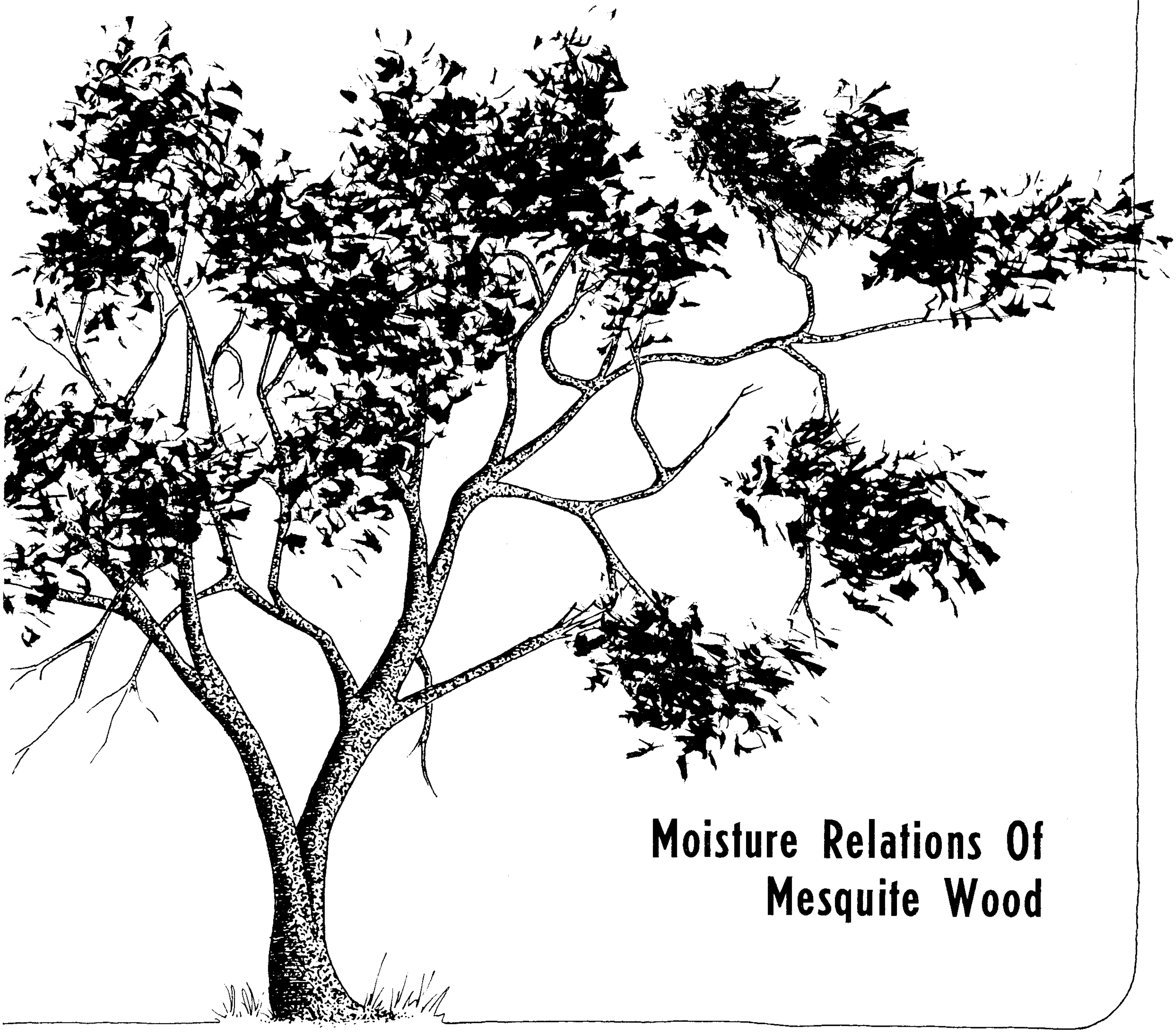

Moisture Relations Of Mesquite Wood

TEXAS FOREST SERVICE

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MOISTURE RELATIONS OF MESQUITE WOOD

By
Allen T. Wiley
Wood Technologist
Texas Forest Products Laboratory

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INTRODUCTION

The approach that the Texas Forest Products Laboratory has taken toward solution of the mesquite *(Prosopis sp.)* problem in Central and West Texas has been to search for uses for the wood. Our goal is to provide the farmer or rancher a return on the cost of eradicating mesquite.

