Specific Heat of Ovendry Loblolly Pine Wood

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ABSTRACT. In the range of 333 K to 413 K, the specific heat of ovendry loblolly pine (*Pinus taeda* L.) wood was expressed by a linear function of temperature. No relationship was detected with specific gravity, growth rate, or distance from the pith; nor were differences found between earlywood and latewood.

IN THE RESEARCH REPORTED HERE, AN ANALYSIS was made of the specific heat of loblolly pine wood in relation to temperature and three readily measured gross wood characteristics: specific gravity, growth rate, and distance from the pith. Since the chemical composition of loblolly pine wood has been shown to vary with these factors (5), it was thought possible that small variations also exist in specific heat.

To isolate the possible independent relationships of each wood characteristic with specific heat, samples were removed from many stems and stratified by two densities and two growth rates at each of three radial positions in the stem. The specific heat at three temperatures was then determined for the earlywood and the latewood portion of each wood category separately, and the results were compared with those recently obtained by Koch (4) for spruce pine (*Pinus glabra* Walt.).

Procedure

As in a previous study (6), 50 loblolly pines from a stand near Alexandria, La., were felled and bucked. After logs with visible defects had been discarded, the remainder wei slabbed on two sides to the 10th annual rin The resulting cant was ripped along the 10tl 20th, and 30th rings to form five boards. Woo beyond the 30th ring was discarded. Specif gravity (ovendry weight and green volume was determined on a 1-inch sample cut fro the midpoint of each board. On the basis (these preliminary measurements, 90 kilogran of wood were selected for each category i each of two replications in the factorial d sign outlined below. Boards having specif gravities and growth rates near the catego division points were rejected.

Variables in the design were:

1) *Unextracted specific gravity (ovendry weight and green volume)*
   Less than 0.49
   More than 0.49
2) *Growth rate*
   Less than six rings per inch
   More than six rings per inch
3) *Rings from the pith (position in tree)*
   0-10 (corewood)
   11-20 (middle wood)
   21-30 (outer wood)

The stratification of wood into these factorial categories was possible because, f a given number of rings from the pith, tl range of variation in specific gravity a

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growth rate between stems is remarkably large. For example, it is possible to isolate corewood of low density and slow growth from one stem, while corewood from a second stem may be of low density and fast growth. As another example, the outer wood of one stem and the corewood of a second stem may both contain fast-grown wood of high density.

Sample boards in each replication and each category were separately reduced to chips that averaged somewhat less than 2.5 cm. in length, and a random subsample of 1,000 chips was taken from each of the 24 groups. Chips were stored in capped jars at 277K (4°C.)

Specific gravity (for use in subsequent analyses) was measured on 500 of the subsample chips; the method was that described by Smith (8). Specific gravity of extractive-free wood was calculated by reducing the ovendry weight of chips by the weight of the alcohol-benzene extractive content of a matched sample; TAPPI Standard Method T 6 os-59 was used.

Growth rate in rings per inch could not be determined from chips. It was therefore measured, prior to chipping, on the samples used for segregating the boards. Because boards had variable cross-sectional areas, measurements were weighted by area in calculating the mean growth rates, which were then considered representative of the chips.

Specific heats were ascertained on 100 chips randomly selected from each 1,000-chip sample. The chips were air-dried, dissected into earlywood and latewood slivers, and ground to pass a 40-mesh screen in a Wiley mill. The division into earlywood and latewood increased the number of categories to 48.

A Perkin-Elmer DSC-1B differential scanning calorimeter was used for determination of specific heat. The principles and methods of operation have been described by Koch (4).

The experimental procedures also were those of Koch, and are therefore only summarized here. Approximately 10 mg. of meal was randomly selected from each of the wood samples and loaded into small aluminum pans. Five pans were prepared for each sample, in order to provide five within-sample replications. After being covered with lids, the pans were dried in a vacuum oven at 100°C. for 12 hours. Prior to the calorimeter run, the pans were cooled in small desiccators containing phosphorous pentoxide and weighed to the nearest 0.01 mg. After the run, the specimens were again weighed and the average of the two weights was used to compute the specific heat. In all cases, the weight change was less than 0.05 mg. Three scans were made with each sample: 323 to 343, 363 to 383, and 403 to 423 K. Specific heat was calculated at 333, 373, and 413 K.

