Recycling potential of bagasse and wheat straw pulps

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ABSTRACT: This study evaluates the recycling potential of pulps made from nonwoods. We prepared five single species soda pulps of varying yields from bagasse and wheat straw in a laboratory. We also included a commercial bagasse chemimechanical pulp in the study. These pulps were subjected to cycles of sheetmaking, drying, and reslushing. The results of the study show that wheat straw pulps lose relatively little tensile strength and related properties as they are recycled. Bagasse pulps, however, have a low recycling potential, quite similar to that reported for wood pulps. The alpha, beta, and gamma cellulose contents of chemical pulps of wheat straw and bagasse did not change with the process of recycling. The high gamma celluloses in wheat straw chemical pulps seem to be responsible for their high recycling potential. During recycling, bagasse pulps lost significant amounts of fines, whereas fines were nearly completely retained in the wheat straw pulps. This may be because the wheat straw pulps fines have a high bonding potential.

Application: This study can help mills in evaluating appropriate fibers for recycling. It found that wheat straw pulps can be recycled with much less loss in tensile strength than bagasse or wood pulps.

An important feature of cellulosic fibers is that they can be repeatedly used for making paper. However, these fibers undergo irreversible changes in their characteristics as they pass through various papermaking operations, lowering their papermaking potential in subsequent cycles. Low-yield chemical pulps experience significant loss in tensile strength and related properties on recycling [1-11], whereas, mechanical pulps are much more reselient [9, 12-16].

Many researchers have studied the effect of recycling on fiber characteristics, but often the results of these studies are not in agreement with each other. The effect of recycling on zero-span tensile strength (ZSTS) is unpredictable. Howard and Bichard [9] observed no change in ZSTS on recycling of both chemical and mechanical pulps, while Mckee [1] and Horn [4] found a fall in ZSTS on recycling of chemical pulps. However, the freeness of the pulp and the drying temperature differed in the above experiments. Horn further observed that sizing with rosin caused a greater loss in ZSTS of recycled fibers. Pulp viscosity is reported to decrease on recycling [6, 7, 17, 18], but Bouchard and Douek [18] found that the loss in pulp viscosity due to recycling does not correlate with loss in sheet strength. Seth and Chan [19] recommend that ZSTS should be preferred over pulp viscosity in assessing fiber strength. Changes in the chemical composition of fiber on recycling is reported to be insignificant and the chemical analysis of fibers cannot differentiate between virgin and recycled fibers in a paper furnish [18].

The loss in strength properties on recycling is more a function of physical changes in the fiber rather than minor chemical changes. The generally held view is that the strength loss of recycled pulp results from the loss of fiber swelling during drying, which then reduces fiber-fiber bonding. This irreversible loss of fiber swellability is termed "hornification." Scallan and Tigerstrom [20] suggested that hornification is a feature of low-yield pulps. After studying the swelling ability for a series of kraft pulps with yields ranging from 40% to 100%, they found that as the pulp yield decreased, the loss in swellability of fibers after drying increased. Page et al. [21] speculated that the mobility of surface molecules is reduced through the loss of fiber swelling on drying. This, in turn, decreases inter-molecular interaction between two fiber interfaces, resulting in a decrease in fiber-fiber bond strength.

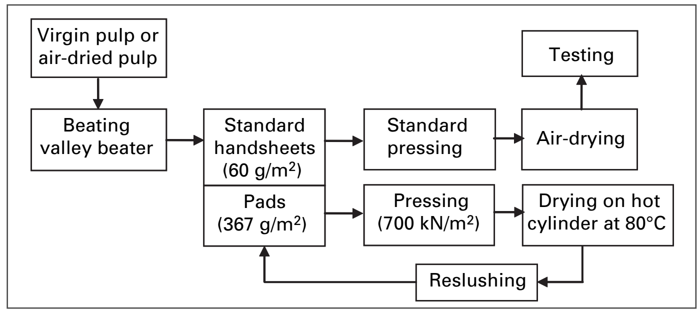
The response of fiber to recycling depends on several factors – raw material, pulping and bleaching conditions, refining, wet pressing, drying temperature, etc. Repeated drying and rewetting of fibers is considered to most significantly lower the recycling potential of pulp fibers [22-26]. The other papermaking operations, such as calendering, printing, deinking, and converting, also affect the recycling potential of fibers in various ways. Scallan and Tigerstrom [20] attributed the irreversible loss of strength in low-yield chemical pulps to its low lignin content. The removal of lignin from the fiber allows greater contact and bonding of carbohydrate components within a fiber.

