Received: 19-01-2017 Accepted: 11-05-2017 Published: 23-08-2017

An easy drying schedule for *Tectona grandis* through vacuum press drying

Sachin Gupta[1], V. S. Kishan Kumar[1]

[1] Forest Products Division, Forest Research Institute, Dehradun, India.

ABSTRACT Drying experiments were conducted on 25 mm thick samples of *Tectona grandis* with the aim of evolving a drying schedule under vacuum press drying. The experiments were conducted under eleven different combinations of water temperature and pressure level inside the chamber. The results were analyzed to understand which combination resulted in highest percentage moisture content (MC) reductions from different initial MC ranges above and below the fiber saturation point of the species. Based on this, a simple schedule was formulated for drying planks of this timber. No serious drying degrades could be observed in the samples in spite of taking them through different drying cycles. It was found by applying this schedule that 25 mm thick samples of teak could be dried to around 7.6% MC levels from around 24% initial MC effectively in three steps. The study illustrated the usefulness of vacuum press drying technique in fast drying of teak.
Keywords: Drying rate; moisture content; pressure; teak wood; vacuum.

Introduction

Vacuum drying of wood has caught the imagination of wood seasoning industries due to much lower drying times. The technique is based on the fact that water in the wood boils at lower temperatures if the ambient pressure in which the wood stack is heated is lowered. The atmospheric pressure also creates a pressure gradient inside the wood helping in faster moisture movement. This helps in enhancing the rate of drying especially through the end grain. The permeability of the wood being dried would obviously affect the overall drying process.

The rapid moisture reduction due to vacuum based drying has been reported by many workers on a variety of species. Twenty-five mm thick samples of Oriental beech (*Fagus orientalis*) and Scots pine (*Pinus sylvestris*) could be brought down from 46-47% moisture to 10-13% moisture content levels in just 48 hours using vacuum drying assisted by infrared heating (ALTUN et al., 2011). Leiker et al. (2004) reported moisture losses between 0.017%/h and 0.075%/h in beech samples when they were vacuum dried with micro wave heating. Trebula; Dekret (1984) reported 3-5 times lower drying times for *Robinia* spp. samples of 50 mm thickness under vacuum drying compared to conventional air-drying. A recent report highlighted the use of vacuum drying in getting high drying rates even below fiber saturation point in the case of *Tectona grandis* (KISHAN KUMAR et al., 2016). It has been reported that samples of *Populus deltoides* could be dried from 90% MC levels to less than 15% MC levels effectively in two steps (KISHAN KUMAR et al., 2008).

Tectona grandis (Teak) is probably the most important species in India which can be ascertained from the fact that almost every wood quality parameter is usually compared with that of this species. It is a moderately refractory species as far as its kiln seasoning characteristics are concerned and has been assigned schedule V (Bureau of Indian Standards, 1993). It is suggested that for 25 mm thick planks of this species requires 13 to 15 days to dry to near 12% MC levels by following this schedule.

In the above context, an attempt was made to evolve a drying schedule for teak samples using vacuum press drying technology by employing random temperature-pressure combinations.

*Corresponding author: kishankumarv@yahoo.com

Materials and Methods

The experiments were carried out in a MASPELL Vacuum Press Dryer (VPD). This unit is explained in detail in an earlier paper (KISHAN KUMAR et al., 2008). Heated water circulating through platens provides heat to the wood planks kept between adjacent platens through conduction. A ring type vacuum pump facilitates reducing pressure in the chamber whenever required.

Fifty-three samples of 600 mm length and 50 to 150 mm widths were prepared from 25 mm thick teak planks plain sawn from a single log for the study. All these samples were stacked between the top two platens. The initial weights of these samples were recorded prior to placing them between the platens. The spaces between the remaining platens were stacked by filler material to complete the charge of the kiln.

The temperature and pressure controls of the VPD were manually operated with the temperature of the circulating hot water being read on the control panel and the pressure inside the chamber being read on a pressure gauge attached to the chamber for that purpose. Eleven different combinations of water temperature and pressure inside the chamber were used which are designated as treatments T1 through T11. These treatments are listed in Table 1.

