Quality Improvement of Paper made from Agricultural Residues

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ABSTRACT

Agricultural residues are important fibrous raw materials for Paper Industry in India. The paper quality evaluation related studies carried out at CPPRI revealed that the papers produced by many of the Indian Mills had wide variation in the strength and optical characteristics inspite of the fact that raw material, its processing methods and types of paper machines and their configuration were almost similar. One of the causes identified in the present investigations is the variation in the formation indices of different papers produced by them. The medium sized paper mills, which are mainly based on the agricultural residues have relatively inferior formation (formation index 31 to 93) as compared to big mills based on bamboo and hardwoods (90 to 140). The formation indices of papers manufactured from waste paper by small capacity mills are still poorer (29 to 40). The bonding properties (tensile & burst index) are adversely affected as the formation deteriorates. The extent of reduction in the tensile index ranged from 7.8 to 36.1%, for the bursting strength 9.4 to 34.8 % and for tearing strength 6.7 to 42%. Drop in formation index caused drop in sizing degree, retention of the fillers and sp. scatt. co- efficient values as well. The regression correlation co-efficient between formation index and tensile strength, tearing strength and sp. scattering co efficient was around 0.60 which indicated strong dependence of these properties on the formation. There is a need to diagnose precisely the causes of bad formation in general & millwise specifically so that corrective measures could be taken. Short fibres such as in hardwoods & agroresidues theoretically should produce a paper with better formation as compared to long fibred pulps. As a natural behaviour the cellulosic fibres used for papermaking flocculate when suspended in water. The extent of flocculation depends on the concentration, fibre type, degree of beating, presence of flocculants or dispersants etc. Excessive dosages of alum & wet end chemicals adversely affect the formation. Laboratory studies indicate that addition of alum more than 4%, cationic starch more than 2% & retention aid more than 0.2% should be avoided to get better formation. Dual type retention aids cause the drop in formation relatively to a lesser extent. Since the agroresidues pulps are too weak to stand refining, properly designed deflakers may be a better option to separate fibres for retaining freeness & getting better formation. Optimisation of stock to wire speed ratio, agitation on the wire, table arrangement, the shake, the Dandy on the paper machine and the optimisation of stock charge are some of the important ways to improve paper formation.

INTRODUCTION

Agricultural residues are important fibrous raw materials for Paper Industry in India and other developing countries like China, Mexico, Indonesia, Iran, Pakistan, etc. The ratio of non-wood pulp to total pulp production in such countries is more than 30% (Table I). The general features of agricultural residue pulps are that these contain short length fibres accompanied by substantial amount of non- fibrous components. Such pulps are slow draining type & it is generally considered that paper made from these pulps is of relatively poorer strength than wood pulps. From time to time the evaluation of paper samples received in CPPRI, it was observed that the papers produced by many of the Indian mills had wide variation in strength and optical characteristics,

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its processing methods and type of paper machines and their configuration were almost similar. It is therefore very important that the reasons for such wide variation are examined & methods found out to improve the quality of paper produced from such raw materials.

Paper samples manufactured by 25 Indian paper mills were examined in detail for the different characteristics viz., formation of sheet matrix, strength and optical properties etc. Paper formation was generally found to be inferior. As it is well known that formation not only influences printability, but it can also influence its physical and optical properties. The possible ways of making better paper from these raw materials by improving formation have also been discussed.

RESULTS AND DISCUSSION

Formation and its quantified value for different paper samples:

