DETERMINING THE DRY WEIGHT AND DRY VOLUME OF GREEN ASPEN BOLTS BY USE OF THE WATER DISPLACEMENT TECHNIQUE

Thesis for the Degree of M. S.
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JOHN GRANT HAYGREEN

AN ABSTRACT

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Abstract

Most purchases of boltwood today are based upon either cord measure or green weight. Neither of these methods, as commonly practiced, is reliable for consistently providing information as to the actual weight of dry wood substance present in boltwood. The water displacement technique can be used to provide this information. The actual volume of boltwood can be determined by displacement, and this green volume can then be converted to the corresponding dry weight if the relation between these two values is known.

In this study the ratio of green volume of boltwood to dry weight of wood substance was determined for both peeled and unpeeled bigtooth aspen (*Populus grandidentata* Michx.). The variation of these ratios, i.e., conversion factors, with the diameter of the bolts and the height in the tree was also investigated. It was found that the weight of dry wood in a unit volume of green wood was greater in bolts of larger diameter. The dry weight per unit volume remained constant, however, at different heights in the tree. Conversion factors were determined for bolt diameter classes from three inches to nine inches, and thus a factor which corresponds to the average bolt diameter of

a shipment could be used to estimate the dry weight of wood in the shipment.

Also determined was a factor which can be used to estimate the dry weight of wood from the green weight. Weight and volume losses which occur in aspen boltwood under good air-drying conditions were investigated; and these were used to compare the accuracy of the two types of factors mentioned as affected by changes in moisture content of boltwood after cutting. In unpeeled aspen boltwood, the green volume decreased 1.2 percent after six weeks of drying while the green weight dropped 10.3 percent. Estimating the dry wood substance in boltwood from the green weight appears impractical when an accurate estimate is desired. This is due to the rapid change in weight, and thus in the true conversion factor, when the bolts are subjected to drying. Also of importance in this respect is the fact that wide variation may exist in the moisture content of freshly cut bolts at different seasons of the year.

The disadvantages regarding accuracy of the green weight method of estimating could be overcome by using the water displacement method and the necessary conversion factor. In this study conversion factors are presented for bigtooth aspen grown on one site in central Michigan. Two methods of obtaining conversion factors are outlined in this study, and these methods could be used to obtain factors for any species of boltwood.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

I. INTRODUCTION

Methods of Scaling Boltwood

Most purchases of boltwood today are based upon either cord measure or green weight. Neither of these methods, as commonly practiced, is reliable for consistently providing information as to the actual weight or volume of dry wood substance present. A type of measurement which consistently provides more accurate information would not only make it possible to set purchase prices more realistically, but would be helpful to industry and researchers in the determination of product yield standards. The technique of obtaining the volume of bolts by immersion in water, i.e., by water displacement, has considerable promise of being such a method of measurement.

The possible wide variation in the amount of wood substance contained in a unit cord of 128 cubic feet is well known. Factors such as diameter of bolts, length of bolts, care taken in stacking, amount of bark, moisture content, and neatness of trimming, affect the amount of wood substance in a unit cord. Cord measurement gives only approximate information about the volume of green wood in the unit, and even less information about the volume or weight of dry wood which is present.

The measurement of boltwood by weight also poses several problems. The principal problem lies in the fact that the bolts may lose moisture, and thus weight, quite rapidly after being cut. Therefore, a conversion factor based upon a relationship between freshly-cut wood and its equivalent dry weight becomes progressively greater in error as it is applied to boltwood in progressive stages of drying.

Since the relationship between the actual weight and the dry weight of boltwood is subject to continual change after cutting, any estimate of the dry weight made on the basis of green weight is subject to considerable error unless moisture tests are made. Tests to determine the average moisture content would be necessary even if boltwood is weighed immediately after cutting since within a tree species such as aspen the moisture content may vary during the year. Jensen and Davis (7) found that the average moisture content of the quaking aspen in their samples varied from 80 percent in the summer to 113 percent in the winter. This could mean a difference during the year of approximately 15 percent in the green weight of a unit of dry wood.

Despite its limitations, the selling of boltwood on a weight basis has a number of advantages over selling on a cord basis. Taras (12) lists a number of these: (1) it encourages prompt delivery which is desirable for pulping,

(2) it requires no special handling and thus saves time for both buyer and seller, (3) it provides an incentive for better piling of wood on trucks and thus increases the volume handled by the supplier. Olson (9) states that since his company began purchasing by weight in 1947 they have received no complaints on scaling. Prior to this cord scaling was used and complaints were commonplace.

As stated previously, the limitations of weight and of cord measure could quite possibly be overcome by using the water displacement technique. This method would involve submerging loads of boltwood in a water tank and obtaining the volume of wood, or of wood plus bark for unpeeled bolts, by the change in the water level. If the relationships, i.e., conversion factors, between the volume of green wood, or of green wood plus bark, and the amount of dry[1] wood are established, it would be possible to convert the volume obtained from displacement into the corresponding dry weight.

The average volumetric shrinkage of bigtooth aspen in going from a green to a dry condition is listed in available tables as 11.8 percent. Thus, if a given amount of green aspen boltwood is air-dried to 20 percent moisture content the volume would decrease by only about 4 percent,

[1]Throughout this paper the term "dry" is used to indicate wood or bark in an oven-dried condition unless another moisture content is specified.

whereas the weight could decrease as much as 40 percent. It is thus evident that the amount of dry wood present in a given amount of green wood could be much more accurately estimated throughout progressive stages of air-drying by use of a conversion factor based upon green volume than by use of a factor based upon green weight.

Purposes of the Study

In order to evaluate water displacement as a technique for determining the amount of dry wood in green bolts, information was needed pertaining to the limitations of such a system. Further information in two important areas was deemed necessary in order to evaluate this system.

The primary purpose of this study was to compute factors for converting the green volume of peeled and of unpeeled aspen bolts into estimates of the dry weight of wood substance present. It was also possible to derive conversion factors for converting the green volume of peeled and of unpeeled bolts into estimates of the dry volume of wood present.

The second purpose of the study was to compute a factor for converting green weight of aspen into dry weight; and to compare the accuracy of this factor with the one for converting from green volume to dry weight, as affected by changes in moisture content. In order to make such a comparison the extent and rate of weight and volume losses which occur when aspen boltwood is stacked in an exposed location were determined. The most desirable type of conversion factor would be one which gives an accurate estimate of the dry weight of wood present regardless of the moisture content of the bolts at the time of measurement.

Another purpose of this study was to determine the influence that the diameter of bolt and the location of the bolt in the tree might have upon a single conversion factor applied to all bolts. To determine this, data were obtained on such variables as moisture content, specific gravity of wood and of bark, shrinkage of wood, and the amount of bark.

All conversion factors in this study were computed from data obtained in a sample of bigtooth aspen (*Populus grandidentata* Michx.) which was taken in central Michigan.

II. PROCEDURE

Description of the Sample

All test sections used in the study of physical properties were cut on the same site in the Manistee National Forest in central Michigan.

Bolts for the study of losses in moisture content, weight, and volume during air-drying were obtained from two areas. The first sample, which will be referred to as sample A, was cut at the same location and at the same time as the test sections mentioned in the preceding paragraph. The bolts used in the study of drying losses were cut fifty-two inches long. The ends were coated with a wax emulsion to retard moisture loss. When the bolts were delivered to the drying area a two-inch section was cut from each end.

In sample A, a ten-inch section was cut directly below the bottom cut made to remove a fifty-two inch bolt from the tree stem. There was, therefore, a ten-inch section obtained adjacent to each of the sixty-three test bolts in sample A. These sections were those used to obtain data on the physical properties of bigtooth aspen.

The second sample of bolts used in the drying study was cut on the Allegan State Forest near Allegan, Michigan.

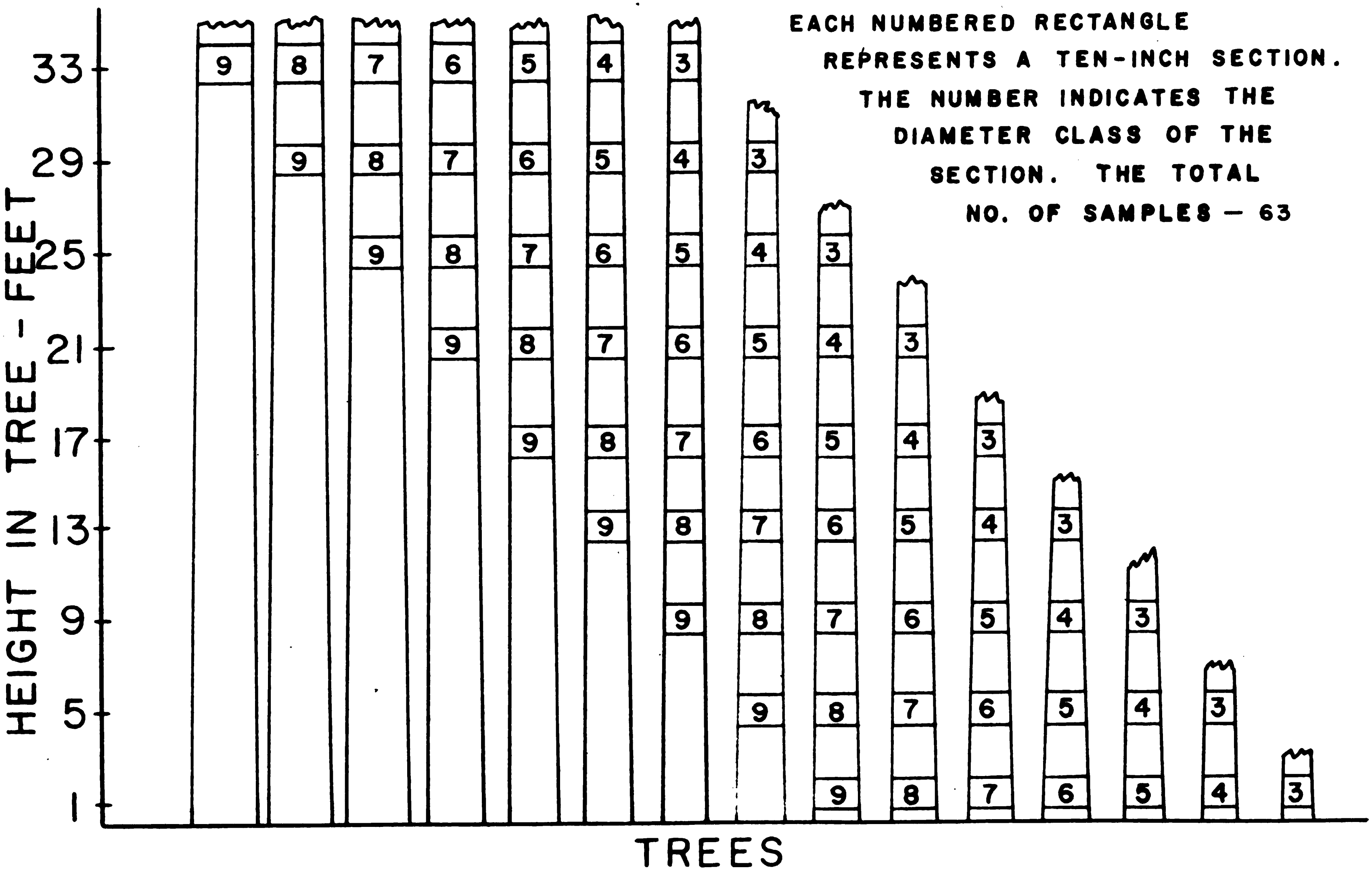

Fig. 1. Pictorial representation of sample A. The diameter class and height of each test section is indicated. The number of trees cut was greater than indicated above.