The samples were preheated for 6 hours with hot water flowing through the platens prior to applying a vacuum-temperature treatment. For this purpose, the water temperature was maintained at 5 degrees below the treatment temperature. The preheating was aimed at allowing the teak samples to attain uniform temperatures throughout their thicknesses. After pre-heating, the temperature was raised to the desired level. As soon as this temperature was achieved, the vacuum pump was switched on and the desired pressure level was achieved inside the chamber. When the desired pressure level was achieved, the water heaters and vacuum pump were switched off. It was noticed that the vacuum and temperature levels inside the kiln were sustained for about further 30 minutes. Thus, one such drying run lasted almost 7 hours (preheating, increasing temperature to the desired level, applying vacuum, maintaining vacuum and temperature after switching off the water heaters and vacuum pump). One drying run constituted applying one such treatment. The sample weights were monitored after each such drying run. The different treatments were applied one after another on different days following no particular sequence.

Table 1. The pressure-temperature treatments used in the study.

Treatment	Temperature (^oC)	Pressure (mbar)*
T1	80	913
T2	80	573
T3	80	353
T4	90	873
T5	90	413
T6	90	313
T7	70	473
T8	70	873
T9	70	373
T10	60	373
T11	60	513

*Note: (The pressure on the gauge was in -100, -200 mbar below the atmospheric pressure. Hence, a pressure of 913 mbar in the Table corresponds to a reading of -100 on the gauge).

The moisture contents of the samples were estimated by oven-drying them at the end of the experiment. Efficiency of a particular treatment was assessed by calculating the Percentage reduction in moisture content (MC_r) due to each treatment (KISHAN KUMAR et al., 2016). The initial moisture contents (MC_i) of samples showed variations due to partial drying of samples during preparation. As a result, unequal replications in different MC_i ranges were encountered during progressive drying and analysis of data has been done accordingly.

Collected data on samples was grouped into ranges below and above the Fiber Saturation Point (FSP). Further subranges have also been made for MC_i values above FSP in view of en-mass flow of free water sensitive to capillarity. Drying below FSP being diffusion phenomena, the MC_i data in this range were kept as such. Data with less than three replicates in a particular MC_i range was not considered for analysis.

The values of MC_r (percentage) for a given MC_i interval range were transformed suitably (Ahrens et al., 1990) and analysis of variance (ANOVA) was carried out on the transformed values. For a clearer understanding of the efficiency of each treatment, Duncan's subsets were formed to arrive at the best treatment in a particular MC_i range. The best treatments in each MC_i range were considered for developing a drying schedule.

Ten samples which showed MC_i approximately in the 19-30% range (based on their calculated oven dry weights) and prepared from plank from the same log as in the original experiment were used for testing the schedule. These samples were placed between two adjacent platens and the required pressure-temperature combinations were applied as before. The only difference was that the samples were not taken out for weighing in between. After the desired steps were completed, the samples were taken out and their weights were recorded. Each of these were then oven dried to calculate their actual MC_i and final moisture content (MC_f).

Results and Discussion

The FSP of teak is reported to be around 19% (Jain et al, 2000). Thus, an MC_i range of 10% to 19% was formed below this value. The ranges above FSP were divided into 19%-30% and 30%-50%

A total of 36 readings were found to lie in the 30%-50% MC_i range across various treatments applied on the 53 samples. As drying progressed, 93 readings were found to lie in the 19%-30% MC_i range under different treatments. Once most of the samples dried to below FSP levels, there were 230 MC_i readings lying in the 10-19% range across various treatments applied. The percentage reductions in the moisture contents due to applied treatments (MC_r) were calculated as explained in the methodology section. The MC_r values had a wide range from as small as 2.43% to 33.15% depending on the pressure-temperature treatment applied and the MC_i range to which the samples belonged. This corresponds to drying rates of 0.35%/h to 4.74%/h. There are reports of drying rates from 0.7%/h to 20%/h for beech samples under vacuum drying (ALTUN et al., 2011; CIVIDINI et al., 2003).

The calculated and transformed MC_r values were analyzed through one-way ANOVA (Table 2) from which it can be seen that reductions in all the three MC_i ranges differ significantly with applied treatments.

