Chapter 7. **Chips, Sawdust, Planer Shavings, Bark, and Hog Fuel**

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Chapter 7. Chips, Sawdust, Planer Shavings, Bark, and Hog Fuel

Previous chapters have presented material balances that can be used to estimate the fraction of a log recovered in a residue form. There are many factors that affect chip and residue measures and associated conversion factors. These include:

- **Size and geometry**: The differences in physical characteristics of these residues are obvious and affect how they occupy a unit of space.
- **Specific gravity**: Wood and bark densities differ between species (Tables 1-1, 7-5).
- **Moisture content**: Wood and bark moisture contents vary between species (Table 1-1), and water may be added during pond storage and debarking. Buyers and sellers of residues and statistical reporting organizations generally devise some method for correcting to the oven-dry state.
- **Degree of compaction**: Over time, chips and residues will settle due to gravity. Also, mechanical and pneumatic compaction can be used to pack more residue into a given space.

Quantities of chips and residues are measured in units of volume or weight. This chapter discusses volumetric expansion factors and bulk densities for these products, typical units of measure and conversion, and residue yields, and also presents examples that integrate this material.

Expansion Factors, Relative Solid Volume, and Compaction

To illustrate these terms, consider a log containing 5 cubic feet of solid wood (Vsw) that is chipped. Obviously, the chips will occupy more space than 5 cubic feet.

Expansion (Fluffing) Factor

Loose Expansion Factor. Immediately after chipping, suppose the loose chips occupy 15 cubic feet (Vp). The expansion factor (E), also called the *fluffing factor*, is

$$E\ (\text{loose}) = Vp\ /\ Vsw = 15\ \text{ft}^3\ /\ 5\ \text{ft}^3 = 3.00.$$

Note that when Vsw and Vp are measured in cubic meters, the expansion factor has the same value.

Compacted Expansion Factor. Loose chips will settle over time due to gravity, or they may be physically compacted by equipment. Suppose the chips are compacted so the space occupied (Vp) reduces to 12 cubic feet. The expansion factor is

$$E\ (\text{compacted}) = 12\ \text{ft}^3\ /\ 5\ \text{ft}^3 = 2.40.$$

These calculations illustrate the importance of noting the degree of compaction associated with a particular expansion factor. Measures of compaction are discussed below.

Relative Solid Volume

The reciprocal of the expansion factor measures the number of solid cubic feet (cubic meters) that will yield a cubic foot (cubic meter) of residue. Continuing the example, relative solid volume (RSV), also termed *volume occupancy*, is

$$RSV\ (\text{loose}) = 1\ /\ E\ (\text{loose}) = 1\ /\ 3.00 = 0.333.$$

$$RSV\ (\text{compacted}) = 1\ /\ E\ (\text{compacted}) = 1\ /\ 2.40 = 0.417.$$

Some multiply RSV by 100 to express it as a percentage; in this form it is sometimes called a *compaction rate*.

Compaction

Compaction Ratio. A common measure of compaction is the compaction ratio (CR), which is

$$CR = Vp\ (\text{loose})\ /\ Vp\ (\text{compacted}) = 15\ \text{ft}^3\ /\ 12\ \text{ft}^3 = 1.25.$$

$$CR = E\ (\text{loose})\ /\ E\ (\text{compacted}) = 3.00\ /\ 2.40 = 1.25.$$

CR can also be calculated from the relative solid volumes. It has a value of one for loose residue and increases as the particles become more compacted. A maximum value for CR can be estimated if it is assumed that the maximum compaction possible would compress the residue to the original volume of solid wood. Under these conditions:

$$Vp\ (\text{compacted}) = Vsw$$

hence

$$CR = 15\ \text{ft}^3\ /\ 5\ \text{ft}^3 = 3.00.$$

In other words, the limiting value of the compaction ratio is numerically equal to the expansion factor for loose particles.