The later findings suggest that hemicellulose content plays a greater role in guiding the recycling behavior of pulps than does lignin removal [27, 28]. In pulps containing high amounts of xylan, the xylan molecules between the cellulose microfibrils hold them against the tendency to self-associate during drying. Consequently, the cellulose microfibrils remain relatively loose and these fibers regain their flexibility upon rewetting. On the other hand, in low xylan-content pulps, water present in the voids allows strong lateral association between the microfibrils and formation of numerous hydrogen bonds during drying. In contrast with xylan, glucomanan has a stronger affinity with cellulose microfibrils and may even form a crystallized zone with cellulose [27]. Wheat straw, being rich in xylan, should produce pulps of high recycling potential. Blending of wheat straw pulp with softwood pulp in 30:70 ratios resulted in an increase in recycling potential of softwood pulp [28].

In the absence of a unified theory, we have experimentally evaluated the recycling potential of pulps made from different raw materials under different pulping and bleaching conditions. Studies reported in the literature are largely based on

	Bagasse	Wheat straw
Hot water solubility (%)	2.7	9.3
1% NaOH solubility (%)	30.2	38.3
Alcohol-benzene solubility (%)	1.6	3.4
Holocellulose (extratives free) (%)	76.0	73.5
Alpha cellulose (extratives free)(%)	44.4	41.8
Lignin (extratives free) (%)	20.7	21.3
Ash (%)	1.2	6.6

I. Proximate analyses of raw materials.



1. Schematic representation of repeated papermaking process.

Pulp code	WCP42	WCP49	BCP56
Raw material	Wheat straw	Wheat straw	Bagasse
Alkali charged, %	16	16	15
Bath ratio	1:5	1:5	1:5
Cooking temperature, °C	170	160	170
Time to temperature, min	75	90	90
Time at temperature, min	75	100	30
Screened yield, %	42	49	56
Kappa number	18.5	24	22.5
Bleaching sequence	CEH	CEHH	CEHH
Chlorine charged, % o.d. pulp			
C-Stage	3.24	4.68	3.94
H1-Stage	1.39	1.58	0.84
H2-Stage	—	0.94	0.84
Alkali charge E-stage, % o.d. pulp	2.0	2.6	2.4
Shrinkage, %	6.75	10.5	8.5
Brightness, %	74	81.7	82
1% NaOH solubility	8.96	7.81	5.74
α-Cellulose, %	77.72	77.30	82.90
β-Cellulose, %	7.27	10.00	11.20
γ-Cellulose, %	15.01	12.70	5.90

II. Pulping and bleaching data.

Pulp code	WSCP60	BSCP65	BCMP
Raw material	Wheat straw	Bagasse	Bagasse
Yield, %	60	65	-
Brightness, %	48	50	50
Extractives, %	0.36	0.19	0.74
Lignin (%)	7.01	6.92	16.12
Holocellulose (extractive free), %	89.83	92.05	82.48
Ash, %	1.86	0.89	1.73

III. Proximate analyses of higher yield pulps.

wood pulps, especially softwood pulps. Few references are available on the recycling potential of nonwood pulps. In the present study, we have evaluated the recycling potential of pulps made from two important nonwood fibrous raw materials, namely, bagasse and wheat straw.

EXPERIMENTAL WORK

Pulps

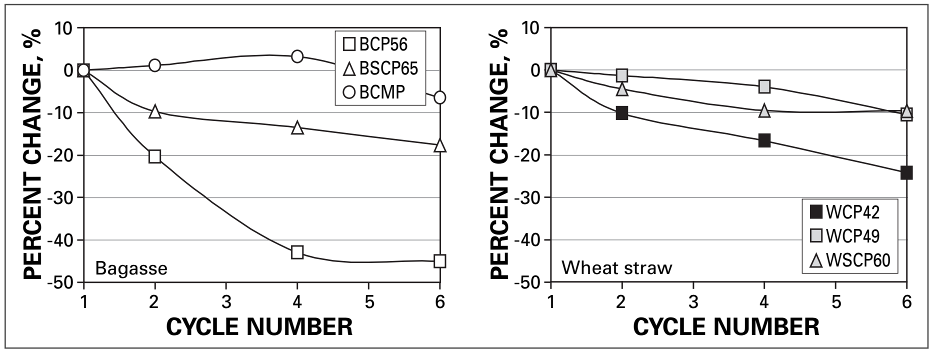
We prepared five single-species pulps of varying yields from wheat straw and bagasse. The wheat straw was screened on a 20-mesh screen in dry condition and then washed with water to remove extraneous dirt. The bagasse was depithed in a laboratory dry-depither and then washed on a 20-mesh screen to remove the pith and dirt. **Table I** lists the proximate analyses of the screened and washed raw materials. We used relevant TAPPI methods for the analysis.

