chemical analyses of solutions and wood samples were done at FRI.

THEORY AND EXPERIMENTAL WORK

Theoretical Considerations

The treatment consisted of three distinct stages: a hot bath, a cold bath, and a diffusion period. Each of these stages was governed by separate physical theories.

1. The Hot Bath

The primary object of this phase was to heat the wood throughout its cross section to expel any air in its cells. In addition to this effect, some boron would enter the wood by diffusion. From tables and graphs derived by MacLean (1952) the time required to heat the central region of green timber to the temperature of the heating medium can be calculated.

During this heating period the uptake of boron by diffusion can be predicted by an equation derived by Harrow (1951) which states:

$$\frac{\text{Solution conc. \%} \times \sqrt{\text{time (hr)}}}{\text{Loading \%} \times \text{thickness (in.)}} = k \quad \ldots \ldots \ldots (1)$$

For the species, size, etc., used in this work, the constant K = *ca.* 12

2. Cold Bath

The object of the cold bath is to obtain a liquid absorption into the wood, and at 100% efficiency this should result in virtual saturation. The volume of solution that can be absorbed in this manner depends on the density and moisture content of the wood, and it can be calculated by the following formula:

$$\text{Max. uptake in kg/m}^3 = (100 - \text{Basic density} \times (\text{Moisture content } \% + 65.4)) \times 10 \qquad \dots \dots \dots \dots (2)$$

No simple formula is known for calculating the required time/temperature drop for cold bath, but, from experience with this and similar processes, it appears that a temperature drop of about 45°C is usually adequate.

3. Diffusion

McQuire (1961) found that temperature had a pronounced effect on the rate of diffusion over a range of 4°—80°C, and that the time required to reach a desired core loading could be calculated from the equation:

$$\text{Diffusion time in days} = \frac{\text{Constant}}{\text{temperature °C}} \qquad \dots \dots \dots \dots \dots \dots (3)$$

With 50-mm-thick radiata pine, where a core loading of 0.2% H_3BO_3 was required in 90% of samples, the value of the constant was found to be about 750 for a mean cross section of 0.75% H_3BO_3

Work Plan Requirements

The basic requirement of the trials was that the results should comply with the TPA specification for boron treatment of light building timber. This calls for a core loading of 0.2% H_3BO_3 in at least 90% of the pieces. From experience with normal boron diffusion treatment it has been found that to obtain a minimum core loading of 0.2% H_3BO_3 a mean cross section loading of about 1.25% H_3BO_3 equivalent is required.

To obtain this loading the following process variables could be manipulated:

(1) The hot bath temperature
(2) The hot bath duration
(3) The solution concentration
(4) The cold bath duration
(5) The temperature drop during the cold bath
(6) The diffusion temperature
(7) The diffusion period

Within the possible extremes of these variables certain limitations were necessary or desirable.

(a) It was desirable to keep the boron solution concentration below 15% W/V H_3BO_3 equiv. so that the solution (polyborate) could be stored unheated without risk of precipitation.

(b) The hot bath temperature should be as hot as possible without actually boiling. It had to be possible to maintain the temperature by some form of thermostatic control.

(c) The diffusion temperature needed to be as high as could be economically maintained to reduce diffusion times to a minimum.

Within these limitations the following arbitrary values were given to some of the above variables:

Hot bath temperature (1) 94°C. Temperature drop during cold bath (5) 45°C, i.e. 94° to 49°C. Cold bath duration (4) 4 hr. Diffusion temperature (6) 49°C.

With these variables fixed the remainder were calculated using the equations given under theoretical considerations.

Hot Bath Duration (2)

For green radiata pine having a basic density up to 480 kg/m³ which is heated in liquid at 94°C, the time required to reach a temperature of 88°C in the centre was calculated as 1 hr 30 min.

Solution Concentration (3)

Substituting in equation (1)

$$\frac{\text{Soln conc. } \% \times \sqrt{1.5}}{\text{Loading } \% \times 2} = 12$$

or loading %　　　　　　= 0.051% solution concentration

and in equation (2) $\left\{\begin{array}{l}\text{taking basic density at 0.48}\\ \text{and moisture content at 135\%}\end{array}\right\}$

Max. uptake　　　　　= (100 — 0.48 (135 + 65.4)) × 10

　　　　　　　　　　= 40 kg/m³

or loading %　　　　　= 0.083% solution concentration

Therefore total loading = 0.051 + 0.083

　　　　　　　　　　= 0.134% solution concentration

To obtain a loading of 1.25%, the solution concentration should therefore be 9.3% H_3BO_3 equiv.

Diffusion Period (7)

As the diffusion percentage (core/cross section %) is approximately linear within the desired range, the diffusion constant was adjusted from 750 for cross section loadings of 0.75%, to 450 for a cross section loading of 1.25%.

Substituting in equation (3)

$$\text{Diffusion time in days} = \frac{450}{49°C}$$

　　　　　　　　　　= 9 days

Because some initial penetration would take place during the liquid absorption in the cold bath it was estimated that this time could probably be reduced to about 7 days.

The Experimental Plant

The plant constructed by PTY Industries was a rectangular steel vat about 2.6 m long, 0.86 m wide, and 0.61 m deep. It was heated by a longitudinal "S"-shaped steam coil in the bottom of the bath. The coil was protected by steel bars across the bath and a slightly angled baffle plate circulated the heat evenly. These reduced the effective depth of the bath to 0.53 m. Provision was made to clamp the timber down by wooden bars which fitted into steel angle slots on the sides of the bath.

FIG. 1—Experimental treatment plant. For key to numbers see below.

