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UPGRADATION OF RUBBER WOOD

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ABSTRACT

Rubber wood, a highly perishable timber, needs to be treated with preservative chemicals to extend its service life. A study was conducted to optimise the conditions of treatment both by diffusion and vacuum-pressure methods. The study has shown that with 10% boric acid equivalent (BAE) solution, wood of thickness up to 50 mm can be easily diffusion treated to adequate loading of chemicals as per Indian as well as various international standard specifications. An optimum diffision storage period required was worked out. It is two, three, nine and twelve weeks for 25,50,75 and 100 mm thick wood respectively, in order to get uniform distribution of chemicals in treated wood.

An economical treatment schedule (15 minutes initial vacuum of 560 mm Hg followed by a pressure of 10 kg/cm^2 for 15 minutes and a final vacuum of 560 mm Hg for 5 minutes - 15'/15'/15') was arrived at in a pilot plant. Treating air-dried wood with 3% BAE solution resulted in a dry salt retention (DSR) of 13.1 kg/m^3. Also the study showed that partially dried rubber wood (with average moisture content around 50%) could be treated under the same schedule with 3% BAE solution and adequate DSR could be achieved. Treatment of green rubber wood (with average moisture content around 75%) under the same schedule with 6% BAE solution resulted in desired DSR. In all these cases, complete penetration of wood was achieved. The economical schedule arrived at in the pilot plant was tested in a commercial treatment plant. This also resulted in desired DSR, showing the success of the schedule for commercial applications.

1. INTRODUCTION

India is one of the leading rubber growing countries in the world. Haridasan and Sreenivasan (1985) and Ipe *et al* (l987) reported that from the annual replanting programme about 0.79 million cubic meter of rubber wood would be available in India per annum, out of which 0.48 million cubic meter comprised the stem wood and the rest 0.31 million cubic meter branch wood. Most of the branch wood is utilised as fuelwood by brick and tile factories. Because of the acute timber scarcity, the stem wood of rubber tree now finds many appiications.

About 90% of the rubber plantations in India is in Kerala. Kishnankutty (1989), from a study conducted in Kerala, reported that out of a total consumption of about 916,000 m^3 round wood during 1987-88, rubber wood accounted for 65%. The major rubber wood consumption is by packing case industry, to the tune of 34.8%; plywood, splints and veneers, 29.6%; followed by furniture and fixtures. This clearly indicates that rubber wood has a significant role in the wood-based industrial economy in India, particularly Kerala.

Conversion of this perishable wood into value-added products through chemical treatment warrants attention since it is available in plenty at comparatively low cost and the plantations are likely to become one of the most promising sources of wood in the country. Further, effective utilization of this wood will relieve pressure on our forests for timber to a great extent.

The study conducted by Gnanaharan and Mathew (1982) on diffusion treatment of rubber wood revealed further areas of research. Accordingly, a study was planned to determine the maximum thickness of wood that could be treated by diffusion process and to optimise the diffusion storage period. Also, it was decided to standardise pressure treatment with boron chemicals and to arrive at an optimum treatment scheduie. Further, it was decided to examine the possibility of treating green rubber wood under pressure process.

2. REVIEW OF LITERATURE

2.1. Biodeterioration

Hong (1982) reported that the decay fungus *Ganoderma applanatum* caused the greatest weight loss of the wood samples and showed a preference for lignin degradation. *Sheizophyllum commune* decayed the samples at a slower rate, but preferred lignin to cellulose whereas *Poria* spp. caused the least weight loss and showed a slight preference for cellulose. Out of the ten commercially important timber species surveyed by Florence (1989) and Florence and Sharma (1990), rubber wood was the most affected by *Botryodiplodia theobromae*.