Compaction Percent. A less common compaction value can be obtained from volume changes. From the example, the maximum compaction from loose chips to solid wood is 10 cubic feet, while the actual compaction is 3 cubic feet. Actual compaction as a percentage of the maximum possible is

$$\text{Compaction \%} = 100 * [Vp\ (\text{loose}) - Vp\ (\text{compacted})] \ / \ [Vp\ (\text{loose}) - Vsw] = 100 * (15 - 12) \ / \ (15 - 5) = 30\%.$$

Summary

Table 7-1 presents expansion factors for various types of residues and corresponding relative solid volumes. Also shown are conversions from Imperial to metric and equivalents when residues are measured in 200 cubic feet volumetric units (see p. 87). Tables 7-2 and 7-3 present additional sources of expansion factor and compaction ratios. The conversion methods applied to the expansion factors in Table 7-1 can also be applied to the expansion factors presented in Table 7-2.

Bulk Density

Bulk density (BD) refers to residue weight divided by residue volume. Suppose the example log has a moisture content of 80% MC_{od} (44.4% MC_W) and specific gravity (SG_g) is 0.48 (see Chapter 1 for definitions). Using methods presented in Chapter 1, wood density is 53.9 wet pounds per green cubic foot. This is composed of 29.9 lb of oven-dry wood plus 24.0 lb of water. The term *basic density* is sometimes used to refer to the oven-dry weight per cubic foot (i.e., 29.9 lb/ft^3). The chips from the 5 cubic-foot log have the following weight distribution:

Condition	Weight (lb)	Percent
Oven-dry wood (W_{od})	149.5	55.6
Water (MC_W)	120.0	44.4
Wood + water (W_{wet})	269.5	100.0

The term *solids fraction* refers to the percentage of total weight that is oven-dry wood.

As was described for solid wood density in Chapter 1, bulk density can be calculated for any combination of numerator (weight) and denominator (volume) moisture contents, hence it is important to specify these conditions. The more common cases are given in the remainder of this section.

Oven-dry Bulk Density

This is the oven-dry weight per green cubic foot of residue. Divide the weight of oven-dry wood (W_{od}) by the residue volume (Vp)

$$BD_{od}\ (\text{loose}) = W_{od} \ / \ Vp\ (\text{loose}) = 149.5\ \text{lb} \ / \ 15\ \text{ft}^3 = 10.0.$$

$$BD_{od}\ (\text{compacted}) = W_{od} \ / \ Vp\ (\text{compacted}) = 149.5\ \text{lb} \ / \ 12\ \text{ft}^3 = 12.5.$$

The same results can also be obtained by dividing the basic density (29.9 lb/ft^3) by the appropriate expansion factor.

These bulk densities indicate the amount of oven-dry wood present in each loose or compacted *green* cubic foot of residue. They are important in residue transactions because purchasers wish to pay only for wood and therefore want the weight of water excluded. The residue volume is green, since these are undried chips fresh from the log. In cases where residues are dried or manufactured from dry wood, these bulk densities would change because wood shrinkage will modify the volume the residue occupies. This will be illustrated below.

Wet Bulk Density

Bulk density can also be calculated with the moisture content included in the weight (total weight per green cubic foot of residue):

$$BD_{wet}\ (\text{loose}) = W_{wet} \ / \ Vp\ (\text{loose}) = (269.5\ \text{lb} \ / \ 15\ \text{ft}^3) = 18.0.$$

$$BD_{wet}\ (\text{compacted}) = W_{wet} \ / \ Vp\ (\text{compacted}) = (269.5\ \text{lb} \ / \ 12\ \text{ft}^3) = 22.5.$$

The same results can also be obtained by dividing the wet wood density (53.9 lb/ft^3) by the appropriate expansion factor. These values are