The screened raw materials were cooked by soda process in a laboratory batch digester. The pulps were washed, screened, and bleached using CEHH or CEH sequence. **Table II** displays the pulping and bleaching data. The consistency in C-stage was kept at 3%, and 10% in the E- and H-stages. The chlorination was carried out for 45 min at ambient temperature with an end pH between 2 and 3. Retention time for extraction was 60 min at 60°C with end pH between 9 and 9.5. Retention for calcium hypochlorite treatment was 150 min at 40°C with end pH between 9.5 and 10.

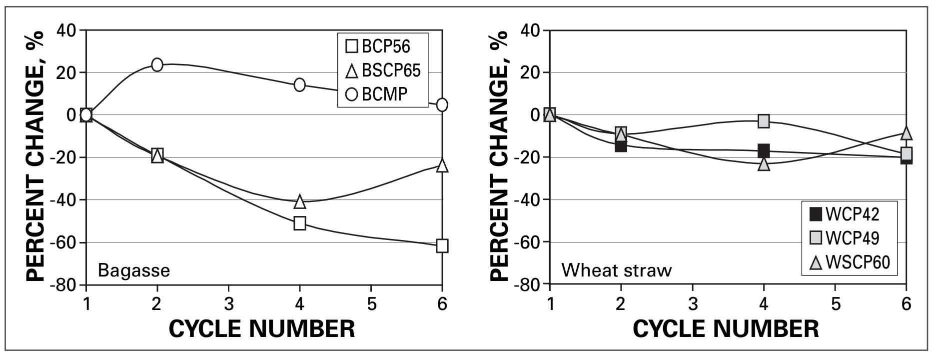
For the preparation of semichemical pulps of bagasse and wheat straw, the screened and washed raw materials were soaked for 15 min in a dilute caustic soda solution to have an even penetration of alkali in the raw material. We drained the soaked raw material over a synthetic cloth and squeezed it to a level that only the required amount of alkali (on oven dry raw material) remained absorbed in the material (4% for bagasse and 5% for wheat straw); the excess alkali was drained. The soaked material was then heated to 100°C and maintained at that temperature for 30 min in a laboratory autoclave. Immediately after cooking, the material was refined in a Sprout-Waldron single disk refiner. After refining, the pulp was disintegrated in a 20 L laboratory disintegrator at 3% consistency and 80°C for 20 min. We also tested a commercial chemimechanical pulp (CMP). **Table III** presents the data for the semichemical pulps and the bagasse CMP. At the beginning of the recycling experiments, wheat pulps WCP42 and WSCP60, and bagasse pulp BCP56 were in their never-dried state, and pulps WCP49, BSCP65, and BCMP were in their air-dried state.

EXPERIMENTAL PLAN

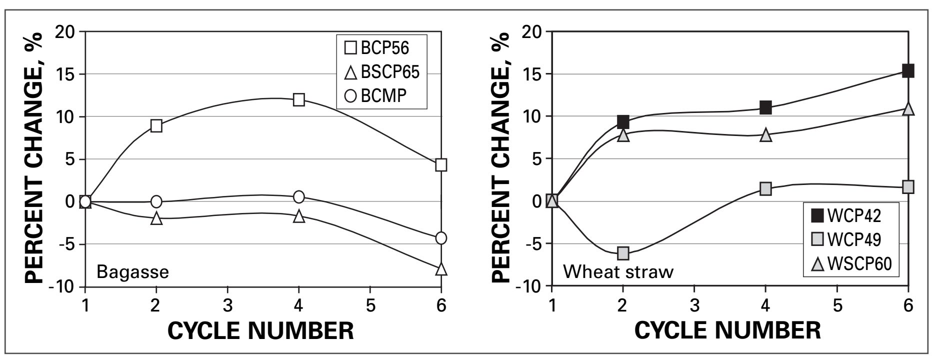
The experiments conducted in this study are shown schematically in **Fig. 1.** Recycling was limited to drying and rewetting of pulps. The sheets between the cycles were made on a laboratory sheet-making machine. The initial freeness of the pulps used for recycling study was kept in the range of 350-300 mL CSF. Chemical pulps were beaten in a valley beater to achieve the desired freeness. Semichemical pulps were refined to the desired freeness at the time of pulp making. From a portion of the pulp, handsheets of 60 g/m^2 were prepared according to the standard method SCAN M5: 76 for the evaluation of various properties of the pulp. To speed up the experimental work, thick pads (350-450 g/m^2) were prepared on the same sheet-making machine from the remaining portion of the pulp. The pads were wet pressed (700 kN/m^2) and dried on a heated cylinder at 80°C. The handsheets and the pads were dried in contact with gloss plates. The backwater was re-circulated during the making of sheets and pads. For subsequent cycles the pads were reslushed in the laboratory disintegrator at 1.2% consistency and remade into handsheets and pads without beating in between.