Mesquite may be considered to exist in two forms, namely the single-stem or tree form and the many-stemmed or brush form. To develop uses only for the solid wood could provide only a partial solution to the problem since the stems of the many-stemmed form are too small for economical production of lumber. Mesquite is a beautiful wood, however, and its possibilities as a raw material for fine furniture, parquete flooring and novelty items should not be overlooked. Possibilities for utilization of mesquite fiber include fuel, particleboard, charcoal, and rumen feed (Soltes 1977).

Since wood is a hygroscopic material and its association with water is unavoidable, the effects of water on a given species must be known if that species is to be utilized effectively.

The moisture content of wood is specified by the ratio of the weight of water to the weight of oven-dry wood times 100 percent. The green moisture content is that of a freshly cut tree. Knowledge of green moisture content is helpful in predicting transportation costs, heat losses in burning as fuel and fuel requirements in drying. The fiber saturation point is the moisture content at which the cell walls are saturated but no moisture is contained within the hollow lumen of the cell. Many wood properties begin to change during drying when the fiber saturation point is reached. For example, resistance to drying increases, strength properties begin to increase, and shrinkage begins to take place.

Dimensional changes occur in dry wood as relative humidity changes, and it can be very helpful to quantify these changes for such purposes as flooring, where expansion must be allowed for to prevent buckling. In a wood of high extractive content such as mesquite, dimensional stability may be relatively high due to a bulking effect. Since mesquite exhibits unusually high resistance to dimensional change, it is desirable, from an academic viewpoint, to understand its behavior and quantify the effect of extractives on such changes.

Wood must be dried before it can be used for most purposes. Each species dries differently, and a kiln schedule is required that will dry the wood as quickly as possible but with a minimum of degrade.

Permeability of a wood is a measure of the ease with which fluids, such as preservatives and pulping liquids, will penetrate a wood. The apparent gas permeability is higher than liquid permeability, due to molecular slippage of the gas in low-permeable media; however, it has been shown to be a good predictor of preservative penetration (Tesoro 1973).

The following is a comprehensive report of several separate studies of the various relationships of water and mesquite wood. The species used in all of these studies is that most common to Texas — *Prospis juliflora* or honey mesquite.

GREEN MOISTURE CONTENT[1]

The green moisture content of mesquite was determined from samples of 100 logs from Brooks County, Texas. The average moisture content was 64.6% while the range was 42-145%. The average specific gravity of these logs was 0.70 with a range of 0.41 to 0.99.

SORPTION ISOTHERM, DIMENSIONAL CHANGES AND FIBER SATURATION POINT OF MESQUITE HEARTWOOD

Materials and Methods

Seven small squares of mesquite heartwood measuring about 0.8 inch across and 0.3 inch thick were cut so that the radial and tangential directions were parallel to the sides. Three squares of southern yellow pine were cut in the same manner so that a check of the experimental method could be made, since data is available for southern pines.

The samples were dried for several days over calcium chloride and then placed in an oven at 104°C for final drying to determine the oven-dry weights, and radial and tangential dimensions. The samples were then placed in desiccators, over saturated salt solutions, of successively smaller humidity depressant, being allowed to reach equilibrium over each solution before being transferred to the next. The desiccators were placed in an incubator and held at 30°C. The moisture content and percent swelling was determined at each equilibrium state.

The salts used and the resulting relative humidities[2] of their solutions were:

$MgCl_2$	31.7%
$Ca(NO_3)_2$	51.0%
$Zn(SO_4)$	88.5%

The samples were then placed over water in a desiccator. Drops of water were placed on each sample to be sure that the samples attained a moisture content greater than the fiber saturation point. This method was used to prevent excessive leaching of extractives in preference to soaking the samples.

[1]Results of unpublished data by D. G. Adams, 1972. Texas Forest Products Laboratory Texas Forest Service, Lufkin, Texas

[2]TAPPI Data Sheet 109, Issued December 1944.

After moisture contents and dimensional changes of specimens over water had been taken, the specimens were again placed over salt solutions using the procedure previously described but in the opposite order.

