Papermaking properties of aspen ultrahigh-yield mechanical pulps

J. N. McGovern
Professor emeritus, University of Wisconsin, Madison, Wis. 53706

T. H. Wegner
Supervisory chemical engineer, USDA Forest Service, Forest Products Laboratory, One Gifford Pinchot Dr., Madison, Wis. 53705-2398

ABSTRACT *Eleven types of aspen ultra-high-yield (90% and above) mechanical pubs were evaluated for their chemical compositions (including sulfur), handsheet strength, and optical properties, fiber length indices, and fiberizing energies. The pulping processes were stone groundwood, pressurized stone groundwood, refiner mechanical, thermomechanical, chemimechanical (alkaline sulfite), chemithermomechanical, bleached chemithermomechanical, peroxide chemimechanical, steam explosion, and biomechanical. Data were obtained from USDA Forest Service reports and other literature. Pulps made using chemical pretreatments of the chips gave considerably higher handsheet strength properties than those produced from the groundwood types. This difference was not explained by chemical compositions. Chemical composition changed little, except for sulfonation of those pubs pretreated with sulfur-containing compounds. The light-scattering coefficients and fiberizing energies were reduced in the pulps from chemically pretreated pubs. The biomechanical pubs showed lignin loss with improved handsheet strength properties.*

KEYWORDS
Chemical analysis
Mechanical pulping
Optical properties
Pulping
Refining
Strength
Sulfonation

In 1856, the first mechanical wood pulp was made in Germany by a hand-operated grinder, and this stone groundwood (SGW) pulp is still being made today. In the 1950s, mechanical pulp was produced in a vertical attrition mill that had been developed in the 1920s for making semichemical pulp. A coarse-fibered, nonpapermaking pulp was developed about 1935, using steam pressure in a pressurized attrition mill. In recent years, combinations of chemicals, steam, and mechanical treatments have made a new class of pulps, called "ultra-high-yield" pulps because of their yields of 90% and higher.

Research and development interest in ultra-high-yield pulping remains intense because the process offers several major advantages over lower-yield chemical pulping processes. Ultra-high-yield processes are less capital intensive, have reduced economies of scale, use less water, do not require expensive chemical recovery systems, and give higher yields. Problems that still must be overcome are:

- Only certain select softwoods and hardwoods can be used.
- Ultra-high-yield processes are comparatively intensive in electrical energy consumption.
- Ultra-high-yield pulps have lower sheet strength properties than chemical pulps.
- It isdifficult toachieve high brightness with ultra-high-yield pulps.
- The color of ultra-high-yield pulp reverts.

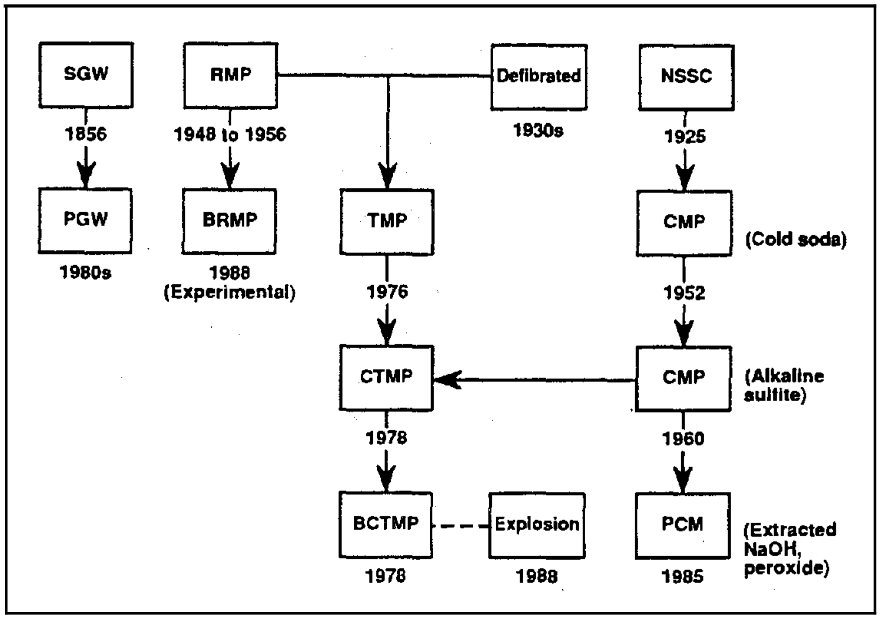
Efforts to get around these problems have led to the development of several ultra-high-yield pulping processes. The user of ultra-high-yield processes needs to have an understanding of the competing processes and the pulp and paper properties achievable with each.