This set of sixty bolts will be referred to as sample B. No ten-inch test sections were cut from this area. These bolts were cut in the woods into eight-foot lengths, and when delivered to the drying area were cut into the desired four-foot lengths. One member of each such pair was peeled and the other was left unpeeled in order to obtain matched specimens for a direct comparison between peeled and unpeeled bolts during air-drying.

Information pertaining to the sites and stands from which the samples were obtained is important as these factors define the populations from which the samples were drawn. Since sample A was used as the basis for data on physical properties, it is the more important sample and will be described in somewhat more detail.

A total of 29 trees were cut in order to obtain the 63 bolts referred to as sample A. The average height of these trees was 54 feet, and the average diameter inside bark at one foot above the ground was 7.3 inches. The average height of what was considered merchantable stem, that is the height to a 3 inch diameter, was 37 feet. These figures do not represent average figures for the stand since the trees were not selected at random, as will be explained later. These averages indicate only the size of trees from which the sample was obtained.

The site index for the stand of sample A was estimated at 68 using the site index curve from Kittredge and

Gervorkiantz (8). Ninety percent of the trees cut were in the 35 to 42 year age class. The average age was 38 years.

The bolts in sample A, and the corresponding ten-inch test sections, were selected to include bolt diameter classes from three inches to nine inches and bolt height classes from one foot to thirty-three feet. Figure 1 illustrates the distribution of sample sections. The diameter class into which the bolts were placed was determined by the diameter inside bark at the lower end. The height in feet of the lower end of the bolt above the ground was assigned as the height class for that bolt.

Seven bolt diameter classes were recognized ranging from three to nine inches. Nine height classes were set up at four-foot intervals. The bolts were cut so that the lower ends were either at a height of one foot, five feet, nine feet, etc., up to thirty-three feet when in the standing tree. The bolts were selected so that there was one bolt of each diameter class in each height class in the final sample. For instance, in the five-foot height class there was one bolt for each diameter class making a total of seven bolts.

In the selection of sample B, no stratification was made involving height in the tree. Six diameter classes were recognized ranging from three inches to eight inches diameter inside bark. Five eight-foot bolts were obtained in each diameter class.

The average age of trees in sample B was 33 years.

The average height of the 11 trees cut to obtain the sample was 47 feet. The site index for this sample was estimated as 65, just slightly less than for sample A.

Determination of Weight and Volume Losses Due to Drying

Weight and volume measurements were taken on both samples A and B every two weeks. Sample A was under study during the summer and fall of 1956, and sample B during the summer of 1957.

The four-foot bolts were stacked on a rack constructed to afford maximum drying conditions. A rough board roof, supported several feet above the pile, kept off direct precipitation; and the drying rack was built six inches above the ground to allow air to circulate beneath the pile.

Since the bolts were protected from direct precipitation but were open to air circulation, the drying conditions were severe compared to those ordinarily found in the woods or in concentration yards. The results of any study of air-drying rates are influenced greatly by weather conditions and piling methods. For the purposes of this study it was felt that information on maximum drying conditions would be the most helpful. With maximum drying rates approximately established, weight and volume losses in the woods can be assumed to be somewhat less for the same period of year.

The bolts were weighed separately, and the weights were recorded by bolt number. The volume of the bolts was determined by immersion in a tank. The inside diameter of this displacement tank was 12.13 inches and the height was approximately eight feet. A sight glass was fitted to the side of the tank; and a steel tape, graduated in inches, was fastened to the glass. Readings were taken before and after a bolt was placed in the tank. The volume equivalent to one inch of displacement in this tank was 0.066 cubic feet.

Determinations Made in the Laboratory

In the laboratory a one-inch cross sectional disk was cut from each ten-inch test section, and was used to determine data on the physical properties. From these green disks the following data were obtained in the order listed: (1) average diameter both inside and outside the bark, (2) weight of wood, (3) weight of bark, (4) volume of wood, (5) volume of bark, (6) average diameter of heartwood. The volumes of wood and of bark were determined separately by the water displacement technique. It was found that the bark was easily removed as a continuous ring and could, therefore, be easily immersed.

All sample disks of wood and strips of bark were oven-dried. The weights and volumes were again obtained. Melted paraffin was used to seal the dried wood and dried bark samples before immersion in water.

From the data obtained, the following calculations were made for each disk: (1) moisture content of wood, bark, and both combined, (2) specific gravity of wood on a green and on a dry volume basis, (3) specific gravity of bark on a green volume basis, (4) volumetric shrinkage of wood and of bark, (5) percent of bark based upon displacement and diameter measurement methods, (6) percent of heartwood. These results were averaged by diameter and height classes. A two-way analysis of variance was computed for each of the above mentioned variables, using diameter of bolts and height in the tree as the independent variables.

Possible variation of the specific gravity of aspen grown in various stands and sites was thought to be of particular importance. Changes in specific gravity from stand to stand would cause corresponding changes in the factor needed to convert green volume to dry weight. In order to obtain some indication as to whether such variations exist, specific gravity was studied in somewhat greater detail than the other variables mentioned in the preceding paragraph. In addition to the independent variables diameter and height as used in the analysis of variance, a third variable - rate of growth - is known to have an important relation to the specific gravity. A multiple correlation (11) using these four variables was computed.

Computation of Conversion Factors

Conversion factors, i.e., the relationships between green weight or volume and dry weight or volume, were computed in two different ways. The first method used was a technique which would be relatively easy for anyone to use who wished to establish a conversion factor for another species. Possible variations and the reasons for them cannot be analysed however. The total green and dry weights and the total green and dry volumes of the test sections were used to establish the desired relationships referred to as conversion factors.

The second method of computing the factors was by using the moisture content, specific gravity, shrinkage coefficient, and percent of bark by volume as determined from the test sections. See Table III for the formulas used. The emphasis in this study was on this method of computation because it was thus possible to better analyse the various elements which make up the conversion factors. All tables and graphs in the study refer to conversion factors determined in this way. A two-way analysis of variance was computed for each different type of conversion factor using bolt diameter and height as the independent variables, the same as was done when testing the physical properties.

Three types of conversion factors were computed: (1) those required to convert green volume to dry weight,

(2) those needed to convert green volume to dry volume, (3) those essential for converting green weight to dry weight. The first two of these were computed for both peeled and unpeeled boltwood.

In actual practice the conversion factors established in this study can be used to estimate the weight or volume of oven-dried wood present in aspen boltwood. The weight or volume of wood at other moisture contents might be desired. This would ordinarily be determined by the moisture content of the product being manufactured. See Appendix B for a discussion of the computation of conversion factors at any moisture content in the case where the second method of computing the factors is used.

TABLE I

TABLE I

PHYSICAL PROPERTIES OF BIGTOOTH ASPEN IN SAMPLE A, AVERAGED BY DIAMETER CLASSES

Physical Properties	Bolt Diameter Classes							Grand Mean
	3 In.	4 In.	5 In.	6 In.	7 In.	8 In.	9 In.	
M.C.[a] Green Wood	83.6	87.4	101.2	92.3	104.1	94.2	94.7	93.9
M.C. Green Bark	70.4	69.3	75.5	70.9	70.7	72.1	74.6	71.9
M.C. Wood Plus Bark	80.9	83.6	96.2	88.3	97.2	90.3	91.0	89.6
Sp. Gr. Wood- Dry Vol. Basis	0.40	0.39	0.40	0.42	0.43	0.44	0.45	0.42
Sp. Gr. Wood- Grn.[b] Vol. Basis	0.36	0.36	0.37	0.38	0.39	0.40	0.40	0.38
Sp. Gr. Bark- Grn. Vol. Basis	0.61	0.60	0.59	0.62	0.60	0.59	0.58	0.60
Vol. Shrinkage of Wood[c]	10.0	8.2	9.0	10.0	9.9	10.2	10.4	9.7
Vol. Shrinkage of Bark[c]	25.2	25.1	27.2	25.0	24.7	26.1	26.8	25.7
Percent of Bark Vol.[d]	14.1	13.7	12.7	12.3	14.1	13.0	13.6	13.4
Percent of Heartwood	10	9	9	14	17	17	18	13

[a] Moisture content.

[b] Green.

[c] Expressed as a percent of the green volume.

[d] Expressed as a percent of the volume of wood plus bark.

