Chapter 8. **Pulp and Paper**

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Pulp is the fibrous mass that results when a pulping process ruptures the bonds in the wood structure that hold the woody cells together. Pulping is done mechanically, thermomechanically, chemically, or with combinations of these treatments. Commercial processes are generally classified as mechanical, chemical, or semi-chemical—the latter being various combinations of chemical and mechanical. Appendix 2, Section G, shows that 82% of 1986 production was chemical pulping, of which 91% is produced by the kraft (sulfate) process. Semichemical pulping accounts for about 7% of production, and various mechanical pulping processes account for the remainder.

Pulp statistics are usually reported in units of weight. The most common are

short ton = 2,000 lb = 907 kg
metric tonne = 1,000 kg = 2,204 lb.

Pulp is generally reported as an air-dried product that is assumed to be 10% water and 90% oven-dry pulp. The actual condition of a shipment may vary somewhat from this definition. Pulp is commonly sold in bales (32 x 32 x 15 inches) which weigh about 500 pounds.

Pulp Yield

Recovery from pulping wood is commonly expressed as the percentage, by oven-dry weight, of pulp obtained from the original wood weight. A recovery value of 45% means that for every 100 oven-dry pounds of wood processed, 45 oven-dry pounds of pulp is produced. When expressed in this manner, pulp yield is mainly a function of the pulping process. There is some difference between hardwoods and softwoods when pulped by chemical processes, due to the difference in chemical make-up between these groups. Table 8-1 provides a summary of common pulping processes and yields. Section G of Appendix 2 shows percentage use of hardwood and softwood species.

Mechanical Pulping

The earliest and one of the most common mechanical pulping methods is the *groundwood* process, in which a *roundwood bolt* is pressed lengthwise against a rough, revolving grinding stone. The wood fibers are torn out of the wood, abraded, and removed from the stone surface with water. A different process, called *refiner mechan- ical pulp* (RMP) utilizes *chips*, which are shredded into fibers between large rotating disks of a device called a *refiner*. The basic RMP process has evolved to employ thermal and/or chemical presoftening of the chips, which reduces energy use and modifies resultant pulp properties; this is typically termed *thermomechanical pulp* (TMP).

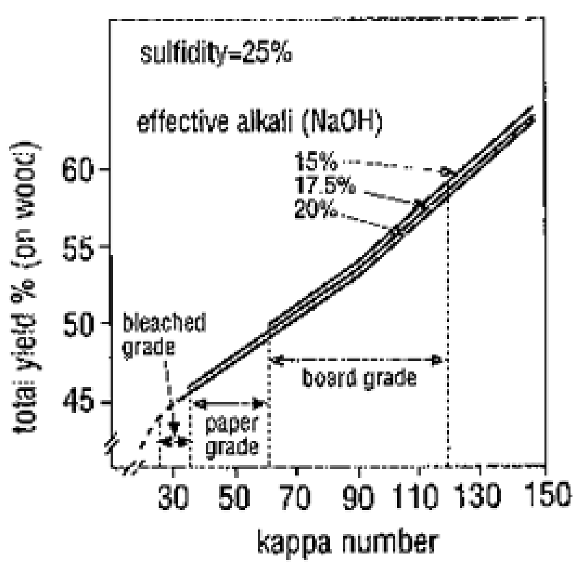
Mechanical pulping has the advantage of converting up to 95% of the dry weight of the wood input into pulp, but the mechanical action requires a large energy input. The pulp forms a highly opaque paper with good printing properties, but the paper is relatively weak and discolors easily with exposure to light. Newsprint is a major product of mechanical pulp. Mechanical pulps are generally produced from long-fibered softwood (conifer) species. The smaller, thinner fibers from hardwoods are more severely damaged by the mechanical action, hence yield a weaker paper. However, some hardwoods, such as poplar, which produces very bright pulp, are mechanically pulped and blended with softwood mechanical pulps to improve optical properties.

Chemical Pulping

In chemical pulping, the fibers in wood are separated by dissolving away the lignin component, leaving behind a fiber that retains most of its cellulose and some hemicellulose. Yields of chemical processes are on the order of 40 to 50% of the dry weight of the original wood input.