Ultra-high-yield pulping originated in (a) the Forest Products Laboratory (FPL) semichemical process of the mid-1920s. with yields of 70–85% and (b) the Asplund Defibration process of the early 1930s. The semichemical process was extended into the 90% yield of chemimechanical pulp (CMP) through the cold soda method in 1952 and the alkaline sulfite method in 1965. The coarse aspen for hardboard pulp, already at the 90% yield level, was extended in 1976 into a papermaking pulp through the thermomechanical pulping process (TMP). The chemimechanical and thermomechanical processes were combined into the chemithermomechanical pulping process (CTMP) in 1978. The bleaching process followed to produce BCTMP. Typical BCTMP uses alkaline sodium sulfite. with hydrogen peroxide for bleaching. Acronyms. time of development. and types of high-yield mechanical pulping processes are given in **Table I. Figure 1** illustrates their interrelations.

Development of high yield pulping

Origin	Acronym	Description
1856	SGW	Stone groundwood
1925	NSSC	Neutral sulfite semichemical
Early 1930s	. . .	Defibrated (Asplund) thermomechanical pulp
1948 to 1956	RMP	Refiner mechanical pulp
1952	CMP	Chemimechanical pulp (cold soda)
1960	CMP	Chemimechanical (alkaline sulfite) pulp
1976	TMP	Thermomechanical pulp
1978	CTMP	Chemithermomechanical pulp
1978	BCTMP	Bleached chemithermomechanical pulp
Early 1980s	PGW	Pressurized stone groundwood
1985	PCM	Peroxide chemimechanical (NaOH-extracted wood)
1988 (under development)	Explosion	Exploded chemimechanical pulp
1988 (under development)	BRMP	Biomechanical pulp (fungal pretreatment of chips)

1. Development and interrelationships of ultra-high-yield pulping processes



The objectives of this study were to determine and evaluate the chemical composition (including sodium and sulfur content), handsheet strengths, fiber length indices, optical properties, and fiberizing energies of 11 types of aspen ultra-high-yield mechanical pulps.

Aspen wood and ultra-high-yield pulps were obtained from different sources and were tested in several laboratories. Many pulps were tested at the FPL and analyzed for their chemical compositions.

Some data were obtained from published reports. All pulps exceeded 90% in yield, although the narrow range of 90–95% made quantitative analysis impractical with regard to yield.

Results and discussion

Chemical composition

The lignin, cellulose, and hemicellulose compositions of the different ultra-high-yield aspen mechanical pulps appeared unaffected by the wide range of pulping treatments applied **(Table II).** Although the results of these tests vary somewhat. no trends were noted. The acid-soluble lignin levels show that certain syringyl groups were not made soluble (in the acid) by the several treating and fiberizing conditions.

The sulfonate contents of the ultra-high-yield pulps. as measured by their sulfur contents (sulfonate = 2.5 × S, expressed as a weight percentage of wood), showed a small but significant sulfonation having taken place in the processes involving the alkaline sulfite pretreatment of the chips (CMP, CTMP, explosion). The explosion pulp had a low but appreciable sulfonate content of 0.4%. It is possible that this appreciable amount could have made the fibers more flexible. with higher strength properties in the handsheets. The pulps made without a sulfite treatment had sulfur (and sulfonate) contents derived from the wood itself (SGW, RMP, TMP, CMP).