TABLE II

PHYSICAL PROPERTIES OF BIGTOOTH ASPEN IN SAMPLE A, AVERAGED BY HEIGHT CLASSES

Physical	Height[g] Classes									Grand
Properties	1	5	9	13	17	21	25	29	33	Mean
M.C.[a] Green Wood	83.5	87.6	96.5	92.0	100.6	95.5	97.8	93.0	98.8	93.9
M.C. Green Bark	57.3	66.5	73.7	70.6	75.5	74.4	75.0	75.0	79.4	71.9
M.C. Wood Plus Bark	77.9	83.6	92.6	88.1	95.5	91.6	93.4	89.2	94.8	89.6
Sp.Gr. W[b]- Dry Vol. Basis	0.45	0.43	0.40	0.41	0.40	0.43	0.41	0.43	0.41	0.42
Sp.Gr. W- Grn.[c]Vol. Basis	0.41	0.39	0.36	0.37	0.36	0.39	0.37	0.39	0.37	0.38
Sp.Gr. B[d]- Grn.Vol. Basis	0.61	0.61	0.60	0.62	0.59	0.59	0.60	0.60	0.59	0.60
Vol. Shrinkage of Wood[e]	9.7	9.6	10.2	9.9	10.1	9.8	9.2	9.0	9.6	9.7
Vol. Shrinkage of Bark[e]	20.7	25.1	25.9	25.3	27.0	27.1	26.7	26.0	27.9	25.7
Percent of Bark Vol.[f]	15.3	13.0	11.4	11.4	13.8	13.5	13.0	14.8	14.3	13.4
Percent of heartwood	13	16	17	16	14	15	15	10	6	13

[a]Moisture content.

[b]Wood.

[c]Green.

[d]Bark.

[e]Expressed as a percent of green vol.

[f]Expressed as a percent of the vol. of wood plus bark.

[g]Height of the bolt above the ground in feet.

TABLE III

DEFINITION OF CONVERSION FACTORS, AND THE FORMULAS USED TO COMPUTE CONVERSION FACTORS

Symbol	Explanation
CF-1	....Factor by which to multiply the green vol. of wood plus bark, in cu. ft., to obtain the dry weight of wood, in pounds.
CF-2	....Factor by which to multiply the green vol. of wood only, in cu. ft., to obtain the dry weight of wood, in lbs.
CF-3	....Factor by which to multiply the green vol. of wood plus bark to obtain the dry vol. of wood.
CF-4	....Factor by which to multiply the green vol. of wood only to obtain the vol. of dry wood.
CF-5	....Factor by which to multiply the green weight of wood plus bark to obtain the dry weight of wood.
B	.......Ratio of the green bark vol. to vol. of wood plus bark.
S	.......Ratio of the vol. of wood shrinkage to vol. of green wood.
SGwd	....Specific gravity of wood on a dry vol. basis.
SGwg	....Specific gravity of wood on a green vol. basis.
SGbg	....Specific gravity of bark on a green vol. basis.
MCw	.....Moisture content of green wood.
MCb	.....Moisture content of green bark.

Formulas Used to Compute Conversion Factors

$$CF\text{-}1 = (1-B)(1-S)(62.32)(SGwd)$$

$$CF\text{-}2 = (1-S)(62.32)(SGwd)$$

$$CF\text{-}3 = (1-B)(1-S)$$

$$CF\text{-}4 = 1-S$$

$$CF\text{-}5 = \frac{(1-B)(1-S)(SGwd)}{(1-B)(SGwg)(1+.01MCw) + (B)(SGbg)(1+.01MCb)}$$

TABLE IV

CONVERSION FACTORS FOR BIGTOOTH ASPEN COMPUTED FROM SAMPLE A, AVERAGED BY DIAMETER CLASSES

Conversion	Bolt Diameter Classes							Grand
Factors[a]	3 In.	4 In.	5 In.	6 In.	7 In.	8 In.	9 In.	Mean
CF-1	19.47	19.43	19.76	20.49	20.91	21.42	21.71	20.46
CF-2	22.47	22.56	22.68	23.36	24.40	24.64	25.16	23.61
CF-3	0.773	0.792	0.794	0.789	0.774	0.782	0.774	0.782
CF-4	0.900	0.918	0.910	0.900	0.901	0.898	0.896	0.903
CF-5	0.435	0.432	0.414	0.430	0.408	0.433	0.427	0.425

[a]See Table III for explanation of conversion factors.

TABLE V

CONVERSION FACTORS FOR BIGTOOTH ASPEN COMPUTED FROM SAMPLE A, AVERAGED BY HEIGHT CLASSES

Conversion Factors[a]	Height[b] Classes									Grand Mean
	1	5	9	13	17	21	25	29	33	
CF-1	21.43	21.03	20.04	20.38	19.56	21.06	20.32	20.62	19.65	20.46
CF-2	25.82	24.22	22.62	23.00	22.45	24.37	23.35	24.26	22.94	23.61
CF-3	0.765	0.787	0.796	0.798	0.775	0.781	0.790	0.775	0.775	0.782
CF-4	0.903	0.904	0.898	0.901	0.899	0.902	0.908	0.910	0.904	0.903
CF-5	0.446	0.443	0.430	0.437	0.411	0.423	0.415	0.416	0.407	0.425

[a]See Table III for explanation of conversion factors.

[b]Height of the bolt above the ground in feet.

III. RESULTS AND ANALYSIS

Conversion Factors Based Upon Actual Total Weights and Volumes

The conversion factors desired were first computed from the total weights and volumes of the test disks. For example, the factor used to convert green volume in cubic feet to dry weight in pounds was found by dividing the total number of pounds of dry wood in the one-inch thick test disks by the number of cubic feet of green wood and bark in these disks.

Using this method of calculation the conversion factor for aspen used to convert the green volume of wood plus bark to the dry weight of wood was found to be 21.06. Thus, a load of unpeeled boltwood with a volume of 1000 cubic feet, as determined by immersion, contains an estimated 21,060 pounds of dry wood substance.

The six following conversion factors were determined from the total weights and volumes of the test disks.
To estimate the dry weight of wood in pounds:

(1) Multiply the green volume of unpeeled aspen, in cubic feet, by 21.06.

(2) Multiply the green volume of peeled aspen, in cubic feet, by 24.30.

(3) Multiply the green weight of unpeeled aspen

by 0.422.

(4) Multiply the green weight of peeled aspen by 0.507.

To estimate the dry volume of wood:

(5) Multiply the green volume of unpeeled aspen by 0.781,

(6) Multiply the green volume of peeled aspen by 0.901.

It will be seen that the first two conversion factors vary approximately 3 percent from the same factors as calculated by the second method, which will be discussed later. The differences are believed to have occurred as a result of errors in the measurement of the dry volume of the test disks. These measurements were used only in computing the factors by the second method.

The remaining portions of this paper deal with the physical properties of aspen and with conversion factors derived and analysed in a different way and in more detail than was done in the preceding discussion.

Physical Properties of Bigtooth Aspen

The determination of average conversion factors and of the variation of these factors were two of the primary objectives of this study. The significance of differences in the conversion factors between diameter and height classes was established by means of analysis of variance. The conversion factors, however, were computed from a number of variables such as specific gravity, percent of

TABLE VI

SUMMARY OF THE RESULTS OF ANALYSIS OF VARIANCE ON PHYSICAL PROPERTIES OF BIGTOOTH ASPEN

Physical Properties	Sample Mean	Variation Between Bolt Diam. Classes	Variation Between Height Classes
M.C.[a] Green Wood	93.9%	NS	NS
M.C. Green Bark	71.9%	NS	**
Sp. Gr. Wood on Dry Vol. Basis	0.42	**	NS
Sp. Gr. Bark on Green Vol. Basis	0.60	NS	NS
Vol. Shrinkage of Wood	9.7%	NS	NS
Bark Volume[b]	13.4%	NS	*

NS.... Analysis of variance showed no significant differences between the means of the classes.

*..... An actual difference between the means of the classes was indicated at the 5% level.

**.... An actual difference was indicated at the 1% level.

[a]Moisture content.

[b]Expressed as a percent of the vol. of wood plus bark.

TABLE VII

RESULTS OF THE MULTIPLE REGRESSION, SPECIFIC GRAVITY OF WOOD THE DEPENDENT VARIABLE

Specific Gravity of Wood Y	Diam. of Bolts X_1	Rings Per Inch X_2	Ht. Above Ground X_3
Correlations of Y with X's	+.471	-.399	-.144
Standard Regressions of Y on X's	+.185	-.331	-.257