Results

Table 1 summarizes the wood-property and specific-heat determinations for each wood

Table 1. GROSS WOOD CHARACTERISTICS AND SPECIFIC HEAT DETERMINATIONS.[1]

Rings from pith	Specific gravity Unex-tracted	Specific gravity Ex-tracted	Rings per inch	Specific heat of earlywood at — 333 K	Specific heat of earlywood at — 373 K	Specific heat of earlywood at — 413 K	Specific heat of latewood at — 333 K	Specific heat of latewood at — 373 K	Specific heat of latewood at — 413 K
0-10	0.426	0.399			0.3656			0.3695	0.4074
0-10	.451	.418			.3659			.3714	.4042
0-10	.500	.446			.3696			.3671	.3994
0-10	.514	.448			.3666			.3684	.3993
11-20	.445	.412			.3684			.3740	.4080
11-20	.473	.452			.3678			.3681	.3993
11-20	.528	.506			.3708			.3680	.4049
11-20	.536	.515			.3682			.3721	.3987
21-30	.458	.470			.3609			.3662	.4007
21-30	.444	.431			.3680			.3716	.4027
21-30	.573	.551			.3722			.3692	.4039
21-30	.524	.505			.3686			.3643	.3988
Grand mean	.489	.459			.3677			.3692	.4023

[1] Each numerical value for specific heat is the average of 10 replications. Specific gravity and rings per inch are based on two observations.

category. All measured gross wood properties exhibited a wide range and reflected the method of specimen preparation. Unextracted specific gravity varied from 0.421 to 0.633, extracted specific gravity from 0.396 to 0.616, and growth rate from 4.11 to 12.39 rings per inch. Error analysis indicated that individual values for specific heat were accurate to three significant figures. Because observations were numerous, the averages listed in Table 1 are reasonably accurate to four places.

Table 2. — EFFECT OF STUDY VARIABLES ON SPECIFIC HEAT OF OVENDRY LOBLOLLY PINE WOOD.[1]

Factor	Specific heat
Unextracted chip specific gravity	
Less than 0.49 (avg. 0.449)	0.3658
More than 0.49 (avg. 0.529)	.3658
Number of rings from pith	
0-10	.3656
11-20	.3672
21-30	.3645
Rings per inch	
Less than 6 (avg. 5.10)	.3660
More than 6 (avg. 9.26)	.3656
Tissue type	
Earlywood	.3660
Latewood	.3656
Temperature of observation	*
333 K	.3265
373 K	.3684
413 K	.4024

[1]All factors were tested by variance analysis at the 0.05 level; significant differences are indicated by *.

Table 2 lists the average specific heats according to unextracted chip specific gravity, rings per inch of growth rate, rings from the pith, temperature of observation, and tissue type.

As expected, specific heat differed significantly with changes in the temperature of observation. For the combined earlywood and latewood data and for all levels of chip specific gravity, rings from the pith, and rings per inch of growth rate, specific heat averaged 0.3265 at 333, 0.3684 at 373, and 0.4024 at 413 K. Because the samples were selected to fill certain position, growth-rate, and specific-gravity categories, the means of specific heat at each temperature do not necessarily represent the species.

No significant differences in mean specific heats were detected among the remaining primary variables, but the interaction of tissue type and temperature of observation was significant in variance analysis. Stepwise multiple regression analysis of specific heat on temperature for each separate tissue type was used to clarify this apparent interaction. Factors considered were temperature of observation and the square of temperature of observation; the equations were tested at the 95-percent level of significance.

The best equation for each tissue type was

$$C_p\ (lw) \qquad 0.0064377 + 0.0009623\ T \qquad (1)$$

$$C_p\ (ew) \qquad 0.0164204 + 0.0009372\ T \qquad (2)$$

where:

$C_p\ (ew)$ and $C_p\ (lw)$ = specific heat of earlywood and latewood respectively.

T temperature of observation in Kelvin.

The specific heats of latewood and of early wood both were linear functions of temper ature of observation. The equation for early wood accounted for 87 percent of the tota variation with a standard error of 0.0116. Th equation for latewood accounted for 90 per cent; the standard error was 0.0104.

Although variance analysis indicated tha the relationship of specific heat and temper ature differed between tissue types, a covari ance analysis revealed no significant differenc between the earlywood and latewood regres sions. Thus, the earlywood and latewood dat were pooled (144 observations) and the fol lowing equation was developed:

$$C_p \qquad 0.0115321 + 0.0009497\ T \qquad (3$$

Specific heat of the pooled earlywood an latewood data also was a linear function c temperature. The equation accounted for 8 percent of the total variation in specific hea the standard error was 0.0110. Confidenc limits at the 95-percent level of probability were as follows:

Temperature (K)	Specific Heat
333	0.32788 ± 0.000075
373	0.36588 ± 0.000030
413	0.40388 ± 0.000075

As previously noted, none of the gross wood factors of specific gravity, growth rate, or distance from the pith proved significant by variance analysis. In addition, after the effect of temperature was considered, no gross wood factor was significant in regression analysis of earlywood or latewood either separately or pooled.