Properties of aspen ultra-high-yield pulps

The strength indices—tensile. tear. and burst — of handsheets produced from the various pulps appear to fall into three general levels:

1. Groundwood type (SGW, PGW, and RMP)
2. Thermotreated type (TMP)
3. Chemical and chemical-therm0 type (CMP, CTMP, BCTMP, PCM, explosion).

The ratios of the highest to the lowest strengths were: 2.5 for tensile. 1.5 for tear, and 5.8 for burst **(Table III).** These ratios show that the various high-yield pulping processes produce

II. Selected chemical components of aspen wood and pulps

	Lignin, %		Carbohydrates as sugars, %			
Material	Klason	Acid soluble	Glucose	Xylose	Manose	Sulfur, %
Wood	20.5	3.0	54.2	18.2	2.0	0.015
SGW	21.5	3.1	65.8	21.0	1.0	0.01
RMP	19.6	...	52.5	18.1	2.2	0.01
TMP	20.4	2.6	55.2	19.6	0.6	0.01
CMP[a]	19.3	3.8	57.6	14.0	2.3	0.02
CMP[b]	. . .	. . .	. . .	. . .	. . .	0.043
CTMP	18.5	3.4	57.7	22.5	1.6	0.09
PCM	18.8	4.1	50.3	18.5	1.7	. . .
Explosion	. . .	. . .	. . .	. . .	. . .	0.16

[a]Cold soda. [b]Alkaline sulfite.

III. Handsheet strength indices

		Indices		
Process	Freeness, mL CSF	Tensile, Nm/g	Tear, mN•m²/g	Burst, kPa • m²/g
SGW	105	28.2	2.2	0.86
PGW	105	18.4	2.8	0.90
RMP	120	28.1	2.8	0.66
TMP	110	27.6	3.2	1.10
CMP (cold soda)	110	63	5.45	3.11
CMP (alkaline sulfite)	100	49	5.0	...
CTMP	105	51.8	6.4	2.4
BCTMP	110	50	5.0	...
PCM	100	...	...	5.7
Explosion	100	70.6	6.1	...

IV. ***Densities of handsheets produced from ultra-high-yield pulps***

Process	*Freeness, mL CSF*	*Pulp density, kg/m³*
SGW	105	410
PGW	100	330
RMP	120	410
TMP	110	400
CMP	110	642
CTMP	105	518
Explosion	100	620

aspen pulps that can vary greatly in strength properties. Burst index varied the most. followed by tensile index and tear index. Therefore, the user of ultra-high-yield pulping processes has latitude in achieving differing strength properties through selecting the pulping processes.

The densities of handsheets produced from the series of aspen ultra-high-yield pulps **(Table IV)** fell into two general levels. Handsheets produced from pulps made without chemicals in the chip treatments (SGW, PGW, RMP, TMP) were much lower in density than those produced with chemical pretreatment (CMP, CTMP, explosion). The chemical treatment, although causing little sulfonation as already seen, apparently enabled the pulp fibers to arrange themselves more compactly.

The fiber fines content is an important factor in a papermaking pulp, as measured by the amount of material retained and passed by a 0.075-mm screen in the Bauer-McNett fractionation system. The fines contents decreased with (a) the use of a disc attrition mill in place of a grindstone, (b) the use of thermomechanical fiberizing conditions, and (c) the application of chemicals plus the thermomechanical conditions. Fiber length index, as determined from Bauer-McNett screen classifications. increased with the use of a disc refiner and applications of steam alone or with chemicals **(Table V).**

Aspen wood is naturally relatively light colored. This trait is reflected in the ultra-high-yield pulps by mechanical fiberizing with handsheet brightness values of 62–64% **(Table VI).** These pulps can be used unbrightened in certain paper grades. The other processes involving chemical and steam actions that reduce brightness values below 60% would probably need brightening for use. The cold soda CMP pulp process decreased brightness to 44%. For opacity, all the pulps except the CTMP and explosion had opacities above 90%. This level would probably favor use in printing papers.