Formation is defined as the visual appearance of the sheet when held up to the light. Formation encompasses the structure of the sheet and deals mainly but not exclusively with the flocs in the sheet, their size, distinctness and their distribution. Basically a well-formed sheet will have a uniform fibre distribution with very faint small flocs evenly distributed through out the sheet. The sheet can look flocculated with large distinct flocs, or very uniform with small flocs or streaks or bunchy or open. The best way to define and quantify formation is with the use of a proper instrument, which has been adopted in these studies. Sheet matrix of different paper samples were studied for the different characteristics in detail. Formation indices measured using Paprican Microscanner of different paper samples manufactured by different mills are recorded in Tables II to IV. Results indicated a wide variation in the formation index value. The lowest formation index value observed for a very badly formed sheet was 24 & the highest 140 for the paper formed relatively as best. Some mills using agricultural residues as main fibrous raw materials have quite low formation value (formation index 31), whereas it is as high as 120 for other mills with similar type of raw materials (Tables III, IV). In general, the medium sized mills, which are based on agricultural residues, have relatively poorer formation (formation index 31 to 93) as compared to big mills based on bamboo and hardwoods (formation index 90-140) with few exceptions. The formation of paper manufactured from waste paper by Small capacity paper mills is quite low in the range 29 to 40. All the paper samples studied had lower value of formation than imported papers (formation index 172). The imported papers manufactured even from 100%-recycled paper had much better sheet formation (formation index 82). It is quite contrary to the expectations as straw pulps being short fibred should give better formation than wood pulp. Wood fibres are thin walled fibres and are more flexible than straws. When wood fibres form the paper network by lying one fibre on the other there are more chances of contact with each other and very little last portion is left free unbonded which could not bend. The shorter the fibre (like Straws) the greater the proportion of its length which is undistorted or straight. Conversely, longer the fibre greater the proportion which come in contact or can absorb energy much like the compression of the spring. This is the reason that long fibres form larger or more difficult to disperse flocs than short fibres. The lower values of formation index obtained in the case of short fibred agricultural residues pulps which should have been the other way round suggests that the problem needs a proper attention and there are definitely good chances to find the solution. Mostly the paper makers in India evaluate formation by traditional visual method. Even today the sheet is spread onto a light table for formation check against transmitted light. This visual expression corresponds pretty well to the true basis weight variation for uncalendered paper samples that are made of chemical or mechanical pulp without filler or coating, but it fails for paper grades which are very complicated in the furnish composition and manufacturing conditions. The evenness of material distribution is no more visually assessable now a day.

The material property of paper having great influence on its perceived quality and profitability is uniformity of its distribution of its material content. Formation is also defined as the evenness of distribution of the fibre mass in paper (2). According to Sara's definition, the formation is a grammage variation occurring at a wavelength interval of 0 to 70-100mm(3). Norman (4) suggests that that the term "mass formation " should be used to denote small-scale grammage variation, because "formation" is very general and has a wide definition. The most important single property which a paper maker must achieve is to make it as uniform as possible. Formation is one of the most important structural parameters for all grades of paper and board, because it influences nearly all-important properties of the product. Paper is formed continuously by pulsed filtration process from an aqueous suspension of largely natural cellulose fibres having mean fibre length about 1mm, with possible addition of some polymeric retention aids and inorganic fillers. Making idealized uniform sheet is quite difficult as papers are made from naturally grown fibres, so no two are even truly identical, more over it is difficult to lay one fibre over the other like brick layers of a wall. The reason papers are not truly random is that commercial paper making stock concentration is too high. Even at 0.2% consistency there are so many fibres present per unit volume that they interfere or interlock with each other. In doing so, fibre networks with much larger, high concentration zones- the so-called fibre flocs than the densest portion of random network are formed. These networks have appreciable mechanical strength which makes them difficult to break up. Paper is known to have a stratified or layered structure by virtue of hydrodynamics

Table I : Production of non wood pulp by different countries in 1997 (thousand tonnes) based on data in reference 1.

Country	Non wood pulp	Total pulp	Non wood : total (%)
China	12238	17380	70.41
India	930	1900	48.94
Colombia	141	317	44.47
Mexico	134	442	30.30
Thailand	108	572	18.88
Argentina	124	749	16.55
Turkey	31	356	8.70
Zimbabwe	2	33	6.10
Iran	10	160	5.88
Indonesia	79	2979	2.65
Yugoslavia	1	44	2.27
Japan	16	11490	0.14
Brazil	52	6347	0.82
France	2	2832	0.07
Hungry	12	12	100
Algeria	5	5	100
Iraq	4	4	100
Tunisia	14	14	100

Table II: Formation indices of different paper samples from different mills and their effect on strength, optical and other characteristics of paper (Small capacity mill)