Table 2. ANOVA of MC_r in the three MC_i ranges.

MC_i Range	Source of variation	df	Mean Square	F	Sig.
50-30%	Treatments	4	203.38	22.98	<0.001
	Error	31	8.85		
30-19%	Treatments	5	827.34	78.42	<0.001
	Error	87	10.55		
19-10%	Treatments	9	1855.39	149.51	<0.001
	Error	220	12.41		

Table 3 gives the actual average values of MC_r obtained under different treatments for different MC_i ranges and grouped into different subsets using Duncan's homogeneity test.

It is pertinent to note that none of the 53 samples exhibited any type of drying degrade like surface cracking, end splitting or deformation. This is in spite of the fact that all of them were subjected to the 11 vacuum-temperature treatments during the whole experiment.

Table 3. Average moisture content reductions in (%) under different treatments grouped into Duncan's subsets

MC_i Range	Treat.	Subsets of MC_r						
		1	2	3	4	5	6	7
	T9	7.09						
50-30%	T1	8.27						
	T8	10.48						
	T10		19.95					
	T7			**26.77**				
	T9	4.31						
	T1	5.77						
30-19%	T8		12.23					
	T10		13.53	13.53				
	T7			17.02				
	T2				**29.34**			
	T9	2.43						
	T1	3.43						
	T4		6.86					
	T11		9.53					
19-10%	T7			16.97				
	T10			18.83	18.83			
	T6				21.41	21.41		
	T3					24.28	24.28	
	T2						26.43	
	T5							**33.15**

It can be seen from Table 3 that the maximum reduction in MC below FSP is caused by T5 by about 33.15%. In the above FSP ranges of 19-30 and 30-50%, T2 and T7 respectively resulted in higher MC reductions. These two treatments do perform reasonably well in the below FSP level as well (with MC_r of 26.43% and 16.97% respectively). Thus, we can effectively bring down MC of teak from an initial value of 50% using three temperature-pressure steps as given in Table 4.

It is pertinent to mention that an earlier work reported that it is possible to dry 25 mm thick *Populus deltoides* samples from 90% MC to below FSP levels in two simple steps using vacuum press drying (KISHAN KUMAR et al., 2008).

Table 4. Schedule for Teak wood.

MC range (%)	Temperature (°C)	Pressure (mbar)
50-30	70	473
30-19	80	573
19-10	90	413

An example of implementing the schedule with the schedule given in Table 4 for an MC_i of 50% can be illustrated as shown in Table 5. Thus, one can arrive at near 12% MC from an initial 50% in 4 steps.

Table 5. An illustration of the schedule for drying from 50% Initial MC.

Temperature (°C)	Pressure (mbar)	MC (%)
70	473	50
70	473	37
80	573	27
90	413	19
MC_f		12.7

Testing of the drying schedule

The above schedule was tested on 10 teak samples which were obtained from the same log from which the earlier 53 samples were prepared. These ten samples had approximate initial MC in the range of 25-30% (based on their calculated oven-dry weights). 25% was assumed as the initial MC to test the schedule. With the calculated MC_r values, the steps for drying these samples from 25% MC_i can be given as in Table 6.

Table 6. Steps for drying from 30% Initial MC.

Temperature (°C)	Pressure (mbar)	MC (%)
80	573	25.0
90	413	17.7
90	413	11.8
	MC_f	7.9

Thus only 3 runs were applied to the ten samples exactly as was done during the experiment. The samples were taken out on the 4th morning after allowing them to cool in the nights after each run and their final weights were recorded. The oven dry weights of all these samples were estimated in the laboratory and their actual MC_i and MC_f were calculated. These are given in Table 7.

Table 7. Initial and final moisture contents of test samples.