[A] HEATING SYSTEM CONTROLS

1. Main steam line
2. Steam trap & drain
3. Main supply valve
4. Temperature control valve
5. Steam line to coil
6. Thermostat
7. Thermostat capillary tube
8. Electrical supply to (4)
8a. Electrical signal from (4) to (10)
9. Dial thermometer
9a. Ditto (removed when lid is open)
10. Temperature regulator

[B] TREATMENT VAT

11. Vat (metal tank)
12. Insulated walls to vat
12a. Insulated lid to vat
12b. Insulated floor to vat
13. Longitudinal "S" steam coil
14. Strainer
15. Steam trap and drain
16. Metal baffle plates
17. R.s.c. timber bearers
18. R.s.c. timber clamp slots
19. Fixing for overhead lifting device
20. Supporting structure
21. Hinge to lid

[C] SOLUTION TRANSFER SYSTEM

22. Sump
23. Pump isolating valve

24. Pipeline to pump
25. Electrical supply to pump motor
26. Switch in (25)
27. Pump & motor
28. Common return pipe
29. Flexible return hose to tank D
29a. Ditto (position to tank E)
30. Supply valve from D to A
31. Supply pipe from D to A
32. Supply valve from E to A
33. Supply pipe from E to A
34. Flexible supply hose from either D or E
    to A

[D] SOLUTION STORAGE TANK

35. A/H = air hole/vent
36. Solution contents gauge
39. Supporting structure

[E] SOLUTION STORAGE TANK

37. A/H = air hole/vent
38. Solution contents gauge
39. Supporting structure

[F] ELECTRICAL MAINS SUPPLY DISTRIBUTION
     POINT

40. Mains supply

[G] WORK BENCH

[H] WALK WAY

[J] INSTRUMENTS & RECORDS SHELF

A thermostatic valve was placed on the inlet side of the coil so that temperatures could be controlled at between 38° and 100°C.

The bath was insulated by a double layer of 25-mm timber with a sheet of aluminium-backed building paper between the two layers. A hinged lid was similarly constructed.

Two storage cylinders were constructed from 204-litre drums welded end to end giving a total storage of about 1200 litres.

An outlet pipe from the bath was connected to a small centrifugal pump so that solution could be transferred from the bath to either storage tank. Transfer from the storage tanks to the bath was by gravity.

A recording thermometer was connected to the bath so that temperatures could be recorded during the hot and cold bath and also during diffusion. During diffusion enough solution could be left in the bath to cover the coils but not to touch the bottom tier of boards. The thermometer and thermostat controller were situated about half depth in the bath.

Details of this plant (except for the recording thermometer) are shown in Fig. 1.

Experimental Procedure

Each charge consisted of 42 pieces of 100 × 50 mm radiata pine 2.43 m long. The pieces were selected to be wholly (or nearly wholly) sapwood, and were freshly sawn at the time of treatment. Each charge was made up of seven tiers of six pieces, and the tiers were separated by 13-mm fillets. Cross sectional samples were cut from each end of the pieces before treatment to calculate basic density, moisture content, and oven dry weight. All pieces were weighed before and after treatment, and some were also weighed at intermediate times such as at the completion of the hot bath and/or after the cold bath. The schedules used and details of the type of material are shown in Table 1.

Results

Boron Uptake

(1) By Diffusion during the Hot Bath: From each of charges A and B, 10 samples were taken at the conclusion of the hot bath; these were analysed for cross section loadings of H_3BO_3. The mean retention of the 20 samples was 0.87% with a range of 0.58%-1.25%.

From equation (1), using a total time of $3\frac{1}{4}$ hr (mean for the two charges) the calculated retention expected is 0.86%. Thus the agreement between expected and actual retentions was extremely good.

(2) By Solution Uptake during the Cold Bath: Calculations based on basic density and

TABLE 1—Schedules and type of material

Charge No.	A	B	C	D
Number of pieces	42	42	42	42
Condition — rough sawn (R.S.) or gauged (P.G.)	R.S.	R.S.	P.G.	R.S.
Basic density — mean and range (Kg/m3)	451 (390–521)	457 (386–547)	444 (389–552)	462 (384–516)
Initial moisture content % — mean and range	135 (84–169)	132 (98–172)	129 (89–165)	131 (104–159)
Solution conc., % H_3BO_3 analysed and (calculated)	11.6 (10)	11.5 (10)	11.3 (10)	6.4 (5)
Hot bath temperature $^{\circ}$C	94	94	94	94
Time heating (hr — min.)	1–55	1–30	1–35	0–55
Time at max. temperature (hr — min.)	1–30	1–30	1–30	1–30
Total time equivalent on hot bath	2–30	2–15	2–15	1–55
Cold bath temperature initial and final $^{\circ}$C	55–49	63–49	41–43	55–49
Cold bath time hr — min.	3–00	4–50	4–00	3–50
Mean diffusion temperature $^{\circ}$C	48	50	49	52

initial moisture content (equation (2)) indicate that a solution uptake of about $96 \, kg/m^3$ should be possible if complete saturation is to be attained. This would represent a mean retention increase of about 2.5% H_3BO_3. Actual uptakes as determined by increases in moisture content were only $16 \, kg/m^3$ or an increase in retention of 0.41% H_3BO_3 This figure may be fairly inaccurate, however, as the samples lost weight rapidly when they were removed from the bath (still at $49°C$) and it is probable that the true uptake figure was something between these two extremes. The overall drop in solution level in the bath during the cold bath period indicated an uptake in the region of $48 \, kg/m^3$, and this would represent a retention increase of 1.23%.

Cross section analyses of all pieces in charges A and B after treatment showed the mean retention to be 2.12% with a range of 0.68%-3.52%. If the retention of 0.87% (as determined during the hot bath) is deducted from this, a figure of 1.25% is obtained. This supports the use of an uptake volume during the cold bath of about $48 \, kg/m^3$.

In charge "C" the overall retention was slightly higher—2.20%—and this would be expected because of the slightly greater surface area to volume ratio of the planer-gauged material.

In the final charge, the solution concentration was reduced by 44%, and this resulted in a reduction of 50% in the mean cross section loading.