Kraft (Sulfate) Process. Because of advantages in chemical recovery and pulp strength, the kraft process dominates the industry. It represents 91% of chemical pulping and 75% of all pulp (Appendix 2, Section G). It evolved from an earlier soda process (using only sodium hydroxide as the active chemical) and adds sodium sulfide to the cooking chemical formulation. This is the process associated with the foul odor problem in the environment. A number of pulp grades are commonly produced, and the yield depends on the grade of product. Unbleached pulp grades, characterized by a dark brown color, are generally used for packaging products and are cooked to a higher yield and retain more of the original lignin. Bleached pulp grades are made into white papers. Figure 8-1 shows a pulping curve and relationship between yield, kappa number, and corresponding product. Nearly half of the kraft production is in bleached grades, which have the lowest yields. In Figure 8-1, kappa number refers to the result of a test of the amount of residual lignin in the pulp – lower kappa meaning less lignin. Effective alkali and sulfidity refer to conditions of certain key chemical aspects of the process (for details see Smook 1992). Curves such as shown in Figure 8-1 also differ with wood species.

Figure 8-1. *Kraft pulp yield vs. kappa and effective alkali charge. Source: Smook (1992).*



Sulfite Process. This process uses different chemicals to attack and remove lignin. Compared to kraft pulps, sulfite pulps are brighter and bleach more easily, but are weaker. Sulfite pulps are produced in several grades but bleached grades dominate production. Yields are generally in the range of 40 to 50%, but tend toward the lower end of this range in bleached grades. Compared to the kraft process, this operation has the disadvantage of being more sensitive to species characteristics. The sulfite process is usually intolerant of resinous softwoods, tannin-containing hardwoods, and any furnish containing bark.

Hybrid Pulping Methods

A number of processes are hybrids of chemical and mechanical methods and have intermediate yields. Generally, chips are partly softened or digested with chemicals and then are mechanically converted to fiber, usually in disk refiners. *Chemimechanical* pulping, typically used on hardwoods, softens chips prior to usual mechanical action and has yields in the 80 to 90% range. *Semi-chemical* pulping involves greater cooking and delignification prior to mechanical refining; yields are somewhat lower, depending on the degree of cooking.

Dissolving Pulp

Dissolving pulps are specialty pulps used for chemical conversion into products such as rayon, cellophane, and cellulose acetate. These pulps can be made by either a modified kraft (prehydrolysis) or sulfite process in which the aim is to obtain a pulp of pure cellulose. Since essentially all lignin and hemicellulose are removed, dissolving pulps have the lowest yields, on the order of 35%.

Estimating Wood Required per Ton of Pulp

It is also common to express pulp yield as air-dry or oven-dry tons of pulp per cord or other unit of wood volume. Alternatively, the reciprocal of these measures indicates the number of cords or other wood unit required per ton of pulp. In addition to the factors discussed above, these measures are affected by wood density. Yield is generally higher (less wood is required) for denser species.

To estimate wood required per ton of pulp, the following information is needed: (1) moisture content of pulp, (2) pulp yield, and (3) specific gravity of the species used as raw material.

There are several variations in calculating wood requirements, due to the different measures of pulp (short ton, metric tonne) and different measures for the wood raw material (cubic foot, cubic meter, bone-dry unit). A bone-dry unit (BDU) represents 2,400 pounds of chips or residues. See Chapter 7 for further discussion of chip and residue measures and conversions. Basic formulas are:

Example 1

How many cubic feet of solid western hemlock wood are needed to produce one short ton (2,000 lb) of oven-dry bleached kraft pulp (kappa 30)?

Formula 1 gives 10 = [(2,000 lb – DP) / 2,000 lb] * 100

solving: DP = 1,800 lb of oven-dry fiber per ton of pulp.

Formula 2 gives 45 = (1,800 lb / DW) * 100

solving: DW = 4,000 lb oven-dry wood per ton of pulp.

Here the yield of bleached kraft pulp is assumed to be 45% (Figure 8-1).

Formula 3 gives 4,000 lb = V * 0.42 * 62.4 lb/ft^3

solving: V = 153 cubic feet of green wood per ton of pulp.

Here 0.42 is the specific gravity of western hemlock (Table 1-1).

Example 2

How many cubic meters of solid western hemlock wood are needed to produce one tonne (1,000 kg) of oven-dry bleached kraft pulp (kappa 30)?

Formula 1 gives 10 = [(1,000 kg – DP) / 1,000 kg] * 100

solving: DP = 900 kg of oven-dry fiber per tonne of pulp.

Formula 2 gives 45 = (900 kg / DW) * 100

solving: DW = 2,000 kg oven-dry wood per tonne of pulp.

Here the yield of bleached kraft pulp is assumed to be 45% (Figure 8-1).