Results

The sorption isotherm (moisture content versus relative humidity) of mesquite is given in Figure 1. The adsorption - desorption hysteresis is apparent. The average adsorption - desorption ratio was 0.78 for mesquite and 0.83 for pine. Values in the literature for southern yellow pine range from 0.73 to 0.92 (Choong 1969a).

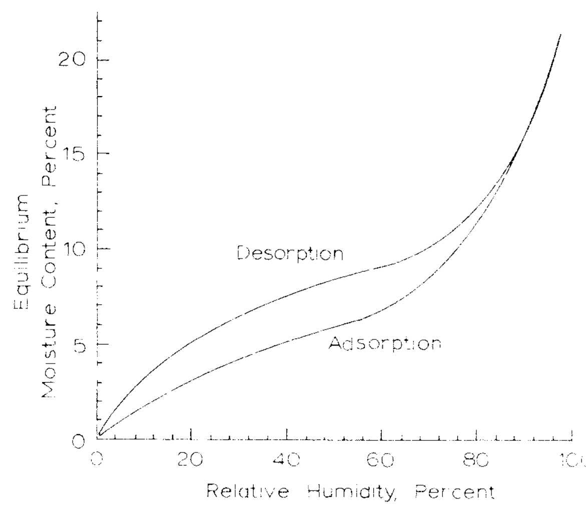

Figure 1. Sorption isotherm of mesquite.

The fiber saturation point was determined by assuming a straight line relationship between shrinkage and equilibrium moisture content. The equation for the line was found by the least squares method and extrapolated to zero shrinkage, at which point the equilibrium moisture content is at the fiber saturation point. These lines are given for the radial and tangential directions in Figure 2. The average fiber saturation point was calculated to be 21.6%. The average fiber saturation point for the pine specimens was 28.6%, which compares favorably with other work (Choong 1969b).

Total average shrinkage of the mesquite samples was 3.2% in the tangential direction and 1.6% in the radial direction. This is somewhat different from previous work (Durso, et. al. 1973) which gives values of 2.6% and 2.2%, respectively. However, the volumetric shrinkage, if estimated as the sum of tangential and radial shrinkage, is the same.

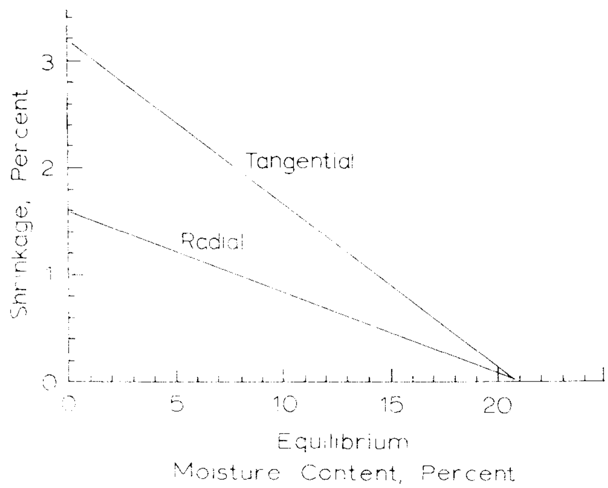

Figure 2. Shrinkage of mesquite.

EFFECT OF EXTRACTIVES ON DENSITY, MAXIMUM MOISTURE CONTENT AND SWELLING OF MESQUITE HEARTWOOD[3]

Materials and Methods

All of the specimens were taken from previously prepared physical test samples and machined to 2 × 2 inches. The specimens were cut to 0.125 inch in length. Growth rings closely paralleled the tangential surface. Four groups of 30 samples each were used to determine extractive content, density, maximum moisture content, and maximum swelling. One group served as a control and was not extracted; otherwise, it was treated the same as those that were extracted.

Extraction was carried out in a reaction kettle large enough to hold the 30 samples from each group. Solvents used were as follows: (1) hot distilled water, (2) 1:2 mixture of benzene and 95% ethanol, and (3) a sequence of hot water and the benzene-ethanol mixture. All samples in groups (1) and (2) were extracted for three successive 4 hour periods or a total of 12 hours. Both steps in extracting group (3) were by the same time schedule. The kettle was equipped with a reflux condenser to prevent loss of solvent from the system. After each period of 4 hours, the contaminated solvent was replaced with fresh solvent. The solvent was highly discolored after the first period and only slightly discolored after 8 hours. Hardly any discoloration of the solvent was noted after 12 hours, perhaps indicating that extraction under these conditions was nearly complete.