$$\hat{Y} = 0.465 + 0.004X_1 - 0.004X_2 - 0.001X_3$$

Standard Error of the Estimate = 0.036

Multiple Correlation Coefficient = 0.506

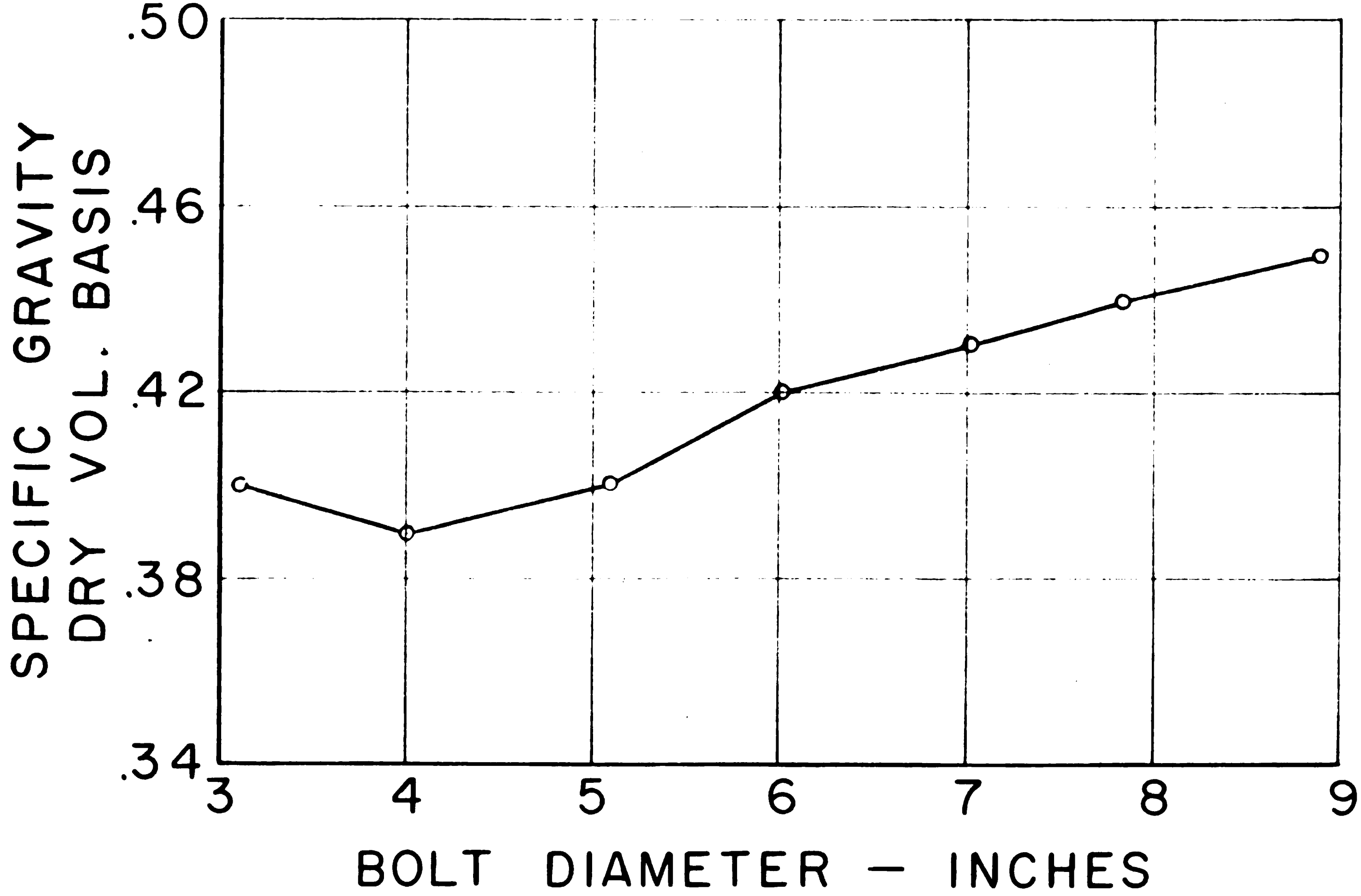

Fig. 2. Graph of the relation of specific gravity of wood on a dry volume basis to bolt diameter measured inside bark.

bark, and percent of shrinkage of wood. The extent of change of these variables will be considered first in order that the variations found in the conversion factors may be better understood.

The specific gravity of wood is an important element used in the formula for converting green volume to dry weight, and for this reason it was investigated with the aid of both analysis of variance and multiple correlation. See Table VI for the results of analysis of variance and Table VII for the results of the multiple correlation. Specific gravity based upon dry volume rather than green volume was used in the analysis of specific gravity in this work. This was done because weight per unit of dry volume was needed when computing the conversion factors.

Specific gravity was found to vary significantly between bolt diameter classes, but not between height classes. Figure 2 illustrates the increase of specific gravity with diameter. The increase of specific gravity with diameter could be partially due to differences in both the amount of heartwood and the growth rate. The percent of heartwood was somewhat more constant beween diameter classes than was the rate of growth. Heartwood varied only from 9 to 18 percent. Since the rate of growth varied from 6 rings per inch to 22 rings per inch this variable was investigated further. The correlation coefficient of bolt diameter and specific gravity was found to be slightly higher and opposite in sign than the correlation coefficient of rings per inch and specific gravity. Refer to Table VII.

The correlation indicated that the specific gravity increased with an increase in diameter, but decreased with an increase in the number of rings per inch. The standard error of the estimate for the multiple regression was found to be 0.036. This indicates that the regression formula does an adequate job of estimating the specific gravity. The multiple correlation coefficient of 0.506 was significant at the one percent level.

When considering the partial regression coefficient of rings per inch on specific gravity it is to be remembered that if ring width were used instead of rings per inch the regression coefficient would be positive in sign instead of negative. Paul (10) states that work at the United States Forest Products Laboratory on five species of the genus Populus indicates that there is a negative regression for ring width on specific gravity. The reason for this contradiction cannot be explained by the writer.

The average volumetric shrinkage of wood based upon green volume was found to be 9.7 percent. This figure did not vary significantly with either bolt diameter or height classes.

The percent of bark volume is the third important

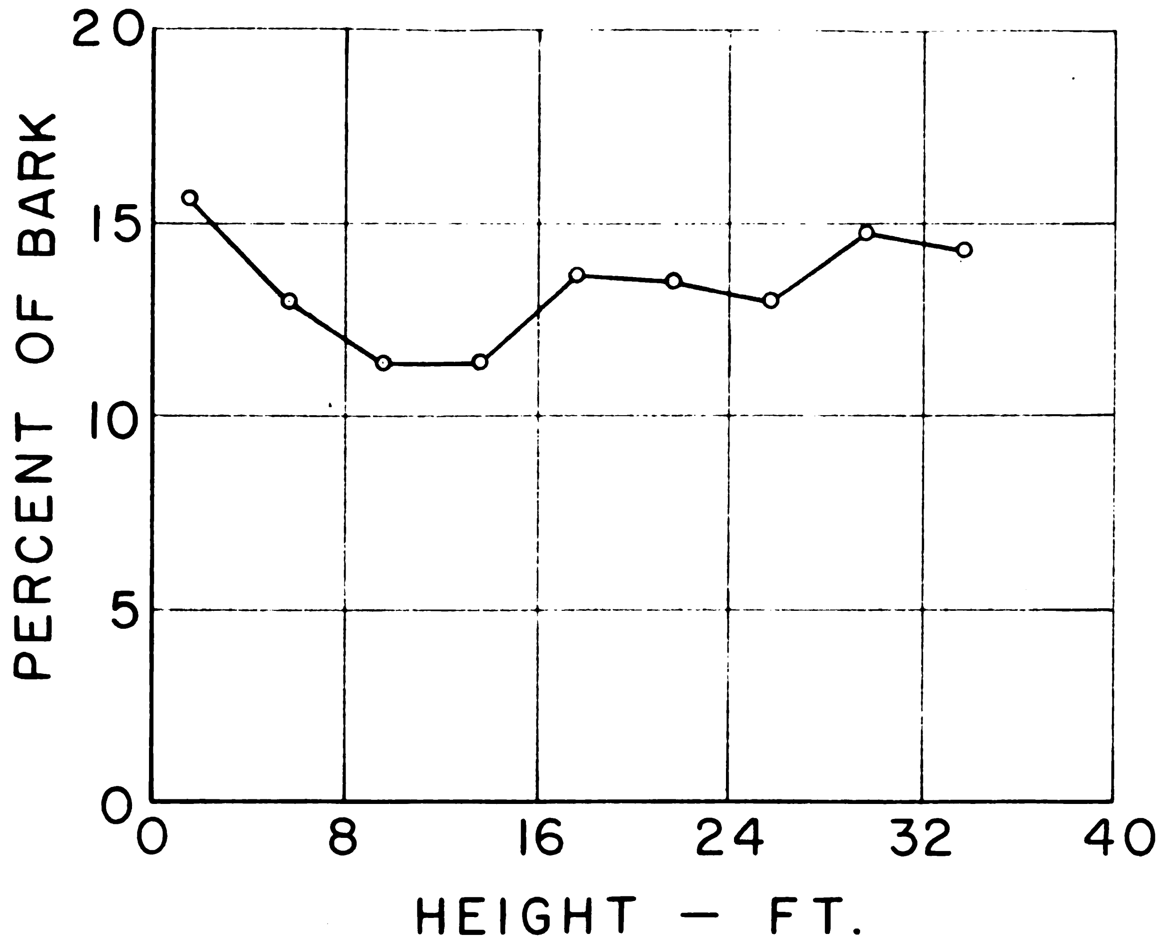

Fig. 3. Graph of the variation in the volume of green bark with height in the tree. Volume of bark is expressed as a percent of the volume of wood plus bark.

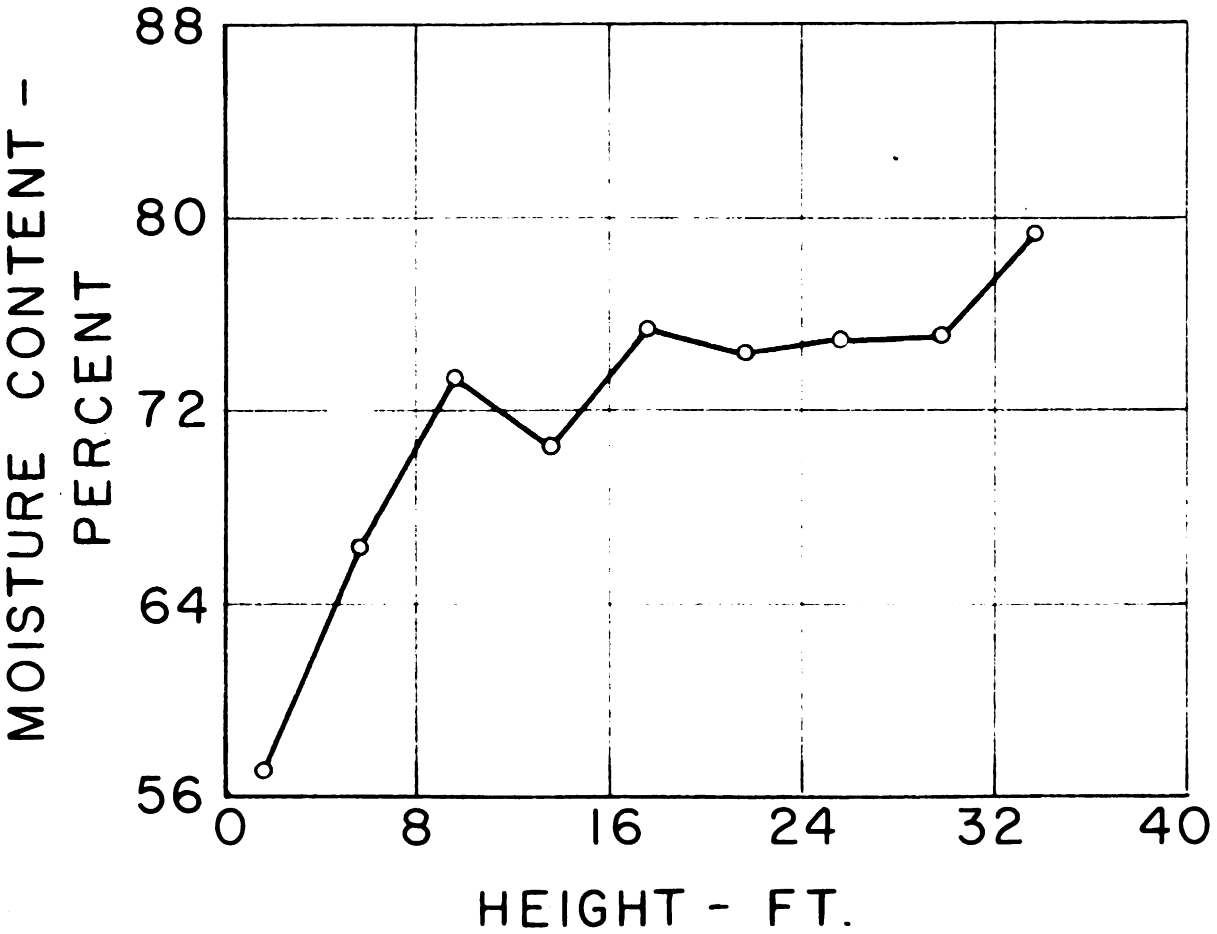

Fig. 4. Graph of the variation of moisture content of green bark with height in the tree.

