Recycling Potential of Wheat Straw Pulp

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ABSTRACT

Bleached soda pulp of wheat straw was prepared in the laboratory. The pulp was subjected to repeated drying-wetting cycles. Handsheets were prepared between the cycles. The pulp showed a drop in tensile strength and burst strength on recycling. The recycling behaviour of wheat straw pulp has been observed to be more or less similar to that reported for bleached softwood chemical pulp. The magnitude of change is less than that for wood pulps. A sharp decrease in air resistance of the sheets was observed. An excellent linear relationship between scattering coefficient and WRV is observed.

INTRODUCTION

The quality of pulp decreases with increased recycling. The magnitude of this decrease depends on the type of fibre and its processing. Repeated drying and wetting of pulp produces the greatest irreversible effect on the pulp quality. The recyclability of pulps has been studied by a large number of researchers during last fifty years. The reported results have many contradictions and a generalization has not been possible. Most of the experiments have been conducted for wood pulps, obtained at different yields and bleached to different brightness level. Recycling potential of non-wood pulps has not been studied in much detail. In one study (1), it was shown that the recycling potential of the softwood pulp could be increased by blending it with straw kraft pulp. We are presenting here the results of a study on the effect of recycling on whole-wheat straw pulp.

The available literature reveals that it is the physical changes in the fibre, which causes reduction of the strength on recycling rather than the chemical changes. Bouchard and Douek (2) have noted that changes in the chemical properties of pulp during recycling are relatively minor. Chemical analysis of the fibre can not be used for differentiating between the virgin and recycled fibres in a paper furnish. They observed a partial depolymerization of cellulose during recycling of kraft pulp, but to assess its contribution to the decrease in the strength of pulp was difficult.

The chemical composition of the fibrous raw material may influence the recycling behaviour of the pulp fibres. It is well accepted that the chemical pulps exhibit pronounced changes, while mechanical pulps remain relatively insensitive to recycling. Many researchers (3-5) attributed this difference to the relative amount of lignin present in the fibre. However, subsequent studies revealed some inconsistency about the role of lignin in the recycling behaviour of pulps (6-7). Cao et al (8) studied the effect of hemicellulose and lignin on recycled pulp quality using hemlock pulps. The amount of pentosans in the pulps played a critical role in their recycling potential, with pulp recyclability improving with higher pentosan content. This effect was observed in both low yield and high yield pulps. On the other hand, the lignin content did not significantly affect the recycling potential of these pulps. In the present study, changes in the physical characteristics of the pulp during recycling have been observed.

EXPERIMENTAL

Single specie wheat straw pulp was prepared in the laboratory. Wheat straw was taken from the nearby area during the harvesting season of the wheat. The straw was screened to remove dirt and sand. The A+20 mesh fraction was taken for study. The chemical composition of the straw was determined using appropriate test methods. Proximate chemical analysis of the wheat straw used in this study is given in Table 1. The upgraded material was cooked in a laboratory batch digester under the pulping condition as given in Table 2. The pulp was then bleached in laboratory using a CEH sequence maintaining conditions as given in Table 3.

The bleached pulp was subjected to repeated sheet making and slushing in the laboratory. The schematic diagram of the recycling experiments is given in Fig. 1. The pulp of initial freeness of 490 ml was beaten in a Valley beater to a freeness of 349 ml. A sufficient number of handsheets of 60 g/m² were prepared from a portion of the beaten pulp. From the remaining pulp, pads of 367 g/m² were prepared on the same sheet making machine. The backwater was recirculated during making of sheets and pads. The handsheets were wet pressed and airdried according to the standard method SCAN M5:76. The pads were wet pressed at a slightly higher pressure (700 KN/m²) and dried on a heated drying cylinder at 80°C. During drying the handsheets and pads were kept in contact with gloss plates. For subsequent cycles the pads were re-slushed in the laboratory disintegrator at 1.2% consistency before making handsheets and pads for the next cycle. The reslushed pulp was not beaten between the cycles. The testing sheets were prepared only for zero, 1, 3 and 5 cycles. The handsheets were evaluated for the properties given in Table 4. Relevant Tappi Standard methods were used for the testing of handsheets.