2. Effect of recycling on tensile index of pulps.



3. Effect of recycling on burst index of pulps.



4. Effect of recycling on tear index of pulps.

RESULT AND DISCUSSION

Tensile and burst strength

Recycling caused loss in tensile and burst strength of bagasse and wheat straw pulps, as shown in **Figs. 2 and 3**. The low yield chemical pulps showed a greater loss than did the higher yield semichemical pulps. The bagasse CMP showed a minimum change in strength properties. Between the two raw materials, bagasse pulps suffered greater loss in strength than wheat straw pulps. The change in tensile and burst indices on recycling of pulps indicates that the wheat straw pulps have a higher recycling potential than the bagasse pulps. The loss in strength of bagasse pulp is of the order of the loss reported for softwood and hardwood pulps [6]. The semichemical pulp of wheat straw showed an unusual behavior in that the tensile and burst strength in virgin state were higher than those of chemical pulps (**Table IV**). These strengths did not reduce to a large extent on recycling. The recycling potential of the wheat straw semichemical pulp is quite high in comparison to all other pulps.

Tear strength

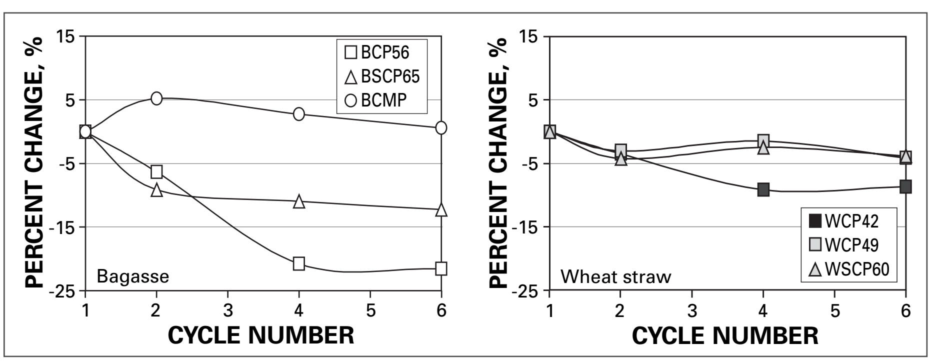
Figure 4 shows the percentage change in tear index as a function of the number of recycling cycles. No definite trend is visible for change in tear strength on recycling. For some pulps it increases with recycling, for others it decreases or remains unchanged. As tear index has a complex relationship with fiber length, fiber strength, and fiber-fiber bonding [29, 30], and all of these factors are affected by recycling to varying extents, a generalization on the dependence of tear strength on recycling has been difficult.

Zero-span tensile strength (ZSTS)

Recycling appears to affect zero-span tensile strength of pulps (**Fig. 5**). A decrease in ZSTS was observed for chemical and semichemical pulps, the bagasse pulps showing a greater change than the wheat straw pulps. The lower the yield of pulp, the greater was the loss in ZSTS. For bagasse CMP, the ZSTS showed an increase on recycling. Small increases in ZSTS for mechanical and chemimechanical pulps have also been reported [13]. Boucai [31] has observed that, besides the intrinsic fiber strength, zero-span tensile strength depends on fiber-fiber bonding. ZSTS is also dependent on crimps and kinks in the fiber [19, 32]. We, therefore, cannot say that the change in ZSTS on recycling noticed in our experiments is due to the loss of fiber strength. The effect of recycling on ZSTS appears to be high when the changes in fiber bonding and fiber curling are high, for example,

