Effect of Recycling on Properties of Sheets Obtained From Mechano-Chemical Pulp

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ABSTRACT:- Mechano-Chemical pulp produced from rice straw (short fiber) conforming to newsprint grade was used for the present investigation with an aim to study the effect of recycling on the properties of hand sheets made from short fiber. Fiber classification was done on Bauer-McNett classifier and hand sheets were made from the unbleached and unsized pulp on a British Sheet Former. The pertinent properties studied were a few physical properties, strength properties and optical properties. It was observed that most of the results were in accordance with the theoretical expectations.

It was observed that with the increase in number of recycles porosity, burst, tensile, and double fold decreased while smoothness and Cobb$_{60}$ increased. The results of bulk and printing opacity were observed to be at variance from those of previous studies based on long fibers. These properties were found to decrease with the increase in number of recycles, thus contradicting the theoretical expectations, based on studies of long fibers.

INTRODUCTION

Indian paper industry faces a shortage of indigenous fibrous raw materials. India has a forest cover of merely 18% in contrast to the minimum requirements of 33% for a balanced eco-system. So, further pressure on forests for providing raw material for paper industry has to be avoided.

Increased use of secondary fibers is being practised all over the world as a means of cutting down the demand on virgin fiber resources and reducing environmental damage. Greater use of waste paper results in lower specific energy usage, lower water and chemical demand, lower investment costs, besides lesser dependence on forests and agricultural residues and reduced pollution load generation.

Despite the importance of recycling, paper and pulp industries are reluctant for this practice as the recycled fiber loses many strength properties as also some optical and surface properties. It is also well known that the fiber flexibility, bonding strength and dimensional stability deplete after a few recycles. Since successive recycles lead to generation of increased quantity of fines, substitution of a definite fiber fraction by virgin fiber will be necessary to maintain pulp quality. The aim, therefore, should be to achieve about 50% of production targets through recycling.

Pulp of good quality conforming to newsprint grade, having higher yield and good strength can be produced from chemi-mechanical or mechano-chemical pulping processes. This can be seen from the

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experimental works of Gopinath and Sadawarte (1), Basu et al (2, 3, 4, 5) and Arnomisky et al (6, 7).

Indian paper industry now uses non-conventional agri-residues to the extent of 30-40% of the total raw material demand. The paucity of conventional woody raw material is forcing their more extensive usage. Hence, pulp made from non-conventional materials will be more relevant to the Indian context in the future.

A few studies based on the recycle of conventional long fibered commercial pulps have been reported by Horn (8), Konig (9), Klungness(10), McKee (11), Guest et al (12) and Moore (13).

However, till date, no study has been conducted on the effect of recycling of sheets based on high yield, non-wood fibers of shorter length. Hence an attempt has been made in this paper to experimentally determine the effect of recycling on such fibers. Hence this will probably be a first systematic, prelusive investigation paving the way for future studies.

EXPERIMENTAL PROCEDURE:

Raw Material Preparation

The raw material used was rice straw collected from local villages, stored for 2-3 months, blended uniformly and cut into pieces 3 to 4 cm. in length and the dusts are separated. The raw material analysis was conducted with the dust fraction passing through 40 but retained on 60 mesh. The proximate and chemical analysis is presented in Table-1.

Table-1.

Raw Material Analysis of Rice Straw:

1.	Moisture Content	9	%
2.	Moisture Content in Dust	9.8	%
3.	ASH Content	13.36	%
4.	Silica Content	6.25	%
5.	Pentosan Content	18.35	%
6.	Hot Water Solubility	23.18	%
7.	Cold Water Solubility	26.3	%
8.	1 NaOH Solubility	47.73	%
9.	Lignin Content	24.48	%

Pulping Technique

Mechano-chemical pulping was carried out. Care was taken to ensure that fibers were treated lightly enough to produce high yield newsprint grade pulp. The pulping was done in a hydrapulper at low temperature and high bath ratio conditions. The various pulping parameters are listed in table-2. Properties of the pulp produced are listed in table-3.