Balasundaran and Gnanaharan (1990a) reported the decay resistance of rubber wood against *Gloeophyllum trabeum* and *Polyporus versicolor*, brown rot and white rot fungus respectively and classified the timber as 'non-resistant' towards decay fungi. Ananthapadmanabha *et al* (1990) tested the differential natural decay resistance of rubber wood against *Gloeophyllum trabeum, Fomesamosus, Choetomium globosum, Ceratocystis ulmi, Polyporus meliae, P. versicolor and P. hirsutus.* Both the above studies concluded that rubber wood had the least natural resistance to some of the common tropical decay fungi, even though the resistance to different fungi appeared to be relatively different. Santhakumaran and Srinivasan (1990) stated that rubber wood was easily degradable in marine conditions.

Gnanaharan and Mathew (1982) listed ten insect borers attacking rubber wood in Kerala and reported that *Sinoxylon anale* caused the most serious damage. Abood ***et*** al (l992) reported that *Minthea rugicollis* is the most destructive and commonly found insect borer species attacking dried rubber wood in Malaysia.

2.2. Prophylactic treatment

Hong et al (1982) reviewed the biodeterioration problems of rubber wood and the control measures against sapstain, mould, fungi and insect borers. The common method of control is the dip treatment using a preservative mixture of 1-2% sodium pentachlorophenoxide (NaPCP) and 1.5% borax. Synthetic pyrethroids and organic solvent based preservatives are used in much smaller quantities.

Hong (1981) screened 18 preservatives for their efficacy against sapstain and mould fungi isolated from rubber wood. Sodium pentaclorophenoxide was used as the standard. Only one, Basiment 9230, was found to match NaPCP in terms of overall antfingal activity. Six other commercial products: Busan 30, Benomyl, Brassicol, Fennotox S2, Mitrol PQIC and Mitrol PQIL were found promising and warranted further tests. Gnanaharan and Mathew (1982) reported that 0.3% Busan in 10% BAE solution could not control fungal growth in rubber wood. Higher doses of Busan were not tried as they would not be cost effective. Gnanaharan (1986) reported that two formulated products of alkyl ammonium compounds, namely, Sinesto B (at 2.0% a.i. concentration) and Akzo EN494 (at 0.7% a.i. concentration), had potential to replace NaPCP used for the purpose. Florence (1989) reported that the appiication of sodium azide could inhibit the growth of fungi. But the compound is hazardous due to its explosive nature.

Hong (1980) stressed the importance of taking proper care while kiln-drying the rubber wood in order to reduce the loss due to the staining fungus *Botryodiplodia theobromae*.

2.3. Boron diffusion treatment

Diffusion treatment with boron compounds is simple, cheap and an effective way of protecting wood from biodeterioration. Because the borates have low mammalian toxicity, and they are colourless, odourless and easy to handle, boron treatment became popular as a preferred method of protecting timber especially in New Zealand and Australia. Research on preserving wood with borates has been reviewed by Cockcroft and Levy (1973) and Bunn (1974). Because of the recent environmental concerns on toxic chemicals like arsenic and chromium in the CCA type of preservatives, worldwide interest is now focused on the application of boron compounds for timber preservation. The status ofresearch on borates as wood preserving compounds in the United States was reviewed by Barnes *et al* (1989). An international conference was held in 1990 to take stock of the worldwide status of boron compounds as wood preservatives (Hamel, 1990). Works on protection of western woods with boron compounds, mainly fusedborate rods and sodiumoctaborate tetrahydrate, were reported by Lebow and Morrell (l989), Morrell and Lebow (1991) and Morrell *et al* (1990, 1992). The latest development in this field is the vapour phase boron treatment. detailed by Bergervoet *et al*(1992), Burton *etal*(1990) and Turner *et al*(1990). In developing countries interest still exists in the boron diffusion treatment because the treatment method is simple and inexpensive.