Mill No.	Sample No.	Furnish	Formation Index	Tensile Index (N.m/g) Avg.	Burst Index Avg.	Tear Index Avg.	Cobb (g/m^2) Avg.	Sp.Scatt. coeff. (m^2/kg)	Ash (%)	Brightness (%)	Opacity (%)	FSI (km)
1	1	Waste paper	40	38.5	1.80	3.25	23.4	36.2	2.4	58.7	92.1	12.1
	2	Waste paper	35	35.5	1.50	2.90	25.2	34.4	2.0	58.4	91.4	
			(14.3)	(9.1)	(16.7)	(10.8)	(7.7)	(5.0)	(16.7)	2(0.5)	2(7.6)	
2	1	Waste paper	37	20.5	1.05	3.05	24.8	22.1	6.5	57.7	92.6	12.2
	2	Waste paper	30	15.5	0.85	2.75	27.3	19.1	4.5	57.2	92.0	
			(19.0)	(24.4)	(19.0)	(9.8)	(10.0)	(13.6)	(30.8)	(0.9)	(0.7)	
3	1	Waste paper	30	15.5	.90	2.85	25.2	20.4	8.1	55.6	93.8	11.8
	2	Waste paper	25	11.0	.65	1.65	28.4	17.5	6.6	55.4	93.0	
			(16.7)	(29.0)	(27.8)	(42.0)	(12.7)	(14.2)	(18.5)	(0.4)	(0.9)	
4	1	Waste paper	35	24.5	1.05	2.90	25.4	35.4	14.8	57.1	93.0	11.4
	2	Waste paper	29	20.0	0.85	1.80	27.6	32.0	13.2	56.5	93.6	
			(17.1)	(18.3)	(19.0)	(37.9)	(8.7)	(9.6)	(10.8)	(1.1)	(0.4)	
5	1	Waste paper	36	23.5	1.25	3.50	18.0	54.4	18.2	59.7	91.6	12.6
	2	Waste paper	24	15.0	0.70	2.20	20.2	44.2	15.9	59.2	92.1	
			(33.3)	(36.2)	(44.0)	(37.1)	(12.2)	(18.8)	(18.7)	(0.8)	(0.6)	
6	Imported	Waste paper	82	47.5	2.40	6.30	17.5	25.5	12.5	78.5	90.6	14.4

Figures given in parenthesis are percentage drop/change in the value of property due to deterioration of formation.

Table III : Formation indices of different paper samples from different mills and their effect on strength, optical and other characteristics of paper (Medium capacity mill)

Mill No	Sample No.	Furnish	Formation Index	Tensile Index (N.m/g) Avg.	Burst Index Avg.	Tear Index Avg.	Cobb (g/m^2) Avg.	Sp.Scatt. coeff. (m^2/kg)	Ash (%)	Brightness (%)	Opacity (%)	FSI (km)
1	1 2	Straw & softwood	64 57 (10.9)	39.0 32.5 (16.7)	1.55 1.25 (19.4)	4.05 3.00 (24.7)	18.5 22.7 (22.7)	33.6 29.2 (13.1)	16.4 13.5 (17.7)	69.1 69.4 (0.4)	90.3 89.9 (6.4)	10.2
2	1 2	Straw & softwood	47 39 (17.0)	28.5 24.0 (15.8)	1.10 0.95 (13.6)	3.20 2.80 (12.5)	20.7 23.4 (11.5)	28.5 25.5 (10.5)	15.6 14.8 (5.1)	68.7 68.1 (0.9)	91.4 90.0 (0.2)	10.4
3	1 2	Bagasse & softwood	46 40 (13.0)	20.5 17.5 (14.6)	1.20 1.00 (16.7)	4.95 3.50 (29.3)	20.0 22.4 (10.7)	27.5 24.5 (11.6)	6.6 4.5 (31.1)	71.4 71.0 (0.6)	87.6 87.2 (0.5)	10.6
4	1 2	Straw & softwood	59 49 (16.5)	39.5 27.5 (30.4)	1.50 1.10 (26.7)	3.40 2.40 (29.4)	19.5 21.2 (8.0)	38.5 35.5 (7.8)	17.5 15.2 (13.1)	68.0 67.9 (0.1)	91.2 90.0 (0.7)	10.8
5	1 2	Straw & Rag	89 80 (11.3)	32.0 26.0 (18.8)	2.40 2.05 (14.6)	2.50 2.05 (18.0)	20.5 21.9 (6.8)	42.8 39.5 (7.7)	18.9 16.7 (11.6)	73.3 73.0 (0.4)	90.5 89.9 (0.7)	11.0
6	1 2	Straw & Rag	93 85 (8.7)	28.4 26.0 (8.5)	1.35 1.10 (18.5)	3.30 2.90 (12.1)	17.1 18.5 (8.2)	44.6 41.4 (7.2)	26.4 24.2 (8.2)	74.1 73.3 (1.1)	91.1 90.0 (1.2)	11.1
7	1 2	Straw	36 31 (13.9)	29.5 24.5 (16.9)	1.10 0.90 (18.2)	3.00 2.80 (6.7)	19.5 21.5 (10.3)	35.5 33.2 (6.5)	15.2 14.8 (2.6)	68.5 68.1 (0.6)	92.4 92.2 (0.2)	9.4
8	1 2	Bagasse & softwood	57 50 (12.3)	31.5 27.5 (12.7)	1.40 1.10 (21.5)	4.70 4.10 (12.8)	20.5 21.8 (6.3)	35.1 33.8 (3.7)	15.2 9.0 (15.9)	72.5 71.5 (1.4)	89.4 88.8 (0.7)	10.4
9	1 2	Baggase & softwood	56 66 (17.9)	32.5 41.5 (28.8)	1.60 1.75 (9.4)	2.35 2.65 (12.8)	22.0 19.2 (14.6)	34.1 36.5 (7.0)	13.6 14.5 (6.6)	71.5 70.5 (1.4)	88.8 87.0 (2.0)	10.6
10	1 2	Straw & softwood	98 56 (42.9)	34.0 20.0 (41.1)	1.70 1.40 (17.6)	4.60 3.70 (19.6)	18.6 22.8 (18.4)	43.0 38.5 (11.6)	11.5 9.2 (20.0)	69.9 69.0 (1.3)	91.4 90.2 (1.3)	10.8
11	1 2	Straw & softwood	52 45 (13.5)	41.5 29.5 (28.2)	1.50 1.30 (13.3)	3.50 2.95 (15.7)	19.6 21.8 (11.2)	34.3 31.0 (9.6)	12.4 10.6 (14.5)	68.5 67.6 (1.3)	91.2 90.0 (1.3)	10.3