Table-2.

Pulping Parameters

Temperature	=	80°C
Bath Ratio	=	1 : 15.7
Consistency	=	6 %
NaOH Dosage	=	10 %
Time of Cook	=	90 minutes

Table-3.

Properties of Pulp

Ash Content	=	7.27 %
Silica Content	=	3.40 %
Kappa Number	=	21.65

Refining and Washing

Two pass refining was necessitated to eliminate the clumps remaining due to the mild pulping conditions employed. Simultaneous dilution with water was done to prevent excessive fiber cutting during refining. The refined pulp was then washed thoroughly.

Sheet Formation and Testing

Sheets of 50 gsm were made on British sheet former and air dried. The basis weight was checked and the sheets were evaluated for surface, optical, and strength properties, Sheets prepared from virgin pulp are referred to as zero-recycle.

Bauer-McNett Classification

Samples were drawn from the pulp slurry after each recycle and subjected to Bauer-MeNett classification. Fractions were collected on screens sizes of 20, 40, 60 and 80 mesh and weighed. The results are tabulated in table-4 and plotted in figure-1. The average fiber length was found by microscopic study

Table-4.

Variation in Fiber Retention With Number of Recycles

Mesh Size	Fraction of Fibers Retained in Each Recycle (% By Weight) Recycle 0	1	2	3	4	5
20	24.15	21.16	17.18	17.92	16.96	11.78
40	29.10	29.16	30.70	27.95	27.43	3.95
60	22.20	18.75	4.56	15.76	24.8	23.88
80	3.00	10.59	21.01	27.34	20.78	39.33
-80	21.55	20.34	26.55	11.03	10.03	21.06

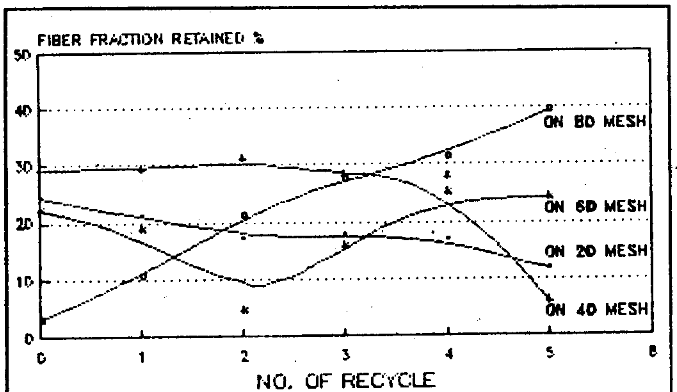

FIG 1: FIBERS RETAINED ON MESH vs RECYCLE NUMBER

and major variations were not found.

Recycle Experiments

After testing, the sheets and cuttings were repulped in a laboratory disintegrator. In all cases attempts were made to prepare sheets with basis weights as near 50 gsm as possible for strength, optical and surface properties' measurement.

The experimental data are presented in tables-5 to 7 and are plotted as percentage of initial (Zero recycle) values, for ease of comparison in figures-2 to 5.

RESULTS AND DISCUSSIONS

Smoothness

As evident from the results, the smoothness steadily increases with recycling due to a steady increase of fines content in the pulp. This increase is due to the knocking off of the external projections

Table-5.

Variation of Strength Properties With Recycles

Recycle Number	Burst	Tensile	Tear	Double Fold
0	210.15	36.92	2.29	5.8
1	108.52	25.61	2.34	5.5
2	112.51	15.96	3.97	5.0
3	94.03	13.48	3.82	3.9
4	90.20	11.38	3.42	---
5	82.68	9.32	3.24	---

Table-6.

Variation of Optical Properties With Recycles

Recycle Number	Printing Opacity
0	0.93
1	0.92
2	0.6965
3	0.6328
4	0.5670
5	0.5767

Table-7.