[3]From unpublished manuscript by D. G. Adams, 1972. Mesquite, extractives, density, moisture content, and swelling. Texas Forest Products Laboratory, Texas Forest Service, Lufkin, Texas.

Following the extraction steps, the samples were flushed with cool distilled water until all the organic solvent was removed. The samples were vacuum-dried for 2 hours. After oven-drying to constant weight at 105°C, the samples were cooled and weighed. Radial, tangential and thickness measurements were taken to establish oven-dry conditions.

Each group of samples was then placed in a vacuum desiccator and submerged in distilled water. The desiccator was subsequently evacuated. Each group remained under vacuum for 24 hours or until no detectable bubbles could be seen rising in the water or being formed on the surface of the pieces. At this point, the vacuum was released. Since the samples were submerged, water replaced air in the wood. A series of alternating vacuum and release cycles were conducted until the samples appeared to be fully saturated.

Following saturation in distilled water, the samples were removed one at a time from the water, wiped dry and weighed. Again, radial, tangential and thickness measurements were taken and extractives content, density, percent swelling, and maximum moisture content were determined. (Adams 1972b).

Results and Discussion

The replacement of water in the cell lumen by extraneous material suppresses shrinkage and swelling and also lowers the fiber saturation point (Stamm 1964). This phenomenon is known as bulking. Many woods, among them redwood (*Sequoia sempervirens*) and mesquite, contain large amounts of extractives. Once the extractives have been removed, the wood exhibits a more normal reaction in terms of its dimensional change when subject to water vapor.

Hillis (1962) reported that ground mesquite wood extracted with water showed a 15.5% loss in weight. Goldstein and Villereal (1972) extracted ground mesquite heartwood with a 1:2 mixture of benzene - 95% ethanol and determined the extractive content to be 12.2% of the total weight. The same wood was then extracted in hot water. An additional 5.8% water-soluble extractives were removed. A total of 18% extractives then was removed using the organic solvent - hot water sequence.

Table 1. Density, Moisture Content, and Swelling of Mesquite Wood After Extraction.

Extraction Method	Extractives[1] (%)	Density[2] (g/cc)	Maximum moisture[2] content (%)	Maximum[2] swelling (%)
None	-----	0.819	49.26	4.86
Benzene-Alcohol	1.82	0.783	57.73	5.57
Water	9.53	0.726	69.99	6.61
Water, Benzene-Alcohol	13.44	0.709	82.93	8.29

[1]Extractives based on ovendry weight.
[2]Based on conditions after extraction.

The extractives content of mesquite, as determined in this study, is summarized in Table 1. The largest percent extractives, 13.44%, was removed using the hot water, ethanol-benzene sequence. The hot water technique removed 9.53%, while those removed by the solvents alone accounted for 1.91% of the total weight. The total amount of extractives removed by the two-step sequence is quite comparable to that reported by Goldstein and Villereal. However, the relative percentages removed during each step does seem to merit some explanation.

According to Browning (1967) resin and fatty acids and their esters, waxes, unsaponifiable substances, coloring matter, etc., are soluble in organic solvents. Substances soluble in water include inorganic salts, sugars, polysaccharides, cycloses, cyclitols, and some phenolic materials.

Without knowing the relative portions of material soluble in the solvents used, it is impossible to verify the data chemically. However, two possible physical explanations are offered for the apparent differences in the organic solvent extractives. First, only a small portion of the substances present are actually soluble in the alcohol-benzene mixture, which would help verify the low values found in this study. The amount of extractives removed during each step of the sequential extraction was calculated. During the hot water step 11.25% extractives were removed, while only 2.19% (total of 13.44%) were removed by the organic solvent. The 2.19% extractives is comparable to the removal of 1.91% extractives during the single-step extraction using the organic solvent mixture. However, it is still far below the value obtained by Goldstein and Villereal of 12.2%.

