Heat of Combustion of Various Southern Pine Materials

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ABSTRACT. As measured with an oxygen-bomb calorimeter, heats of combustion averaged about 8,600 Btu/ovendry lb. for stemwood, rootwood, earlywood, and latewood. In stemwood, 54 percent of the variation was related to extractive content. Values for bark were greatest in samples from the base of the tree and decreased with increasing height in tree. Values for resinous wood varied directly with extractive content. Needles and mixed bark had higher heats of combustion than stemwood. Spruce pine bark produced less heat than mixed bark from the other southern pine species. Samples from tops had lower values than other woody portions; of all tree parts, old cones ranked lowest. Dried kraft black liquor averaged only 5,965 Btu/ovendry lb.

When a southern pine tree is harvested, only about 60 percent by weight is put to immediately useful human purposes. Stump, roots, and top are left in the woods to decay, and bark creates a major disposal problem at mills receiving the logs and bolts. Spent black liquor from the manufacture of kraft pulp is rich in unutilized lignin. These materials have some value as fuel, and large-scale use for this purpose would conserve other energy sources.

This paper reports a study of the heats of combustion of various southern pine materials. The chief interest was in bark, rootwood, stemwood, bark and wood from tops, and dried kraft black liquor. In addition, samples of cones, needles, knots, resinous stumpwood, and charcoal were tested. The information provides a basis for comparing heat values of various southern pine materials and should be helpful in determining their worth for fuel as compared to other possible uses.

Heats of combustion were determined by oxygen-bomb calorimetry. In this procedure, a weighed sample is burned in an oxygen-filled metal bomb submerged in a measured quantity of water, all held within an insulated chamber. By observing the rise in water temperature from the explosive combustion of the sample, the number of heat units liberated may be calculated. The values thus derived represent the total amount of heat obtainable from ovendry material, with n[o] deduction for losses. The heat obtained by burn[-]ing in open systems is considerably less, as som[e] escapes in the form of steam and other gases.

Literature Review

Heat of combustion varies considerably wit[h] chemical content. Resin, tannins, lignin, terpene[s] and waxes have high heat values; carbohydrate[s] are relatively low in energy. Brown *et al.* (1952) state that hardwoods contain 8,300 to 8,700 Btu/ ovendry lb., whereas softwoods range from 9,00[0] to 9,700. The higher value for conifers is at[-]tributed to their greater resin and lignin content.

The caloric value of wood is negatively co[r-]related with moisture content. Kollmann an[d] Cote (1968, p. 150) give values of 8,100 Btu/ lb. for ovendry wood, 6,840 for air-dry wood, an[d] 5,940 for wood at 30 percent moisture conten[t]. Parr and Davidson (1922) reported 8,836 Btu/ lb. for ovendry pine, and 8,050 for samples wit[h] 8.88 percent moisture.

Several authors have tested various portion[s] of southern pine trees. Chang and Mitche[ll]

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(1955) found that slash pine bark (at 6.4 percent moisture) produced 9,002 Btu/lb. Madgwick (1970), working with Virginia pine, reported 9,035 Btu/ovendry lb. for mature leaves, 8,875 for wood from live branches of 17-year-old trees, 8,695 for live branchwood from trees 18 to 59 years old, 8,530 for bole wood, 8,425 for bole bark, and 9,018 for male flowers at pollen shed. Hough (1969) measured 9,365 Btu for ovendry sand pine twigs, and found that needles averaged 8,900 Btu for loblolly pine, 9,615 for sand pine, and 9,370 for slash pine.

Methods

Samples

Loblolly pine stemwood and spruce pine bark were sampled in some detail. Most other samples were composites of equal weights of material from either the four major southern pines (loblolly, slash, longleaf, and shortleaf) or from all 12 species, varieties, and races (Sternitzke and Nelson 1970).

Loblolly pine. — Stemwood samples from 50 mature trees were factorially divided as follows:
- Specific gravity: <0.49 and >0.49
- Growth rate: <6 rings and >6 rings/in.
- Rings from the pith: 0-10, 11-20, and 21-30

Exact values for each of these variables, and data on percentage of latewood and chemical composition, had been determined previously for each sample.

Earlywood and latewood. — A composite sample from one tree of each species, variety, and race for each of the two tissue types. Earlywood and latewood were dissected from wedges taken at three heights along the stem: 1 foot above ground, one-third tree height, and two-thirds tree height.