Table 7-1. *Residue expansion factors and related conversions.*

Residue	(1) Expansion factor: ft^3 residue per ft^3 solid wood (m^3 residue per m^3 solid wood)	(2) Relative solid volume: ft^3 solid wood per ft^3 residue (m^3 solid wood per m^3 residue)	(3) ft^3 solid wood per m^3 residue	(4) m^3 residue per ft^3 solid wood	(5) m^3 solid wood per ft^3 residue	(6) ft^3 residue per m^3 solid wood	(7) ft^3 solid wood per unit residue	(8) m^3 solid wood per unit residue	(9) Units residue per ft^3 solid wood	(10) Units residue per m^3 solid wood
Pulp chip (loose)	2.86	0.350	12.36	0.081	0.00991	100.91	70	1.98	0.0143	0.505
Pulp chip (compacted)	2.50	0.400	14.13	0.071	0.01132	88.34	80	2.27	0.0125	0.441
Sawdust	2.50	0.400	14.13	0.071	0.01132	88.34	80	2.27	0.0125	0.441
Planer shavings	4.00	0.250	8.83	0.113	0.00708	141.24	50	1.42	0.0200	0.706
Bark[a]	2.35	0.425	15.01[a]	0.067[a]	0.01204[a]	83.06[a]	85	2.41	0.0118[a]	0.415[a]
Hog fuel	2.74	0.365	12.89	0.078	0.01033	96.80	73	2.07	0.0137	0.484

Source: Column 1 from Dobie and Wright (1972); columns 2-8 calculated by the author.

[a]In the case of bark, column headings should be interpreted as relating quantity of bark residue to quantity of solid bark.

Column 2 = reciprocal of the expansion factor
Column 3 = column 2 multiplied by 35.315 ft^3/m^3
Column 4 = reciprocal of column 3
Column 5 = column 2 divided by 35.315 ft^3/m^3
Column 6 = reciprocal of column 5
Column 7 = 200 divided by the expansion factor
Column 8 = column 7 divided by 35.315 ft^3/m^3
Column 9 = reciprocal of column 7
Column 10 = reciprocal of column 8

useful for estimating actual weights and loadings on equipment.

For the same compaction, knowledge of moisture content allows conversion between BD_{od} and BD_{wet}:

$$BD_{wet} = BD_{od} * (1 + MC_{od} / 100).$$

Effect of Drying (Shrinkage) on Bulk Density

Bulk densities of dry residues or residues manufactured from dry wood will differ from those in the preceding example. One reason is that the type of residue may be different. Examples are planer shavings and sander dust obtained when kiln-dried wood is surfaced; these residue forms may have different expansion factors. Another reason is that because wood shrinks as it dries, the residue occupies less space. Since many secondary wood products industries, such as millwork and furniture, utilize dry wood, their oven-dry bulk densities will be higher and their wet bulk densities will be lower due to the effects of shrinkage and lower moisture content. See Example 1.

Summary

This section has demonstrated how various factors affect bulk density calculations. Tables 7-2 and 7-3 present data illustrating the influence of mill source (residue type) and species on bulk densities. It should be obvious from the discussion that bulk density is ambiguous without clear statement of the species (wood specific gravity), type of residue, degree of compaction, and the moisture content of both the numerator and denominator.

Units of Residue Measure and Conversions

The 200 Cubic Foot Volumetric Unit

A unit representing 200 cubic feet of space is a very common measure for residues. It is sometimes referred to as a *gravity packed unit* (GPU). Care should be taken when the word *unit* is used, since it may refer to other measures (e.g., bone-dry unit in the next section).

Example 1

Suppose 5 cubic feet of solid green wood is dried to 10% MC_{od} (9.1% MC_w) and that the species has SG_g = 0.48 and 15% total volumetric shrinkage.

As seen in Chapter 1, shrinkage reduces the volume of solid wood to 4.5 cubic feet. If this dry wood is chipped with the same equipment that converted the green log into 15 cubic feet of green chips, the expansion factor of 3.00 predicts that the loose dry chips will occupy 13.5 cubic feet. The same result is obtained by applying volumetric shrinkage to the drying of the green chips to 10% MC_{od}. If the dry chips are compacted to the same degree as the green chips, the compacted volume is 10.8 cubic feet.