Variation of Surface Properties With Recycles

Recycle Number	Smoothness (ml/min)	Bulk (m^3/kg)	Cobb$_{60}$ (gm/cm^2)	Prosity (ml/min)
0	1100.79	0.00142	115.3	1200
1	1211.02	0.00165	112.18	1172.91
2	1350.31	0.00145	128.21	1508.26
3	1453.80	0.00148	127.7	1623.38
4	1594.27	0.00136	127.65	1285.71
5	1646.78	0.00116	189.9	979.54

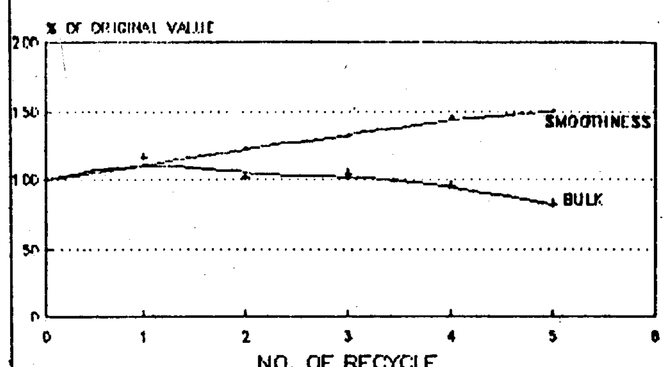

FIG 2: VARIATION OF SMOOTHNESS AND BULK WITH NUMBER OF RECYCLES

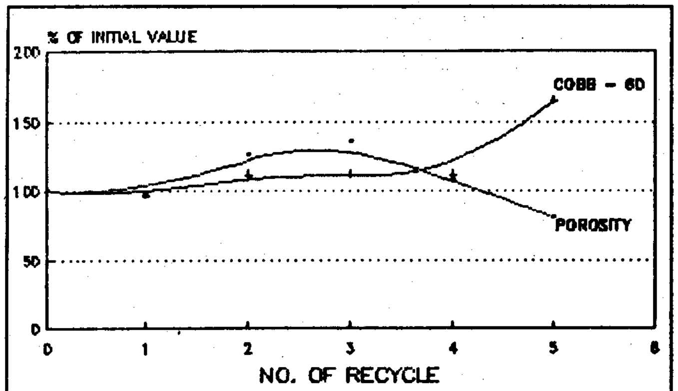

FIG 3: VARIATION OF POROSITY AND COBB-60 WITH NUMBER OF RECYCLE

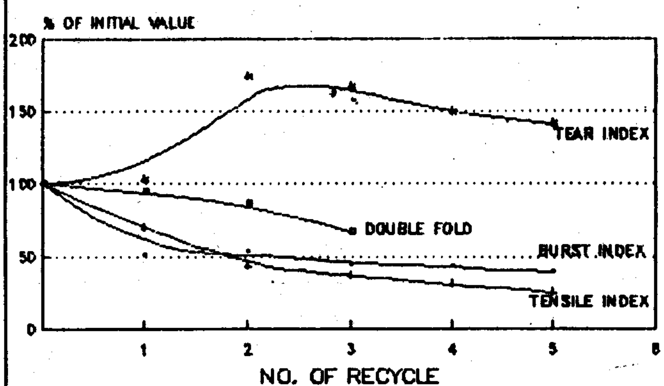

FIG 4: VARIATION OF STRENGTH PROPERTIES WITH NUMBER OF RECYCLES

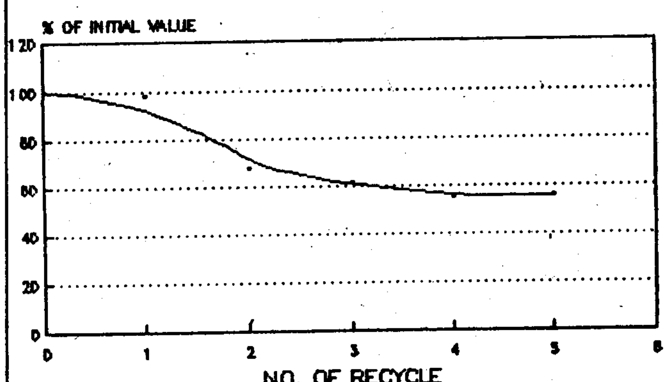

FIG.-5 : VARIATION OF PRINTING OPACITY WITH RECYCLES

on the fibers during recycling. These fines fill in the hills and valleys of the sheet, thus making the surface smooth. Moreover, with increased recycling, the fibers slightly shorten and become slimmer, and are ideal for producing smooth papers according to wright (14).