Spruce pine bark. — Inner and outer bark from 72 trees throughout the major range of the species. Variables were:
- Geographic location: 4 areas
- Age of trees: 15, 30, or 45 years
- Growth rate: <6 or >6 rings/in. 1 foot above ground
- Height: 1 foot above ground, at a 4-inch top, and half-way between these levels.

Mixed bark. — A composite sample for each of three heights from 11 southern pines (all species except spruce pine).

Roots. — A composite from one tree of each species, variety, and race. Samples were from large lateral roots near the base of the tree.

Top. — Composite sample of wood and bark from the 1-inch top of one tree of each species, variety, and race.

Needles. — Composite sample from one tree of each of the four major species. Samples were from the lower, middle, and upper crown.

Cones. — Composite sample of old, open cones from each of the four major species.

Stumpwood. — Samples from old-growth, resinous, longleaf pines, separated into three specific gravity classes.

Knots. — Resinous, decay-resistant knots picked from the forest floor in a longleaf stand.

Resin. — Liquid samples collected from mechanically injured trees.

Charcoal. — Commercial briquettes produced from southern pine bark and wood residues.

Kraft black liquor. — Dried residue of samples collected on six consecutive days after tall oil had been removed.

All samples except stumpwood, knots, and resin were ground to pass a 60-mesh screen, and ovendried. The extremely resinous stumpwood and knots could not be screened after grinding. To minimize loss of volatiles, resin, stumpwood, and knotwood were dried at room temperature over multiple changes of desiccant.

Calorimetry

Heats of combustion were determined with a Parr 1241 adiabatic oxygen - bomb calorimeter with automatic jacket controls. The manufacturer's recommendations for operation were followed. Approximately 0.5 g of sample was placed in an open combustion capsule, sprayed lightly with a fine water mist, and placed in the bomb. The bomb was charged with 20 atmospheres of oxygen. Initial temperature after stabilization and final temperature after ignition were recorded. Interior surfaces were rinsed, the washings were titrated with sodium carbonate solution for nitric acid correction, and the remaining fuse wire was measured.

Gross heat of combustion, H_g, in cal./g was computed by the equation:

$$H_g = \frac{(t_f - t_a)\ W - e_1 - e_2}{m}$$

t_a = temperature at time of firing, corrected for thermometer scale error, °F.

t_f = final maximum temperature, corrected for thermometer scale error, °F.
W = energy equivalent of the calorimeter, calories per °F.
e_1 = correction, in calories, for heat of formation of nitric acid, = ml of 0.0725 N alkali.
e_3 = correction, in calories, for heat of combustion of fuse wire.
m = ovendry weight of sample, g.

Multiplication of calories per gram by 1.8 gives Btu/lb.

Despite repeated efforts to eliminate the problem, a very small carbon residue remained after combustion of most samples. Because of this difficulty, values may be slightly higher than reported, but the difference would not be greater than 50 Btu in the worst samples accepted.

Results

Average heat of combustion for loblolly pine stemwood was 8,600 Btu/ovendry lb. Caloric values were regressed against data on percent of latewood, extractive content, growth rate, specific gravity (unextracted and extracted), and content of holocellulose, alpha-cellulose, hemicellulose, and lignin. Growth rate, specific gravity, and percent of latewood proved nonsignificant at the 0.05 level. Extractive content was positively correlated with heat of combustion and accounted for 54 percent of the variation (Fig. 1). Variation

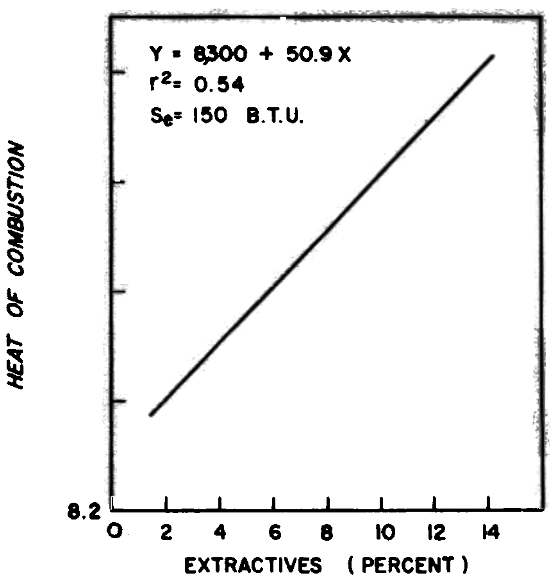

Figure 1. — Correlation between heat of combustion of ovendry loblolly pine stemwood and alcohol-benzene extractive content.