Formula 3 gives 2,000 kg = V * 0.42 * 1,000 kg/m^3

solving: V = 4.76 cubic meters of green wood per tonne of pulp.

Here 0.45 is the specific gravity of western hemlock (Table 1-1).

Example 3

How many cords of western hemlock wood are needed to produce one short ton of oven-dry bleached kraft pulp?

Example 1 found that 153 cubic feet of solid green wood are needed per ton of bleached Douglas-fir kraft pulp. Assuming a cord contains 80 cubic feet of solid wood (Chapter 3), this is equivalent to 1.91 cords/ton.

Example 4

How many cubic feet of gravity-packed western hemlock chips are needed to produce one short ton (2,000 lb) of oven-dry bleached kraft pulp?

To answer this question, one must know the relationship between wood volume before and after chipping. This depends on chip geometry, degree of settling and compaction, and so forth, which are discussed in Chapter 7. In this example it is assumed that chips occupy 2.5 times the original solid wood volume (see Table 7-1).

Example 1 found that 153 cubic feet of solid western hemlock wood were needed to produce a ton of pulp. The equivalent amount of chips is 2.5 times greater, or 382.5 cubic feet.

Example 5

How many "units" of western hemlock chips are needed to produce a ton of oven-dry bleached kraft pulp?

A "unit" typically refers to a 200 cubic foot container. Example 4 found that a ton of bleached kraft pulp requires 382.5 cubic feet of western hemlock chips. Division by 200 reveals that this is equivalent to 1.91 units.

Example 6

How many bone-dry units (BDU) of chips are needed to produce an oven-dry ton of pulp?

Example 1 found that 4,000 pounds of oven-dry wood are needed per ton of pulp. Since one BDU equals 2,400 pounds of oven-dry wood, the answer is

(4,000 lb/ton pulp) / (2,400 lb/BDU) = 1.67 BDU/ton pulp.

Example 7

How many bone-dry units (BDU) are needed to produce an oven-dry tonne of pulp?

Multiply the result from Example 6 by

(2,204 lb/tonne) / (2,000 lb/ton) = 1.102 ton/tonne.

Hence, 1.67 BDU/ton * 1.102 ton/tonne = 1.84 BDU/tonne.

Formula 1. $MC_W = [(WP - DP) / WP] * 100$

MC_W = pulp moisture content on total weight basis (%)

WP = pulp weight including moisture

DP = oven-dry weight of pulp

Formula 2. $Y = (DP / DW) * 100$

Y = pulp yield (%)

DW = oven-dry weight, wood raw material

Formula 3. $DW = V * SG_g * F$

V = green volume of wood raw material

SG_g = wood specific gravity (see Table 1-1)

F = density of water = 62.4 lb/ft^3 or 1,000 kg/m^3

In Examples 1 through 7 the pulp moisture content is assumed to be 10%. These examples illustrate both the information needed and computational steps involved in developing the common conversion factors of interest. The reader can substitute yields for other processes, specific gravities for other species, and other pulp moisture contents.

Appendix 2, Section G, presents overall average values of wood consumption in manufacturing pulp in 1986. It should also be noted that about 31% of the solid pulpwood used is actually in the form of residue by-products from other wood industries (Haynes 1990).

Paper and Paperboard

When paper and paperboard are produced, converted, and sold, several measurements are important. This section briefly discusses them and provides some illustrative data. Industry statistics are usually reported on a weight basis, and the standard weight conversions found in Appendix 1 can be used.

Basis Weight and Grammage

When paper and paperboard are produced and converted, two key characteristics are weight and area. Production is generally reported in tons, and products are sold on either a weight or an area basis depending on the needs of the customer.

Basis Weight. The common measure in the United States, *basis weight*, is "the weight, in pounds, of a predetermined number of sheets having a specific size" (Scott 1989). The predetermined number of sheets is the *ream*. Generally 500 sheets form a ream, but a ream contains 480 sheets for some products. Since various producers and converters need different size sheets, a variety of basic sizes have evolved over time. Table 8-2 indicates basic size and basis weights for several grades (500 sheet ream). For example, cover papers have basis weights of 40, 50, 60, 65, 70, 80, 100, and 130; all are based on a 500 sheet ream of 20 by 26 inch sheets.

Unfortunately, these basic sizes have no common relationship; hence, conversions among them require knowledge of actual sheet size and number of sheets involved. Essentially, the calculations require prorating the actual size and number of sheets to the standard basis size for the grade and to the number of sheets in a ream. Saltman (1991) provides a number of illustrative practical examples. To further complicate matters, the U.S. Government Printing Office uses a unit of 100 sheets, and basis weight for paperboards is usually given as pounds per 1,000 square feet.