Gnanaharan and Mathew (1982) reported that rubber wood could be treated by diffusion process with 10% BAE solution containing 0.5% NaPCP. They achieved a 0.4% BAE dry salt retention (DSR) in samples of thickness 25 mm with a dipping time of 40 minutes in 10% BAE solution and a diffusion storage period of four weeks. This method of treatment provided protection against decay fungi (Balasundaran and Gnanaharan, 1990b), insect borers (Gnanaharan *et al*, 1983) and termites (Varma and Gnanaharan, 1989). Florence and Sharma (1990) reported that the bacterium *Bacillus subtilis* had the potential as a bio-control agent against sapstain fungus *Botryodiplodia theobromae.* The effect of immersion time on loading and distribution of boric acid in rubber wood was reported by Dhamodaran and Gnanaharan (1984). This study showed that dry salt retention increased with increase in immersion time although the rate of increase was low. For higher thicknesses, prolonged immersion time reduced the DSR

2.4. Vacuum-pressure impregnation treatment

Hong *et* al (l982) reported ihar rubber wood couid be easiiy treated by Bethel vacuum-pressure process using copper-chromium-arsenate (CCA) preservatives. Tan *et al* (1983) treated 57 mm thick green rubber wood with a 3% BAE solution by employing an initial vacuum of about 0.9 kg/cm^2 for 45 minutes followed by a pressure of 10.5 kg/cm^2 for 75 minutes and a final vacuum for 15 minutes. achieving a DSR of 7.5 kg BAE/m^3. Hong and Lien (1989) reported the effect of different treatment schedules on the boron impregnation of rubber wood. Salamah *et al* (1989) tried double vacuum process and they achieved a core loading of 0.2% BAE in rubber wood. But the schedule employed by them was too lengthy, a vacuum period of 225 minutes and a pressure period of 150 minutes.

Gnanaharan and Dhamodaran (1990) reported that rubber wood could be stored under water up to a period of four months successfully and the ponded wood could be impregnated with boron as well as CCA compounds to the desired DSR level.

3. MATERIALS AND METHODS

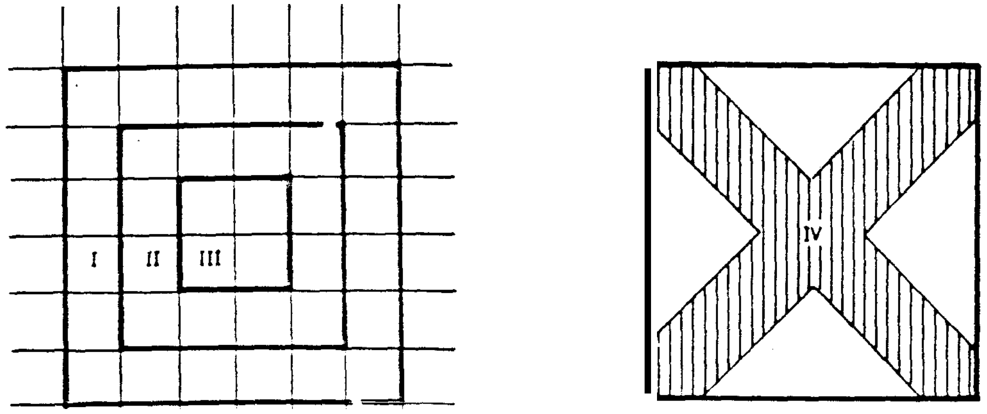
3.1. Diffusion treatment

Fresh green rubber wood samples of length 300 mm and cross-sections 25 x 25 mm; 50 x 50 mm; 75 x 75 mm and 100 x 100 mm were selected for the study. Fifteen samples in each category were treated by simple diffusion method with 10%BAE solution. This is the maximum concentration that can be prepared in room temperature without heating the solution. The dipping time was 40, 160,360 and 640 minutes respectively for the 25,50,75 and 100 mm thick samples as calculated by the formula derived by Gnanaharan (1982). The weight of the samples before and after the treatment was recorded in order to calculate the DSR. The moisture content and density of the samples were determined by oven-dry and water displacement methods respectively. After the treatment. the samples were kept for diffusion storage (close packing in polythene bags) in order to get a uniform distribution of chemicals in the treated wood.

Out of the 15 samples in each size kept for diffusion storage, a set of five samples was with drawn at three different intervals as mentioned below:

Sample size (mm x mm x mm)	Diffusion storage withdrawal period (No. of weeks)		
25 x 25 x300	2	3	4
50 x 50 x300	3	5	8
75 x 75 x 300	6	9	12
100 x 100 x 300	9	12	16

From each sample. sub-samples were taken from the surface, middle and core portions (Fig. 1a) for determining the distribution of chemicals. Also. two diagonal samples were taken as 'overall' (Fig. 1b) in order to determine the **net** average DSR in each sample. The samples were sliced into very thin sections and subjected to chemical analysis, as per the procedure of Wilson (1959), in order to determine the actual dry salt retention.



