CALCULATIONS OF THE VOID VOLUME IN WOOD

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Abstract

A general equation is given for the calculation of the fractional void volume of wood at any moisture content from the specific gravity of the wood, the true specific gravity of wood substance (average value 1.46), and the specific gravity of the adsorbed water. At moisture-content values corresponding to the fiber-saturation point and above, the generally used equation involving the apparent specific gravity of wood substance obtained by water displacement (average value 1.53) can be used, but this equation gives false results below the fiber-saturation point. The values for the fractional void volume vary almost linearly with the moisture content below as well as above the fiber-saturation point, but the two portions of the curve have different slopes.

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Calculations of the void volume of wood in seasoning, preservation, and other treating studies have in the past been made, using values for the specific gravity of wood substance obtained from water or aqueous solution displacement measurements. These values can be satisfactorily used when the moisture content of the wood is at the fiber-saturation point[2] or above, but lead to false results at lower moisture-content values. The apparent specific gravity of wood substance determined in water should not be used in conjunction with the dry weight-dry volume specific gravity as Kollmann (5) has done if accurate results are desired. The reason for this is that water displacement does not give a true measure of the specific gravity of wood substance, due to the fact that water is so strongly adsorbed within the wood structure that it becomes compressed on the wood surface (7, 9). Measurements of the specific gravity of wood substance in aqueous systems will thus be too high. Helium displacement measurements, on the other hand, give what appears to be a true measure of the specific gravity of wood substance (9), being nonadsorbed (1, 4) and the molecules being sufficiently small to penetrate the void volume completely.

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[2] The moisture content at which the cell walls are saturated, but no free water exists in the grosser capillary structure, which for most woods is approximately 30 percent by weight of the dry wood.

The recently obtained helium displacement value for the specific gravity of white spruce wood substance, 1.46, will be used in the following calculations, as well as the apparent specific gravity of white spruce wood substance, 1.53, obtained from water displacement measurements (9). The specific gravity of wood substance varies slightly with variations in the species of wood. Stamm (7) obtained values for the apparent specific gravity of wood substance varying from 1.51 to 1.55 for nine different species from water displacement measurement. Dunlap (2) obtained values varying from 1.50 to 1.56 for seven species from aqueous salt solution displacements. The average of these, 1.53, is identical with the above white spruce value and is recommended for use in general calculations where the apparent specific gravity of wood substance is applicable. European investigators have, in general, used 1.56 as an average value which they have taken from the old measurements of Sachs (6) and Hartig (3). This value, however, seems a little high in the light of the more recent measurements (2, 7).

The fractional part of the total volume of wood that is made up of voids, V_f, can be calculated from the general formula

$$V_f = 1 - g\left(\frac{1}{g_o} + \frac{m_s}{\rho_s} + \frac{m}{\rho}\right) \tag{1}$$

in which g is the specific gravity of the wood on a dry weight and volume at the current moisture content basis, g_o is the true specific gravity of the wood substance, m_s is the adsorbed moisture content in grams per gram of dry wood (the moisture content at or below the fiber-saturation point), m is the free moisture content (the moisture in excess of the fiber-saturation point), ρ_s is the average density of the adsorbed water, and ρ is the normal density of water at the temperature of the measurements.

The density of the adsorbed water at the fiber-saturation point can be calculated from the difference between the reciprocals of the true specific gravity of wood substance, g_o, and the apparent specific gravity of wood substance determined in water, g_a. This difference, 0.031 cc, represents the contraction occurring in the water adsorbed on a gram of wood. The average density of the adsorbed water at the fiber-saturation point is thus

$$\rho_s = \frac{m_s}{\frac{m_s}{\rho} - \left(\frac{1}{g_o} - \frac{1}{g_a}\right)} \tag{2}$$

which gives a value of $\rho_s = 1.113$ for $m_s = 0.30$ at 25° C. Values of ρ_s for lower moisture-content values are plotted in figure 1 against the moisture content. These values were calculated from the adsorption-compression data given by Stamm and Seborg (10) and Stamm and Hansen (9).