TABLE VIII

SUMMARY OF THE RESULTS OF ANALYSIS OF VARIANCE ON CONVERSION FACTORS

Conversion Factors[a]	Sample Mean	Variation Between Bolt Diam. Classes	Variation Between Height Classes
CF-1	20.46	**	NS
CF-2	23.61	*	NS
CF-3	0.782	NS	NS
CF-4	0.903	NS	NS
CF-5	0.425	NS	NS

NS... Analysis of variance showed no significant difference between the means of the classes.

*.... An actual difference between the means of the classes was indicated at the 5% level.

**....An actual difference was indicated at the 1% level.

[a]See Table III for an explanation of conversion factors.

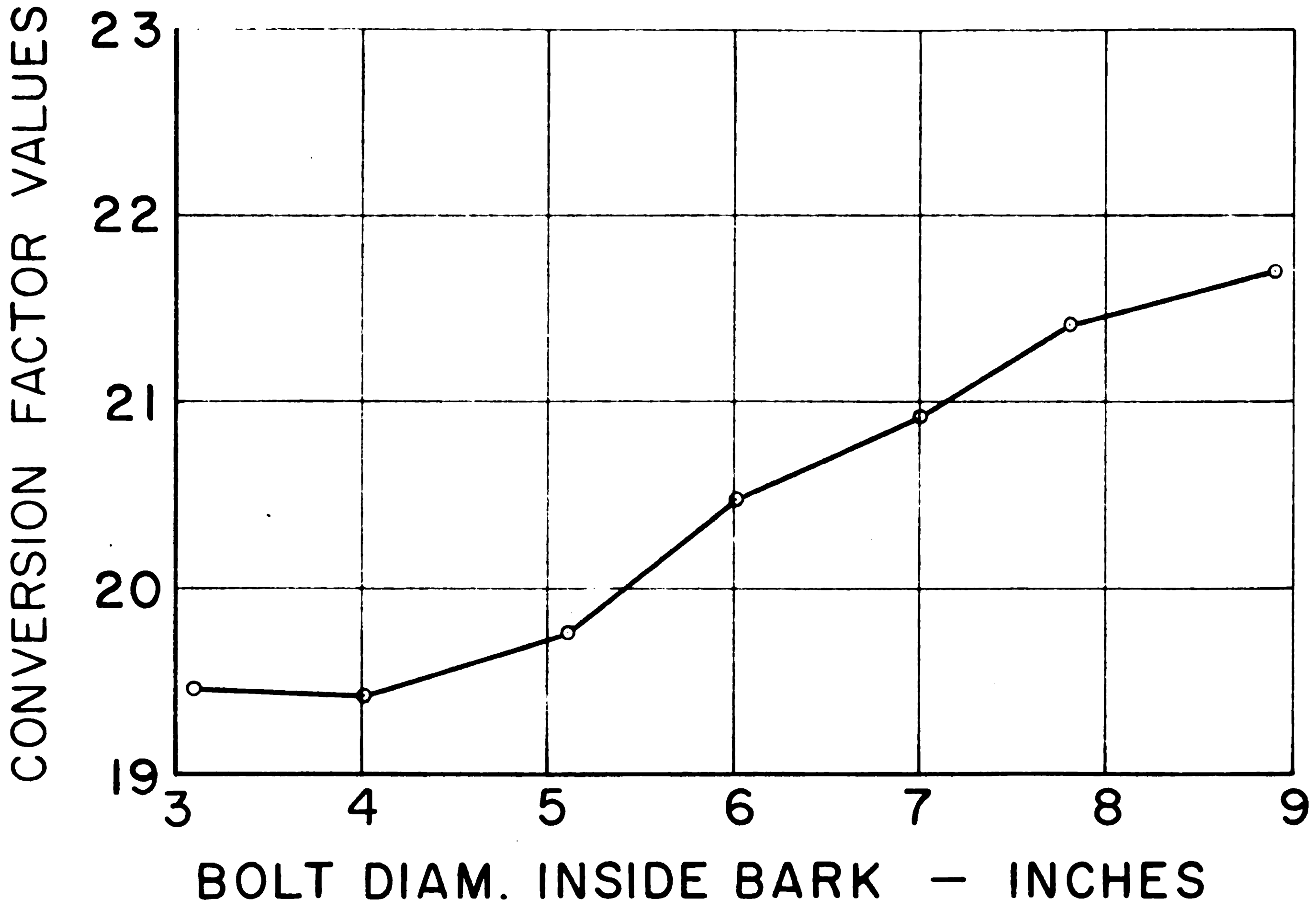

Fig. 5. Graph of the variation of conversion factor number one with bolt diameter.

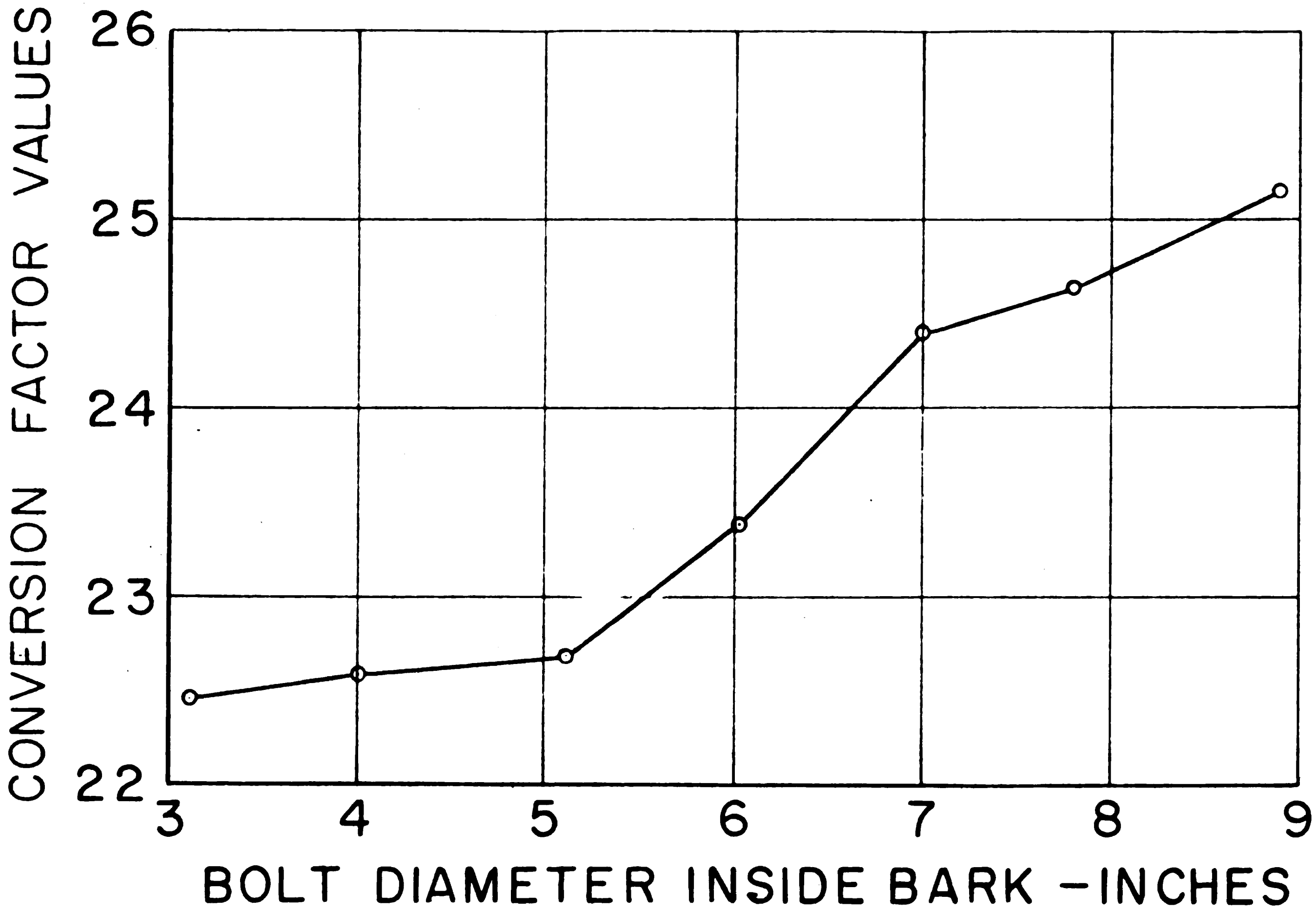

Fig. 6. Graph showing the variation of conversion factor number two with bolt diameter.

variable used in computing some of the conversion factors. The average percent of bark by volume in this sample was found to be 13.4 percent. The analysis of variance indicated that this value varied significantly with the height in the tree but not with the diameter of the bolts. This relationship is illustrated in Figure 3.

Several other physical properties of bigtooth aspen were investigated during this study, though these were not used in computing conversion factors. The specific gravity of bark averaged 0.60 on a green volume basis. This comparatively high specific gravity is an important consideration when comparing transportation costs of peeled and unpeeled wood. In this sample, while bark amounted to only 13.4 percent of the total volume of wood plus bark it amounted to 18.0 percent of the total green weight.