The second, and perhaps more meaningful explanation, is that the material normally soluble in an organic solvent such as that used, was simply not as accessible in the solid wood as in the ground wood. Obviously, this is at least partially true. How much of the difference between 2% (average of 1.82 and 2.19) and 12.2% is accounted for by this second reason is unknown. However, the limited physical accessibility in the solid wood hardly accounts for the total discrepancy.

Table 2. Cutting Percentages and Number Before Drying and Drying Degrade Measured Before and After Planing.

Batch	Cuttings before drying		Degrade Before planing		Degrade After planing	
	Percent	Number	Percent	Number	Percent	Number
1	61.2	1.6	4.4	+0.2	3.2	0.0
2	63.2	1.8	2.3	0.0	2.5	+0.1
3	57.4	2.2	−5.7	+0.1	−6.3	−0.1
4	57.2	1.8	−3.9	−0.1	5.3	+0.1
5	49.8	1.1	7.7	+0.1	---	---

[1]Positive sign indicates an increase, while negative sign indicates a decrease.

Two other determinations, volumetric swelling and moisture content, followed the trend set by the extractives (Table 2). That is, ranking the values from lowest to highest, the benzene-alcohol extraction gave the lowest values while the highest values were given by the two-step sequence. Sandwiched in between are those values obtained with the hot water extraction only. Densities showed an inverse relation with extractives but in the same order of treatments as mentioned above. That is, the highest densities were obtained using water extraction only, while the lowest values were obtained in the two-step extraction.

DRYING 4/4 MESQUITE

Materials and Methods

Twenty-five logs, 4 to 6 feet long, and ranging from 5 to 17 inches in diameter were obtained from Brown County, Texas. The logs were stored under water spray and reduced to 4/4, random width, 4-foot lumber on a small sawmill. Each batch of lumber was cut just prior to drying.

An attempt was made to divide the logs so that the board footage would be about the same in each drying run. This proved very difficult, however, since the larger logs had a greater proportion of heart rot and splits, which ran both radially and circumferentialy through the logs. The number of such splits appeared to increase toward the center of the logs, so that often only the boards taken from near the bark were salvageable. Logs up to 10 inches in diameter were of relatively high quality throughout. Batches 1-4 contained respectively 61.9, 72.0, 46.9, and 38.4 board feet of lumber.

Since most of the boards rated below any National Hardwood Standard grading classification, a grading scheme was devised by which the product sought was a board from which novelty items could be cut. The minimum allowable clear cutting area was 24 sq. in., with a minimum width of 1½ inch. No splits, checks, rot, or wane were allowed within a clear cutting. Worm holes and tight knots were allowed if they appeared on one side only. Boards with less than 20% of the surface area included in the cuttings were discarded.

Clear cuttings were delineated on each board prior to drying. The percentage of board area included in clear cuttings and the number of cuttings required was recorded for each board before and after drying. The boards were then planed just enough to remove the saw marks, and regraded.

Degrade was taken as the average decrease in cutting percentage. Since it is desirable that a minimum number of cuttings make up a given percentage, the average increase in cutting number was taken as a secondary indication of degrade.

Batches 1-3 were subjected to kiln schedules of increasing severity, the conditions of which are summarized in Figures 1-3. Drying was stopped when the average moisture content of the charge had reached 6%. Batch 4 was air dried until the average moisture content reached 15%. The batch was kiln dried under conditions of 170°F dry bulb and 100°F wet bulb temperature to bring the moisture content down to 6%. A fifth batch, containing 7 boards was dried in an oven at 220°F.

An analysis of variance was carried out on the percentage degrade values of batches 1-4 to find out if any of the schedules were preferrable in this regard.

Results and Discussion

Summaries of the three kiln drying runs are given in Figures 3 through 5. Cutting percent, cutting number, and degrade for batches 1-5 are given in Table 2. Total drying times for the three schedules were 20, 15, and 10 days. As can be seen in Table 2, degrade was slight by all three schedules, and there was no apparent increase in degrade with increasing severity of schedule.