The U.S. system is very cumbersome and can lead to confusion and misunderstanding. Grammage, as defined below, is gaining popularity, since it is simpler and is widely used internationally.

Grammage. In the SI or metric system, basis weight is called *grammage*, which is the weight in grams per square meter (Scott 1989). This definition eliminates confusion caused by different standard sizes and different ream counts. Table 8-2 shows how basis weights of various grades relate when expressed in grammage. In the U.S. system, book and cover papers both have a basis weight of 50 within the range for each of these grades. Table 8-2 shows that the grammages are 74 and 135, respectively. This difference was masked by the U.S. practice of measuring basis weights on 25 by 38 inch and 20 by 26 inch areas, respectively. Table 8-3 provides factors for converting basis weights.

Thickness (Caliper)

Thickness is an important determinant of stiffness. In addition, paper thickness determines overall thickness of finished products such as books, and hence the space they will occupy. In the United States, thickness is in inches, with the terms *point* and *mil* used to refer to thousandths of an inch. In the SI or metric system, thickness is in micrometers. Table 8-4 presents comparable thickness measures for several paper grades.

Density and Bulk

Two additional properties of interest are density and bulk. Apparent density, in grams per cubic centimeter, is obtained by dividing grammage by thickness. Density in grams per cubic centimeter (g/cc) can be converted to pounds per cubic foot (lb/ft^3) by multiplying by 62.4. Density influences most physical, mechanical, and other properties. Bulk is the reciprocal of density. It measures the volume in cubic centimeters (cc) occupied by one gram of paper or the volume in cubic feet occupied by one pound of paper. See Example 8.

Example 8

Tables 8-2 and 8-4 indicate that index bristol, with grammage of 253 g/m^2 (basis weight 140 lb), has a thickness of 0.25 mm (0.0098 inch).

Density, g/cc = 253 g/m^2 / (1,000 * 0.25 mm) = 1.012 g/cc.

(The number 1,000 results from 1 m^2 = 10,000 cm^2 and 1 cm = 10 mm.)

Density, lb/ft^3 = 1.012 62.4 = 63.2 lb/ft^3

or

$$\frac{140\ \text{lb}}{500\left[\dfrac{25\ 1/2}{12} * \dfrac{30\ 1/2}{12} * \dfrac{0.0098}{12}\right]} = 63.5\ \text{lb}/\text{ft}^3$$

Bulk, cc/g = 1/1.012 = 0.988 cc space per gram.

Table 8-1. *Summary of major pulping processes.*

Process	Acronym	Treatment: Chemical	Treatment: Mechanical	Pulp yield %	Wood used	Form of wood	Relative strength[a]: Softwood	Relative strength[a]: Hardwood
Mechanical								
Stone groundwood	SGW	None	Grinder	93-95	Softwood (mostly)	Bolts	5	3
Pressure groundwood	PGW	None	Grinder	93-95				
Refiner mechanical	RMP	None	Disk refiner (pressure)	93-95	Softwood (mostly)	Chips	5-6	3
Thermomechanical	TMP	Steam	Disk refiner (pressure)	80-90	Softwood	Chips	6-7	—
Chemithermomechanical	CTMP	Sodium sulfite or sodium hydroxide	Disk refiner (pressure)	80-90	Hardwood	Chips	—	5-6
Chemimechanical	CMP	Sodium sulfite or sodium hydroxide	Disk refiner	80-90	Hardwood	Chips	—	5-6
Semichemical								
Neutral sulfite	NSSC	Sodium sulfite + sodium carbonate	Disk refiner	70-85	Hardwood	Chips	—	6
Green liquor	GLSC	Sodium hydroxide + sodium carbonate	Disk refiner	70-85				
Nonsulfur	—	Sodium carbonate + sodium hydroxide	Disk refiner	70-85				
Chemical								
Kraft (sulfate)	—	Sodium hydroxide + sodium sulfide	None	45-55	Both	Chips	10	7-8
Sulfite	—	Calcium bisulfite in sulfurous acid	None	40-50	Both	Chips	9	7
Magnefite	—	Magnesium bisulfite in sulfurous acid	None	45-55				
Soda	—	Sodium hydroxide	None	40-50	Hardwood	Chips	—	7-8
Soda-oxygen	—	Sodium hydroxide + oxygen	None	45-55				
Soda-anthraquinone	SAq	Sodium hydroxide + anthraquinone	None	45-55				
Dissolving								
Prehydrolysis kraft	—	Steaming and kraft (two-step process)	None	35				
Acid sulfite	—	Acid sulfite (Ca, Na)	None	35				

Sources: Smook (1992) and Young et al. (1989).