Using the methods explained in Chapter 1, we will find the weight density of this dry wood to be 36.55 lb/ft^3. Of this, 33.2 pounds are oven-dry wood and 3.35 pounds are water. The weight distribution of the dry chips is

Condition	Weight (lb)	Percent
Oven-dry wood (W_{od})	149.5	90.9
Water (MC_w)	5.0	9.1
Wood + water (W_{wet})	164.5	100.0

Note that the solids fraction has risen to 90.9%. Using the previously calculated expansion factor for loose chips, bulk densities are

$$BD_{od} \text{ (loose)} = 149.5 \text{ lb} / 13.5 \text{ ft}^3 = 11.1.$$

$$BD_{wet} \text{ (loose)} = 164.5 \text{ lb} / 13.5 \text{ ft}^3 = 12.2.$$

Calculations for compacted chips are similar except the compacted chip volume of 10.8 cubic feet is substituted. These results can also be obtained by dividing "basic" and wet wood densities by the loose expansion factor.

Note that the cubic foot volume here refers to volume that remains after shrinkage to 10% MC_{od} rather than the original green volume. The difference between the oven-dry and wet bulk densities has narrowed. The oven-dry bulk density increased because the volume occupied by the dry wood is less. The wet bulk density is also based on the smaller volume occupancy, but this is offset by the great reduction in weight of water. Hence the net effect is for the wet bulk density to decrease.

The solid equivalent of a unit varies depending on particle geometry and degree of compaction. Table 7-1, column 7, divides the expansion factors into 200 to estimate the number of solid cubic feet of wood (or bark) that will expand to fill a unit.

Table 7-2. *Bulk density expansion factor and related measures.*

A. Effect of species and type of source mill on chips

		Composition (%)				Bulk density lb/ft³		Bulk density kg/m³		Compaction	Relative solid volume		Expansion factor	
Species	Source	OD wood	MC_w	Wood SG_g		Loose	Compacted	Loose	Compacted	ratio[a]	Loose	Compacted	Loose	Compacted
Douglas-fir	Sawmills	53	47	0.40	OD	8.3	10.5	133	168	1.26	0.33	0.42	3.01	2.38
					Wet[b]	15.7	19.8	251	317					
	Veneer and plywood	56	44	0.40	OD	7.9	10.0	127	160	1.26	0.31	0.40	3.15	2.50
					Wet	14.1	17.9	227	286					
	Planer mills	78	22	NA	OD	8.4	10.7	134	171	1.28	0.33[c]	0.43[c]	2.99[c]	2.34[c]
					Wet	10.8	13.7	176	219					
Western hemlock	Sawmills	49	51	0.38	OD	7.8	9.9	125	158	1.26	0.33	0.42	3.04	2.40
					Wet	15.9	20.2	255	322					
	Veneer and plywood	52	48	0.36	OD	7.9	9.7	127	156	1.23	0.35	0.43	2.83	2.31
					Wet	15.2	18.7	244	300					
	Planer mills	80	20	NA	OD	8.9	11.4	142	182	1.28	0.38[c]	0.49[c]	2.60[c]	2.03[c]
					Wet	11.1	14.2	178	228					
Western redcedar	Sawmills	50	50	0.30	OD	6.6	8.1	105	130	1.24	0.35	0.43	2.86	2.31
					Wet	13.2	16.2	210	260					
	Shake mills	48	52	0.29	OD	6.0	8.1	96	129	1.34	0.33	0.44	3.02	2.25
					Wet	12.5	16.9	200	269					
Red alder	Yard chipper	51	49	0.37	OD	8.4	10.4	134	167	1.25	0.36	0.45	2.76	2.22
					Wet	16.5	20.4	262	327					

Source: Weyerhaeuser Company, Source Characterization Summary, 1979, unpublished report.

[a] Compacted bulk density / loose bulk density.

[b] "Wet" bulk densities are calculated at the indicated moisture contents.

[c] Since no wood specific gravity was obtained at planer mills, the average specific gravity for saw and plywood/veneer mills was used in calculating these values.