To test whether the relationship of temperature on specific heat was masking the effect of the gross wood factors, a multiple regression analysis was made at each of the three temperatures separately. In this analysis, none of the wood factors was significant when the earlywood and latewood data were considered separately, nor when the data were pooled by tissue type.

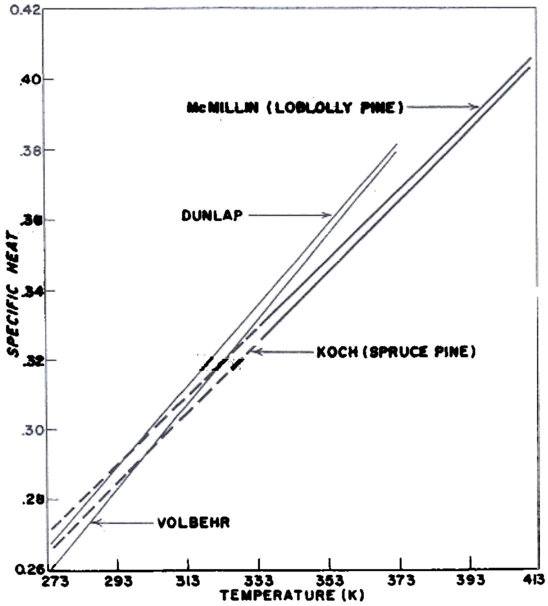

Figure 1.—Relationship of specific heat to temperature as reported by Dunlap, Volbehr, Koch, and McMillin.

Discussion

For the intensity of sampling used, and in the range of 333 to 413 K, the specific heat of loblolly pine wood stratified by specific gravity, growth rate, and position in the stem was expressed as a linear function of temperature only. This relationship is in agreement with the results reported by Koch (4) for ovendry spruce pine wood.

Figure 1 shows the regression line of specific heat on temperature obtained in the present research and that reported by Koch (4). The dotted portions of these lines extrapolate below the range of the data, and it is assumed by both researchers that the relationship between specific heat and temperature remains linear at temperatures lower than 323 K. Also illustrated are the earlier results of Dunlap (2) and Volbehr.[1]

Although the relationship was not statistically tested, it can be seen from the figure that, while the slope of the line for loblolly pine is very similar to that for spruce pine, the level of the relationship appears higher for loblolly than for spruce pine. The slopes of both the loblolly and spruce pine relationships are considerably less than those for the data of Dunlap and Volbehr.

Figure 1 also indicates that the specific heat of loblolly pine at the 273K intercept is somewhat greater (0.2709) than that obtained for spruce pine (0.2651). With 95-percent confidence, it can be said that the true value of loblolly pine specific heat at the 273 K intercept is within the range of 0.2706 to 0.2712. Koch (4) reports a true 273 K intercept for spruce pine in the range of 0.2620 to 0.2683.

Because the specific heats of loblolly and spruce pine wood at 273 K were obtained by linear extrapolation, an attempt was made to verify the intercepts by direct observation. Measurements at the desired 273 K were not possible with the available instrumentation, but specific heat at 283 K was determined on an ovendry sample of spruce pine tree wood from Koch's study (4) and on a 50/50 mixture of ovendry loblolly pine latewood and earlywood. The experimental procedures were those previously discussed, except that the

[1]Original not seen. Information is from Beall (1), and Narayanamurti and Jain (7).

specimens were tested in an insulated chamber cooled with dry ice and acetone. Ten observations were made on samples of each species. The averaged results at 283 K were:

Loblolly Pine		Spruce Pine	
Predicted	Observed	Predicted	Observed
0.2804	0.2825	0.2752	0.2720

From these values, it seems reasonable to assume that the relationship of specific heat on temperature remains essentially linear in the range of 273 to 313 K, and that the intercepts given at 273 are probably valid.

The foregoing discussion suggests that differences in specific heat within the southern pines may exist but are so small as to be of little practical importance. This inference seems reasonable, since the southern pines are generally considered similar in their chemical composition. In species of substantially different chemical composition, specific heats may differ considerably, as noted by Geiger (3), and Narayanamurti and Jain (7).

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