Figures given in parenthesis are percentage drop/change in the value of the property due to deterioration of formation.

Table IV : Formation indices of different paper samples from different mills and their effect on strength, optical and other characteristics of paper (Large capacity mill)

Mill No	Sample No.	Furnish	Formation Index	Tensile Index (N.m/g) Avg.	Burst Index Avg.	Tear Index Avg.	Cobb (g/m^2) Avg.	Sp.Scatt. coeff. (m^2/kg)	Ash (%)	Brightness (%)	Opacity (%)	FSI (km)
1	1	Bagasse &	110	49.5	2.05	4.50	20.7	44.2	15.2	77.5	89.8	11.0
	2	bamboo	100	45.5	1.85	4.20	21.9	39.8	14.0	77.0	89.2	
			(9.1)	(8.1)	(9.8)	(6.7)	(5.8)	(10.0)	(7.9)	(0.7)	(0.7)	
2	1	Hardwood	120	47.0	2.30	6.10	17.8	48.2	14.5	77.5	90.2	13.2
	2	& bamboo	91	30.0	1.50	5.10	18.3	44.3	12.6	76.5	89.9	
			(24.2)	(36.1)	(34.8)	(16.4)	(2.8)	(8.1)	(13.0)	(1.3)	(0.3)	
3	1	Hardwood	140	49.5	3.10	5.90	18.8	42.7	15.1	78.9	91.2	13.4
	2	& bamboo	120	40.5	2.65	5.10	20.4	38.9	13.8	78.0	90.5	
			(13.0)	(18.2)	(11.7)	(13.6)	(7.9)	(8.9)	(8.6)	(1.1)	(0.8)	
4	1	Bamboo &	68	28.0	1.40	6.20	18.4	39.8	14.5	77.0	87.5	15.5
	2	hardwood	58	24.5	1.20	5.50	19.1	37.5	13.1	76.5	87.2	
			(14.7)	(12.5)	(14.3)	(11.3)	(3.8)	(5.8)	(9.7)	(0.7)	(0.3)	
5	1	Bagasse &	120	38.5	2.05	5.00	18.6	37.9	15.2	78.5	90.1	11.8
	2	softwood	100	35.5	1.75	4.50	19.8	35.4	13.8	78.1	89.8	
			(16.7)	(7.8)	(14.6)	(10.0)	(6.5)	(6.6)	(9.2)	(0.5)	(0.3)	
6	1	Hardwood	106	42.5	1.90	5.80	17.4	39.2	13.5	78.9	91.2	13.1
	2	& bamboo	94	37.0	1.65	5.04	18.6	36.5	12.8	78.0	90.6	
			(11.3)	(12.9)	(13.2)	(13.1)	(6.9)	(6.9)	(5.2)	(1.1)	(0.7)	
7	1	Hardwood	110	47.5	2.85	5.80	17.4	47.5	15.5	78.9	90.5	12.6
	2	& bamboo	100	42.5	2.45	5.50	18.5	45.5	13.9	78.5	90.2	
			(9.1)	(10.5)	(14.0)	(5.2)	(6.3)	(4.20)	(10.3)	(0.5)	(0.3)	
8	1	Hardwood	95	38.5	2.45	4.90	17.6	46.5	14.5	79.9	90.4	12.7
	2	& bamboo	80	35.5	2.10	4.70	18.8	43.5	13.2	78.5	89.8	
			(15.7)	(7.8)	(14.3)	(4.1)	(6.8)	(6.5)	(9.0)	(0.5)	(0.7)	
9	1	Hardwood	115	46.5	2.30	6.10	17.2	48.3	12.6	78.8	90.2	11.8
	2	& bagasse	100	31.0	2.00	5.80	18.9	46.3	11.2	78.5	89.7	
			(13.0)	(33.3)	(13.0)	(4.90)	(9.9)	(4.1)	(4.1)	(0.4)	(0.6)	
10	1	Hardwood & softwood (Imported)	172	41.0	3.05	6.75	17.1	37.5	24.9	90.2	89.8	12.1