The light-scattering coefficient is an indicator of unbonded surfaces. It is affected favorably by reduced handsheet density, reduced drainage, and disintegration of whole fibers. Where light-scattering coefficients were available in Table VI, the CTMP decreased below an arbitrary level of satisfaction of 60 m²/kg needed in printing papers.

Fiberizing or refining energies

Mechanical pulping that produces pulps in the ultra-high yields of 90% and above vary in their refining energies according to the process, wood species, process variables, degree of fiberizing freeness, and final product. A compilation from available literature of fiberizing energies for commercial ultra-high-yield processes based on aspen wood shows a wide variation within any one process and among processes. Fiberizing or refining energies taken for processes at nominal freeness of 100 mL CSF (Canadian Standard Freeness) are given in **Table VII.**

The application of steam was observed to increase energy requirements for fiberizing, or refining. This determination was made by comparing the energy requirements for PGW to SGW and TMP to RMP. The use of chemical treatments was observed to decrease refining energy requirements. This observation was made by

V. Fiber classification results

Process	Bauer–McNett fractionation system: Freeness, mL CSF	Fines,* %	Fiber length, index, mm
SGW	105	77.4	0.073
RMP	90	59.1	0.082
TMP	110	40.8	0.093
CTMP	105	29.4	0.092

*Percentage of pulp retained on and passing a 75-μm screen (Tyler series 585, 297,149, 75 μm).

Process	Freeness, mL CSF	Brightness, %	Opacity, %	Light-scattering coeff., m^2/kg
SGW	105	64	96	73
PGW	105	62	...	73
RMP	120	64	93	62
TMP	110	57	95	69
CMP[a]	110	44	...	...
CTMP	105	60	86	48
Explosion	100	53	81	...
BRMP[b]	100	41	95	...
BRMP[c]	100	43	93	...

[a] Cold soda.
[b] *Phanerochaete chrysosporium* (BKM–1767) pretreated.
[c] *Phlebia tremellosa* pretreated.

VII. Fiberizing or refining energies taken for processes

Pulp	Refining energy, GJ/1000 kg
SGW	3.6
PGW	4.3
RMP	5.9
TMP	7.3
CMP	3.1
CTMP	6.2
Explosion	3.6

Nominal freeness = 100 mL CSF

VIII. Chemical composition of ultra-high-yield aspen biomechanical pulp(BRMP)

Material	Composition, %: Klason lignin	Glucose	Xylose	Mannose
BMP	174	56.3	17.4	1.5
BRMP[a]	14.1	64.5	18.2	0.6
BRMP[b]	12.4	62.0	16.8	1.7

[a] *Phanerochaete chrysosporium* (BKM–1767) pretreated.
[b] *Phlebia tremellosa* pretreated.

IX. Handsheet properties of biomechanical pulps (BRMP)

Process	Freeness, mL CSF	tensile strength, Nm/g	Tear strength, mN•m^2/g	Burst strength, kPa•m^2/g	Density, kg/m^3	Brightness, %	Opacity, %	Light-scattering coeff., m^2/kg
RMP	100	35.3	2.68	1.00	427	65	92.6	61.4
BRMP[a]	100	52.8	4.53	2.05	394	41	94.9	40.7
BRMP[b]	100	51.9	6.01	2.14	426	43	93.3	38.2
TMP	111	27.6	3.2	1.1	400	57.3	94.8	69.4

[a] *Phanerochaete chrysosporium* (BKM–1767) pretreated.
[b] *Phleba tremellosa* pretreated.
Grammage = 60 g/m^2

comparing the energy requirements of CMP to RMP and CTMP to TMP.