The average moisture contents of green wood and of green bark were also established, and were used in computing a factor used to convert from green weight to dry weight. An analysis of variance indicated no significant differences in the moisture content of the wood between the bolt diameter classes or the height classes. The average green moisture content of the wood, for all bolt diameters, was found to be 94 percent. A significant variation was indicated in the moisture content of the bark between the height classes. Figure 4 illustrates the increase in moisture content of bark with increased height in the tree.

This might be expected since in aspen rough bark is often found in the lower portion of the stem. The average green bark moisture content was 72 percent.

Findings Related to Conversion Factors

For discussion purposes the relationships between green weight or volume and dry weight or volume are considered under three headings. Table VIII contains the average value for each conversion factor and an indication of the variation with diameter and height. Figures 5 and 6 illustrate the variation of these relationships with bolt diameter classes in the cases where a statistically significant difference was indicated.

The first kind of relationship investigated was that between green volume and dry weight. This relationship was computed for both peeled and unpeeled boltwood, i.e., conversion factors number one and number two. The analysis of variance indicated that both of these factors differed significantly between diameter classes, but not between height classes.

This first kind of conversion factor can also be thought of as the number of pounds of dry wood in a cubic foot of green wood. It follows that as the specific gravity increases, as it has been found to do as bolt diameter increases, the factors number one and number two will also increase.

TABLE IX

WEIGHT AND VOLUME LOSSES OF FOUR-FOOT UNPEELED ASPEN BOLTS, SAMPLE A, OBSERVED UNDER GOOD AIR-DRYING CONDITIONS

Measurements From Sample A	No. of Days Elapsed Since Initial Measurement								
	0[a]	14	29	42	55	69	83	97	130
Total Wt. in Lbs.	3060	2931	2835	2746	2672	2598	2505	2448	2403
Total Vol. in Cu. Ft.	59.35	59.06	58.87	58.64	58.49	58.30	58.07	57.98	58.12
M.C. of Wood Plus Bark	90%	82%	76%	70%	65%	61%	55%	52%	49%
Cumulative Weight Loss[b]	---	4.2%	7.4%	10.3%	12.7%	15.1%	18.1%	20.0%	21.5%
Cumulative Volume Loss[c]	---	.48%	.82%	1.19%	1.44%	1.78%	2.16%	2.31%	2.07%

[a]Initial readings were taken on July 26, 1956.

[b]Expressed as a percent of the initial green weight.

[c]Expressed as a percent of the initial green volume.

TABLE X

WEIGHT AND VOLUME LOSSES OF FOUR-FOOT PEELED AND UNPEELED ASPEN BOLTS, SAMPLE B, OBSERVED UNDER GOOD AIR-DRYING CONDITIONS

PEELED BOLTS				
Measurements From Sample B	No. of Days Elapsed Since Initial Measurement			
	0[a]	12	27	41
Total Wt. in Lbs.	883	701	654	623
Total Vol. in Cu. Ft.	19.08	18.84	18.70	18.56
M.C. of Wood Plus Bark	98%	57%	46%	39%
Cumulative Weight Loss[b]	---	20.6%	26.0%	29.5%
Cumulative Volume Loss[b]	---	1.26%	1.97%	2.73%

UNPEELED BOLTS				
Measurements From Sample B	No. of Days Elapsed Since Initial Measurement			
	0[a]	12	27	41
Total Wt. in Lbs.	1075	1019	974	919
Total Vol, in Cu. Ft.	21.91	21.75	21.66	21.49
M.C. of Wood Plus Bark	95%	85%	76%	67%
Cumulative Weight Loss[b]	---	5.3%	9.4%	14.5%
Cumulative Volume Loss[b]	---	0.73%	1.12%	1.90%

[a]Initial readings were taken on June 21, 1957.

[b]Expressed as a percent of the initial green measurement.

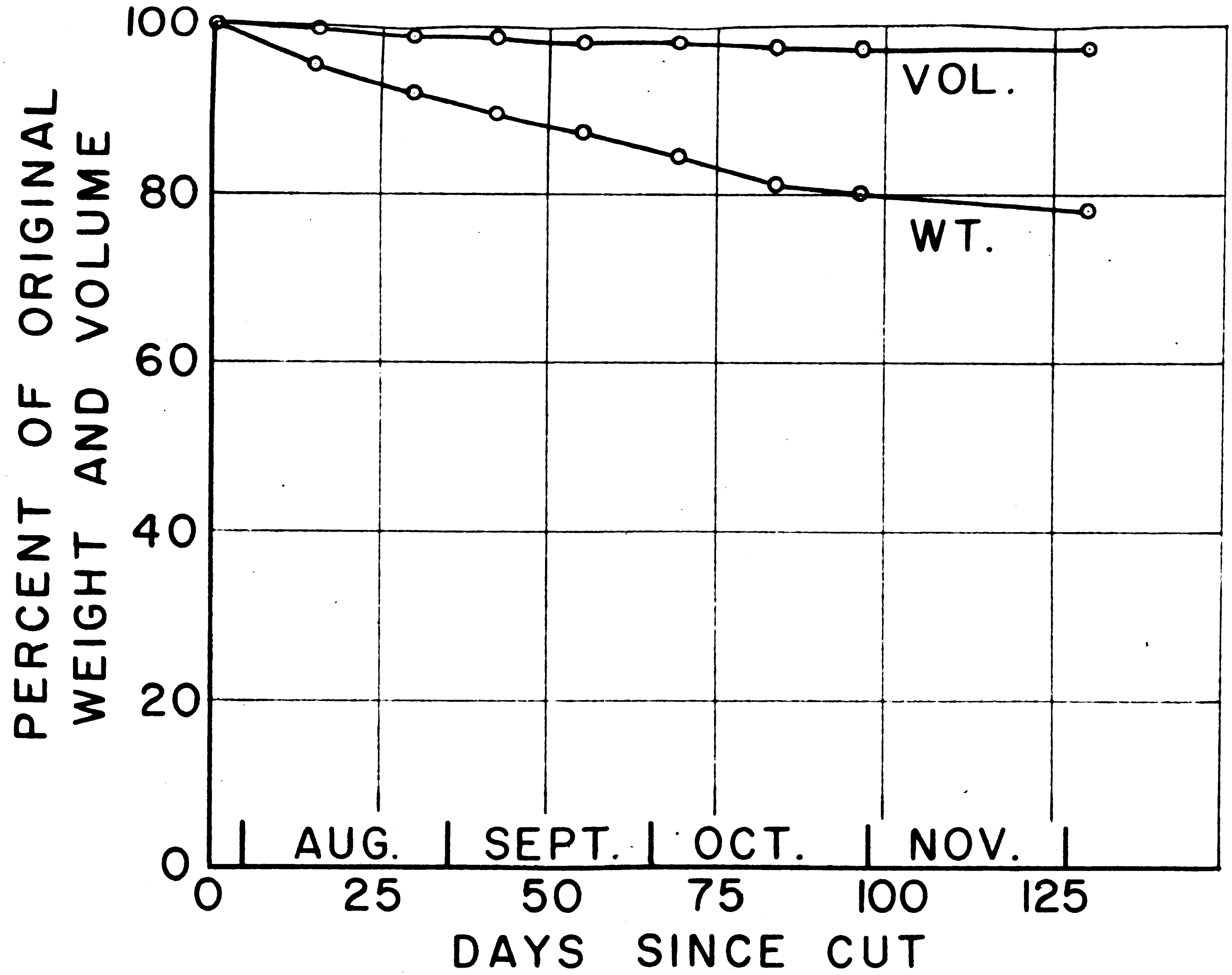

Fig. 7. Graph showing volume and weight losses of unpeeled aspen boltwood from sample A.

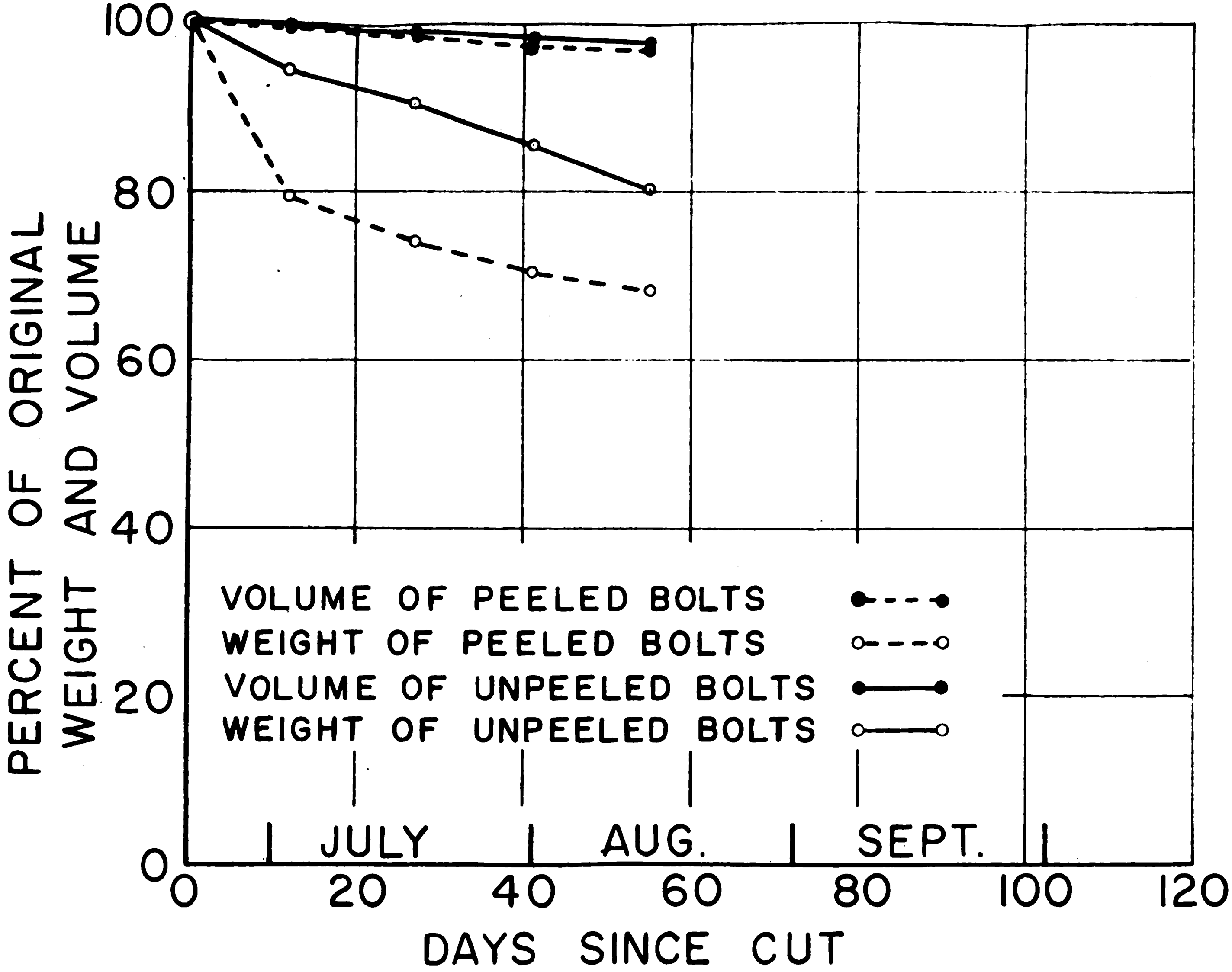

Fig. 8. Graph showing weight and volume losses observed in both peeled and unpeeled aspen bolts under good air-drying conditions. Data are from sample B.