B. Effects of residue type

Residue type	Composition (%) OD wood	Composition (%) MC_w	Wood SG_g		Bulk density lb/ft^3 Loose	Bulk density lb/ft^3 Compacted	Bulk density kg/m^3 Loose	Bulk density kg/m^3 Compacted	Compaction ratio[a]	Relative solid volume Loose	Relative solid volume Compacted	Expansion factor Loose	Expansion factor Compacted
Hogged fuel (51% bark)	55	45	NA	OD	9.1	11.9	146	190	1.30	0.31	0.40	3.22	2.50
				Wet[b]	16.5	20.9	265	345					
Hogged plywood trim	93	7	NA	OD	8.6	11.2	137	179	1.31	0.32	0.43	3.12	2.33
				Wet	9.2	12.0	147	192					
Flakes	55	45	NA	OD	5.3	7.2	85	115	1.35	0.24	0.33	4.16	3.03
				Wet	9.6	13.1	155	209					
"Green" shavings	66	34	NA	OD	3.9	5.4	63	86	1.37	0.16	0.22	6.25	4.55
				Wet	5.9	8.2	95	130					
"Dry" shavings	91	9	NA	OD	8.7	11.1	140	178	1.27	0.31	0.41	3.22	2.44
				Wet	9.6	12.2	154	196					
Sawdust and sawdust/ shavings mix	54	46	NA	OD	8.7	11.0	139	177	1.27	0.31	0.40	3.22	2.50
				Wet	16.1	20.4	257	328					
Screen fines	52	48	NA	OD	8.2	10.4	132	166	1.26	0.29	0.37	3.45	2.70
				Wet	15.8	19.9	254	319					
Sander dust	94	6	NA	OD	15.5	20.3	248	325	1.31	0.58	0.76	1.72	1.32
				Wet	16.5	21.6	264	346					

Source: Weyerhaeuser Company, Source Characterization Summary, 1979, unpublished report.

[a]Compacted bulk density / loose bulk density.

[b]Wet bulk densities are calculated at the indicated moisture contents.

Table 7-3. *Average moisture content (MC_w) and bulk density of various wood residues.*

Residue	MC_w	Bulk density (lb/ft^3) Green Mean	Green SE	Oven-dry Mean	Oven-dry SE
U.S. South					
Hardwood sawdust and bark	45	25.8	0.30	14.2	0.11
Mixed pine-hardwood sawdust	41	23.1	0.44	13.7	0.31
Clean hardwood pulp chips	43	22.9	0.55	13.1	0.58
Hardwood whole-tree chips	35	20.4	0.11	13.2	0.06
Pine whole-tree chips	40	18.8	0.10	11.3	0.08
Hogged dry trims (hardwood)	12	15.7	0.40	13.8	0.23
Shavings (hardwood)	8	10.8	0.59	9.8	0.55
Western		Oven-dry density (lb/ft^3)			
Hogged fuel		7.9 - 11.4			
Sawdust		8.0 - 11.2			
Bark		8.5 - 12.6			
Secondary mill sawdust		8.8 - 14.0			
Shavings		3.8 - 7.9			

Sources: U.S. South: Harris and Phillips (1989). Western: Risbrut and Ellis (1981).
SE = standard error.

Column 9 presents reciprocals of column 7 (i.e., number of units that will result when one solid cubic foot is converted into the corresponding residue type). Column 8 presents the metric counterpart to column 7 (i.e., the number of solid cubic meters that will expand to fill a cubic meter of space with the particular residue).

Conversions:

1 unit = 200 ft^3 = 5.66 m^3.

1 m^3 = 35.315 ft^3 = 0.177 unit.

Weight Measures

The common weight measures and conversions used in transactions and in various statistical sources are shown in Table 7-4. The weight of a bone-dry unit (BDU) was obtained by experimentally weighing a number of cords of Douglas-fir slab wood that were dried to 3 to 7% moisture content. The average weight, nearly 2,400 pounds, has become a standard basis for measuring residues.

Of these weight measures, the long ton is the least common but is found in some statistical reports. Due to moisture content variation, weights are generally corrected to a zero percent moisture content (oven-dry or bone-dry). Consequently, actual shipping weight will be much greater. Two useful conversions are (Appendix 1, Table 2):

To convert lb/ft^3 to kg/m^3 multiply by 16.0185.
To convert kg/m^3 to lb/ft^3 multiply by 0.062428.