(A) (B)

Fig 1. Sub-sampies for chemicai analysis. (A) I. 'Surface' (area of cross-section - 5/9); II 'Middle' (area of cross-section - 3/9); III. 'Core' (area of cross-section - 1/91 (B) IV 'Overall' (two diagonals).

3.2. Vacuum-pressure impregnation treatment

Air-dried (MC 12-18%) samples of rubber wood sizes 63 x 63 x 1000 mm were impregnated with 3% BAE solution. The study was conducted in a pilot type preservative cylinder (0.3 m diameter and 2.0 m long). A vacuum of 560 mm Hg and a pressure of 10 kg/cm^2 were used in the study. Final vacuum was maintained at 560 mm Hg for 5 minutes in all the trials. To arrive at the optimum treatment schedule. the effect of varying the initial vacuum time and the pressure treatment time on solution pick-up was studied.

To study the effect of different moisture levels on the uptake of chemical solution, three levels of moisture were tried: green wood (MC about 75%), partially dried (MC about 50%) and air-dried (12-18% MC). The dimensions of the test samples remained the same as above. Trials were taken with 6% BAE solution (w/w) for green wood.

The solution uptske (kgm^3) of each of the test samples was determined from the weight difference before and after the treatment and the volume of wood; the dry salt retention (DSR) was obtained by muitiplying the uptake by solution concentration. BAE percentage retention was determined by dividing DSR(kg/m^3)by the decsity of wood (kg/m^3). The penetration of chemicals in the treated wood was tested as per Indian Standard IS:2753 (ISI, 1991).

4. RESULTS AND DISCUSSION

4.1. Diffusion treatment

The average moisture content of the samples was 60% and density 550 kg/m^3. The average dry salt retention (DSR), in terms of kg BAE/m^3 varied from 3.4 to 2.1 and in terms of %BAE, from 0.6 to 0.38 for 25 to 100 mm thick sizes (Table 1). For these sizes the effect of different diffusion storage periods on the distribution of chemicals in the treated wood is given in Table 2. It can be seen that the British Wood Preservers' Association's (BWPA) specification requirement of a net average DSR of 0.4% BAE (see BCL, 1972) can be achieved within a diffusion storage period of two weeks for 25 mm thick cross-section and within three weeks for 50 mm thick cross-section. In the case of 75 and 103 mm thick cross-sections, the 'overall' DSR achieved was around 0.3% BAE only. But it can be seen that in all these cases, the DSR in the core is greater than or equal to 0.2% BAE, which is sufficient to offer protection, as per the New Zealand specification, for hardwoods susceptible to *Lyctus* beetle attack (McQuire, 1962). This clearly indicates that there is no need for keeping rubber wood of up to 50 mm thickness for longer diffusion storage period as normally suggested for other hardwood species: four weeks for every 25 mm thickness (see Vinden *et al*, 1990). In the case of 75 and 100 mm thick sizes, the minimum diffusion storage period tested, 6 and 9 weeks respectively, are just adequate to achieve the DSR required as per the New Zealand specification of 0.2% BAE in the core. To ensure better protection, it would be desirable to go for a diffusion storage period of 9 weeks and 12 weeks for the 75 and 100 mm thick cross-sections respectively. This results in a core loading of 0.24 and 0.22% BAE retention for the 75 and 100 mm thick sizes respectively. Further increase in the diffusion storage period did not result in appreciable increase in the DSR. Also it can be seen that the chemicals are distributed more or less uniformly within the samples of various thicknesses for the suggested diffusion storage periods.