Table 1. Proximate chemical analysis of wheat straw

Non-structural constituents	
Hot water solubility (%)	9.5
1% NaOH Solubility (%)	40.1
Ash (%)	8.23
Structural constituents	
Alcohol-Benzene Solubility (%)	3.45
Holocellulose (extractives free) (%)	72.94
Alpha cellulose (extractives free) (%)	41.6
Lignin (extractives free) (%)	21.6

Table 2. Pulping conditions

Alkali charged (%)	16
Bath ratio	1:5
Cooking Temperature °C	170
Time to temperature (min)	75
Time at temperature (min)	75
Screened yield (%)	42
Kappa number	18.5

Table 3. Bleaching conditions

	C-Stage	E-Stage	H-Stage
Consistency (%)	3	7.5	7.5
Temperature °C	25	60	40
Retention time (min)	45	60	120
Bleach chemical charge (as active chlorine) (%)	3.15	-	1.35
Alkali charge (%)	-	2.7	To adjust pH
End pH	3	9.5	10
Brightness (%)	-	-	71

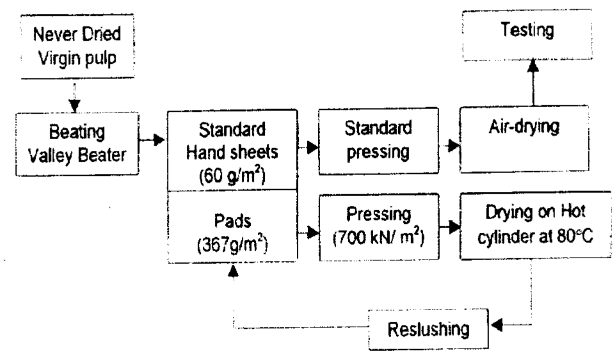

Fig. 1 Schematic representation of repeated paper making process.

RESULTS AND DISCUSSION

Pulp properties

The freeness of wheat straw pulp decreases on recycling. The drop in freeness is greatest, about 20%, in the first cycle. The decrease in the freeness of the pulp was observed although the Baur McNett fibre classification remained nearly unchanged with recycling as shown in Table 5. A drop in freeness on recycling of chemical softwood pulps has been reported by Howard and Bichard (9).

As shown in Fig. 2, the tensile index and burst index decrease and tear index increases on recycling of the wheat straw pulp. These observations are similar to those reported by other workers (9-12) for chemical softwood pulps. However the magnitude of change in these properties for wheat straw pulps is less than the generally reported value for the chemical softwood pulps. Zerospan tensile index shows a slight decrease with recycling. It decreases by 8.7% after six cycles. McKee (10) has also reported a decrease in zerospan tensile strength of 15% in seven cycles for softwood unbleached kraft pulps. However, in McKee's experiments, the handsheets were dried on a hot cylinder and the pulp was rebeaten the cycles. Howard and Bichard observed no change in wet and dry zerospan tensile strength for both chemical and mechanical pulps, when the pulp was not beaten between the cycles and the sheets were airdried. TEA index values show little change on recycling.

Apparent density of the sheet decreases on recycling

Table 4. Properties of handsheets measured at different cycles

Properties	0-cycle	1-cycle	3-cycle	5-cycle
Freeness (ml)	349	279	275	280
WRV (g/100g)	220.8 (2.11)	185.7 (1.36)	157.1 (1.15)	148.11 (1.91)
Apparent densit (g/cm^3)	0.65 (5.7)	0.64 (4.04)	0.595 (4.25)	0.63 (4.29
Gurley air resistance, sec	144.31 (14.4)	16.21 (15.97)	8.67 (5.96)	13.3 (6.12)
Zero span Tensile Index (J/g)	83.2 (2.18)	81.6 (5.6)	75.5 (9.14)	75.9 (3.04)
Tensile Index (J/g)	59.9 (6.39)	53.8 (2.55	49.9 (2.77)	45.4 (11.21)
Elongation (%)	2.9 (12.311)	3.08 (3.24)	2.88 (13.31)	3.04 (9.92)
Sp. Elastic Modulus (MN-m/Kg)	7.19	6.13	5.86	5.43
TEA Index (J/g)	1.3 (17.42)	1.3 (5.54)	1.1 (16.19)	1.1 (19.66)
Burst Index ($kPam^2/g$)	3.27 (5.33)	2.8 (3.5)	2.71 (9.8)	2.61 (9.26)
Tear Index (mNm^2/g)	4.31 (2.76)	4.71 (2.69)	4.78 (1.45)	4.97 (3.36)
Fold Endurance	1.57 (10.69)	1.34 (8.6)	1.31 (5.14)	1.36 (9.19)
R_∞ (%) FMY/C	72.39 (1.34)	71.7 (0.15)	70.86 (0.26)	70.58 (1.61)
R_0 (%) FMY/C	63.14	63.58 (0.98)	64.37 (0.68)	64.63 (0.77)
Scat. Coeff. (m^2/kg)	35.13	39.66	42.61	43.34
Opacity (%)	87.22	88.68	90.84	91.57