Diffusion

The progress of diffusion was studied by taking samples at various periods from 2 to 11 days after the start of diffusion. These were examined visually after cut sections had been sprayed with pyrocatechol violet, and were analysed for core and cross section retentions. The penetration patterns obtained in charge A after the hot bath, the cold bath, and 3 and 7 days' diffusion are shown in Figs. 2-5. Core retentions for all charges are given in Table 2.
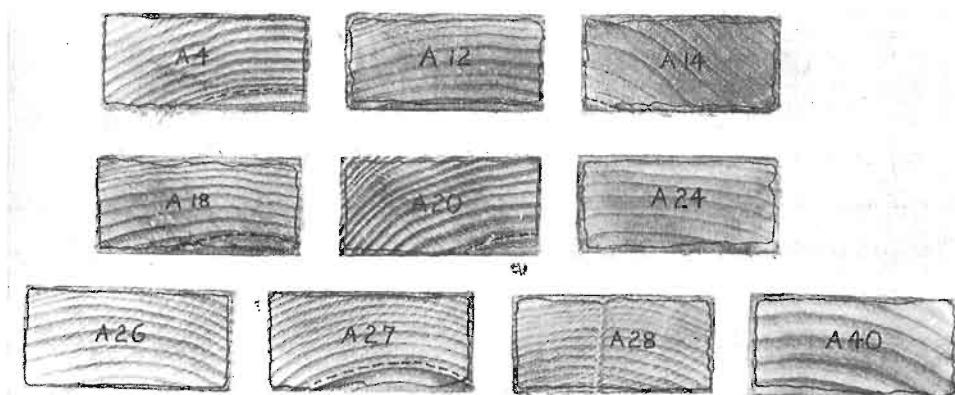

FIG. 2—Boron penetration after hot bath
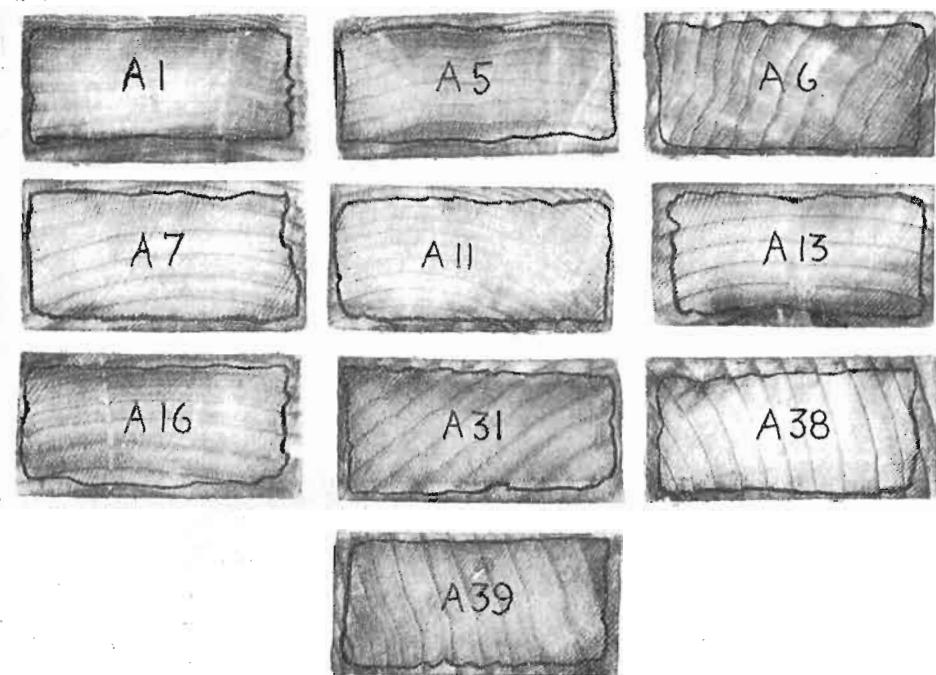
FIG. 3—Boron penetration after cold bath
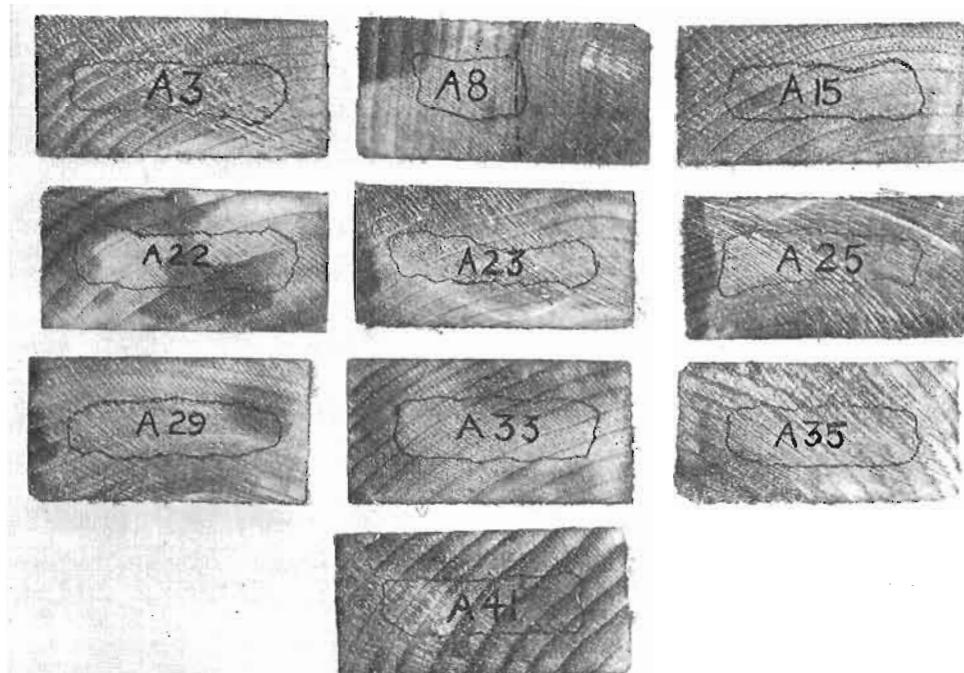
FIG. 4—Boron penetration after 3 days' diffusion
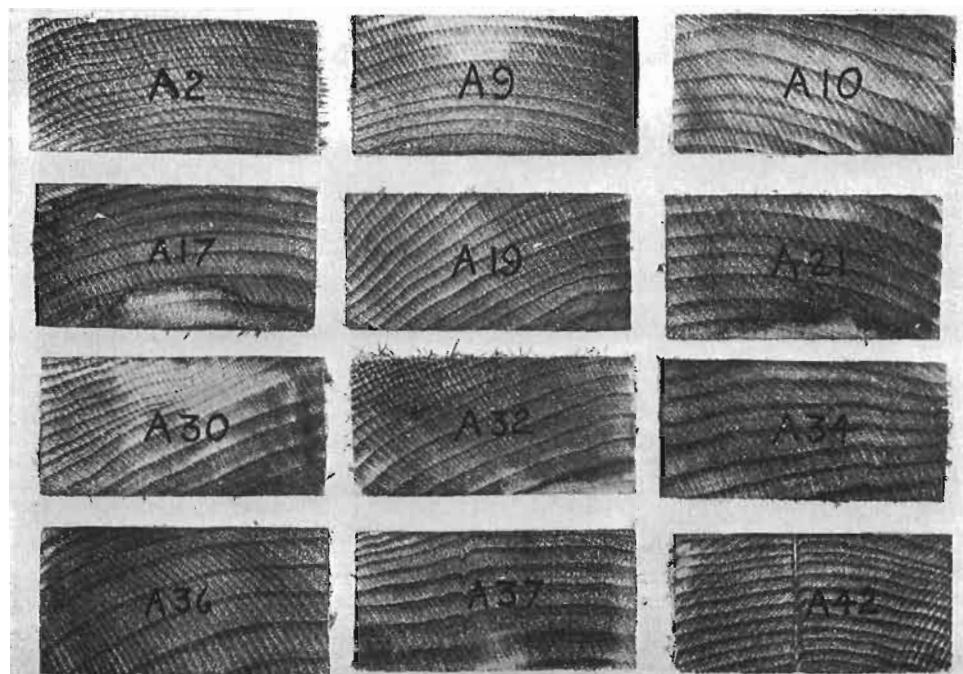
FIG. 5—Boron penetration after 7 days' diffusion

