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SPECIFIC HEAT OF WOOD--FURTHER RESEARCH REQUIRED TO OBTAIN MEANINGFUL DATA

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The specific heat of wood is an important physical property, especially in the areas of wood drying, fire performance of wood, and other applications relating to heat transfer. Unfortunately, inadequacies are apparent in the information available on specific heat of wood. Hopefully this discussion will suggest caution in using the published values as well as stimulate a further examination of this property.

Information on the specific heat of wood over the temperature range of 0° to 100° C. is scant. One of the most accessible references (7)[1] reports a value of 0.42 for the specific heat of wood without specifying the temperature or moisture content. Data covering the higher ranges of temperature, particularly with regard to pyrolysis and charring are simply not available.

[1]Underlined numbers in parentheses refer to Literature Cited at the end of the Note.

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The term "specific heat" is commonly used interchangeably with heat capacity and thermal capacity. Thermal capacity and heat capacity are generally considered synonomous. Specific heat is the ratio of the heat capacity of a substance to that of water at 15° C. Since the heat capacity of water at this temperature is unity, heat capacity and specific heat are numerically equivalent.

The mean heat capacity, or less accurately but more commonly, the mean specific heat, $\bar{c}$, is defined by

$$\bar{c} = \frac{\Delta q}{\Delta T} \qquad (1)$$

where q = heat energy, cal/g
T = temperature, °C

Tests on wood are usually performed at constant pressure. In this case, the mean specific heat at constant pressure, $\bar{c}_p$, is

$$\bar{c}_p = \frac{\Delta q_p}{\Delta T} = \left(\frac{\Delta H}{\Delta T}\right)_p \qquad (2)$$

where H = enthalpy.

The mean specific heat at constant volume, $\bar{c}_v$, is defined by

$$\bar{c}_v = \frac{\Delta q_v}{\Delta T} = \left(\frac{\Delta E}{\Delta T}\right)_v \qquad (3)$$

where E = internal energy.

The relation between $\bar{c}_p$ and $\bar{c}_v$ for wood-composite materials requires an empirical evaluation (17) and will not be discussed further.

The true specific heat at constant pressure, c_p, is found in the limiting case where

$$c_p = \lim_{\Delta T \to 0} \left(\bar{c}_p\right) = \lim_{\Delta T \to 0} \left(\frac{\Delta H}{\Delta T}\right)_p \qquad (4)$$

giving

$$c_p = \left(\frac{\partial H}{\partial T}\right)_p \qquad (5)$$

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Both equations (2) and (5) may be considered as definitions and therefore identities.

Equation (5) may be integrated to give

$$\Delta H = \int_{T_o}^{T_1} c_p \, dT \tag{6}$$

but, from equation (2), $\Delta H = \bar{c}_p \Delta T$,

and

$$\bar{c}_p = \frac{1}{\Delta T} \int_{T_o}^{T_1} c_p \, dT \tag{7}$$

which relates the mean and true specific heat over the finite interval of $\Delta T = T_1 - T_o$ where $T_1 > T_o$.

Dunlap (4) and Volbehr[2] both assumed a linear relationship between c_p and T for wood in the form of

$$c_p = A + BT \tag{8}$$

where T is temperature in degrees Centigrade.

Inserting equation (8) into equation (7) and integrating,

$$\bar{c}_p = \frac{1}{\Delta T}\left[\frac{A\Delta T + B\left(T_1^{\,2} - T_o^{\,2}\right)}{2}\right]$$

or

$$\bar{c}_p = A + \frac{B}{2}(T_1 + T_o) \tag{9}$$

(when $\Delta T \rightarrow 0$, the above equation reduces to equation (8)).

If a reference temperature of 0° C. is used, equation (9) reduces to

$$\bar{c}_p = A + \frac{BT_1}{2} \tag{10}$$

[2] Volbehr, B. Swelling of wood fibers. Doctoral thesis, Kiel. 1896.