	Cycle	BCP56	WCP42	WCP49	BSCP65	WSCP60	BCMP
CSF, mL	1	335	349	334	289	306	224
	2	317	279	239	260	260	257
	4	386	275	248	238	255	359
	6	410	280	248	241	241	372
WRV, g/100g of pulp	1	203.04	220.76	177.33	210.92	259.17	162.89
	2	170.32	185.68	166.33	189.87	214.75	161.22
	4	137.9	157.05	163.76	155.84	186.7	153.68
	6	130.61	148.11	149.36	150.8	179.54	155.38
Apparent density, g/cm^3	1	695.41	648.81	681.16	597.92	601.29	355.56
	2	640.96	640.96	708.93	604.57	599.1	342.12
	4	628.63	627.78	694.01	592.22	570.91	382.21
	6	622.86	628.76	689.27	565.22	590.09	392.5
Air resistance (Gurley), sec.	1	129.25	144.3	77	195	720	4.5
	2	70.5	16.21	68	116	178	4.75
	4	26.13	8.67	70	107	121	5.5
	6	17.5	13.33	55.67	110	140	5
P-s porosity, mL/min	1	103.25	91	166.33	74.8	32.8	>750
	2	210.63	>750	179.33	138.4	84.4	>750
	4	649.6	>750	159.33	139	95.5	>750
	6	>750	>750	235	132.8	91	>750
P-s roughness, µm, 20 Kfg/cm^2	1	4.09	4.19	3.81	5.17	4.39	>6
	2	4.42	4.42	3.42	>6	5.01	>6
	4	4.78	4.86	3.59	>6	5.28	>6
	6	4.85	5.01	3.59	>6	5.28	>6
Tensile index, J/g	1	60.74	59.9	35.91	43.46	63.17	23.92
	2	48.34	53.8	35.23	39.35	60.07	24.24
	4	34.65	49.9	33.90	37.4	57.78	24.73
	6	33.39	45.4	32.15	35.39	56.45	22.28
Burst index, kPam^2/g	1	3.65	3.27	2.16	1.83	4.56	0.73
	2	2.96	2.8	1.98	1.52	4.12	0.79
	4	1.79	2.71	2.08	1.11	3.49	0.73
	6	1.4	2.61	1.74	1.39	4.17	0.67
Tear index, mNm^2/g	1	3.93	4.31	4.34	4.21	3.85	3.49
	2	4.28	4.71	4.10	4.15	4.16	3.51
	4	4.4	4.78	4.38	4.13	4.14	3.53
	6	4.1	4.97	4.42	3.88	4.27	3.36
Zero-span tensile index, J/g	1	92.54	83.2	68.41	79.95	93.71	52.87
	2	86.66	81.6	66.33	72.40	90.12	55.42
	4	73.33	75.5	67.42	71.60	91.31	54.36
	6	72.58	75.9	65.56	69.98	90.29	53.21
Scattering coefficient, m^2/Kg	1	24.49	35.13	41.75	22.76	17.64	38.85
	2	27.97	39.66	43.05	25.17	20.67	37.06
	4	30.81	42.61	42.36	27.20	21.56	36.40
	6	31.08	43.34	43.26	26.33	21.58	36.43
Abs. coefficient, m^2/kg	1	0.77	1.85	0.84	0.98	0.91	5.58
	2	0.68	2.22	1.14	1.49	0.98	6.13
	4	0.70	2.55	0.99	1.37	1.15	6.56
	6	0.71	2.66	1.25	1.49	1.26	7.14

IV. The effect of recycling on properties of pulps.



5. Effect of recycling on zero-span tensile index of pulps.

for low yield chemical pulps. Low yield pulp fibers are flexible and tend to curl during recycling operations. They also lose their bonding ability to a greater extent than do higher yield pulps. On the other hand, high yield pulp fibers are stiffer and have lesser tendency for curl.

Alpha, beta, and gamma cellulose

The proportions of alpha, beta, and gamma cellulose do not change with recycling of bagasse and wheat straw pulps (**Table V**). Bagasse chemical pulps suffer a greater loss in tensile and burst strength than do the wheat straw chemical pulps. The higher gamma cellulose content of wheat straw pulps seems to have a profound effect on preserving their recycling potential, as speculated by Cao et al. [27].

Water retention value (WRV)

Fiber swelling, measured in terms of WRV, decreased with recycling of all types of bagasse and wheat straw pulps studied (**Fig. 6**). We used a centrifugal force of 30N for 20 min for determination of WRV. Several experimental trials gave a stable and reproducible value of WRV at these conditions. A gradual reduction in WRV—up to six cycles—was observed for these pulps, unlike wood pulps where the major loss in fiber swelling is reported to occur in the first cycle [6, 9, 12, 13]. WRV is linearly related with the tensile index, but different lines are obtained for different pulps.

Scattering coefficient

Scattering coefficient increases on recycling of all the pulps, except BCMP. **Figure 7** shows a linear relationship between rise in scattering coefficient and loss in tensile strength for all chemical and semichemical pulps of wheat straw and bagasse. WCP49 has shown very little rise after six cycles and relatively lower loss in tensile index. **Figure 8** shows that there is a linear relationship between scattering coefficient and WRV for all the chemical and semichemical pulps under study. This suggests that the physical changes that cause reduction in WRV are also responsible for increase in sheet scattering of the pulps.

Apparent density

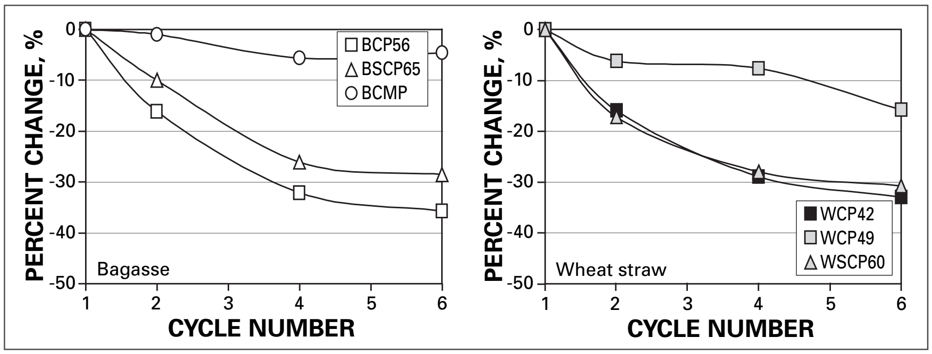
As shown in **Fig. 9**, apparent sheet density of chemical pulps of wheat straw and of bagasse decreases on recycling of pulp. The lower the yield of chemical pulp, the greater the decrease in sheet density. The magnitude of change in sheet density is much less for wheat straw pulps than for bagasse pulps.