TABLE 2—Core retentions after various diffusion periods

Charge	Diffusion days	No. of Analyses	Core retention — % H_3BO_3	
			Mean	Range
A	3	10	0.05	0.03–0.12
	7	12	0.34	0.16–0.84
B	2	8	0.04	0.00–0.08
	6	8	0.44	0.17–0.87
	7	42	0.49	0.14–1.21
C	7	36	0.51	0.27–1.02
D	3	6	0.06	0.03–0.08
	5	6	0.12	0.06–0.16
	7	6	0.43	0.09–0.72
	11	42	0.46	0.23–1.18

Core retentions are not comparable from one treatment to another if the overall retentions are different, but this can be overcome by comparing the diffusion percentages (i.e., core retention as a percentage of the cross section retention) at different periods.

In Fig. 6 diffusion percentages (taken from all four charges at every sampling time) are plotted against diffusion time.
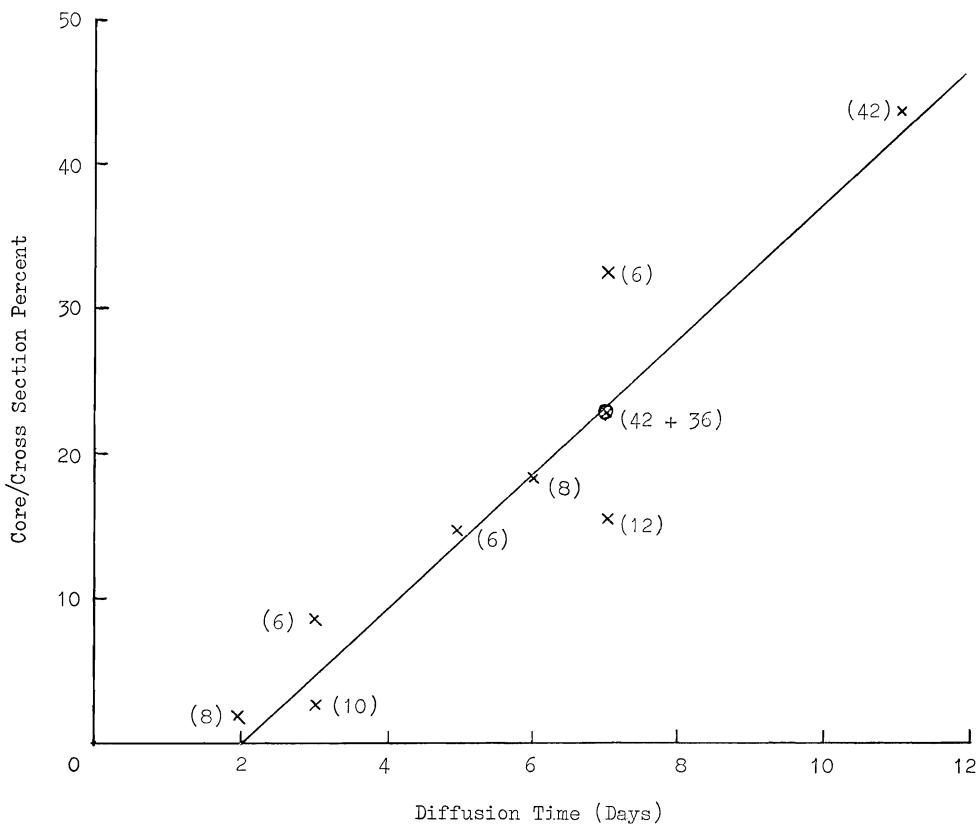

FIG. 6—Diffusion rates at 49°C — radiata pine, 100 × 50 mm

These results confirm that an approximately linear relationship exists between diffusion percentage and time at least up to diffusion percentages of 50%. To compare these results with earlier unpublished work on diffusion at elevated temperatures, the results from the earlier tests are shown in Fig. 7.