The equation widely used for the relation of the true specific heat with temperature for ovendry wood is that determined by Dunlap (4):

$$c_p = 0.266 + 0.00116T \quad (11)$$

where T = temperature over the interval of $T_o = 0°$ C. to $T_1 = 100°$ C. A wood sample undergoing a temperature change of T_o to T_1 where $T_o \neq 0°$ C. has a mean specific heat in this range of

$$\bar{c}_p = 0.266 + 0.00058\ (T_1 + T_o) \quad (12)$$

If $T_o = 0°$ C. the equation reduces to

$$\bar{c}_p = 0.266 + 0.00058T_1 \quad (13)$$

Dunlap's equation was based on the data points shown in figure 1, where the point at 106° C. was the mean value of 100 samples. Dunlap found no correlation between specific heat and temperature over the range of 100° to 112° C. and determined a mean value of 0.327 for this range. All other points shown are for single samples. Obviously the fit of the curve is not particularly satisfactory. However, Dunlap ackowledged that this correlation of specific heat with temperature was a preliminary investigation which included errors in transferring the ovendry samples to the Bunsen ice calorimeter used, and he stated: "The values given are subject to correction when a large number of runs from different temperatures have been made. They are advanced at the present time merely to set forth the best knowledge at hand."

Apparently unknown to Dunlap, a previous work relating the mean specific heat of wood fibers to temperature and moisture content had been completed in 1896 by Volbehr[2]:

$$\bar{c}_p = 0.2590 + 0.000975m + 0.000605T_1 + 0.000015mT_1 \quad (14)$$

where T_1 is the endpoint temperature over the range of 0° to 100° C. and m = 0 to 27 percent moisture content.

When m = 0,

$$\bar{c}_p = 0.2590 + 0.000605T_1 \quad (15)$$

which is remarkably similar to Dunlap's equation. Volbehr's equation is compared with Dunlap's (modified to the equation (12) format) in figure 1. In both