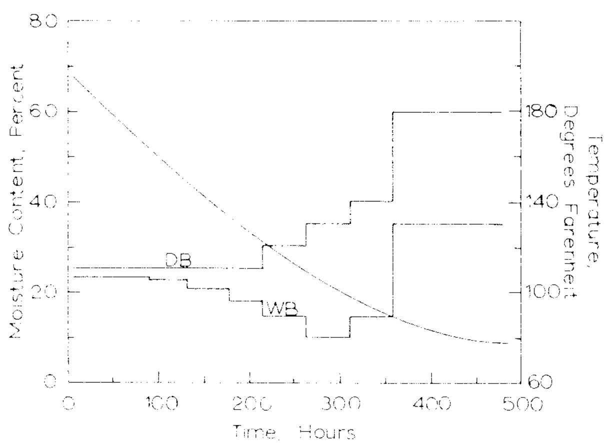

Figure 3. Dry bulb (DB) and wet bulb (WB) temperatures and moisture content of charge as functions of time for batch 1.

There is only one reference in the literature to drying of mesquite (Marshall 1945). It was reported that air drying of mesquite was a "long and tedious process" and that samples which had been air dried for one year began to check immediately when placed in a drying oven with only a slight rise in temperature. Batch 4 was air dried to test this statement. As can be seen in Table 4, air drying proved to be as satisfactory as kiln drying.

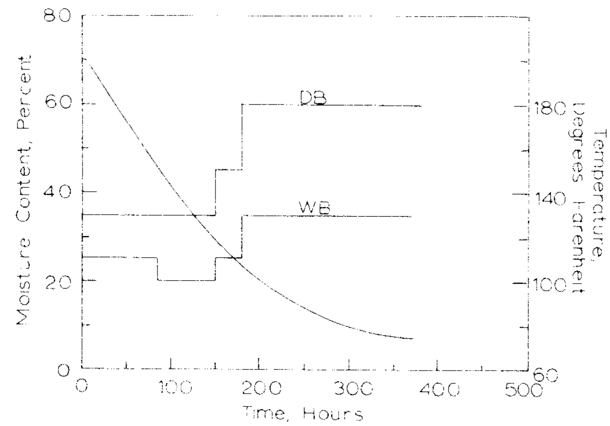

Figure 4. Dry bulb (DB) and wet bulb (WB) temperatures and moisture content of charge as functions of time for batch 2

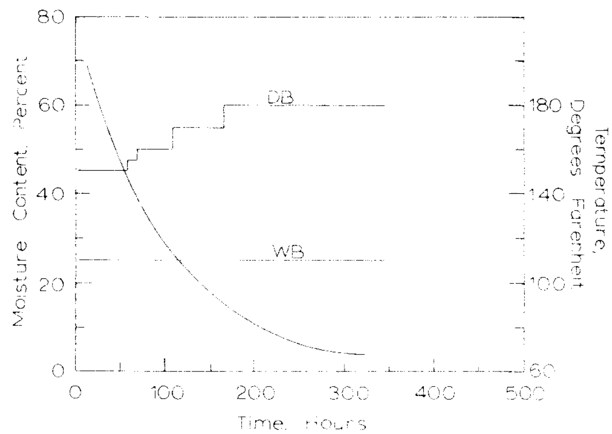

Figure 5. Dry bulb (DB) and wet bulb (WB) temperatures and moisture content of charge as functions of time for batch 3.

Table 3. Summary of Analysis of Variance of Degradation of Mesquite Wood, After Drying but Before Planing.

Source	Degrees of freedom	Sum of square	Mean square	F
Among	3	11	3.67	0.04
Within	100	9,209	92.09	
Total	103	9,220		

Table 4. Summary of Analysis of Variance of Degradation of Mesquite Wood, After Drying and Planing.

Source	Degrees of freedom	Sum of sqaure	Mean square	F
Among	3	122	40.6	0.978
Within	100	4,154	41.5	
Total	103	4,276		

Analysis of variance summaries are given for batches 1-4, for conditions before (Table 2), and after (Table 3) planing. Treatments were the drying methods, while observations were the percent degrade for each board. The analysis confirmed that no difference in degradation exists between drying methods in this regard. The mean square error is larger after planning than before because planing often revealed splits that were not visible before planing, in addition to removing some surface checks. Also, since the clear cutting lines were removed during planing, greater experimental error was encountered in trying to reassess the maximum cutting percent.

The purpose of drying batch 5 so quickly was to attempt to find a drying rate which would cause profuse checking. Large checks were found in the sapwood, but little checking occurred in heartwood.