Figures given in parenthesis are percentage change/drop in the value of the property due to deterioration of formation.

of its forming by pulsed filtration like the mechanism, as forecast by Finger and Majewski (5) then proved and explained by Radvan et al (6). The standard reference structure for paper is therefore a stack of planar random net works of fibres for which many statistical geometric properties are known analytically (7-11).

EFFECT OF FORMATION ON PAPER CHARACTERISTICS

Strength Characteristics:

To see the effect of formation on the sheet characteristics, paper samples manufactured by a particular mill with same furnish composition but different formation indices were compared for different characteristics. It was observed that the bonding properties (tensile index, burst index) were adversely affected with deterioration in formation (Tables II, III, IV). The extent of drop observed in the tensile index was from 7.8 to 36.1%. Similarly for bursting strength and tearing strength it ranged from 9.4 to 34.8% and 6.7 to 42.0% respectively. The regression correlation co-efficient between formation index and tensile strength, tearing strength and sp. scattering co efficient was around 0.60 indicating substantial influence on formation on these properties. The pulp fibres used by different mills based an agricultural residues were having similar fibre strength as indicated by FSI values, but the paper produced by them was having quite different characteristics. This indicated that improvement in formation would help to improve these properties to remarkable extent without any change in the raw material.

Sizing and filler retention:

Deterioration in the formation had also caused drop in the sizing degree and retention of the filler in the sheet to the extent of 2.8 to 22.7% and 2 to 31.1% respectively (Tables 111 & IV). Due to poor formation it is very likely that considerable portion of useful fines are not retained in the sheet.

Optical characteristics:

Specific. scattering coefficient is an important property for writing and printing grade papers. Reduction in the formation values also caused drop in this property, which means that opacity of the paper having poor formation will be on the lower side. This is probably due to light areas in the sheet, which do not scatter back the light but allow it to pass through. Improvement in formation may enhance the scattering coefficient.

FACTORS AFFECTING THE PAPER FORMATION:

Factors that affect the paper formation are mainly of two types: those related to fibre characteristics and those related to process parameters. Morphological features of the fibres such as fibre length and coarseness affect the structure of paper (3,12, 13). This was shown in the statistical geometry approach of Kallmes and Corte (14,15) and in subsequent work of Corte and Dodson(16). They found that the variance of "random" sheets (sheets formed in ideal condition with no fibre interaction) was solely defined by the fibre geometrical morphology and sheet basis weight. This was verified experimentally by Herdman and Corte, who formed handsheets at extremely low dilution from fibres cut to different lengths (12). It is generally accepted that shorter fibres yield a better formation. Sara observed this phenomenon by studying the formation of great number of commercial samples made from variety of pulps (3). Most paper grades requiring a high degree of uniformity use shorter hardwood fibres or fibres reduced in length during refining. Smith studied the formation potential of various pulps (17). The formation potential is defined as the experimental relationship between the formation index of a sheet and the consistency of the pulp suspension from which it is made. He found out that for each furnish there is a consistency and degree of refining that give an optimal formation The agricultural residues pulps are short fibred pulps and due to the slow drainage nature are usually not given refining treatment by Indian paper mills. Generally these produce paper of poor formation which needs to be improved. In the present investigations some of the parameters involved in papermaking were examined for wood, bamboo, bagasse and wheat straw pulps to find the causes. The effect of alum, cationic starch, retention aid dosages were examined, which are illustrated in Tables V to VIII.

Addition of alum:

Addition of alum more than 4 % adversely affected the formation index. At 8% alum level the formation values got reduced by about 21 %, 13 % and 24% for wood pulp, bamboo pulp and bagasse pulp respectively. This reduction in the formation index caused the drop in tensile strength from 77.5 to 65 N.m/g, bursting strength from 5.85 to 4.70 kPa.m^2/g, tearing strength from 14.4 to 13.5 mN.m^2/kg for soft wood pulp. The drop in these properties for bamboo pulp was tensile index 42.0 to 35.5 N.m/g, bursting strength 2.70 to 2.30 kPa.m^2/ and tearing strength 5.20 to 4.70mN.m^2/g. Similar drop was observed for the bagasse and wheat straw pulps also.