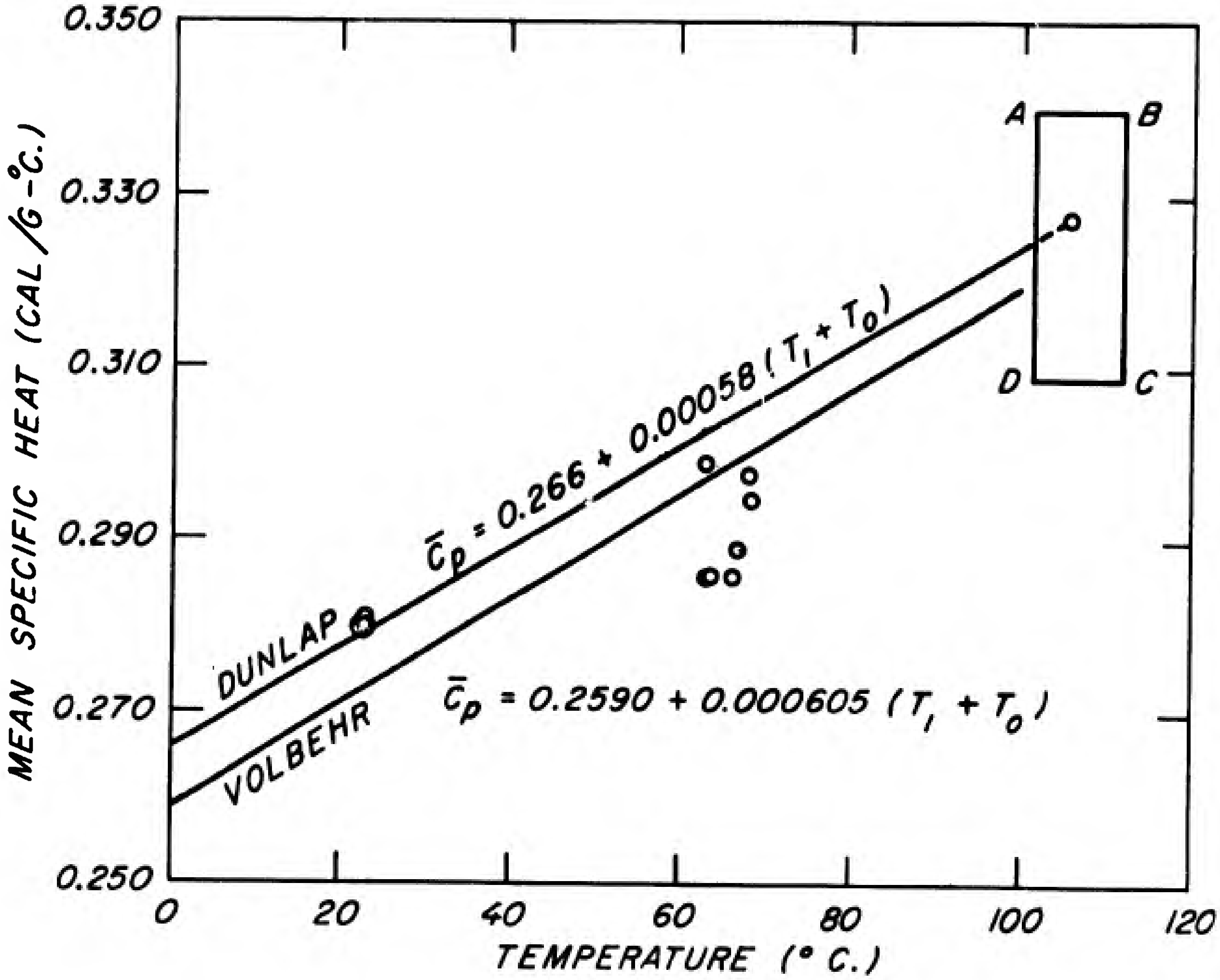

Figure 1.--Variation of mean specific heat of ovendry wood with temperature where T_o = 0°C. The rectangle ABCD represents the limits of values for 100 runs in Dunlap's study. Points shown are Dunlap's data.

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studies, Bunsen ice calorimeters were used so that the endpoint for each measurement was 0° C. In the application of equation (15), T_1 should be replaced by $T_1 + T_o$.

The proper form for each equation is then

$$\bar{c}_{p(D)} = 0.266 + 0.00058(T_1 + T_o) \quad (16a)$$

$$\bar{c}_{p(V)} = 0.2590 + 0.000605(T_1 + T_o) \quad (16b)$$

where subscripts D and V designate Dunlap and Volbehr, respectively. The true specific heat at any temperature, T, is then found by replacing $T_1 + T_o$ in the above equation with 2T. It is not known if the additional significant figure in equation (16b) is accurate. Also, the acid treatment used to separate the wood fibers for Volbehr's study could have changed the true values.

Wilkes and Wood (19) obtained a mean specific heat value of 0.341 for wood fiberboard (density of 0.232 g/cm^3) over the range of 27° to 100° C. The calculated value over this range from the equation of Dunlap is 0.340 and from the equation of Volbehr, 0.336. A study of the variation of specific heat of wood mentioned by Kanter (8) over a moisture content range of 0 to 140 percent and temperature range of -40° to +100° C. gave the following equation (estimated from the graph presented) for the specific heat of ovendry wood:

$$\bar{c}_p = 0.37 + 0.00060T \quad (17)$$

In this case, the intercept at T = 0° C. is much higher than for either equations (16a) or (16b), while the slope is almost identical to that obtained by Volbehr. However, in addition to Kanter's high value at 0° C. the data points are not given, and the source was reported to be an unpublished work of another investigator.

Dunlap found no correlation between species and specific heat; however, one report (13) on Indian woods gives a range of values of from 0.310 to 0.413 for nine species (presumably at room temperature). Many authors (5, 6, 8, 10, 12) have reported the variation of specific heat of wood with both temperature and moisture content, but except for the report of Kanter (8), none cover a large range of moisture content.