The 49°C line (interpolated between the experimental values for 40°C and 60°C gives a diffusion percentage of about 25% at 10 days, whereas in Fig. 6 the value is over 35% for the same time. The higher diffusion percentages obtained in the recent tests are almost certainly caused by the improved initial penetrations from the hot and cold baths.
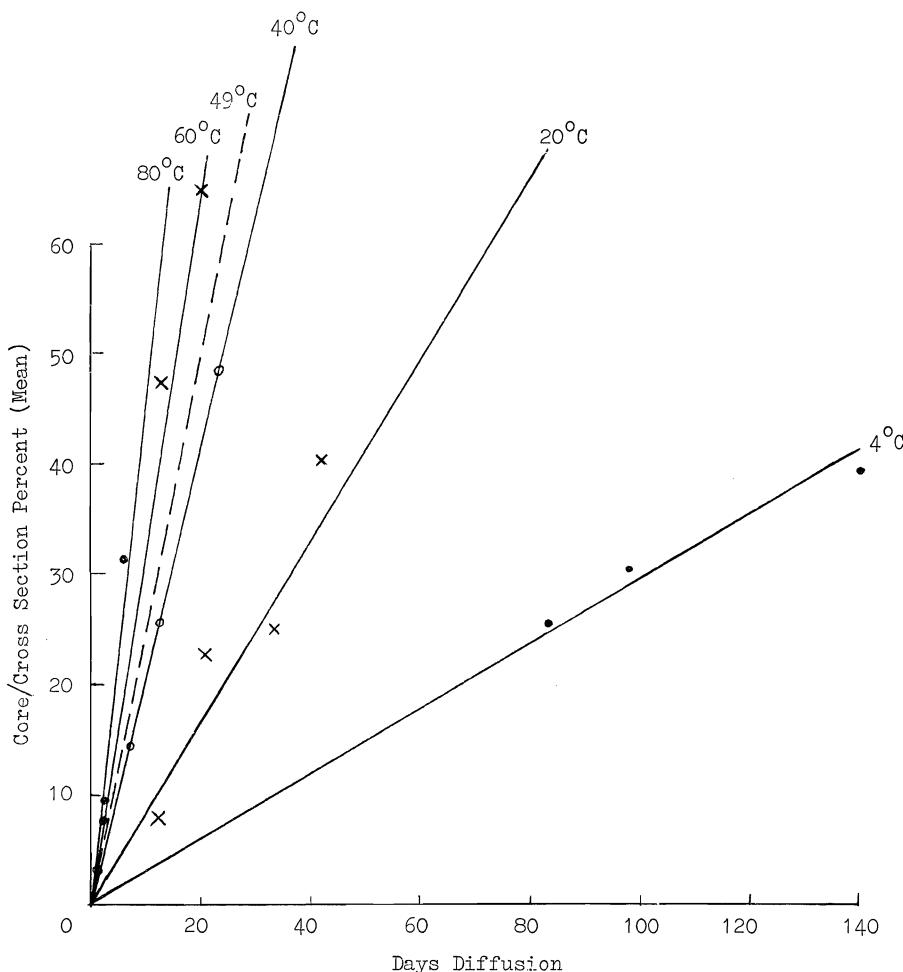
FIG. 7—Diffusion rates at various temperatures for 100 × 50 mm radiata pine treated by momentary immersion

The range of core retentions was fairly great, with coefficients of variation of up to 45%. This is probably no higher than the range of retentions in similar material treated by momentary immersion however, and has a safety factor in that where the statistical distribution is skewed (as could be caused by some pieces in a charge being partly dry), the greatest deviations from normality would be on the side of over-treatment. The reverse would happen with material treated by momentary immersion.

Conclusions

The uptake of boron during the hot bath was consistent, and could be calculated with considerable accuracy. The uptake during the cold bath was less than was estimated from calculations based on density and moisture content, but it was still greater than

the uptake which would be obtained by leaving the wood in the hot bath for a similar length of time. Penetration was much improved by following a hot bath with a cold bath, and this gave a very good start to the diffusion.

From the results obtained, schedules were derived for testing under conditions of commercial operation.

DEVELOPMENT AND OPERATION OF A COMMERCIAL ACCELERATED DIFFUSION PLANT

Following the successful trials in the experimental plant, a full-sized commercial plant was developed at Putaruru. This plant, which was designed and built by PTY Industries Ltd, was commissioned for operation early in 1970. The general layout and most of the individual features are shown in Figs. 8 and 9. The main items are:
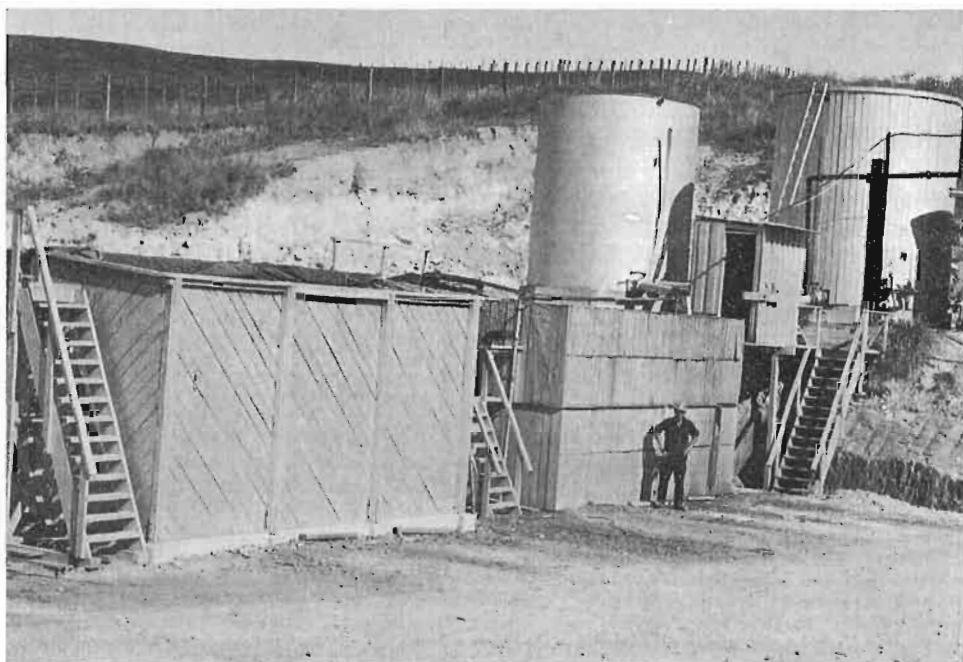
FIG. 8—PTY Industries' commercial treatment plant at Putaruru. **See** Fig. 9 for details.