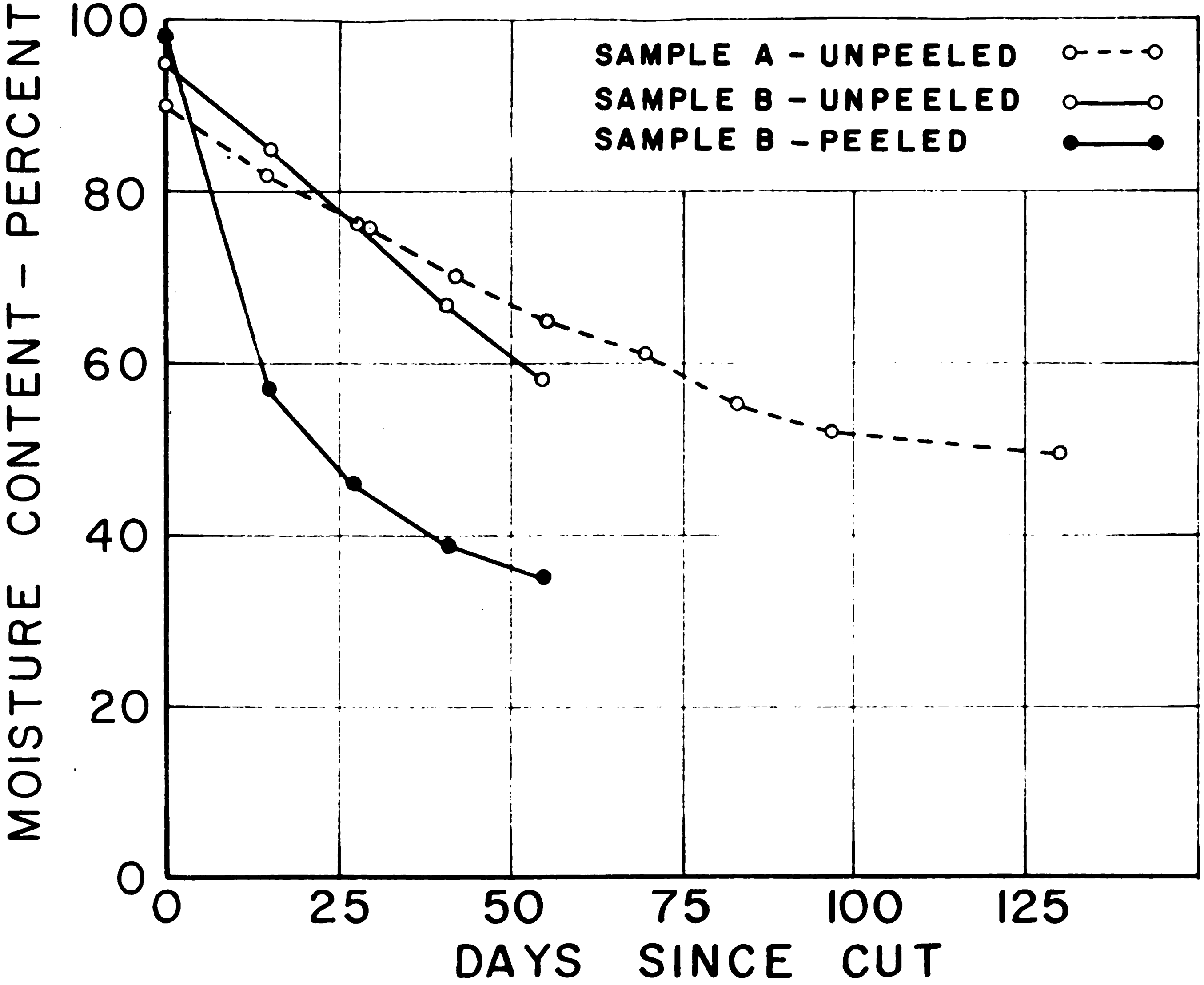

Fig. 9. Graph of the moisture content of peeled and unpeeled aspen bolts during air-drying in an exposed location.

The second kind of relationship investigated was that between green volume and dry volume. This factor was also divided into two types: (1) the relationship for unpeeled boltwood, i.e., conversion factor three, (2) the relationship for peeled boltwood, i.e., conversion factor four.

No significant differences in the means of factor number three or number four were indicated between bolt diameter or height classes. The hypothesis that the means are equal throughout these classes was thus accepted. Such a finding might be expected since neither percent of bark nor wood shrinkage were found to vary significantly with diameter. A significant difference was noted, however, in the percent of bark at different height classes. Wood shrinkage and bark volume were the only data used to compute factor number three. Wood shrinkage alone was used to compute factor four.

The last kind of relationship investigated was that between the weight of green wood plus bark and the dry weight of wood alone. Such a factor could be combined with the present practice of green weight measurement of boltwood to produce an estimate of the dry weight.

The reason for computing this last kind of factor was to see if such a relationship would be subject to variation with diameter and height. No statistically significant differences were noted between the means of the bolt

diameter or the height classes. Some of the variables used to compute this factor were found to vary with height or diameter, but when combined in this manner these did not produce a significant change in the factor from class to class. It is to be remembered that the moisture content of green wood is a variable used in the computation of this factor; and thus, any change in the moisture content will result in a change of the true conversion factor.

Drying Rates of Aspen Boltwood

The percent of weight and volume losses for sample A and sample B are presented in Table IX and Table X. These losses are illustrated in Figure 7 and Figure 8. The moisture content of the bolts during the drying period, including the bark for the unpeeled wood, is graphed in Figure 9.

The unpeeled bolts in sample A and sample B lost an average of 0.6 percent on volume and 4.7 percent in weight during the first two weeks of drying. After six weeks of drying these losses had increased to 12 percent of the original weight and 1.5 percent of the original volume. The differences in the drying rates between the unpeeled bolts in samples A and B can be attributed to the weather differences during the summers of 1956 and 1957, and also to the differences in the dates on which the samples were cut.

The loss in weight of the peeled bolts was considerably greater, for a given period of time, than that for the unpeeled bolts. In sample B the peeled bolts lost almost four times as much weight as the unpeeled during the first two weeks of drying. After six weeks the peeled bolt weight loss was only twice that of the unpeeled.

Volume loss in the peeled bolts was also higher than in the unpeeled, but not to the extent of the weight losses. During the first six weeks volume losses were found to be about 1.5 times as great for the peeled wood as for the unpeeled. It should be noted that after one month of drying the peeled stock had lost only about 2 percent of the original volume.

As previously described, the conditions under which these losses were recorded were such that approximately maximum air-drying rates prevailed. In most locations in Michigan the decreases in weight and volume in boltwood would likely be less that the decreases observed in this study.

IV. DISCUSSION

All data used in the calculation of conversion factors were obtained from one site and from one age group. The conversion factors as determined in this study can, therefore, be assumed to apply exactly only under similar conditions. Further study is necessary to determine if these relationships hold for other age groups and other sites. Age is probably of less importance in Michigan than is site, since most merchantable aspen in Michigan is found in age groups not too far different from that of the sample. Some inferences can be drawn regarding variation in conversion factors on other sites from the information obtained in this study and from other available data.

The volume measurements obtained by displacement can be converted to either volume or weight at any desired moisture content as dictated by the moisture content of the final product. In most cases estimated weight will give more information about yield of the final product than will the estimated volume; but in some cases the yield of boltwood expressed as volume may be desired.

In this study the ratio of dry volume to green volume remained constant throughout the height and bolt diameter classes. This means that an organization purchasing aspen boltwood on a dry volume basis, as established by displacement, could expect to receive the same dry volume per dollar regardless of whether the bolts purchased averaged four inches or nine inches in diameter. Therefore, on a dry volume basis the unit cost can be considered essentially constant if all bolts are cut from approximately the same site.

The weight of dry wood in a cubic foot of green bigtooth aspen was found to increase with an increase in bolt diameter and also with an increase in the growth rate. Therefore, a company purchasing aspen on a dry weight basis, as computed from the displaced water volume using the average factor, could expect to receive more dry wood per dollar when buying larger diameter or more rapidly grown material. A more nearly constant unit cost could be maintained if the conversion factor corresponding to the average diameter of bolts in the shipment were used to compute the dry weight. The variation of dry weight due to diameter and growth rate could be expected to be similar on other sites, though the average conversion factor would be subject to change from that presented in this work.

An example will illustrate the differences that could occur in the amount paid for a unit of boltwood based upon dry weight as computed using the average conversion factor, and that computed using the factor corresponding to the average bolt diameter of the shipment. Assume that 10,000 cubic feet of green unpeeled aspen averaging nine inches in diameter is purchased for 30 cents per hundred pounds. Using the average conversion factor of 20.46 the weight of dry wood is estimated as 204,600 pounds. Using the conversion factor for nine-inch bolts of 21.71 the dry wood is estimated to weigh 217,100 pounds.