Kühlman (12) used the Krischer method of measuring thermal conductivity and thereby obtained specific heat values over the range of -60° to +80° C. and 0 to 30 percent moisture content. Several points were confirmed using the

Bunsen ice calorimeter method. The variation of specific heat of ovendry wood appeared to be linear and close to Dunlap's values.

The relationship between specific heat and moisture content does not follow a simple method of mixtures (9, 11, 12, 17), but exhibits a nonlinear behavior, as Volbehr noted. Another problem with Dunlap's equation is that an error persists in the literature in quoting the equation. Several authors (2, 5, 15) have reported the intercept of the equation at 0° C. as 0.226 instead of 0.266.

Sufficient information on techniques is available in the literature (1, 16), and several references (3, 6, 14, 18) include the basic concepts of determining the specific heat of cellulosic materials. Further studies are needed, as Dunlap originally stated, to either confirm or modify the equations of Dunlap and Volbehr.

Literature Cited

1. American Society for Testing and Materials
   1961. Mean specific heat of thermal insulation. ASTM Designation C 351-61.

2. Brown, H. P., Panshin, A. J., and Forsaith, C. C.
   1952. Textbook of Wood Technology. McGraw-Hill, New York.

3. Byram, G. M., Sauer, F. M., Fons, W. L., and Arnold, R. K.
   1952. Thermal properties of forest fuels. Interim Tech. Rep. AFSWP-404, Division of Fire Research, U.S. Forest Service.

4. Dunlap, F.
   1912. The specific heat of wood. U.S. Dep. Agr., Forest Serv. Bull. 110.

5. Emchenko, M. P.
   1958. The specific heat of wood. Derev. Prom. 7(5):18-19 [Russ.].

6. Hearmon, R. F. S., and Burcham, J. N.
   1955. Specific heat and heat of wetting of wood. Nature 176:978.

7. Hodgman, C. D., Editor
   1962. Handbook of chemistry and physics. Chemical Rubber Publ. Co., Cleveland.

8. Kanter, K. R.
   1957. The thermal properties of wood. Nauka i Tekhnika 6(7):17-18. (U.S. Dep. Com., Office Tech. Serv. OTS 60-51033).

9. Kelsey, K. E., and Clarke, L. N.
1956. Effect of temperature and initial moisture content on the heat of wetting of wood. Australian J. Appl. Sci. 7:160-175.

10. Kollmann, F.
1934. Concerning the thermal properties of wood. Gesundh. Ing. 57(18): 224-227 [German].

11. ______
1936. Technologie des Holzes. Springer, Berlin.

12. Kühlman, G.
1962. Investigation of the thermal properties of wood and particleboard in dependency from moisture content and temperature in the hygroscopic range. Holz als Roh- und Werkstoff 20(7):259-270 [German].

13. Narayanamurti, D., and Jain, N. C.
1958. A note on the specific heat of wood. Curr. Sci. 27(3):97.

14. Stamm, A. J., and Loughborough, W. K.
1935. Thermodynamics of the swelling of wood. J. Phys. Chem. 39:121-132.

15. Tiemann, H. D.
1951. Wood Technology, Constitution, Properties, and Uses. Pitman, N.Y.

16. U.S. National Bureau of Standards
1961. Precision measurement and calibration. II. Heat and mechanics. Nat. Bur. Stand. Handbook 77, pp. 212-276.

17. Wahba, M., and Nashed, S.
1950. Change with temperature of the heat of wetting of dry cellulose in water, and its bearing on the specific heat of the adsorbed water and of the swollen cellulose. Nature 166:998.

18. Ward, R. J., and Skaar, C.
1963. Specific heat and conductivity of particleboard as functions of temperature. Forest Products J. 13(1):31-38.

19. Wilkes, G. B., and Wood, C. O.
1942. The specific heat of thermal insulating materials. Heat. Pip. Air Cond. 14:370-374.

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