Note: The values given in the table are the average values and the value in the brackets is the coefficient of variation for that property.

Table 5. Baur McNett Fractionation at different cycles

	0-cycle	1-cycle	3-cycle	5-cycle
R28 (%)	15.82	16.06	16.86	16.26
R48 (%)	34.52	33.68	33.82	34.01
R100 (%)	20.8	19.98	20.48	20.02
R200 (%)	14.35	15.02	15.86	15.22
P200 (%)	14.51	15.26	12.98	14.49

as shown in the Fig. 3. After third recycle some increase in density was observed. As shown in Fig. 3 there was a sharp drop after first recycle in the air resistance of the sheet as measured by Gurley method. The air resistance values remained more or less the same on subsequent recycling of the pulp. It may be due to the changes in the hemicellulose content of the pulp on recycling. Scattering coefficient of sheets increases with the number of cycles, shown in Fig. 3. After six cycles. an increase of about 23% in scattering coefficient was observed.

Fibre Bonding

Page (13) proposed that tensile failure of paper could be expressed in terms of fibre strength and bond strength as given in Eq. 1

$$\frac{1}{T} = \frac{1}{F} + \frac{1}{B} \qquad (1)$$

Where T = Tensile strength, F= Fibre strength, B- Bonds strength.

He derived an equation for tensile strength of paper in terms of a few basic fibre and paper properties (i.e. length and cross sectional dimensions of the fibre, and relative bonded area), as mentioned below

$$\frac{1}{T} = \frac{9}{8Z} + \frac{12C}{bPL\ (RBA)} \qquad (2)$$

Where

T = Tensile strength (J/g)

Z = Zero span tensile strength (J/g)

C = Fibre Coarseness (g/m)

P = Fibre perimeter, m

L = Fibre length (weight average) (m)

b = Fibre bond strength (N/m^2)

RBA = Relative bonded area (%)

$$RBA = \frac{S_0 - S}{S_0} \qquad (3)$$

Where

S_0 = Scattering coefficient of an unbounded sheet

S = Scattering coefficient of a paper sheet

The tensile strength increases linearly with increasing bond strength per unit area and fibre length at low levels of bonding. As T increases, improvements in the bonding parameters are progressively less effective and the fibre strength (measured in terms of zerospan tensile strength) becomes more important.

Some workers (14, 15) used Eq. 1 and found that the effect of recycling is considered greater on the bonding contribution than the effect on the fibre strength. Ellis and Sedlachek (16) reformulated Eq. 2 to obtain a relationship between the tensile properties of the sheet and scattering coefficient of the sheet as in Eq. 4.

$$\left(\frac{1}{T} = \frac{9}{8Z}\right)^{-1} = \frac{b}{\gamma} - \left(\frac{b}{\gamma S_0}\right) \qquad (4)$$

where $\gamma = \frac{12C}{PL}$

A plot of Page parameter, $\left(\frac{1}{T} = \frac{9}{8Z}\right)^{-1}$ as a function of scattering coefficient, S, has been shown in Fig. 4. The data show a linear relationship with a coefficient of regression of 0.92. This suggests that b/γ remains constant on recycling as also observed by Ellis and Sedlachek. They have also shown for both softwood and hardwood that the ratio C/PL remains nearly constant during recycling suggesting that b, fibre-fibre bond strength, also remains constant. Under these conditions the plot can be used to determine the value of S_0, scattering for zero bonding. A value of S_0 = 51.53 m²/kg has been calculated from the intercept and the slope of the Page plot. The decrease in relative bonded area on recycling of the wheat straw pulp is shown in Fig. 5.