No cupping was observed in any of the batches. Bow, crook and twist were significant, and the severity appeared to increase with severity of drying schedule. A color change, from greyish brown to various shades of pink frequently occurred, and the depth of change appeared to increase with severity of schedule. No instance of honeycombing was observed, and collapse occurred only in batch 5. Casehardening was slight to moderate in all batches. Absence of cupping, checking and honeycomb is probably related to the high dimensional stability of mesquite.

The large amount of checking which occurred in the sapwood of batch 5 was proposed to be due to greater shrinkage in the sapwood than in heartwood. To test this hypothesis, 36 green sapwood specimens were cut for total shrinkage determination. Of these, 12 specimens were from just inside the bark, 12 were from just outside the heartwood, and 12 were from approximately midway between the bark and the heartwood. Shrinkage was determined in the tangential direction. Specimens from the bark-side shrank an average of 5.0%, those midway between bark and heartwood shrank an average of 4.2%, while those adjacent to heartwood shrank an average of 3.6%, indicating decreasing shrinkage in the direction away from the bark. Shrinkages were significantly different at the 95% level. Since previous studies indicated tangential heartwood shrinkage of 3.2 and 2.6%, the data appears to support the hypothesis.

The high degree of bow, crook and twist which occurred in all batches is due to the large amount of cross grain inherent in the bent, twisted logs from which boards are taken. This could be a serious hinderance to use of the wood in furniture, but this type of warpage may be kept to a minimum by air drying. Application of kiln weights might help prevent warpage during kiln drying.

PERMEABILITY OF MESQUITE HEARTWOOD

Procedure

Permeability was measured in the longitudinal, radial, and tangential directions of mesquite heartwood. Six specimens, each from a different tree were tested. Specimens measured ⅝ inch in diameter and were about ¾ inch long. The end of the specimens were shaved with a razor blade to reduce surface flow resistance as described by Choong et. al. (1975). The specimens were subjected to nitrogen flow, each at a single average pressure, with no attempt to correct for molecular slippage, since previous work has shown conventional techniques to be meaningless when dealing with wood (Wiley and Choong, 1975). The apparatus used was that described by Choong, et. al. (1974).* Apparent gas permeability was calculated by the formula:

$$K_a = \frac{Q\mu L P_a}{A \Delta P \bar{P}}$$

where K_a is the apparent permeability in Darcy's, Q if the flow rate in cm^3/sec, L is the length of the specimen in cm, A is the cross sectional area in cm^2, μ is the viscosity in centipoise, P_a is the pressure in atm. at which flow measurements are taken (1 atm.), ΔP is the pressure drop across the specimen, and $\bar{P}$ is the average of the upstream and downstream pressures, also in atm.

Results

Results of the tests are given in Table 5. Permeability averaged 0.40, 0.0019, and 0.0017 Darcy in the longitudinal, radial, and tangential directions, respectively. Comparison of these results with those given by Choong, et. al. (1974) for 22 hardwood species, indicates that mesquite is of low, but not unusually low, permeability.

Table 5. Permeability of Mesquite Wood.

	Mean (Darcy)	Range (Darcy)
Longitudinal	0.40	0.19 - 0.57
Radial	0.0019	0.00066 - 0.0052
Tangenital	0.00174	0.00052 - 0.0021

*Measurements were taken by personnel at the Louisiana State University, School of Forestry, Wood Physics Laboratory.

CONCLUSION

Several of the wood-moisture relations of mesquite were studied. Green moisture content averaged 64.6%. The fiber saturation point was found to be 21.6%. The sorption curve was derived and reported. Dimensional changes were studied as a function of equilibrium moisture content. Total shrinkage was found to be 3.2% in the tangential and 1.6% in the radial directions. The removal of extractives from mesquite heartwood was found to decrease density, increase maximum moisture content, and increase total swelling. The magnitude of those effects was dependent upon the amount of extractives removed, as related to the extraction method. Due to its unusually low shrinkage, mesquite can be dried with very little checking under a relatively severe 10-day schedule. A constant-temperature 220°F schedule caused profuse checking in the sapwood. This effect was related to the greater shrinkage of sapwood than of heartwood. Permeability of mesquite averaged 0.40, 0.0019, and 0.0017 Darcy in the longitudinal, radial and tangential directions, respectively.

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