If one were to meet the New Zealand specification of 0.2% BAE in the hardwood core, it can be concluded from Tables 1 and 2 that up to 100 mm thick sizes can be diffusion treated. Instead, if the BWPA specification of a net average DSR of 0.4% has to be achieved, then only up to 50 mm thick sizes can be diffusion treated with 10% BAE solution. This means, to satisfy both the specifications, rubber wood up to 50 mm thickness can be diffision treated effectively with 10% BAE solution at room temperature. In tropical countries like ours, as biodegradation is more intense, it is desirable to adopt the BWPA specification of a net average DSR of 0.4% BAE in the treated rubber wood. For diffusion treatment of thicker sizes, solution concentration has to be increased from 10% BAE, for which heating is essential to prepare the solution and to maintain the concentration.

Table 1. Dry salt retention in rubber wood of different thicknesses treated by diffusion method.

Sample size (mm x mm x mm)	kg BAE/m^3			BAE%	
	Mean	Range	CV%	Mean	Range
25 x 25 x 300	3.4	2.5-5.2	27.5	0.60	0.45-0.94
50 x 50 x 300	2.9	2.2-3.8	13.8	0.53	0.41-0.70
75 x 75 x 300	2.3	1.1-3.9	29.1	0.43	0.21-0.73
100 x 100 x 300	2.1	1.2-3.4	28.3	0.38	0.21-0.62

(n=15)

Table 2. Dry salt retention (%BAE) determined by chemical analysis in samples kept for different diffusion storage periods.

Size (mm x mm)	Diffusion storage period (weeks)	BAE% Overall	Surface	Middle	Core
25 x 25	2	0.45	0.59	0.48	0.41
	3	0.47	0.60	0.51	0.41
	4	0.54	0.61	0.56	0.42
50 x 50	3	0.40	0.42	0.35	0.30
	5	0.43	0.46	0.39	0.34
	8	0.48	0.50	0.40	0.36
75 x 75	6	0.32	0.33	0.26	0.21
	9	0.33	0.35	0.29	0.24
	12	0.37	0.38	0.32	0.25
100 x 100	9	0.30	0.31	0.24	0.20
	12	0.31	0.34	0.28	0.22
	16	0.34	0.35	0.32	0.25

The earlier studies by Balasundaran and Gnanaharan (1990b), Gnanaharan *et al* (1983) and Varma and Gnanaharan (1989) reported that a net average DSR of 0.4% BAE offered protection against fungi, insect borers and termites.

4.2. Vacuum-pressure impregnation treatment

4.2.1. Effect of varying the initial vacuum period

In the full-cell process, initial vacuum is applied to ensure that the cell lumens become empty and the whole lumen can be filled with the preservative chemical solution. However, there was no study reported in the literature on the effect of varying the duration of initial vaccum period. While varying the vacuum period from 0 to 30 minutes at an interval of 15 minutes, an interesting phenomenon was noticed (Table 3). The DSR was maximum when the initial vacuum was retained for: 5 minutes. One might expect the chemical pickup to increase with increasing the duration of vacuum period. However, maintaining the vacuum for 30 minutes resulted in low DSR. The DSR obtained with 15 minutes vacuum was more than double the value obtained with no vacuum (0') or vacuum for 30 minutes. To confirm this phenomenon, trials were taken with

Table 3. Effect of varying initial vacuum period on the dry salt retention (DSR) of air-dried rubber wood.

Treatment Schedule vac./pr./vac. (minutes)	DSR (kg/m^3)			BAE%	
	Mean	Range	CV%	Mean	Range
Trial I					
0/15/5	**6.3**	**05.2-07.1**	**11.8**	**1.1**	**0.94-1.27**
15/15/5	**13.1**	**12.0-14.3**	**07.8**	**2.3**	**2.14-2.56**
30/15/5	**5.8**	**04.5-08.2**	**24.9**	**1.2**	**0.88-1.78**
Trial II					
10/15/5	**6.5**	**04.9-07.1**	**30.2**	**1.3**	**0.90-1.88**
15/15/5	**13.9**	**09.3-18.8**	**24.6**	**3.2**	**1.70-4.90**
20/15/5	**5.4**	**04.0-06.3**	**17.2**	**1.1**	**0.79-1.26**

(n=5)

initial vacuum period of 10, 15 and 20 minutes to see whether there was any inversion effect on DSR. Here also it was noticed that DSR was maximum with the vacuum period of 15 minutes. Decreasing or increasing the duration of vacuum even by 5 minutes resulted in low DSR. While these trials confirmed the trend observed in the first set of trials, they failed to explain the peculiar phenomenon. It was decided to verify this while studying the effect of varying the pressure treatment duration.