Water Retention Value

Most workers have observed that there is a decrease in the swellability of the chemical fibres on recycling. A similar behavior is observed for wheat straw pulp also. This can be shown by change in water retention value (WRV) of the pulp. We conducted several trails to determine WRV by changing centrifugal force and the duration of the application of this force. It was found that use of 30 N force for 30 min gave the lowest values of the water retained in the pulp and the results were reproducible.

WRV of the pulps were determined at different number of recycles of the pulp, it decreases on recycling. After six cycles percent reduction in WRV is 33% for the wheat straw pulp. This value is much higher than a reduction of 13% for softwood bleached sulphate pulps as reported by Yamagishi and Oye (12). Fig. 6 shows that the value of WRV has an

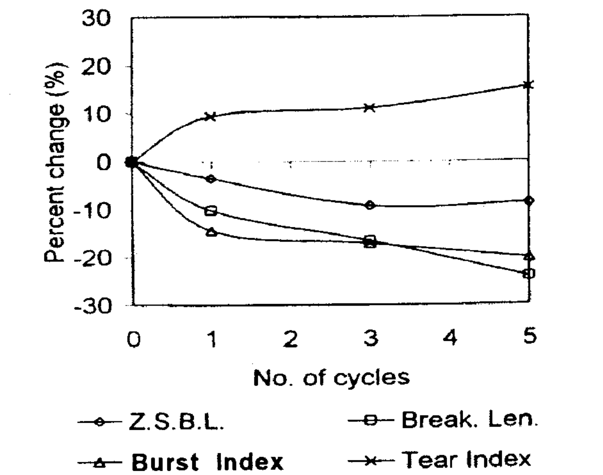

Fig. 2 Percent change in strength properties.

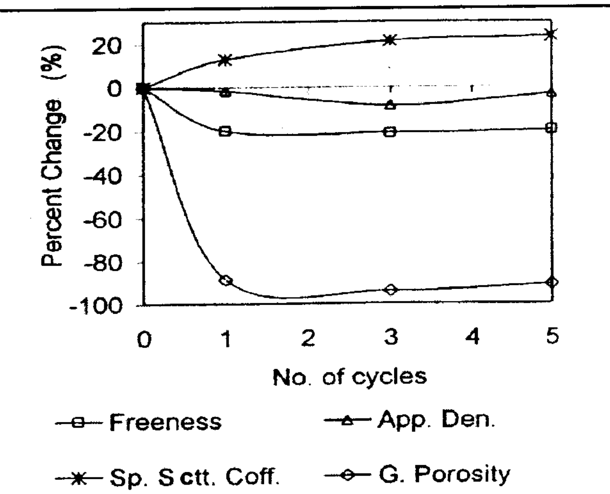

Fig. 3 Percent change in the structural properties.

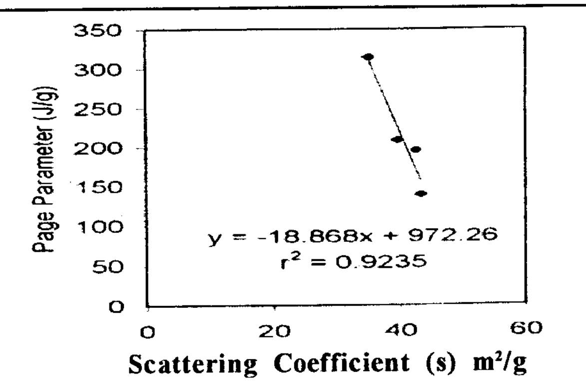

Fig. 4 Page Parameter Vs. Scattering Coefficient.

excellent linear correlation with the scattering coefficient, indicating that WRV is a measure of fibre bonding. Alpha, beta and gamma cellulose contents of the pulp were determined for the virgin pulp and after three cycles as shown in Table 6. There was a small increase in the alpha cellulose content at the expense of beta and gamma cellulose. This is consistent with the reduction in WRV of recycled pulps. The hemicellulose content of wheat straw pulp, as indicated by gamma cellulose, is higher than the hemicelluloses present in lowyield bleached chemical pulps of wood. This is probably the most important factor in favour of better recyclability of wheat straw pulps than wood pulps.