After fourth recycle, the rate of generation of fines decreases due to the lesser amount of fiber projections available for being knocked off and also due to reduced cutting action on the already short fibers. Moreover, by now, the hills and valleys are evened out by the fines and any extra amount has less effect in increasing the smoothness. Thus the rate of increase of smoothness slightly falls after fourth recycle.

Bulk of Sheets

The graph obtained for the variation of bulk with recycles shows an initial increase in the first recycle followed by subsequent decrease, contrary to expectations developed from past studies.

Primarily, the increase in bulk is due to the high rate of generation of fines. In the first recycle the virgin fibers have numerous external projections ready to be knocked off. The generation of these fines decreases the external fibrillation of the fibers and thus decreases the bonding. Moreover, according to Jayme (15), recycling causes, "hornification" of the fibers; thus increasing the stiffness and adversely affecting the bonding.

After the first recycle, the total amount of fines increases but the rate of increase of fines is lesser than that previously. This is probably due to the fact that the fibers, already shortened by the first recycle, are less subjected to cutting action. After the knocking off of the external fiber protuberances primarily, this is the main source of fines generation at later stages. Thus the effect of fines on the bonding and hence bulk, is reduced at later stages. However, the downright decrease of fibers first form the mat on which the lighter fines plug in at later stages in the sheet-former. Thus the weight of the sheet increases without a corresponding increase in its thickness. This causes an increase in the density or a decrease in bulk as found at later recycling stages.

Porosity

As evident from the graph, the porosity increases primarily due to the great decrease in the bonding due to the high amount of fines generated. This results in lowering the compactness of the sheet and increasing the porosity. More-over, this increase may be due to the decrease in the effective diameter of the straw fibers caused by the knocking off of the bristles on the fiber surface, as found by Arnomosky et at. (16).

Thereafter, on further recycling, during the formation of the sheet inside the sheet former, the long fibers settle first to form a mesh on which the floating fines come down, plugging the sheet and decreasing the porosity of the sheet. The curve also verifies the inverse relationship of porosity with density of the sheet.

$Cobb_{60}$

The testing of $Cobb_{60}$ on low gsm sheets as used in our study is not very reliable since the water percolates through, affecting the mechanism of absorption. Anyway, our experimental results as seen from the graph of $Cobb_{60}$ variation with the number of recycles, are in good accordance with the explanations.

Primarily, the $Cobb_{60}$ increases steadily with the steady increase of the fines content. Then, although the plugging of the sheets occurs due to the setting of the fines on the paper mesh, decreasing the porosity, $Cobb_{60}$ still increases as the increased fines content on the surface tend to absorb more and more water. Finally, the fines are no longer packed inside the fiber mesh and being freely present on the surface, they are in a position to absorb much more water thus increasing the $Cobb_{60}$ values greatly after fourth recycle.

Strength Properties (Fig.4)

Burst

Burst strength of a sheet is a complex function of its tensile and stretch. Hence the similarity of the curve to that for tensile index variation as seen from the graph supports this fact.

However, the rate of decrease of burst falls before the decrease of the tensile. This is probably due to the inverse proportionality of burst to the bulk of the sheet as given by Clark (17) alongwith the increase of stretch due to the low inter-fiber bonding.

Tensile

The tensile strength of the sheet depends on the fiber dimensions and on the extent and strength of bonds. According to Kane (18), fiber dimensions has little effect and the main reason for tensile strength variations is due to the latter.