in the proportions of other chemical constituents had only minor effects. A negative correlation with number of rings from the pith reflects the distribution of extractives in the stem:

Rings from pith	Heat of combustion	Alcohol-benzene extractives
	(Btu/ovendry lb.)	(%)
0-10	8,795	9.6
11-20	8,565	4.8
21-30	8,445	3.8

Heats of combustion for earlywood, latewood, and rootwood were not significantly different — all averaged about 8,600 Btu/lb. Samples from the 1-inch top (wood and bark) averaged significantly less — 8,395 Btu (Table 1).

Heat value of spruce pine bark was greatest in samples from the base of the tree. At greater heights up the stem the outer bark becomes thinner and the inner bark — which probably has less heat value — thus makes up proportionately more of the sample. Geographic region, growth rate, age of tree, and bark specific gravity had no significant effect.

Heat of combustion of the mixed bark samples was greater than for spruce pine bark and also was negatively correlated with height above ground. The values are somewhat lower than Chang and Mitchell's (1955) results for slash pine bark, but are higher than those reported by Madgwick (1970) for Virginia pine bark.

Liquid resin had the highest heat of combustion, 14,625 to 16,250 Btu/lb. Variation in values was large, as the samples were difficult to mix thoroughly and therefore not homogenous.

Resinous stumpwood had the following values/ovendry lb.:

Alcohol-benzene extractives	Sp. gr. (ovendry wt. and vol.)	Heat of combustion	Coeff. of var.
(%)			
26.9			
31.3			
35.4			

Table 1. — HEATS OF COMBUSTION OF VARIOUS SOUTHERN PINE MATERIALS.

Material	Btu/ovendry lb.		No. of determinations	Coefficient of variation
	Mean	Range		%
Resin		14,625 - 16,250	4	4.56
Charcoal, commercial	12,335	11,225 - 12,740	20	2.65
Resinous stumpwood, longleaf pine		10,250 - 10,840	18	—
Decay-resistant knots, longleaf pine		10,140 - 11,490	16	—
Needles, 4 major species	9,030	8,935 - 9,105	8	.65
Mixed bark, all species except spruce pine				
One foot above ground	8,985	8,870 - 9,140	8	1.06
Midheight	8,825	8,650 - 8,910	8	.95
4-inch top	8,700	8,550 - 8,835	8	.99
Loblolly pine stemwood	8,600	8,310 - 9,352	96	2.54
Earlywood, all species	8,610	8,470 - 8,760	18	1.01
Latewood, all species	8,585	8,385 - 8,755	18	1.20
Rootwood, all species	8,605	8,560 - 8,680	4	.64
Spruce pine bark				
One foot above ground	8,705	8,310 - 9,105	48	2.21
Midheight	8,595	8,040 - 8,975	48	2.22
4-inch top	8,550	8,170 - 8,920	48	2.24
Tops, all species (wood and bark at 1-inch top)	8,395	8,015 - 8,745	12	2.25
Old cones, 4 major species	8,130	8,085 - 8,190	4	.54
Kraft black liquor	5,965	5,820 - 6,130	6	2.04

Alcohol-benzene extractives	Heat of combustion	Coeff. of var.
(%)	(Btu)	(%)
28.7	10,230	0.67
29.4	10,320	0.47
32.8	10,400	1.16
39.9	11,225	1.93

Needles had higher heat value (9,030 Btu/lb.) than either wood or bark. Alcohol-benzene extractive content was 28.8 percent.

Old cones averaged 8,130 Btu/lb. — less than any other tree part. Charcoal briquets averaged 12,335 Btu, a value somewhat lower than that for pure carbon (approximately 14,100 Btu). The ash content of the briquets and the low heat value of the binder starch used in their manufacture may account for the difference. Dried black liquor residue had a comparatively low heat of combustion (5,965 Btu), as resins and fatty acids had been removed in the tall oil separation.

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