The fractional void volume of wood at or above the fiber-saturation point can be calculated from the following equation as well as from equation (1):

$$V_f = 1 - g\left(\frac{1}{g_a} + \frac{m_s + m}{\rho}\right) \tag{3}$$

In this case the compression of the adsorbed water is disregarded in the second term in the parenthesis by assuming that $\rho_s = \rho$. It is accounted for, however, by substituting g_a for the true density of wood substance, g_o. The equality of equations (1) and (3) at or above the fiber-saturation point can be demonstrated by substituting equation (2) in equation (1).

To illustrate the change in void volume with changes in moisture content the specific case of a western white pine specimen with a specific gravity on a swollen-volume basis of 0.365 and on dry-volume basis of 0.405 will be considered. This particular specimen upon slow drying to the oven-dry condition to avoid stresses gave a volumetric shrinkage of 9.5 percent on the external dimension basis. The shrinkage measurements also gave a fiber-saturation point of 0.29 (8). Considering the shrinkage directly proportional to the moisture lost (8) values of g for different moisture-content values below saturation were calculated. Using these values of g and values of ρ_s taken from figure 1, the fractional void volumes were calculated for different moisture-content values below the fiber-saturation point, using equation (1). These values, together with those for higher moisture-content values, are plotted in figure 2. The fractional void volume is shown to vary almost linerarly with moisture content below as well as above the fiber-saturation point, but the two portions of the curve have different slopes. Because of the nonlinear relationship between the specific gravity of the adsorbed moisture and the moisture content (fig. 1) the fractional void volume-moisture content relationship is not strictly linear below the fiber-saturation point. The deviation is just detectable on the scale on which figure 2 is drawn only for very high specific gravity woods. It is thus possible in calculations of the fractional void volume of wood over the whole moisture-content range to use equation (1) only for dry wood, in which case all but the first parenthesis term drops out and consider the relationship between V_f and m_s linear up to the fiber-saturation point, above which equation (3) can be used.

In an earlier publication (8) it was shown that the fiber cavities of wood show only a very slight change in cross section when the wood shrinks and swells under stress-free conditions. This can be further demonstrated by void volume calculations. The fractional void volume of the western white pine at the fiber-saturation point, 0.652, is increased to 0.723 when the wood is oven dried. When the latter value is referred to the green volume rather than the dry volume by correcting for the external dimensional shrinkage of 9.5 percent, in order to put the value on the basis of the same number of fibers as for the green wood, a value of 0.652, which is identical to the value for green wood, is obtained.