Biomechanical pulping

A recent approach to ultra-high-yield pulping through altering lignin and its cellulosic fiber bonds is the pretreatment of wood chips with white-rot fungi, which are known to attack lignin in wood. The results of a four-week treatment of aspen chips with *Phanerochaete chrysosporium* (BKM-1767) or *Phlebia tremellosa* when compared with the chemical composition of aspen RMP pulp are given in Table VIII. The fungal treatment caused a small decrease in lignin content and a corresponding increase in cellulose measured as glucose. The measured hemicellulose content (xylose and mannose) remained relatively unchanged.

The fungal-treated aspen chips showed increases in handsheet strengths in ratios of 1.5–2.2, as shown in **Table IX** (e.g., 35.3 to 51.9, 2.68 to 4.53, 1.00 to 2.14). This improvement places the pulps from the fungal-treated chips to be near the same level as the CTMP with its chemical treatment of the aspen chips (Table III). The fungal pulp. however, decreased considerably in unbleached brightness and light-scattering coefficients. Biopulping is an experimental concept currently under investigation.

Conclusions

Ultra-high-yield aspen mechanical pulps showed little change in chemical composition (except biomechanical pulps). However, there were substantial changes in handsheet properties, depending on the use of chemical, biological. and steam pretreatments of chips.

The pulps that produced the strongest handsheets showed a reduction in optical properties and fiberizing energy.

The pulps from alkaline sulfite treatment of the chips showed small but significant degrees of sulfonation.

Experimental procedures

Test samples

Ultra-high-yield aspen mechanical pulps were obtained or made as follows:

1. Aspen wood, SGW, and PCM pulp were obtained from commercial Midwest sources.
2. Aspen, TMP, and CTMP pulps were obtained from a commercial laboratory and tested at the FPL.
3. CMP (cold soda), RMP, and BRMP were made at the FPL (*1*).

Pulp testing

The pulps were tested for the different properties according to TAPPI methods. Handsheets (60 g/m^2) were produced according to TAPPI Test Method T 205. Burst, tear, and tensile indices were measured according to TAPPI T 403, T 414, and T 404, respectively. Brightness, opacity, and light scattering were measured using an Elrepho photometer.

Screen classification and fiber length index determinations were done according to TAPPI T 233 (Tyler series 595, 297, 149, 75 μm). The chemical element S was determined by inductively coupled plasma (ICP) spectroscopy. Lignin content was determined by the method of Effland (*2*), and sugar contents were measured by high-pressure liquid chromatography (*3, 4*).

Literature results

Test results for certain pulps were obtained as follows: PGW (*5*), CMP (alkaline sulfite) (*5*), BCTMP (*6*), and explosion (*7*). ❱

Literature cited

1. Myers, G. C., Leatham, G. F., and Wegner, T. H.. Tappi J. 71(5): 105(1988).
2. Effland, M. J., Tappi 60(10): 143 (1977).
3. Pettersen, R. C., Schwandt, V. H., and Effland, M. J., J. Chromatography Sci. 22: 478(1984).
4. Wentz, F. E., Marcy, A. D., and Gray, M. J., J. Chromatography Sci. 20: 349(1982).
5. Wong, A., Review of pulping and papermaking properties of aspen, Canadian Biodeterioration, Canadian Bulletin, Canadian Forestry Service and The Alberta Forest Service, April, 1987.
6. Sharman, P. M., Pulp & Paper 63(5): S1(1989).
7. Kokta, B. V., Ahmed, A., and Zhan, H.-y., 1989 Wood and Pulping Chemistry Conference Proceedings, TAPPI PRESS, Atlanta, p. 697.

The authors thank the University of Wisconsin Biotechnology Center (UWBC) and the UWBC/FPL Biopulping Consortium for the biopulping data. The Biopulping Consortium includes 20 pulp. paper. and related companies. the UWBC, and the FPL.

Received for review Oct. 26, 1990.

Accepted Feb. 12, 1991.