Fines adversely affects the bonding and so the primary steady decrease in tensile is due to high rate of fines generation. It is also supplemented by increased hydration of the hemicelluloses with the number of recycles, thus decreasing the inter-fiber bonding. At later stages, as the rate of generation of fines decreases, the decrease in bonding and thus in the tensile strength is at lesser rate.

Tear

According to studies at Institute of Paper Chemistry (19), tear strength depends mainly on the total number of fibers involved in the rupture and the extent and strength of bonds alongwith fiber length.

Primarily, due to the increased generation of fines, the extent of bonding increases although their strength decreases. So now the fiber is bound at many places, though by weaker bonds and thus the energy required in pulling out such a fiber increases. Moreover, upon drying, the open structure of the fiber walls shrink and internal bonding occurs which does not disintegrate even on rewetting. These factors cause the initial increase in the tear. However, at later stages, the increase in the fines content causes a decrease in the bonding strength affecting the tear strength more strongly rather than the increasing number of bonds, thus causing the tear index to steadily fall.

Double Fold

It is not a very reliable test for such low strength papers as their tensile is so low that the standard weight used in the Schopper fold tester (790 gm.) may be more or comparable to the tensile strength. That is the reason why the values for the latter recycles could not be found out. Anyway, the results obtained are in accordance with the theory. The decrease in double fold with recycling is due its consistent relationship with the elastic flexibility of fibers which steadily decreases. However, primarily, the increase in the bulk, which affects the folding endurance positively, helps in partly neutralizing the greater decrease due to decrease of flexibility and the rate of decrease of double fold is low. However, later, the reduction is rapid due to increased fiber stiffness at each recycle.

Optical Properties (Fig.5)

Printing Opacity (R_0/Roo):

It is directly proportional to the scattering and absorption power of paper. The scattering power depends on the number of air-fiber interfaces which decreases with increased fibers coming in optical contact.

At later stages, the increased fines content causes plugging of the sheet. They have the same refractive index as the fiber and act as single particles of the size of the agglomerate, thus reducing the number of interfaces and hence the scattering power. This is the main cause for the high rate of decrease of the opacity from first to second recycle. Till first recycle, the decrease in the opacity was partially neutralized by the positive effect of increase of bulk on the opacity. The decrease in the opacity is also affected by the decrease in the absorption power of the sheet due to the slight decrease of lignin with increased recycling.

At later stages, however, the rate of decrease of opacity falls probably due to the amount of the fines being more than the void spaces. These fines, which are unable to come in optical contact with the fibers, increase the number of interfaces and thus partially neutralizes the decrease in the opacity, thus causing the rate of decrease of opacity to fall.

CONCLUSIONS

On repulping of paper, the bonding strength of fibers decrease due to the reduction of the external fibrils which get knocked off by the light mechanical treatment. These appear as fines in the stock, and being very light, settle late and are retained on the mesh of long fibers causing sheet pulgging. They thus act as fillers, increasing the smoothness, decreasing the porosity but since their refractive index is same as that of the fibers, they reduce the opacity. The bonding of the fibers progressively decreases due to reduction in the fiber flexibility with recycling.

From a detailed analysis of the experimental data and its interpretations through graphs, the conclusions made are as follows:

1. With increased recycling, the tensile, burst and double fold decrease progressively. Tear shows a primary increase but then decreases after second recycle.
2. The printing opacity, unlike that for long fibers, steadily decreases with each recycle.
3. The bulk of the sheets increases slightly but then decreases unlike long fibered species. Both smoothness and $Cobb_{60}$ increase steadily and the porosity increases to a maximum at third recycle and then falls.
4. The amount of fines progressively increases with the number of recycles.

Thus it can be said that the effect of recycling on short fibered, high yield species is markedly different from other pulps in some spheres. Thus there is requirement of more experimental work in the field for a more detailed understanding of the effect of recycling on such fibers in order to enable us to judge the feasibility and find the optimum number of recycles for reusing such papers which are very common in our daily life and can be good sources of waste paper for recycling.

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