4.2.2. Effect of varying the pressure treatment period

The following treatment schedules, to study the effect of varying pressure treatment period and also to see the peculiarity of 15 minutes initial vacuum period, were tried: 0'/30' (initial vacuum for 0 minutes and pressure for 30 minutes); 10'/30'; 15'/30': 15'/45'; 15'/60';20'/30';30'/30' and 30'/60'. Results obtained with these trials and that of the previous trials are combined and presented in Table 4 for easy comparison. It is seen that increasing the pressure treatment time (for the initial vacuum period of 0, 10, 20 and 30 minutes) resulted in increasing DSR. This is to be normally expected. However, in the case of initial vacuum period of 15 minutes, there was no advantage in increasing the pressure treatment period. This clearly shows that the optimum initial vacuum period is 15 minutes. Further studies are needed to understand why the chemical pickup reaches maximum with initial vacuum period of 15 minutes and then it drops.

The Indian Standard (ISI, 1982) recommends a boric acid retention of 6.5 kg/m^3 for building timbers for internal use. Out of the 13 different schedules tried, 10 schedules met this requirement. Out of these 10 schedules, the most economical schedule is the one with 15 minutes intial vaccum, 15 minutes pressure and 5 minutes final vacuum period.

To ensure 0.2% BAE in the core in radiata pine, McQuire (1962) found that the overall DSR should be about 1% BAE. As the average density of rubber wood is around 550 to 600 kg/m^3, allowing for a 1% BAE retention will be equivalent to a DSR of 5.5 to 6 kg/m^3. This is close to the Indian Standard recommendation of 6.5 kg/m^3. The DSR obtained in air-dried rubber wood using the economical schedule arrived in the study is more than double this amount. This clearly shows that rubber wood can be treated even at higher moisture levels.

Table 4. Effect of varying initial vacuum and pressure period on the dry salt retention of air-dried rubber wood.

Treatment Schedule vac./pr./vac. (minutes)	DSR (kg/m^3)			BAE%	
	Mean	Range	CV%	Mean	Range
0/15/5*	6.3	5.2- 7.1	11.8	1.1	0.94-1.27
0/30/5	8.7	7.1-10.2	3.4	1.6	1.33-1.92
10/15/5*	6.5	4.9- 7.1	30.2	1.3	0.90-1.88
10/30/5	7.7	5.9-10.0	18.4	1.6	1.19-2.24
15/15/5*	13.1	12.0-14.3	7.8	2.3	2.14-2.56
15/15/5*	13.9	9.3-18.8	24.6	3.2	1.70-4.90
15/30/5	13.9	12.6-15.4	7.4	2.5	2.16-2.75
15/45/5	11.2	9.3-15.7	23.0	2.2	1.87-2.74
15/60/5	13.2	10.9-15.9	16.5	2.8	2.20-3.60
20/15/5*	5.4	4.0- 6.3	17.2	1.1	0.79-1.26
20/30/5	6.9	6.3- 7.5	7.4	1.4	1.19-1.59
30/15/5*	5.8	4.5- 8.2	24.9	1.2	0.88-1.78
30/30/5	10.1	8.9-11.1	9.4	1.8	1.57-2.09
30/60/5	14.8	13.6-16.5	9.3	2.9	2.60-3.29

*Taken from Table 1
(n=5)

4.2.3. Effect of varying moisture levels

The economical schedule was chosen and 370 BAE solution was used for treating partially dried (50% MC) and green (75% MC) rubber wood. The results are given in Table 5. Where as partially dried rubber wood just met the DSR value recommended in the Indian Standard, it was very low (3.8 kg/m^3) in the case of green rubber wood. Tan *et al* (1983), using a 3% BAE solution, obtained a DSR of 7.5 kg/m^3 in 57 mm thick green rubber wood. However, this was possible with a pressure treatment time of 75 minutes at 10.5 kg/cm^2 pressure. As boron chemicals are diffusible, it was decided to increase the concentration of the treatment solution rather than increasing the pressure treatment time. One more trial of green wood was taken with 6% BAE solution and the average DSR obtained was 13.5 kg/m^3 (Table 5). This shows that green rubber wood can be treated. By choosing the right concentration level of the treatment solution, the required chemical retention values can be met even when the moisture level is high.