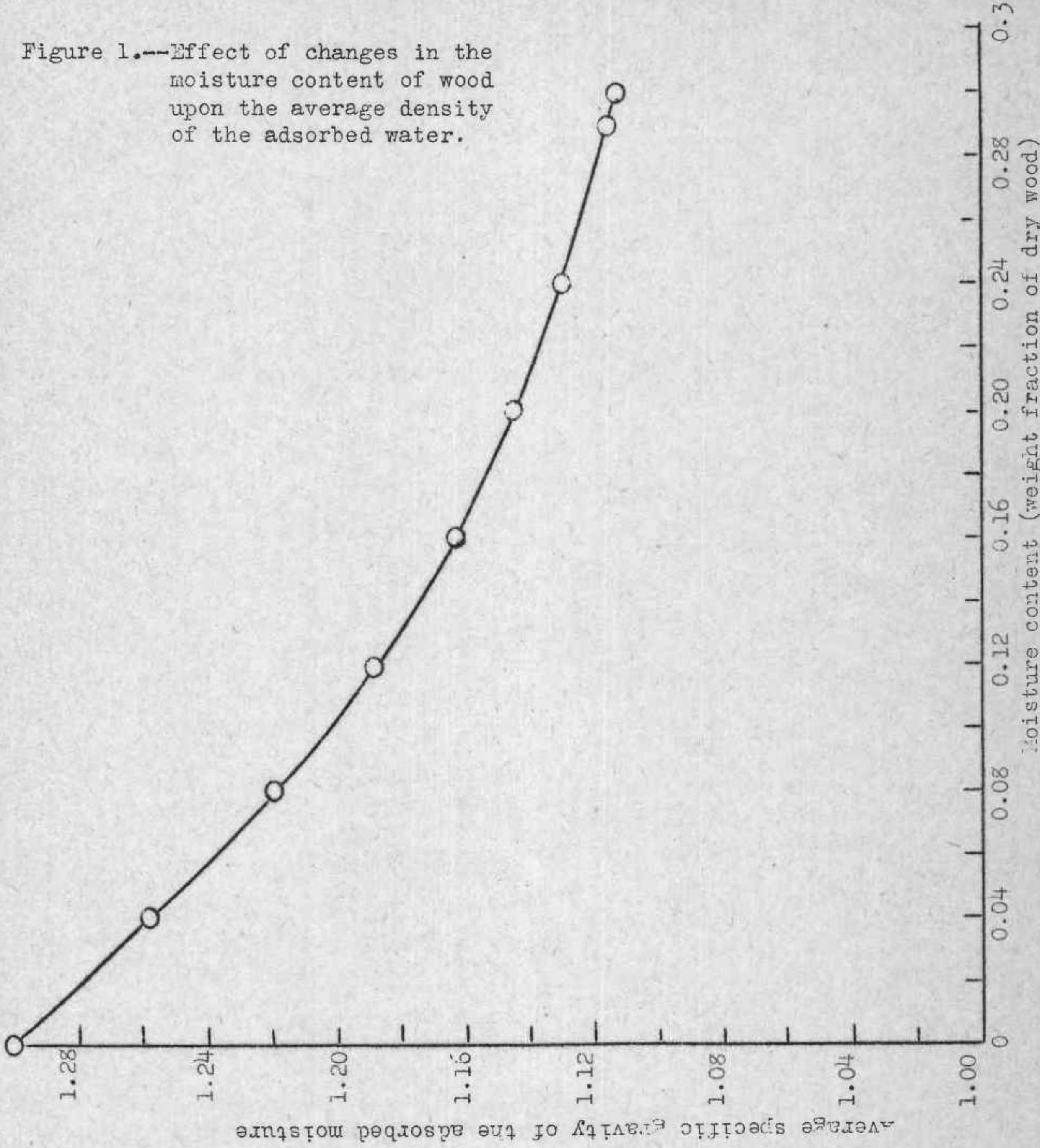

Figure 1.--Effect of changes in the moisture content of wood upon the average density of the adsorbed water.