[a]Very "rough" ranking based on full range of pulp strengths.

Table 8-2. *Examples of basis weight and grammage for several grades of paper, based on a 500 sheet ream (basic sheet size in parentheses).*

Basis weight						
Bond, ledger, mimeo, writing (17 x 22)	Cover (20 x 26)	Postcard, wedding bristol (22-1/2 x 28-1/2)	Index Bristol (25-1/2 x 30-1/2)	Glassine, news, tissues, wrapping (24 x 36)	Book, bible, offset, blotting (25 x 38)	Grammage (g/m^2)
x				x	20	30
9				x	x	34
x				x	24	36
11				x	x	41
x				x	30	44
13				30	33	49
x				x	35	52
15				x	x	56
x				x	40	59
16				x	x	60
x				40	x	65
x				x	45	67
x				x	50	74
20				x	x	75
x				50	x	81
x				x	60	89
24				x	x	90
x				60	x	98
x				x	70	104
28				x	x	105
x	40			x	x	108
x	x			70	x	114
x	x			x	80	118
32	x			x	x	120
x	x			80	x	130
x	x	x		x	90	133
36	50	x		x	x	135
x	x	x		90	x	146
x	x	67		x	x	147
x	x	x		x	100	148
40	x	x	x	x	x	150
x	60	x	x	x	x	162
x	x	x	90	100	x	163
x	x	80	x	x	x	175
x	65	x	x	x	x	176
	x	x	x	x	120	178
	70	x	x	x	x	189
	x	90	x	x	x	197
	x	x	110	x	x	199
	x	x	x	125	x	203
	80	x	x	x		216
	x	x	x	x		218
	x	100	x	x		219
	x	x	x	150		244
	x	x	140	x		253
	x	x	x	x		262
	x	120	x	x		263
	100	x	x	x		270
	x	x	x	175		285
	x	x	x	x		306
	x	140	170	x		307
	x	x	x	200		325
	x	x	x	x		349
	x	160	x	x		351
	130	x	x	x		352
		180	x	x		395
		x	220	x		398
		x	x	250		407
		200	x	x		438

Sources: Adapted from Saltman (1991) and Scott (1989).

Table 8-3. *Factors for converting basis weights from one basic size to another.*

Convert to:	g/m^2	17 x 22	24 x 36	25 x 38	25 x 40	1,000 ft^2	Actual ft^2
Convert from: g/m^2	1.000	0.266	0.614	0.676	0.711	0.205	—
17 x 22 - 500	3.759	1.000	2.311	2.541	2.675	0.770	1,300
24 x 36 - 500	1.627	0.451	1.000	1.100	1.158	0.333	3,000
25 x 38 - 500	1.480	0.394	0.909	1.000	1.052	0.303	3,300
25 x 40 - 500	1.406	0.374	0.864	0.950	1.000	0.288	3,470
1,000 ft^2	4.882	1.299	3.000	3.298	3.472	1.000	1,000

Source: Scott (1989).

Example: To convert from 60 lb (25 x 40-500) to basic size (17 x 22-500) look up the multiplying factor associated with (25 x 40-500) in the "Convert from" column and (17 x 22-500) in the "Convert to" row. The new basis weight is calculated as follows:

60 lb (25 x 40-500) x 0.374 = 22.4 lb (17 x 22-500).

Paper	**mm**	**Inches**	**"Points"**	**Micrometers**
Capacitor	0.0076	0.0003	0.3	7.6
Glassine	0.03	0.0012	1.2	30
Facial tissue	0.065	0.0025	2.5	65
Tablet	0.075	0.003	3.0	75
Newsprint	0.085	0.0033	3.3	85
Duplicator	0.095	0.0037	3.7	95
Rag bond	0.11	0.0043	4.3	110
Kraft envelope	0.13	0.0051	5.1	130
Index bristol	0.25	0.0098	9.8	250
Corrugating medium	0.23	0.009	9.0	230
Linerboard	0.23-0.64	0.009-0.025	9-25	230-640
Chipboard	0.15-0.41	0.006-0.016	6-16	150-410
Cardboard blanks	0.30-2.0	0.012-0.0780	12-78	300-2,000

Source: Scott (1989).