1. A treating vat about 6.1 × 3.05 × 3.05 m. It is constructed of mild steel plate, reinforced with steel angles and channels, and has a set of vertical steam heating coils along the centre. The spaces on either side of the heating coils can accommodate three packets of timber stacked one above the other. A full charge thus consists of six packets. The vat is located on ground level and has a heat insulating covering of 50-mm timber on the outside; removable, close-fitting lids cover the top.

2. A diffusion chamber about 6.1 × 3.66 × 3.05 m. The chamber is an aluminium-lined wooden shell with tight-fitting lids and vertical heating coils similar to

P.T.Y. INDUSTRIES LTD.

ACCELERATED BORON DIFFUSION PLANT *
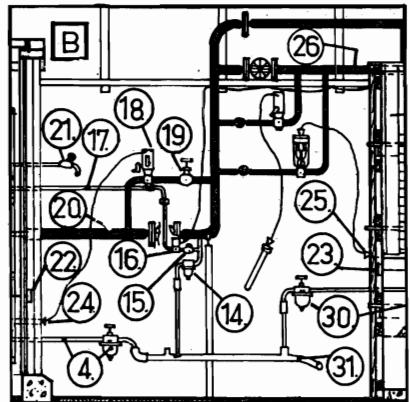
ENLARGED
ELEVATIONS
OF
B

support

PLAN

*(Incorporating Letters N.Z. Patent Nº 154551)

"Improved Diffusion Process for Treating Timber"
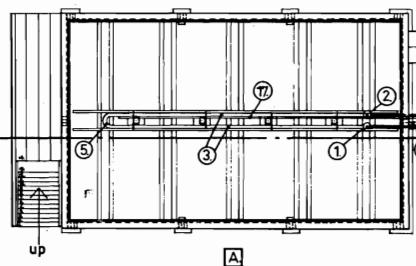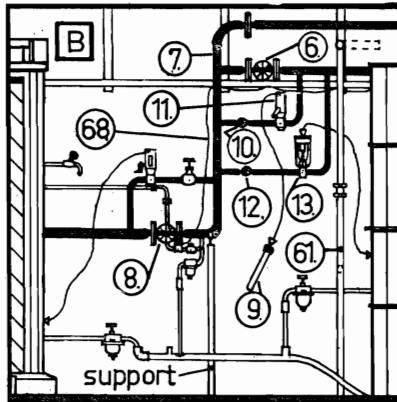
those in the treating vat. Humidity is maintained close to saturation by means of a steam spray line placed above the heating coils. An electric timer opens a valve on this spray line for 20-30 sec at 20 min. intervals.

3. Two 50 000-litre storage tanks together with piping, valves, and a transfer pump complete the plant. As it was possible to place the storage tanks on a higher level than the treating vat, filling is by gravity, and the return to storage is by pumping. The storage tank for hot solution has a well-insulated shell and has internal coils to heat and maintain the contents at 94°C, the operating temperature of the hot bath. The cold storage tank is without insulation or heating coils.

Preparation of Solutions

No special equipment has been required for mixing treating solutions. The required volume of water is heated in the treating vat and the required amount of salt is added to this while it is being circulated through the hot storage tank and the vat. After all the solution has been well mixed and pumped back to the hot storage tank a sample is taken to determine the concentration. A proposed alternative is to meter fresh water into the storage tank, heat it overnight, and then add the salt while the diluted solution is circulated through the treating vat. This will reduce the loss of treating time incurred by heating water in the treating vat. The solution concentration can be determined by hydrometer or by a relatively rapid and simple chemical analysis.

Operation

The charge is loaded and fastened with the cross bars which prevent the packets floating during flooding, the hot solution is run in, and the steam coils are turned on. There is usually a temperature drop caused by the cooling effect of the cold timber and about 30 min. heating is required to reach the hot bath temperature. As the central heating coils have sheet metal shrouding on either side, the heated solution rises to the top where the flow divides itself in either direction across the packets and down the sides to the bottom. It is then drawn into the space below the heating coils and reheated. This ensures a circulating flow around the charge and heats the timber satisfactorily.

At the end of the hot bath, the hot solution is pumped back to the hot store tank and then the charge is reflooded from the cold store tank for the period required by the treating schedule. The solution transfer must be fairly rapid to obtain as great a differential as possible between the hot and the cold bath. A normal charge of 16.5 m³ requires about 27 000-32 000 litres of solution for adequate coverage, and this volume can be pumped out and replaced in approximately 15 min. using a 200-mm low-head centrifugal pump and 200-mm diameter pipes.

At the completion of the cold bath the load is transferred to the diffusion chamber, and the lids are fitted to provide reasonably vapour-tight diffusion storage. The thermostatically controlled heating coils and the spray line are brought into action, and the diffusion state is maintained at the pre-determined temperature and humidity for the required period. Generally this operation requires from 3 to 7 days, so that one treating vat could serve a number of diffusion chambers. If the treating vat is not required for further treating it can be used as an additional diffusion chamber.

Loading and unloading have been by using a fork-lift truck fitted with a short jib,

but as a permanent installation an overhead gantry crane would be desirable. This would facilitate accurate placing of the packets and minimise the risk of damage.

Steam was used as the heating medium for convenience and because surplus boiler capacity was available on the site. However, the heating requirements could be met by direct-fired oil-burning equipment or possibly electricity.

The main heat usage is that required to heat the cold timber throughout the thickness of the pieces. Once the operating temperatures are reached, the heat demand is confined to maintaining the temperature by making good the heat loss to atmosphere; there is no heat used in the diffusion process itself. Therefore, good heat insulation of the hot storage tank, the treating vat, and the diffusion chambers reduces the total heat demand very considerably. To determine average steam usage for a complete treatment, the steam condensate was collected and measured for several charges of 50-mm radiata pine. The average usage was found to be 190 kg steam for each m^3 of wood.