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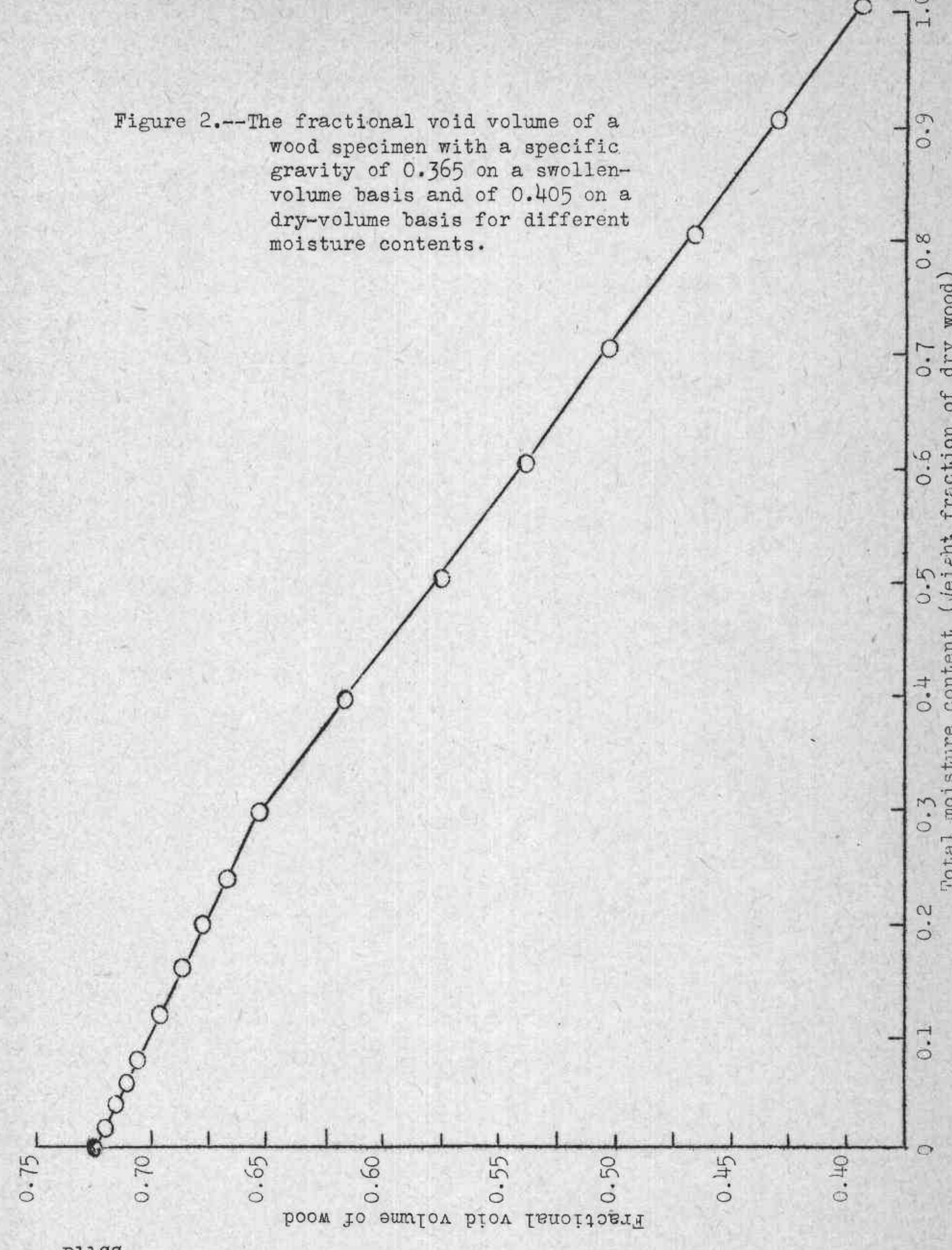

Figure 2.--The fractional void volume of a wood specimen with a specific gravity of 0.365 on a swollen-volume basis and of 0.405 on a dry-volume basis for different moisture contents.

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Literature Cited

1. Davidson, G. J. J. Text. Inst. 18:T175 (1927).

2. Dunlap, F. Jour. Agric. Research 2:423 (1914).

3. Hartig, R. Untersuch. Forestbott. Inst., München 2:112 (1882).

4. Howard, H. C. and Hulett, G. A. Jour. Phys. Chem. 28:1082 (1924).

5. Kollmann, F. Z. Ver Deut. Ing. 78:1399 (1934).

6. Sachs, J. Arb. Bot. Inst., Würzburg 2:291 (1879).

7. Stamm, A. J. Jour. Phys. Chem. 33:398 (1929).

8. Stamm, A. J. Ind. Eng. Chem. 27:401 (1935).

9. Stamm, A. J. and Hansen, L. A. Jour. Phys. Chem. 41:1007 (1937).

10. Stamm, A. J. and Seborg, R. M. Jour. Phys. Chem. 39:133 (1935).