In this example the amount to be paid as determined by use of the average conversion factor would be $614, as compared to $651 for the amount computed using the factor for the actual bolt diameters. This represents a difference of about 6 percent. In this example it is well to recognize that the dry weight computed from the factor for average actual diameter is a better estimate of the actual dry weight than is the weight from the average factor, though it is not necessarily the true dry weight.

When comparing weight and water displacement as ways to estimate the amount of dry wood in boltwood, the change in these values due to drying prior to measurement is an important consideration. As an illustration, assume that a unit of unpeeled boltwood when freshly cut would sell for $16.00 whether sold by green weight or by volume from displacement. After six weeks of drying under conditions as described for sample A, this wood would bring $15.81 if sold by volume, as determined by displacement, and only $14.36 if sold by weight. After eighteen weeks this unit would bring $15.66 if sold by volume and only $12.56 if sold by weight.

When buying by weight the unit cost of dry wood substance would be subject to considerable variation with changes in the length of time from cutting until weighing. It is to the buyer's advantage to buy wood that is partially dried unless the buyer prefers green wood due to the nature of the manufacturing process. Jeffords (6) points out that where green wood is preferred, buying by weight has the advantage of encouraging producers to haul when green.

As has just been illustrated, the price set by the displacement method does decrease slightly as the elapsed time between cutting and measurement increases. If peeled bolts were used in the preceding example rather than unpeeled bolts the price based on volume after six weeks would be $15.56 rather than $15.81. Both of these losses can be considered slight when compared to those of the price as set by weight measure.

When comparing the accuracy of displacement and green weight as means of establishing the dry wood content of aspen boltwood two points are of primary importance. The first is that changes in the estimate due to drying losses are much greater for the green weight system. A maximum change during one month for the displacement method would be about 2 percent, while for the weight method the change could amount to 30 percent.

The second point is that the estimate of dry wood content made from the green weight will change with variations in the moisture content of the green bolts. This moisture content is known to vary up to 30 percent between different seasons of the year. Moisture content has no effect upon the estimate made from the volume of displaced water.

The design and construction of a displacement tank for use by industrial or research organizations is beyond the scope of this work. A brief description of such a tank would, however answer the question of what equipment is needed. A simple rectangular tank large enough to accommodate one or two cords should be practical for use at one-machine particle board plants. The sight gauge used should preferably be fitted with a vernier scale reading to 32nds or 64ths of an inch, or could be calibrated to read directly in cubic feet. In a ten foot square tank a one-inch displacement of water would indicate 8.3 cubic feet of boltwood. Loading and unloading of the displacement tank could be performed by cranes or power hoists already available at most plants.

V. CONCLUSION

Boltwood is ordinarily measured by either cord or weight methods. The price paid for wood under these methods is determined by the quantity of wood, bark, water, and sometimes air in terms of these units of measure. The water displacement technique can be used to determine the amount of dry wood in terms of weight or volume in green boltwood. Therefore, by use of this technique purchases can be based not upon an arbitrary quantity, but upon the amount of wood that will actually be used in the manufacturing process. Information pertaining to the actual amount of wood substance being used in a process would prove helpful in both research on yields from various processes and to industry when establishing standards as methods of control.

The factors used to convert green volume to dry weight and to dry volume have been determined in this work for bigtooth aspen from one site classification. Further study is necessary to determine if these factors are the same for aspen from other sites and for other age classes. The ratio of dry volume to green volume remained constant for both peeled and unpeeled bolts despite changes in both bolt diameter and the height in the trees from which the bolts were cut.

The ratio of dry weight to green volume would logically increase with an increase in the specific gravity of the wood. On the site studied, specific gravity of wood increased with increases in diameter and in growth rate. Average conversion factors were computed for each diameter class. These can be used to give a more accurate estimate of the dry weight present than would be obtained by the use of just one factor for all diameters.

Green weight measurements can also be used to estimate dry weight by the use of conversion factors. Such a system is impractical when an accurate estimate is desired due to the wide variation of the moisture content during the year, and also due to the rapid change in the conversion factor when the bolts are subjected to drying.

APPENDIX A. STATISTICAL TABLES

TABLE XI

COMPUTATION OF CORRELATION COEFFICIENTS AMONG FOUR MEASUREMENTS OF BIGTOOTH ASPEN

		Diam. of Bolt Inside Bark X_1	Rings Per Inch X_2	Height Above Ground X_3	Sp. Gr. of Wood on Dry Vol. Basis Y
Sum		378.1	702.6	1076	26.45
Mean		6.00	13.75	17.08	.419
X_1	SX^2, etc.	2508.710	3836.380	6438.300	161.131
	Correction	2269.200	4216.710	6457.707	158.741
	Sx^2, etc.	239.510	-380.330	-19.407	2.390
	$\sqrt{Sx^2}$, etc.	15.476	445.555	1283.370	5.074
	r's		-.854	-.015	.471
X_2	SX^2, etc.		8664.520	11165.900	291.217
	Correction		7835.663	11999.961	294.980
	Sx^2, etc.		828.857	-834.061	-3.763
	$\sqrt{Sx^2}$, etc.		28.790	2387.400	9.439
	r's			-.349	-.399
X_3	SX^2, etc.			25254.000	445.820
	Correction			18377.396	451.749
	Sx^2, etc.			6876.604	-3.929
	$\sqrt{Sx^2}$, etc.			82.925	27.189
	r's				-.144
Y	SY^2				11.2123
	Correction				11.1048
	Sy^2				.1075
	$\sqrt{Sy^2}$				.328

TABLE XII

ANALYSIS OF VARIANCE OF SPECIFIC GRAVITY OF WOOD ON A DRY VOLUME BASIS

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	.0274	6	.00457	3.44**	2.30	3.20
Height	.0153	8	.00191	1.44	2.14	2.90
Error	.0638	48	.00133			
Total	.1065	62				

ANALYSIS OF VARIANCE OF THE MOISTURE CONTENT OF GREEN HEARTWOOD AND SAPWOOD COMBINED

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	2783.3	6	463.88	2.10	2.30	3.20
Height	1721.6	8	215.20	.97	2.14	2.90
Error	10627.8	48	221.41			
Total	15132.7	62				

TABLE XIII

ANALYSIS OF VARIANCE OF THE PERCENT OF WOOD SHRINKAGE TO AN OVEN-DRIED CONDITION

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	32.94	6	5.49	2.21	2.30	3.20
Height	8.21	8	1.03	.42	2.14	2.90
Error	119.02	48	2.48			
Total	160.17	62				

ANALYSIS OF VARIANCE OF THE RATIO GREEN BARK VOLUME OVER VOLUME OF WOOD AND BARK

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	26.80	6	4.47	.87	2.30	3.20
Height	106.54	8	13.32	2.59*	2.14	2.90
Error	247.16	48	5.15			
Total	380.50	62				

*Indicates significance at the 5% level.

TABLE XIV

ANALYSIS OF VARIANCE OF THE MOISTURE CONTENT OF GREEN BARK

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	285.91	6	47.65	.98	2.30	3.20
Height	2394.61	8	299.33	6.13**	2.14	2.90
Error	2343.25	48	48.82			
Total	5023.77	62				

ANALYSIS OF VARIANCE OF CONVERSION FACTOR NUMBER THREE[a]

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	.005	6	.0008	1.33	2.30	3.20
Height	.008	8	.0010	1.67	2.14	2.90
Error	.030	48	.0006			
Total	.043	62				

[a]See Table III for explanation of conversion factor.

**Indicates significance at the 1% level.

TABLE XV

ANALYSIS OF VARIANCE OF CONVERSION FACTOR NUMBER ONE[a]

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	47	6	7.80	3.79**	2.30	3.20
Height	23	8	2.[illegible]	1.41	2.14	2.90
Error	9[illegible]	48	2.06			
Total	169	62				

ANALYSIS OF VARIANCE OF CONVERSION FACTOR NUMBER FOUR[a]

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	.0034	6	.00057	2.28	2.30	3.20
Height	.0009	8	.00011	.44	2.14	2.90
Error	.0119	48	.00025			
Total	.0161	6[illegible]				

[a] See Table III for explanation of conversion factors.

**Indicates significance at the 1% level.

TABLE XVI

ANALYSIS OF VARIANCE OF CONVERSION FACTOR NUMBER TWO[a]

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	67.24	6	11.207	3.00*	2.30	3.20
Height	52.10	8	6.513	1.74	2.14	2.90
Error	179.19	48	3.733			
Total	298.53	62				

ANALYSIS OF VARIANCE OF CONVERSION FACTOR NUMBER FIVE[a]

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.05}$	$F_{.01}$
Diameter	.0060	6	.0010	1.05	2.30	3.20
Height	.0112	8	.0014	1.47	2.14	2.90
Error	.0459	48	.00095			
Total	.0631	62				

[a]See Table III for explanation of conversion factors.

*Indicates significance at the 5% level.

APPENDIX B. DETERMINATION OF CONVERSION FACTORS USED TO ESTIMATE THE WEIGHT AND VOLUME AT ANY MOISTURE CONTENT

The conversion factors presented in this work can be changed in such a way as to be used to estimate the amount of wood, by weight and volume, present at moisture contents other than zero percent. In the formulas used to compute factors for conversion to dry volume, i.e., factor number three and number four, only the percent of shrinkage portion needs to be changed from that shown in the formulas in Table III. The percent of shrinkage to zero percent moisture content is multiplied by $\frac{30 - M}{30}$ to give the percent of shrinkage at the moisture content in question. M represents this moisture content.

When computing factors to convert green volume to the weight at moisture contents other than zero percent, the shrinkage portion and the specific gravity portion of the formulas for factors number one and number two must be changed. The factor must then be multiplied by one plus the moisture content to allow for the weight of the additional water.

The specific gravity on a basis of volume at zero percent moisture content can be changed to specific gravity at other moisture contents by use of the formula;

$Sm = \frac{Sd}{1 + (.009)(Sd)(M)}$ where Sd represents the specific gravity on a basis of volume at zero percent moisture content, and Sm represents the specific gravity on a basis of the volume at the desired moisture content. This formula is explained by Brown, Panshin, and Forsaith (1).

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