Table 5. Effect of moisture levels on the dry salt retention (DSR) of rubber wood treated by vacuum-pressure method.

Condition of wood	DSR (kg/m^3)			BAE%	
	Mean	Range	CV%	Mean	Range
3% BAE solution					
Air-dried* (12-18% MC)	13.1	12.0-14.3	7.8	2.3	2.14-2.56
Partially dried (50% MC) .	6.5	5.2- 7.1	11.5	1.1	0.86-1.18
Green (75% MC)	3.8	3.3-4.6	12.9	0.64	0.53-0.76
6% BAE soiution					
Green (75% MC)	13.5	12.3-14.5	6.7	2.59	2.30-2.87

*Taken from Table I
(n=5)

4.3. Reconfirmation trial in pilot plant

In connection with a training programme, rubberwood of various sizes had to be treated. The average moisture content of the material was around 50% and possessed a mean density of 550 kg/m^3. The economical schedule was selected for the treatment of this material.

Table 6 gives details of the sizes of rubber wood that were treated, the DSR achieved, the mean %BAE retention and number of samples in each thickness. The mean DSR for the various sizes ranged form 5.1 to 9.7 kg/m^3. The pooled mean DSR is 7.3 kg/m^3, which equals to a calculated net average retention of 1.3% BAE and is more than adequate as per the prescription of Indian Standard for buidling timbers for internal use (ISI, 1982). This verifies the validity of the economical scheduie arrived at for boron impregnation treatment of partially dried rubber wood. The DSR decreased with increase in thickness. This is to be expected as all the sizes were treated together by the same schedule. It would be ideal to sort out sizes by thickness and carry out treatment separately to have control on chemical pickup. Otherwise, as was observed here, lower thickness material will tend to absorb more chemical at the cost of the thicker material. This can be seen in the higher retention of chemicals(6.5 kg/m^3 BAE) when the samples of 63 x 63 mm cross-section were treated in the previous trial (Table 5), compared to only 5.8 kg/m^3 BAE obtained even for cross-section of 56 x 56 mm when treated along with samples of other thicknesses (Table 6). If a mixtrure of different thicknesses cannot be avoided, it should be ensured that the thickest material gets the minimum required DSR.

The penetration of chemicals in all the batches of treated wood was tested as per IS:2753 (ISI, 1991) and found to have uniform through and through distribution.

Table 6. Vacuum-pressure impregnation of partially dried rubber wood (50%MC) of assorted sizes with 3% BAE solution employing a treatment schedule of 15'/15'/5'.

Size (mm x mm x mm)	Mean DSR (kg/m^3)	Range	CV%	Mean BAE%	Range	No. of samples
1050 x 25 x 25	9.7	7.9-11.4	15.7	1.75	1.42-2.05	40
600 x 50 x 30	9.1	7.1-10.9	11.7	1.64	1.28-1.96	20
450 x 63 x 38	7.0	6.6- 7.8	5.5	1.26	1.19-1.40	10
458 x 50 x 50	6.9	5.2- 8.8	16.9	1.24	0.94-1.58	10
825 x 56 x 56	5.8	5.2- 6.3	5.7	1.05	0.94-1.13	10
450 x 100 x 63	5.1	4.3- 5.5	7.2	0.92	0.77-0.99	10

4.4. Commercial scale trial

Commercial scale trial was carried out in a 0.9 m diameter and 6 m long treatment cylinder with full load of wood. The same schedule, 15'/15'/5', as tried in the pilot-plant investigation, was used for the treatment, with the exception that the maximum pressure exercised was only 8 kg/cm^2, due to technical restrictions of the particular treatment cylinder used for the study. A 6% BAE solution, as in the earlier study for green wood was used. The cylinder was loaded fully with rubber wood of length 2.75 m and of two different cross-sections, 75 x 75 mm and 88 x 88 mm.