Results of The First Commercial Trials

Commercial treating started early in 1970 after two trial charges were treated to test the various plant functions. Following these, charges 3-9 of 100×50 mm radiata pine, were treated, each with schedules that were varied slightly in the light of previous results. These treatments were observed and thoroughly sampled by Mr C. I. Hutchinson, Forest Research Institute, who later supplied a report containing full analytical results.

The schedules used in charges 4, 6, and 8 are shown in Table 3, and the results obtained are summarised in Table 4.

TABLE 3—Schedules used in commercial trials

| Charge No. | Hot Bath | | | | Cold Bath | | | | Diffusion time (days at 49°C) |
| | Time | | Temperature | Soln conc. % H_3BO_3 | Time | | Temperature | Soln conc. % H_3BO_3 | |
	hr	min.			hr	min.			
4	*4	15	94°C	9.0	2	45	23–35°C	8.8	8
6	3	5	94°C	9.0	3	30	25–39°C	8.5	7
8	*4	25	94°C	9.0	3	25	24–37°C	8.5	8

* For these two charges the temperature was below the required 94°C for approximately half the hot bath period.

On the basis of these results a schedule was submitted to the Timber Preservation Authority (TPA) for approval. On the Authority's request a further six charges were treated and 10 samples were taken from five of these for official TPA analyses. The results were similar to those obtained in the earlier trials with only one substandard sample (below 0.2% H_3BO_3) out of the 50. As this standard was considerably better than the TPA requirement (0.2% H_3BO_3 in 90% of samples), the plant was granted full approval for the treatment of 50-mm radiata pine.

The next series of trials was with freshly sawn tawa (*Beilschmedia tawa* (A. Cann.) Benth. et. Hook.), and 14 charges were treated with various schedules. The material used

TABLE 4—Analytical results from commercial trials

Charge No.	Diffusion period	Packet position	Material	No. of samples	Retention – % H_3BO_3				Core/ X-section %	No.* of sub-standards
					Cross-sections		Core			
					mean	range	mean	range		
4	8	top	RS	7	0.96	0.52-2.10	0.43	0.22-0.86	45	0
		middle	PG	7	1.19	0.69-2.40	0.43	0.29-0.50	36	0
		bottom	RS	7	1.66	1.08-2.37	0.65	0.34-1.14	39	0
6	7	top	RS	8	1.45	1.05-2.00	0.65	0.35-0.94	45	0
		middle	RS	8	1.76	1.16-2.59	0.69	0.36-1.02	39	0
		bottom	PG	16	1.52	0.92-2.61	0.59	0.17-1.16	39	1
8	7	top	PG	8	1.19	0.80-1.84	0.80	0.49-1.46	67	0
		middle	PG	8	1.56	1.09-2.15	0.95	0.65-1.44	61	0
		bottom	PG	8	2.39	1.92-3.00	1.51	0.37-2.88	63	0
	8	top	PG	8	0.85	0.52-1.07	0.61	0.36-0.97	72	0
		middle	PG	8	2.20	1.26-3.15	1.52	0.93-2.75	69	0
		bottom	PG	7	2.55	1.64-3.51	1.53	0.69-3.01	62	0

* Number with core retentions below the TPA minimum requirements of 0.2% H_3BO_3

in these trials was from 20 mm to 50 mm in thickness. Twenty-four samples were taken from each charge and these were analysed in the laboratory at PTY Industries Ltd immediately after the completion of the diffusion period. Of the 336 samples taken, only 10 were found to have substandard core retentions and these occurred mainly in charges where the schedules used had been interrupted by steam failures, or where samples had been taken after only a very short diffusion period. After further sampling of subsequent charges by the TPA, full approval was granted for freshly sawn tawa up to 50 mm in thickness.

A charge of 25-mm rimu (*Dacrydium cupressinum* Lamb.) was then treated, using a hot bath of 2 hr followed by a $2\frac{1}{2}$-hr cold bath (both with 8.5% H_3BO_3 solutions), and 3 days' diffusion at 49°C. Twenty-four samples were analysed, and these showed the mean cross section loading to be 1.66% H_3BO_3 with a mean core retention of 0.59%. Four samples had core retentions below 0.2% H_3BO_3, but these were found to be largely or wholly heartwood which does not require treatment under the TPA specification for building timber treated with boron compounds.

After one year's operation with the commercial plant, the TPA had granted approval for seven schedules covering two timber species; these are detailed in Table 5.

TABLE 5—TPA-approved treatments using hot bath temperatures of 94°C, solution concentrations of 8.5% H_3BO_3 equivalent, and diffusion temperatures of 49°C.

Species	Thickness mm	Hot Bath hr	Cold Bath hr	Diffusion Time days	Fillet Spacing	Timber Conditions*
Radiata pine	25	$1\frac{1}{4}$	2	$3\frac{1}{2}$	12-mm fillet every 4th layer	Green R.S. or P.G.
Radiata pine	50	3	$3\frac{1}{2}$	7	12-mm fillet every 2nd layer	Green R.S. or P.G.
Tawa	20	$1\frac{1}{4}$	$1\frac{1}{2}$	2	12-mm fillet every 2nd layer	Green R.S.
Tawa	25	$1\frac{1}{4}$	2	3	12-mm fillet every 2nd layer	Green R.S.
Tawa	40	2	$2\frac{1}{2}$	5	12-mm fillet every 2nd layer	Green R.S.
Tawa	45	$2\frac{1}{2}$	3	6	12-mm fillet every 2nd layer	Green R.S.
Tawa	50	3	3	7	12-mm fillet every 2nd layer	Green R.S.

* R.S. = rough sawn; P.G. = gauged

Quality Control

Every charge consists of six packets of timber with varying total volumes between 9.4 and 17.6 m³. From each packet four samples are taken at the completion of the diffusion period giving a total of 24 samples per charge. During the developmental stage of the commercial operations these samples were all analysed for core and cross section retentions, but in normal routine operations a spot test with pyrocatechol violet (PCV) is adequate. Any doubtful samples are still analysed, and although these generally prove to have lower than average cores, they are usually above the minima required.