Table 7-4. *Residue weight measures and conversions.*

	Oven-dry (lb)	Oven-dry (kg)	Short ton	Long ton	BDU	Tonne
Short ton	2,000	907.18	1.000	0.909	0.833	0.907
Long ton	2,200	998.18	1.100	1.000	0.917	0.998
BDU	2,400	1,088.62	1.200	1.091	1.000	1.089
Tonne	2,204.62	1,000.0	1.102	1.002	0.919	1.000

Source: Calculated by the author.

Stowage Factor and Compaction in Shipping

Since wood chips and residues are light in weight, compaction is very important to minimize the transporation cost per ton.

Stowage Factor. This is a marine term that measures the cubic volume of cargo space for products of known weights. It represents the number of cubic feet required, including void space, to contain a *long ton* of a product. Therefore, a stowage factor of 120 means that 120 cubic feet of space is needed to stow a long ton of a particular product.

Compaction Percent. Because of variability in moisture content, stowage factors for chips are not reliable and an alternative, compaction percent, is more commonly used. Compaction means the packing of chips so the voids are minimized. The pulp and paper industry defines compaction as the number of bone-dry units (BDU) that can be placed in a 200 cubic foot space. Thus one faces the potentially confusing situation relating BDU (a weight measure) to GPU (a volume measure).

Compaction is usually expressed as a percentage. A 100% compaction means that a BDU occupies exactly 200 cubic feet, which implies a bulk density of 2,400 lb/200 ft^3 = 12 lb/ft^3. Similarly, 90% compaction means that 0.90 BDU occupies 200 cubic feet (bulk density = 10.8 lb/ft^3). With modern shiploading equipment, compaction percentages of 100% or more are commonly achieved.

Compaction percent can be calculated by one of the following formulas.

Compaction percent

$= 100 * BDU * 200 / \text{ship volume, } ft^3$

$= (\text{long tons loaded}) * 1.12 (100 - MC_W) * 200 / (1.2 * \text{ship volume, } ft^3)$

$= 2{,}240 * 200 * (100 - MC_W) / (\text{stowage factor} * 2{,}400)$

$= 186.6 (100 - MC_W) / \text{stowage factor.}$

Residue Yield

Sawdust

The volume of sawdust produced in manufacturing lumber depends on sawkerf thickness, product line (number of saw cut lines), and log diameter. For a given log size and sawkerf, a mill producing smaller lumber items will generate more sawdust than a mill cutting large timbers. The material balance references in Chapter 4 are a good source of average sawdust yields in solid wood equivalent. The sawdust expansion factor in Table 7-1 or 7-2 should be applied to convert these solid wood equivalents to volume of sawdust as shipped.

Pulp Chips

Pulp chips are obtained from three principal sources: (1) whole logs, (2) sawmill slabs, edgings, and trimmings, and (3) veneer mill scraps and peeler cores, if the latter are not sold to stud sawmills or preservative plants for posts. The material balances in Chapters 4 and 5 provide estimates of average chip yields in solid wood equivalent from these processes. The chip expansion factor in Table 7-1 or 7-2 should be applied to convert these solid wood equivalents to volume of chips as shipped. The material balances assume that residues recovered as chips are fully utilized by pulp mills. Actually, a reject loss on the order of 2 to 5% will occur during pulp chip screening. This reject loss will be at the upper or lower end of this range depending on the condition of the chipper, the chip specification, and whether oversize chips are rechipped.

Planer Shavings

The volume of planer shavings obtained depends on the fraction of lumber output that is planed and the difference between the rough and surfaced dimensions. The material balances and computational methods in Chapter 4 can be used to estimate average shaving yields. Since these material balance estimates are in solid wood form, the expansion factor in Table 7-1 or 7-2 must be applied to get volume as shipped.