Addition of cationic starch:

Addition of cationic starches more than 2% caused drop in formation value by about 20%. Due to this drop a negative effect on the strength characteristics was observed. However addition of cationic starch upto 1% had shown improvement in these properties.

Table V: Effect of variation in the dosage of different chemicals on the formation of handsheets made from different pulps (Softwood pulp beaten to 400±20 ml CSF)

Parameter	Formation Index	Tensile Index (N.m/g)	Burst Index (k.Pa.m^2/g)	Tear Index (mNm^2/g)	Sp.Scatt. Co-eff. (m^2/kg)
Pulp as such	114	77.5	5.85	14.4	21.7
Rosin Size (2%)	113	76.5	5.80	14.2	21.1
Alum dose 2 %	114	74.4	5.70	14.1	21.3
4 %	110	72.5	5.20	14.0	22.4
8 %	90	65.0	4.70	13.5	23.5
10 %	77	59.0	4.10	12.0	23.8
Cationic Starch					
1 %	100	82.5	5.90	13.5	16.1
2 %	95	83.4	5.95	13.0	17.2
3 %	80	72.7	5.70	12.0	17.7
Retention aid Polyacrylamide					
0.1 %	100	81.0	5.40	14.0	19.9
0.2 %	95	80.5	5.30	13.8	21.9
0.4 %	90	77.3	5.00	13.0	22.0
0.8 %	76	72.5	4.80	12.1	22.6
Dual retention aid 0.1% cationic 0.2% anionic	112	84.5	6.10	13.9	23.4

Table V I : Effect of variation in the dosage of different chemicals on the formation of handsheets made from different pulps (Bamboo pulp beaten to 400±50 ml CSF)

Parameter	Formation Index	Tensile Index (N.m/g)	Burst Index (k.Pa.m^2/g)	Tear Index (mNm^2/g)	Sp.Scatt. Co-eff. (m^2/kg)
Pulp as such	137	44.5	2.90	5.40	35.4
Rosin Size (2%)	135	43.5	2.85	5.35	34.9
Alum dose 2 %	136	42.0	2.70	5.20	35.5
4 %	125	38.5	2.50	4.90	35.6
8 %	118	35.5	2.30	4.70	36.2
10 %	104	32.5	2.00	4.50	37.8
Cationic Starch					
1 %	130	49.5	3.15	5.00	33.4
2 %	131	50.5	3.20	4.95	33.2
3 %	100	45.5	2.60	4.75	33.4
Retention aid Polyacrylamide					
0.1%	130	40.5	2.60	5.30	34.2
0.2%	110	40.0	2.50	5.30	34.1
0.4%	90	37.5	2.30	5.10	34.0
0.8%	85	34.5	2.00	5.00	34.6
Dual retention aid 0.1 % cationic 0.2% anionic	132	50.5	3.20	5.30	33.5

Table VII : Effect of variation in the dosage of different chemicals on the formation of handsheets made from different pulps (Bagasse pulp beaten to 350±50 ml CSF)

Parameter	Formation Index	Tensile Index (N.m/g)	Burst Index (k.Pa.m^2/g)	Tear Index (mNm^2/g)	Sp.Scatt. Co-eff. (m^2/kg)
Pulp as such	149	50.5	2.50	3.10	17.9
Rosin Size (2%)	149	50.0	2.45	3.10	17.8
Alum dose 2 %	148	50.0	2.45	3.05	18.3
4 %	130	45.5	2.25	2.90	18.5
8 %	112	40.5	1.90	2.70	18.8
10 %	104	35.5	1.60	2.50	19.3
Cationic Starch					
1 %	147	52.5	2.95	2.90	18.1
2 %	146	52.0	2.95	2.85	18.0
3 %	124	45.5	2.50	2.65	18.9
Retention aid Polyacrylamide					
0.1%	145	50.5	2.50	2.90	17.4
0.2%	140	50.0	2.50	2.85	17,5
0.4%	100	47.5	2.20	2.50	17.7
0.8%	80	40.5	1.90	2.00	17.9
Dual retention aid 0.1 % cationic 0.2% anionic	146	50.5	2.40	3.05	17.8

Table VIII : Effect of variation in the dosage of different chemicals on the formation of handsheets made from different pulps (Wheat straw pulp beaten to 350±50 ml CSF)