CONCLUSION

The wheat straw chemical pulp on recycling shows a similar behaviour as by wood chemical pulps. The tensile and burst strengths increase and tear strength decreases on recycling. The loss in strength of wheat straw pulp is less than that for wood pulp, possibly because these pulps have higher hemicellulose content than wood. The decrease in tensile strength on recycling is caused by decrease in relative bonded area although the strength of fibre-fibre bonds remains unchanged. There is a sharp increase in the air permeability of the sheet, as measured by the Gurley method, after first recycle. The value does not change on subsequent recycling of the pulp. WRV of the pulp decreases on recycling. Measurement of WRV by centrifuging for 30 min at 30 N force gives reproducible results.

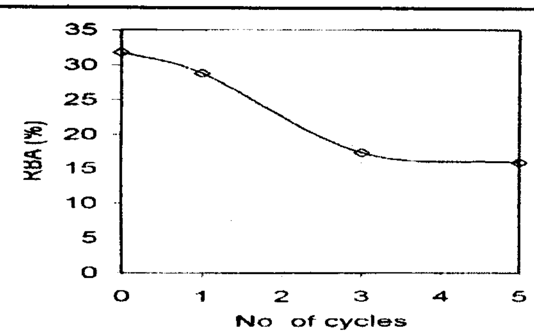

Fig. 5 Relative bonded area versus number of cycles.

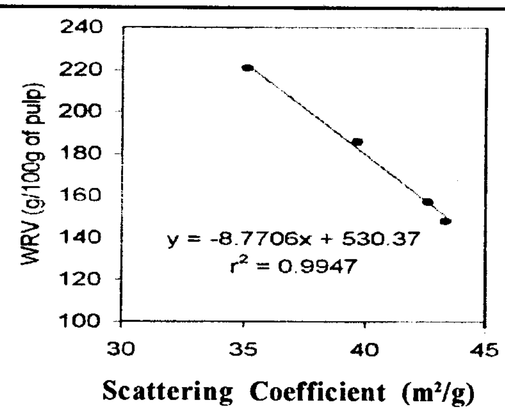

Fig. 6 WRV Vs. Scattering Coefficient

Table 6. Alpha, Beta and Gamma cellulose at 0- and 3 cycles

Cycle	Alpha Cellulose	Beta Cellulose	Gamma Cellulose
0	77.96	7.07	14.97
3	80.3	5.71	13.99

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REFERENCES

1. Aravamuthar R. and Greaves J.S., "The effect of multiple recycles on wheat straw fibres", Tappi Pulping Conf. P. 485 (1998).
2. Chatterjee A., Lee J., Roy D.N., et al., Inter. Paper Physics Conf. Proc., Tappi Press, Atlanta, p. 129 (1991).
3. Lunberg R. and de Ruvo A., Papier Carton cellulose 71 (1) 75 (1980).
4. Minor J.L. and Atalla R. H., MRS Symp. Proc., Vol. 266, Material Res. Soc. Pittsburgh, p. 215 (1992).
5. Klungness J.H. and Caulfield D.F. Tappi J., 65 (12) 94 (1982).
6. Lunberg R. and de Ruvo A., Svensk Paperstid, 81 (8) 266 (1978).
7. Cao B., Tschirner U. and Ramaswamy S. "Impact of pulp chemical composition on recycling", Tappi J., 81 (12) 119 (1998).
8. Howard R.C. and Bichard W., "The Basic Effect of Recycling on Pulp Properties", JPPS 18 (4) J151 (1992).
9. McKee R.C., "Effect of Repulping on sheet properties & Fibre characteristics", Paper Trade J., 155 (21) 34 (1971).
10. Bovin A., Hartler N. and Teder A., "Change in pulp quality due to repeated paper making", Paper Technol. 5: 261 (1972).
11. Yamagishi Y. and Oye R., "Influence of Recycling on Wood Pulp Fibres Changes in Properties of Wood Pulp Fibres with Recycling", Japan Tappi 35 (9) 33 (1981).
12. Page D.H., "A Theory for the Tensile Strength of Paper", Tappi J., 52 (4) 674 (1969).
13. Pycraft C.J. and Howarth P., "Does better paper mean worse waste paper", Paper Tech. and Ind., 21 (10) 321 (1980).
14. Cildir H. and Howarth P., "The effect of re-use on paper strength", Paper Technol. 13, 333 (1972).
15. Ellis R.L. and Sedlachek K., "Recycled Vs. Virgin fibre characteristics. A comparison", Tappi J., 58 (9), 146 (1975).