Bark

Bark volume varies with species, position on the tree, and tree size. Average bark volume can be

Table 7-5. *Bark contents of western species.*

Species	Bark volume, percent of Wood	Bark volume, percent of Total	Inner bark: % of total bark	Inner bark: MC_{od}%	Inner bark: SG_g	Outer bark: % of total bark	Outer bark: MC_{od}%	Outer bark: SG_g
SOFTWOODS								
Cedar								
Western redcedar	16	14	36	88	0.36	64	37	0.38
Yellow (Alaska)	15	13	52	145	0.41	48	79	0.38
Douglas-fir	28	22	38	133	0.45	62	80	0.43
Fir, true	13	12	65	77	0.52	35	40	0.58
Hemlock, western	20	16	54	134	0.45	46	65	0.56
Pine								
Lodgepole	11	10	30	128	0.34	70	42	0.51
Ponderosa	31	24	12	78	0.36	88	21	0.34
Western white	13	12	23	118	0.31	77	75	0.54
Spruce								
Engelmann	15	13	59	121	0.45	41	60	0.53
Sitka	9	9	45	112	0.44	55	55	0.62
HARDWOODS								
Red alder	16	14	56	88	0.52	44	66	0.62
Aspen	20	17	35	121	0.37	65	93	0.54
Birch	22	18	65	68	0.63	35	22	0.66
Black cottonwood	12	11	48	130	0.41	52	77	0.44
Bigleaf maple	19	16	68	134	0.66	32	70	0.45

Source: Smith and Kozak (1971).

estimated either as a percent of total volume (including bark) or as a percent of wood volume:

Bark volume as a percent of total volume

$$(BTV\%) = (dob^2 - dib^2) / dob^2 * 100$$

Bark volume as a percent of wood volume

$$(BWV\%) = (dob^2 - dib^2) / dib^2 * 100$$

where dob = diameter outside bark
dib = diameter inside bark.

For example, for a log measuring 20 inches in diameter inside bark, with bark one inch thick, the bark percentages are

$$BTV\% = (22^2 - 20^2) / 22^2 * 100 = 17.4\%.$$

$$BWV\% = (22^2 - 20^2) / 20^2 * 100 = 21.0\%.$$

This calculation is likely to overestimate the true bark volume because of fissures and voids in the bark. A range of 26 to 28% void volume was found for three softwood species (Krier and River 1968), hence the above results should be reduced by this amount. The recovered bark may be lower, due to miscellaneous losses during harvesting, log handling, and debarking.

Smith and Kozak (1967) developed bark thickness regressions for a variety of western Canadian species. Table 7-5 presents average total bark volume percentages, moisture contents, and specific gravities of inner and outer bark. The bark moisture contents reflect conditions that would normally be found in logs and do not include additional water from pond storage or water added during debarking.

Hog Fuel

Hog fuel is generally a mix of bark, sawdust, and planer shavings. The relative amount of each depends on a particular mill's marketing alternatives for these residues. The mix can be estimated as a weighted average using the information presented in the appropriate yield sections (see Estimating a Hog Fuel Mix below). If an estimate is needed with a high degree of confidence, samples of the hog fuel in question should be analyzed.

Residue Calculation Examples

Estimating Yield from Plywood

The following procedure can be used for lumber, veneer, plywood, and so forth. Assume that it is desired to estimate the number of 200 cubic foot units of chips recovered per 1,000 square feet (3/8 inch basis) of Douglas-fir plywood. The average mill-length block is 15 inches in diameter.

1. From the plywood material balance studies (Fahey and Willits 1991), about 25% of a mill-length veneer block is recovered as chippable residue, and about 50% is recovered as dry veneer. About 12% of the dry veneer will be lost in making plywood, so about 45% of the block will be plywood.
2. Chapter 5 shows that 1,000 square feet, 3/8 inch basis, plywood has a cubic volume of 31.25 cubic feet.
3. Since the cubic volume of plywood (31.25 ft^3) represents 45% of the cubic block volume and since the cubic volume of clean chips represents 25% of the block volume, the solid wood equivalent volume of chips can be estimated by proportions as follows:

   $45 / 31.25 = 25 / x$.

   Solving, yields $x = 17.4$ ft^3 solid equivalent of chips recovered per 1,000 ft^2, 3/8 inch, plywood.
4. Convert the solid chip volume by the compacted chip expansion factor of Table 7-1. Compacted chips

   = 17.4 ft^3 solid chips * 2.50 ft^3 compact chips per solid ft^3 = 43.5 ft^3.
5. Since a unit is 200 cubic feet, there are 43.5 / 200 = 0.218 units of compact chips recovered per 1,000 square feet of 3/8 inch basis plywood.