Fiber classification

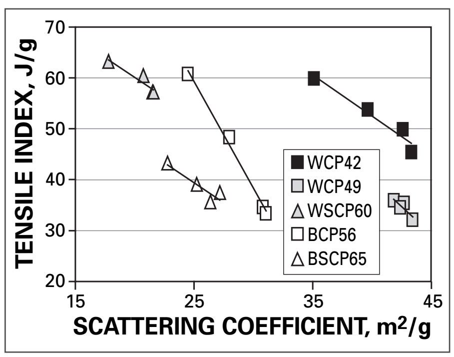
An observation of Bauer-McNett Fiber classification data (**Table VI**) suggests that the recycling potential of a pulp is linked to the fines content (P200) in the recycled pulp. For bagasse pulps, the P200 fraction decreases with recycling, indicating a loss of fines during sheet making between the cycles. For wheat straw pulps, the P200 fraction remains nearly unchanged on recycling, indicating that these fines are better retained in the sheet, possibly through a greater bonding ability than found in bagasse pulp fines. This property of wheat straw pulp fines must contribute to the higher recycling potential of wheat straw pulps. This may be a reason why the recycling potential of softwood fibers improves when blended with wheat straw fibers, as observed by Aravamuthan and Greaves [28]. They noticed that the wheat straw pulp fines helped in fiber bonding. In spite of being finer than the softwood fibers, wheat straw fibers were not preferentially lost in the handsheet making. If we discount for the loss of fines during recycling, the fiber classification remains nearly unchanged, suggesting that the recycling has no major effect on the fiber length. The literature also suggests that fiber length remains unchanged as the effect of drying-rewetting cycles for wood pulps [8-11, 15, 21].

	Cycle No.	α-Cellulose	β-Cellulose	γ-Cellulose
WCP42	I	77.96	7.07	14.97
	IV	80.3	5.71	13.99
WCP49	I	77.7	9.4	12.9
	IV	78.50	8.29	13.21
BCP56	I	82.77	11.27	5.96
	IV	81.76	13.73	4.51

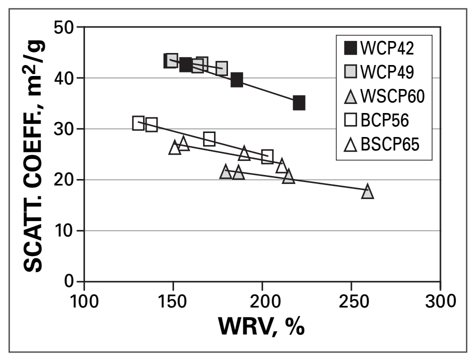
V. Effect of recycling on α, β, and γ-cellulose contents of chemical pulps.



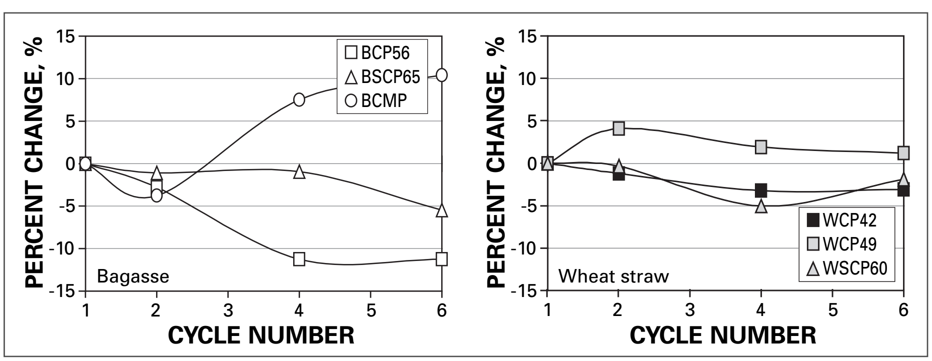
6. Effect of recycling on WRV of pulps.



7. Relationship between tensile index and scattering coefficient of recycled pulps.



8. Relationship between scattering coefficient and WRV of recycled pulps.



9. Effect of recycling on apparent density of pulps.

Freeness

Freeness of wheat straw pulps and semi-chemical pulp of bagasse decreased with recycling, while, freeness of bagasse CMP and chemical pulp increased with recycling (**Fig. 10**). The effect of recycling on pulp freeness appears to depend on the fines content present initially in the pulp. A large increase in freeness on recycling of bagasse chemical and CMP pulps is attributable to the loss of fines in the first cycle. The pulps (WCP42, WCP49, WSCP60 and BSCP65) having high fines content (P200 fraction) showed a decrease in freeness during recycling.