Should a whole charge ever prove to be unsatisfactorily treated, it would be a simple matter to apply the required amount of retreatment. In this respect, the process has a distinct advantage over normal treatment by momentary immersion plus prolonged diffusion.

A charge sheet has been produced, and this makes provision for recording all the relevant data except solution usage. Estimation of salt usage on an individual charge basis has proved unreliable because of the difficulty of measuring solution residues remaining in the treating vat after a charge is removed. Monthly stock reconciliations have indicated a salt usage of about 5.75 kg/m³, and this is in agreement with calculations from cross section analyses.

Treating Costs

Where the annual throughput exceeds about 3,500 m³, the cost of accelerated diffusion treating should be less than with the conventional momentary dip diffusion system. As through-put is increased above this figure, unit treating costs decrease because the plant capital costs do not increase in direct proportion.

From the experience gained with this plant, it has been possible to calculate treating costs for through-puts of varying sizes. In the following example costs are calculated for an annual through-put of 4,720 m³ comprising equal quantities of 25-mm and 50-mm radiata pine timber.

Average charge volume = 16.5 m³
No. of charges required = 286 (143 charges of each size)
Total treating time for 25-mm timber (at 3½ days per charge) = 72 weeks
Total treating time for 50-mm timber (at 7 days per charge) = 144 weeks
Total treating time for all timber = 216 weeks

If a working year consists of 46 weeks, then the number of diffusion chambers required is five, and the estimated cost of a complete plant with five such diffusion chamber is $30,000.

Annual fixed costs:

	$
10% interest on capital	= 3,000
Depreciation (20-yr life)	= 1,500
Estimated maintenance	= 750
TOTAL	= 5,250

Itemised costs are:

25-mm timber — costs per m³	c
Share of fixed costs (based on 1/3 total treating time) =	74.2
Labour — 4 man/hr per charge at $1.50 per hr =	36.4
Salts used at 5.75 kg/m³ =	141.1
Dye, water, power, heating =	51.0
TOTAL =	302.0

50-mm timber — costs per m³		c
Share of fixed costs (2/3 total)	=	148.4
Labour charge (as for 25 mm)	=	36.4
Salts (as for 25 mm)	=	141.1
Dye, water, power, heating	=	85.0
		———
TOTAL	=	411.0

Items not covered in these costs, such as overheads, timber handling, etc., will vary greatly from one sawmill to another, but can be assumed to be the same for either accelerated diffusion or the momentary dip diffusion system.

This plant would be automatically controlled in all stages except for the loading of the treatment vat and the transfer of the charges to the diffusion chambers. Generally, two 25-mm charges or one 50-mm charge can be handled within a normal 8 hr day. Any charge loaded by the end of the day would be automatically controlled through the treatment cycle and then held at the diffusion temperature in the treating vat until it could be transferred to a diffusion chamber. By suitably alternating the 25 mm and 50 mm charges all the handling labour could be confined to a normal 40 hr week.

Conclusions

The first year's commercial operations have confirmed the expectations that accelerated diffusion offers several advantages over the normal dip diffusion system. The most noticeable improvement at PTY Industries has been the reduction of diffusion stock to about one-tenth the volume previously carried for the same total through-put. In addition to this saving, the rapid servicing of special orders, and quick turnover of stock, improve the trading pattern and thus further enhance the profitability of the operation.

The new treatment process has a particular advantage to any mill engaged in the production of gauged framing timbers. With dip diffusion treatment the timber must be treated in the rough sawn state to guarantee sufficient solution pick-up to achieve the required overall retention, and this then necessitates the disposal of treated shavings. These are difficult to incinerate as the boron salts tend to form deposits of hard non-combustible slag. By using the hot and cold bath form of treatment, the surface state of the timber is unimportant, and framing timber which is to be used in an unseasoned condition, can be gauged before treatment. Not only does this produce untreated shavings quite acceptable as boiler fuel, but it also affords some economy in treatment salts. Unfortunately this does not apply to finishing lines which must be machine dressed after seasoning.

A further advantage over the momentary-dip diffusion treatment is that some pre-treatment drying does not inhibit the diffusion process as the moisture (sap) loss is made good during the cold bath. Pre-treatment drying often occurs in the outside boards of packaged timber in dry weather if some delay prevents dipping immediately after sawing. As the lost sap is made up from the cold bath solution, some over-treating occurs, but unless the pre-drying is well advanced, the resultant over-treating is usually of no significance.

The general standard of treatment appears to be considerably higher than that usually achieved with momentary dip diffusion. For the 150 samples of 100 × 50 mm pine analysed by FRI (including the TPA samples) the mean diffusion percentage (core/cross section × 100), was 48% for diffusion periods of 7-8 days. A sample of 38 pieces of 100 × 50 mm pine treated by dip diffusion and diffused for 55-60 days was found to have a mean diffusion percentage of 27%. The variability of core loadings was also very much less than in the dip diffusion treated material. As the hot and cold bath plus accelerated diffusion process is not affected by weather conditions it would prove even more advantageous in areas subject to climatic extremes.

A substantial volume of the timber treated in the accelerated diffusion plant has later been kiln dried without any problems. After many treatments the treating solution darkens, presumably because of some reaction with the steel vessels. This causes a slight discoloration of the timber, but it is only superficial and is completely removed if the wood is dressed.

The commercial application of this process is covered by a patent held by PTY Industries Ltd.

REFERENCES

CARR, D. R. 1957: Timber preservation in New Zealand. **New Zealand Forest Service Technical Paper 14.**

HARROW, K. M. 1952: Impregnation of **Pinus radiata** D. Don building timber with boric acid by diffusion. **New Zealand Journal of Science and Technology 33 (B) (6):** 471-82.

MacLEAN, J. D. 1952: Preservative treatment of wood by pressure methods. **United States Department of Agriculture Handbook 40.**

McQUIRE, A. J. 1961: The effect of temperature on the diffusion rate of boron into green timber. **New Zealand Forest Service, Forest Research Institute, Forest Products Report 73** (unpublished).