Estimating Yield per Cunit of Log Input

Assume a plywood process with the same conditions as indicated above.

1. From the material balance equations (Fahey and Willits 1991), about 25% of a mill-length veneer block is recovered as chippable residue.
2. Yield of chips = 100 ft^3/cunit * 0.25 = 25 ft^3 solid chips.
3. Multiply by the compacted chip expansion factor in Table 7-1.
   Compacted chips = 25 ft^3 solid chips * 2.50 ft^3 compact chips per ft^3 solid chips = 62.5 ft^3.
4. Therefore, a cunit of veneer blocks yields 62.5 / 200 = 0.3125 units of compact chips.

Converting Units of Residue to Weight

How many units of pulp chips equal an oven-dry short ton?

1. Assume the species is Douglas-fir, which has a SG_g of 0.45 (Table 1-1). Table 1-2 shows the weight density at 0% MC_{od}, or 28.1 pounds per solid cubic foot.
2. Divide by the compact chip expansion factor (Table 7-1) to get a bulk density of 11.24 oven-dry lb/ft^3 compact chips. Alternatively, use a bulk density based on samples.
3. Divide 2,000 pounds in a short ton by the bulk density estimate to get the number of cubic feet of compacted chips per short ton:
   2,000 / 11.24 = 178 ft^3.
4. Since a unit is 200 cubic feet, a short ton represents 178 / 200 = 0.89 units under these conditions.

Note: Simple division shows that for a 200 cubic foot unit to exactly equal a short ton, the bulk density would be 2,000 / 200 = 10 oven-dry lb/ft^3 residue. Similar calculations for other weight measures imply oven-dry bulk densities as follows:

Long ton	11.00
BDU	12.00
Tonne	11.02.

Estimating a Hog Fuel Mix

Assume that the hog fuel for a cunit of Douglas-fir logs processed in a sawmill will contain all of the sawdust, planer shavings, and bark produced by the mill.

1. From the material balances in Chapter 4 and the bark section in this chapter, assume the following recoveries as percentages of *green* wood volume: sawdust, 8%; shavings, 5%; bark, 28%. Reduce the bark fraction by 30% to account for fissures, voids, and processing losses so that the net bark fraction is 20%.
2. Column 1 of the table below multiplies these recovery percents by the 100 cubic feet in a cunit to give solid volume yields in cubic feet.
3. Column 2 lists the appropriate residue expansion factors from Table 7-1, and column 3 is the expanded residue volume in cubic feet after multiplying column 1 by column 2.
4. Columns 4 and 5 present MC_{od} and SG_g assumptions. It is assumed that sawdust is generated when processing green wood with an MC_{od} of 80%. The planer shavings are assumed to be generated after kiln drying to an average MC_{od} of 16%. The bark MC_{od} and SG_g are weighted averages of inner and outer bark of Douglas-fir from Table 7-5. Columns 6 and 7 are estimates of wet and oven-dry solid wood densities using Table 1-2.
5. Dividing the solid wood densities of columns 6 and 7 by the expansion factors in column 2 results in residue green and dry bulk densities in columns 8 and 9.
6. Multiplying the residue volume in column 3 by the green and dry bulk densities in columns 8 and 9 results in green and dry residue weights in columns 10 and 11.
7. Totals of columns 3, 10, and 11 give the final hog fuel values of interest.

For the conditions assumed here, a cunit of logs yields 92 cubic feet (0.46 unit) of hog fuel having a green weight of 1,767 pounds (green bulk density of 19.2 lb/ft^3) and oven-dry weight of 972 pounds (dry bulk density of 10.6 lb/ft^3). The hog fuel is equal to 0.40 BDU.

Residue	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Sawdust	10	2.50	25	80	0.45	50.6	28.1	20.2	11.2	506	281
Shaving	5	4.00	20	16	0.45	32.6	28.1	8.2	7.0	163	141
Bark	20	2.35	47	100	0.44	54.9	27.5	23.4	11.7	1,098	550
Total			92							1,767	972