Other properties

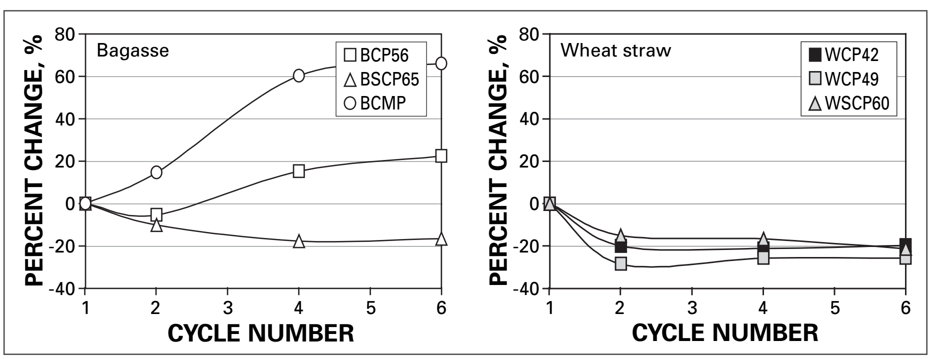
Changes in some other properties of handsheets of different pulps on recycling are given in Table IV. Air resistance showed a decrease with recycling for all the pulps studied. Low yield chemical pulps of wheat straw and bagasse showed a sharp and large decrease in air resistance on recycling. These pulps also showed high loss in strength properties. This is consistent with the usual relationship between the tensile strength, the sheet density and the sheet porosity. For all pulps, the roughness of handsheets increased with recycling. Besides the increase in inter-fiber voids at the paper surface, Klofta and Miller [11] observed that the surface of the fibers themselves became rougher on recycling.

CONCLUSIONS

- The recycling potential of a pulp is dependent on the type of raw material, pulping method, and pulp yield.
- Wheat straw pulps have higher

Pulp Type	Cycles	28-mesh	48-mesh	100-mesh	200-mesh	P200
BCP56	1	20.55	32.02	21.81	11.87	13.75
	2	22.2	33.68	22.00	12.19	9.93
	4	26.04	33.94	21.63	10.23	8.16
	6	—	—	—	—	—
WCP42	1	15.82	34.52	20.8	14.35	14.51
	2	16.06	33.68	19.98	15.02	15.26
	4	16.86	33.82	20.48	15.86	12.98
	6	16.26	34.01	20.02	15.22	14.49
WCP49	1	26.38	31.83	10.04	3.00	28.75
	2	26.43	31.8	12.99	3.65	25.13
	4	25.69	30.12	9.53	5.21	29.45
	6	—	—	—	—	—
BSCP65	1	21.16	22.34	19.86	9.71	26.93
	2	24.08	25.23	15.23	7.03	28.43
	4	—	—	—	—	—
	6	22.07	30.92	23.1	6.91	17.00
WSCP60	1	16.56	25.43	18.9	10.74	28.37
	2	20.39	26.86	20.34	9.54	22.87
	4	22.21	26.51	14.53	8.00	28.75
	6	17.05	28.53	20.3	10.03	24.09
BCMP	1	39.53	28.00	13.37	11.73	7.37
	2	36.82	27.85	13.46	13.77	8.10
	4	40.15	28.98	11.80	14.17	4.90
	6	42.76	29.00	11.07	12.47	4.70

VI. Effect of recycling on Bauer-McNett classification of pulps.



10. Effect of recycling on freeness of pulps.

recycling potential than do bagasse pulps. For both bagasse and wheat straw, the low-yield chemical pulps suffer greater loss in tensile strength than do the higher yield pulps.

- The magnitude of loss in tensile strength of bagasse chemical pulp is of the order of the loss reported for softwood and hardwood pulps.
- During the process of recycling, the loss of fines (P200) of bagasse pulps is considerably higher than the loss of fines of wheat straw pulps. Therefore, on recycling, the freeness of wheat straw pulps decreases considerably. The high recycling potential of wheat straw pulps is, perhaps, due to the high retention of fines in these pulps during recycling.
- The proportions of alpha, beta, and gamma cellulose do not change with recycling for bagasse and wheat straw chemical pulps. However, the initial gamma cellulose content in a pulp seems to affect its recycling potential. The bagasse pulp, due to lower gamma cellulose content, suffered a greater loss in strength than did wheat straw pulp on recycling.
- Water retention value (WRV) of bagasse and wheat straw pulps decreases gradually with recycling. This behavior of nonwood pulps is unlike wood pulps, in which the major loss in fiber swelling occurs in the first cycle.
- Zero-span tensile strength (ZSTS) decreases with recycling for both bagasse and wheat straw pulps. The loss in ZSTS for bagasse pulps is greater than the loss for wheat straw pulps. The lower the yield of pulp the greater is the loss in ZSTS. The loss in ZSTS on recycling may result from an increase in fiber curling rather than a loss in intrinsic fiber strength. **TJ**