The average moisture content of the wood was around 70% and density 550 kg/m^3. An average DSR of 12.9 and 11.8 kg BAE/m^3 (2.36 and 2.14% BAE respectively) was achieved for samples of cross-sections 75 x 75 mm and

88 x 88 mm respectively (Table 7). As in earlier trials, it was observed that as the thickness increased DSR decreased. The pooled mean DSR was 12.4 kg/m^3. The DSR achieved for both the sizes is much higher than the specifications of Indian, New Zealand and BWPA standards for furniture wood. This study confirms that the economical schedule, 15'/15'/5', can be used in commercial scale boron impregnation of rubber wood. As the pressure used in this study was only 8 kg/cm^2 compared to 10kg/cm^2 in the pilot-plant study, it can be seen that lowering the pressure slightly did not affect the achievement of therequired DSR. This suggests that the concentration of treatment solution can be reduced according to the DSR requirement.

Table 7. Commercial scaie vacuum-pressure impregnation of green rubberwood (MC70%)with 6% BAE solution with a treatment schedule of 15'/15'/5'.

Size of wood (mm x mm x m)	DSR (kg/m^3)			BAE%	
	Mean	Range	CV%	Mean	Range
75 x 75 x 2.25	12.9	95-15.9	16.5	2.36	1.73-2.89
88 x 88 x 2.25	11.8	10.1-13.0	8.0	2.14	1.84-2.37

5. SUMMARY AND CONCLUSIONS

Rubber wood, up to 50 mm thickness can be diffusion treated with 10% BAE solution to meet the New Zealand and BWPA specifications(0.2%BAE in the core, and net average of 0.4% BAE respectively). However, treatment of 75 and 100 mm thick sizes with 10% BAE solution can meet only the New Zealand specification. For diffusion treatment of thicker sizes, solution concentration greater than 10% BAE should be used.

The study has optimised the diffusion storage period for rubber wood. A storage of 2, 3, 9 and 12 weeks is required for 25, 50, 75 and 100 mm thick material respectivey to get uniform distribution of chemicals in the treated wood.

Rubberwood can be easily impregnated with boron compounds and the pressure treatment time can be considerably reduced. The initial vacuum period was found to be critical for rubber wood and a vacuum of 560 mm Hg for a duration of 15 minutes was found to be optimum. Increasing initial vacuum period beyond 15 minutes was found to reduce the chemical pick-up considerably.

Although the pick-up increased with increase in pressure treatment time, even 15 minutes was found to give more than adequate loading of chemicals.

The most economical treatment schedule, 15 minutes initial vacuum of 560 mm Hg, 15 minutes pressure of 10 kg/cm^2; 5 minutes final vacuum of 560 mm Hg, gave nearly double the required loading of chemicals in air-dried rubber wood, when treated with 3% BAE solution.

If the concentration of the treatment solution is increased to about 6% BAE, even green rubber wood can be impregnated to achieve the required loading of chemicals. By selecting the proper concentration levels oftreatment solution, desired chemical retention can be achieved in rubber wood at any moisture level.

As rubber wood can be impregnated even in green condition using a higher concentration of treatment solution, attack by the sapstaining fungi before treatment can be avoided. However, as there are certain fungi which can attack boron treated timber (as boron takes care of decay fungi only), a suitable fungicide should be incorporated with the boron solution to take care of the staining problem that might take place after treatment.

The treatment schedule arrived at in this study is both time and energy saving. Also, the chemical is able to penetrate across the whole cross-section of the wood.

The commercial scale trial confirmed that rubber wood in green condition can be pressure treated with boron compounds employing the economic schedule developed. The commercial trial also showed that slight reduction of pressure did not affect the achievement of the desired DSR.

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