Parameter	Formation Index	Tensile Index (N.m/g)	Burst Index (k.Pa.m^2/g)	Tear Index (mNm^2/g)	Sp.Scatt. Co-eff. (m^2/kg)
Pulp as such	151	46.0	2.05	5.10	42.4
Rosin Size (2%)	150	45.5	2.00	5.00	42.3
Alum dose 2 %	149	43.0	1.95	4.90	41.4
4 %	145	40.5	1.90	4.70	40.5
8 %	120	35.5	170	3.80	39.5
10 %	100	30.5	1.40	3.00	37.5
Cationic Starch					
1 %	146	48.5	2.05	4.70	41.1
2 %	142	47.0	2.00	4.50	39.0
3 %	120	44.5	1.80	4.00	38.1
Retention aid Polyacrylamide					
0.1%	146	47.5	2.10	4.80	41.4
0.2%	143	47.0	2.00	4.75	41.0
0.4%	109	43.5	1.80	4.00	39.7
0.8%	89	39.5	1.60	3.00	35.9
Dual retention aid 0.1 % cationic 0.2% anionic	148	45.5	2.00	4.90	42.0

Addition of retention aids:

Retention aids are generally added in paper making to improve the retention of fines and fillers. Excessive dose of a particular retention aid beyond 0.2% had shown adverse effect on the formation. The negative effect on the formation had shown negative effect on the strength characteristics also. Dual type retention aids with proper charge had the adverse effect on formation to a relatively lesser degree.

Refining:

Refining is also a highly effective way of changing the formation. Unrefined fibres are generally stiff and straight and relatively smooth sided. Refining softens the fibres, fibrillates them and creates fibre debris. Refining also promotes fibre collapse, which is essential for good formation. It is fairly obvious that a better formed sheet can be made from a properly refined pulp than from unrefined one, as the more flexible fibres along with fibre debris are going to fill the sheet in better way. For making the paper from the agricultural residues pulps refining is generally avoided in Indian mills due to the reason that unrefined pulp is already slow draining and have freeness in the range 300 to 400 CSF & refining poses paper machine runnability problem. There are generally one or two refiners before fan pump in Indian mills based on agricultural residues, which are put only to fiberize possible fibre bundles. Actually these refiners also cause some increase in slowness and generation of fines which should be avoided. Instead of refiners a deflaker should be preferred which will give more of only fibre separation effect. This needs to be tried on pilot scale.

Stock speed or Jet speed to wire speed ratio (J/W):

Schrader and Svenson (18) clearly showed that formation is quite sensitive to J/W ratio and for practical purposes this ratio should stay between 0.90 and 1.10. They further showed that for the sheets they were making the best formation was obtained at very close to a J/W of 1.0. At low stock consistencies the stock –wire speed difference has little effect on formation on a fourdrinier machine as it is dilute enough for formation to be fully determined by what happens on the wire. At higher consistencies formation is partly determined by the condition of the stock soon after it lands on the wire. If there is sufficient difference between the stock and wire speeds the shear forces created will cause dispersion of the fibres. Thus there is an advantage for formation in running off square (i.e. with a difference between stock and wire speeds). At still higher consistencies the fibres are not so easily dispersed and the beneficial effect of running off square diminishes.

The difference between the stock and wire determines the orientation of fibres in the sheet. As the difference increases there is a greater tendency for fibres to be aligned in the machine direction. When there is no difference in the two speeds, fibre orientation will be close to random as one will get although the component of fibre orientation in machine direction will still exceed that in cross direction due to some alignment by accelerating flows in the flowbox.

Agitation on the wire:

Proper agitation of the stock on running wire is important for good formation. If stock slurry is not agitated after it leaves the slice and lands on the wire, the floc size distribution will get worse. Without agitation on the wire, the fibres had adequate opportunity to flocculate. Good agitation on the wire is essential to good formation and is as important as good turbulence in the headbox. Combinations of foil blade angles and table rolls at lower speed can be used to produce turbulence on the wire (19,20,26,27). There are other modern ways to improve the agitation like Sheraton roll and wunder foil.

Theoretically table activity generated by the Shreaton roll can break the flocs and increase fibre mobility. When drainage is introduced to stock having good fibre mobility (with a Wunderfoil), the drainage distributes fibres uniformly on the small scale.

Kallmes (21) suggests that by installing a Wunderfoil and a driven Sheraton roll in tandem, drainage and table activity can be independently controlled over a wide speed and grammage range. This would be especially beneficial on the early part of the forming table.