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LITERATURE CITED

1. Mckee, R.C., *Paper Trade J.* 155(21): 34(May 24, 1971).
2. Bovin, A., Hartler, N., and Teder, A., *Paper Tech.* 5: 261(Oct. 1972).
3. Cildir, H., and Howarth, P., *Paper Tech.* 13: 333(Oct. 1973).
4. Horn, R.A., *Paper Trade J.,* 159(7/24): 78(Feb. 17, 1975)
5. Pycraft, C.J.H., and Howarth, P., *Paper Tech. Ind.* 21(10): 321(1980)
6. Yamagishi, Y., and Oye, R., *Japan TAPPI J.* 35(9): 33(1981).
7. Klungness, J.H., and Caulfield, D.F., *TAPPI J.* 65(12): 94(1982).
8. Bobalek, J.F., and Chaturvedi, M., *TAPPI J.* 72(6): 146 (1989)
9. Howard, R.C., and Bichard, W., *J. Pulp Paper Sci.* 8(4): J151(1992).
10. Eills, R.L., and Sedlachek, K., *TAPPI J.* 76(2): 143(1993).
11. Klofta, J.L., and Miller, M.L., *Pulp Paper Can.* 95(8): 41 (1994).
12. Chatterjee, A., Kortschot, M., Roy, D.N., and Whiting, P., *TAPPI J.* 76(7): 109(1993).
13. Law, L.N., Valade, J.L., and Quan, J., *TAPPI J.* 79(3): 167(1996).
14. Law, L.N., Valade, J.L., and Li, Z., *TAPPI J.* 79(10): 181 (1996).
15. Eriksson, I., Lunabba, P., Pettersson, A., and Carlsson, G., *TAPPI J.* 80(7): 151(1997).
16. Gratton, M.F., *J. Pulp Paper Sci.* 18(6): J206 (1992).
17. Stockman, L., and Teder, A., *Svensk Papperstid.* 66(21): 822(1963).
18. Bouchard, J., and Douek, M., *J. Pulp Paper Sci.* 20(5): J131(1994)

19. Seth, R.S., and Chan, B.K., *TAPPI J.* 82(11): 115(1999).
20. Scallan, A.M., and Tigerstrom, A.C., *J. Pulp Paper Sci.* 18(5): J188(1992).
21. Gurnagul, N., JU S., and Page, D.H., *J. Pulp Paper Sci.* 27(3): 88(2001).
22. Jayme, G., *TAPPI J.* 41(11): 180A(1958).
23. Lundberg, R., and de Ruvo, A., *Svensk Paperstid.* 91(11): 355(1978).
24. de Ruvo, A., Htun M., Ehrnrooth, E., et al., *Ind. Carta.* 18(6): 287(1980).
25. Stone, J.E., and Scallan, A.M., *Cell. Chem. Tech.* 2(3): 343(1988).
26. Laivins, G.U., and Scallan, A.M., *Transactions of the 10th fundamental research symposium, 1993,* edited by Baker C.F., Pira International, Leatherhead, England, p. 1235.
27. Cao, B., Tschirner, U., and Ramaswamy, S., *TAPPI J.* 81(12): 119(1998).
28. Aravamuthar, R., and Greaves J.S., *TAPPI 1998 Pulping Conference Proceedings,* TAPPI PRESS, Atlanta, Georgia, USA, p. 485.
29. Seth, R.S., and Page, D.H., *TAPPI J.* 71(2): 103(1988).
30. Page, D.H., *TAPPI J.*77(3): 201(1994).
31. Boucai, E., *Pulp Paper Can.*72(10): 73(1971).
32. Mohlin, U.-B., and Alfredsson, C., *Nordic Pulp Paper Res.J.*5(4): 172(1990).

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INSIGHTS FROM THE AUTHORS

Bagasse and wheat straw pulps are relatively weak. We chose this topic to research because we were interested in how they behaved during recycling.

We found that, like wood pulps, low yield chemical pulps of bagasse weaken significantly during recycling. Wheat straw chemical pulps show less reduction in tensile strength on recycling.

In our research we discovered that, during recycling, the fines of bagasse were lost, but the fines of wheat straw remained more or less intact. This information will be useful for paper mills using bagasse and wheat straw pulps.

We wonder whether blending of wheat straw pulp with other pulps can enhance their recycling potential. This would be a logical next step in the work.

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