Sample Nº.	Actual Oven dry weight (gm)	Initial weight (gm)	MC_i	Final weight (gm)	MC_f
1	370	441	19.19	388	4.86
2	382	460	20.39	402	5.21
3	369	451	22.22	393	6.50
4	347	424	22.28	374	7.86
5	675	834	23.56	727	7.70
6	355	442	24.51	388	9.30
7	359	448	24.79	379	5.57
8	646	808	25.08	712	10.22
9	352	443	25.85	387	9.94
10	326	422	29.45	355	8.90
Mean	**418.08**	**517.30**	**23.73**	**450.50**	**7.61**
Standard Deviation	**128.83**	**160.58**	**2.92**	**142.37**	**1.99**
Coefficient. of Variation (%)	**30.81**	**31.04**	**12.32**	**31.60**	**26.10**

Thus, it can be seen that after three runs, the samples have attained 7.61% MC (against 7.9% predicted in Table 6). The test indicates that overall drying rate after 3 runs (effectively lasting for 21 hours) resulted in a moisture reduction of 16.2% accounting for 0.77%/h. This is very similar to the drying rates of 0.7%/h and 0.75%.h reported for beech and scots pine under radio frequency heated vacuum drying (ALTUN et al., 2011). A look at Table 6 in fact suggests that only two runs would be required to bring down the MC from a mean 25% to near 12%. The study clearly illustrates the effectiveness of seasoning teak planks faster using vacuum press drying technique.

Conclusions

An easy drying schedule has been developed for teak that can be applied in a vacuum press dryer which would save a lot of kiln operation time. The study indicates that vacuum press drying can be a powerful tool in fast drying of 25 mm thick teak. In effect, the planks can be dried from 50% MC levels to the required value below FSP in three simple steps. The developed schedule was used to test in drying 25 mm thick samples with mean initial MC of around 24% to nearly 7.6% final MC in just three runs lasting 21 hours. It would be advisable to test this schedule at Industrial level and make suitable adjustments/refining.

Acknowledgments

The authors wish to thank the Director, FRI and Head, Forest Products Division for their constant encouragement. The help rendered by the staff of saw mill, WWF Discipline and WS Discipline are highly appreciated. The interest shown by Dr. NK Upreti of WS Discipline has been of critical help during the entire experiment.

References

AHRENS, W.H.; D.J.COX, D.J; BUDHWAR, G. Use of arcsine and square root transformations for subjectivity determined percentage data. **Weed Science**, v. 38, p. 452–458, 1990.

ALTUN, S.; YAPICI, F.; KORKMAZ, Z. Effects of vacuum drying with infrared heating on some properties of wood. **Annals of Warsaw University of Life Sciences— SGGW: Forestry and Wood Technology**, v. 73, p. 16–22, 2011.

BUREAU OF INDIAN STANDARDS. **Indian standard – Seasoning of Timber – Code of Practice**, IS 1141, 1993. pp. 26.

CIVIDINI, R.; VALENTI, L.; ALLEGRETTI, O. (2003). Investigation on moisture content gradients in Vacuum – Press drying process of Beech elements. In: PROCEEDINGS OF 8TH INTERNATIONAL IUFRO WOOD DRYING CONFERENCE, Brasov, Romania, p. 141- 146, 2003.

JAIN, J.D.; GURU, R.D.; SINGH, R. Physical and mechanical properties of *Mangifera indica* (Mango) and *Syzegium* spp (Jamun) from Dehra Dun (U.P.). **Indian Forester**, v. 126, n.9, p. 948-956, 2000.

KISHAN KUMAR, V.S.; UPRETI, N.K.; GUPTA, S. Scope of vacuum press drying for fast removal of moisture below fiber saturation point. **Drying Technology**, v. 34, n. 10, p. 1204–1209, 2016.

KISHAN KUMAR, V.S.; GUPTA, S.; SHARMA, C.M. Studies on vacuum press drying of *Populus deltoides*. **Indian Forester**, v. 134, n. 6, p. 835-42, 2008.

LEIKER, M.; ADAMSKA, M.A.; GÜTTEL, R.; MOLLEKOPF, N. Vacuum Microwave Drying of Beech: Property Profiles and Energy Efficiency. In: PROCEEDINGS COST E15 CONFERENCE, Athens, Greece, 2004.

TREBULA, P. DEKRET, A. Vacuum drying of robinia timber. **Holzindustrie**, v. 36, n. 4, p. 115–116, 1984.