Table arrangement:

There is no universal table layout for all grades (24). This means that the table arrangement on the machine with a wide speed and grammage range is always a compromise (23). The speed range typical for conventional drainage elements is only ± 15-30m/min of the optimum speed (22). The second limitation of the conventional drainage equipment is that increasing table activity also means increasing dewatering. A proper system to achieve optimum table activity is essential for obtaining good formation.

The Shake:

Shaking is important to spread the stock uniformly on the wire for getting a uniform sheet. At 2000 fpm and above the shake does little or nothing for formation. There is just too little time for the shake to act on the fibres before they have passed out of the shaken zone. However, high frequency shake at speed below 2000 fpm and especially with heavy grammages at speeds of 1000 fpm can produce significant improvement in formation. Investigations have shown that the frequency of shake is more important than amplitude. The higher the frequency the more beneficial is the effect on formation. The effectiveness of the shake in improving formation is roughly directly proportional to the amplitude and square of the frequency and inversely proportional to speed of the machine. This so called shake number, which is defined as

$$S = f^2 a/m$$

Where S = Shake number
f = Frequency, shake/min
a = Amplitude, in
m = Machine speed fpm

Generally shake number above 30 is considered better for formation.

The Dandy:

Historically the dandy roll was used to improve formation of the sheet on slow speed machines where flocculation of the top side of the sheet was inevitable due to poor agitation on the wire and long retention time. The dandy roll was placed in the middle of the suction box section where the sheet was just about to pull dry. There has been lot of improvement in the design and use of Dandies i.e. proper placing, diameter, drive etc. The dandy affects the distribution of filler in the sheet as well and its potential must be utilized fully to obtain a well-formed sheet. It was supposed to rework the top side of the sheet and break up flocs. It was very efficient and there was a marked improvement in formation. At operating speed of 300 fpm or so the dandy was driven by the sheet and the wire. It ran usually on trunion bearing which were set so that the dandy exerted a certain pressure on the sheet. The original dandies were about 12 inches in diameter or smaller, but as machine speeds increased the shear forces between the small dandy and the wire increased to the point the sheet was disrupted. Simple drives were installed and the situation improved, but they were still troublesome to run and many were removed from service.

EXPERIMENTAL:

Testing/Evaluation of paper samples:

Paper samples were conditioned at 27±1°C, 65±2% R.H. before testing. Tests were made according to the following methods: -

- Measured using Paprican micro-scanner Formation index is a ratio that is made up of both the contrast and size distribution components of the sheet formation. A higher formation index means a more uniform sheet.

Tensile index	-	ISO 1924
Burst index	-	ISO 2758
Tear index	-	ISO 1974
Sp. Scattering coefficient	-	SCAN C 2769
Ash content	-	ISO 2144
Cobb	-	ISO 535

CONCLUSIONS

1. Evaluation of paper samples taken from 25 different Indian pulp & paper mills revealed that there is wide variation in formation index values inspite of the fact that the raw material, its processing methods pulp quality and types of paper machine and their configurations were almost similar.

2. The medium sized paper mills, which are mainly based on the agricultural residues, have relatively poorer formation (formation index 31 to 93) as compared to big mills based on bamboo and hardwoods (formation index 90 to 140). The formation index values of paper manufactured from waste paper by small capacity mills are the lowest (29 to 40).

3. One of the causes of quality variation in papers of different mills is the difference in the formation index values. The bonding properties (tensile index, burst index) are adversely affected with deterioration in formation. The extent of difference observed in the tensile index ranged from 7.8 to 36.1%. Similarly for the bursting strength and tearing strength it ranged from 9.4 to 34.8 % and 6.7 to 42% respectively. Deterioration in formation also caused drop in sizing degree, retention of fillers and sp.Scatt. co- efficient values.

4. Excessive dosages of alum, wet end chemicals adversely affected the formation. It was found in the laboratory studies that normally addition of alum more than 4%, catonic starch more than 2%, retention aid more than 0.2% should be avoided to get better formation. The effect of dual type retention aids on the formation drop was relatively lesser.

5. General practice for making the paper from agricultural residues pulps in India is that hardly any refining is done for the pulps. There are generally one or two refiners before fan pump to break fibre bundles. Instead of refiners a deflaker should be preferred which will give mainly fibre separation effect, hence formation will be improved without unduly affecting the slowness of the pulp.

6. For improving the formation some of the following parameters of the paper machine are very important & should be properly monitored & optimised by the individual mill. These may not be the same for different varieties of paper made on the same machine.

   - Stock –wire speed ratio.
   - Agitation on the wire.
   - Table arrangement,
   - The shake.
   - The dandy

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