IMPROVING FILLER LOADING IN THE PAPERS MANUFACTURED FROM INDIGENOUS FIBROUS RAW MATERIALS

(CESS/IPMA PROJECT)

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INDIAN PAPER MANUFACTURERS ASSOCIATION (IPMA)

CENTRAL PULP & PAPER RESEARCH INSTITUTE
SAHARANPUR 247 001 (UP) INDIA

MAY 2003

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based on the work of

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EXECUTIVE SUMMARY

Cost of paper can be reduced appreciably by improving and optimizing the filler retention. Increasing the filler content in paper within certain limits may yield the benefits such as reduced raw material cost, lower steam consumption in drying, improved optical properties and better print quality.

Laboratory scale studies with different types of fibrous raw materials viz. Bagasse, bamboo, wheat straw, eucalypt and softwood pulps indicated that in the absence of any retention aid, the amount of filler retained was highest for wheat straw pulp and lowest for softwood pulp. Eucalypt and bagasse pulps both had comparable filler retention capability but higher than that of softwood pulp. The retention of filler in bamboo pulp was lower than wheat straw, bagasse and eucalypt pulps but higher than softwood pulp. The specific surface area and swollen volume measured by permeability method was higher for wheat straw and bagasse pulps than other pulps.

The filler retention capability is not improved by changing the bleaching sequence as observed in case of CEHH and D/CEHD bleached eucalypt pulps.

With the increase in filler content, softwood, bamboo and eucalypt pulps showed continuous increase in the apparent density. Whereas in the case of bagasse and wheat straw pulps after an increase upto certain filler level a slight drop was observed. Tensile and tearing strength dropped with the increase in filler content. At 15% filler level in the sheet the percent drop in tensile strength observed for softwood, bamboo, eucalypt, and bagasse and wheat straw pulps was 30, 18, 18,21 and 22 percent respectively. The relative drop in the tearing strength with increase in filler content was lowest in the case of softwood pulp. The improvement in the Sp. Scatt. Co- eff. with increased filler content was highest in the case of bagasse and least for eucalypt pulp. The effect on the improvement of Sp. Scatt. Co-eff. for softwood pulp , bamboo and wheat straw pulps was somewhere between bagasse and eucalypt pulps.

Coarser particles of talc are retained better than finer ones. The larger particle size (> 5μm) has lesser disruption effect on the tensile strength than finer particles. The porosity is relatively more improved with coarser particles, whereas reverse had been observed for the specific scattering coefficient for eucalypt pulp.

The filler retention in pulps studied improved by addition of cationic starch, hydrocol (a dual type retention aid), pre flocculation of filler and using described adsorbed additive technique on the filler surface. Hydrocol gave better effect than starch on the filler retention and maintained higher paper strength at increased filler level .Pre flocculation technique gave better results than starch alone but these were slightly lower than hydrocol especially on Sp. Scattering Coefficient improvement. The best results were obtained using pre adsorbed additive method on filler surface. The retention was better (about 0.3 to 3%)than other methods. The effect on the strength was comparable to that for hydrocol system.

Addition of filler caused drop in the wet web TEA index values. Talc caused higher drop than china clay and calcium carbonate. Using pre adsorbed additive on filler surface technique (Polarity treated filler) caused lesser drop in the wet web tensile energy absorption than the other methods.

The filler retention is also improved by adopting refining which improves fibrillation of fibres as indicated by studying the eucalypt pulp devoid of primary fines

Fibre surface charge determinations using a particle charge detector indicated that amongst the different fillers studied, TiO_2 (Anatase) had the highest negative charge followed by china clay, TiO_2 (Rutile), talc and barytes. GCC has slightly positive charge.

Indigenous mill pulps, which are mostly hypochlorite bleached, had 2 to 3 times higher negative charge than imported wood pulps. Bagasse pulp had highest negative charge followed by rice straw, wheat straw, bamboo and softwood. The higher negative charge in indigenous pulps than imported wood pulps will result in their different behaviours towards retention aids, strengthening agents and sizing chemicals. Some of such chemicals, which had been found to be suitable abroad for the imported pulps, may not function satisfactorily for indigenous pulps. Also Indian chemical manufacturers need special care especially from charge point of view to manufacture such chemicals effective for Indian Paper Mills.

With the addition of filler in the blend of bamboo and eucalypt pulp in the ratio 20:80 the printing characteristics like contact factor got improved from 0.42 to 0.53 and saturation density got increased from 1.23 to 1.51 . Soft nip calendaring of filled sheets gave better improvement than hard nip calendaring on these parameters. The print through tendency got reduced with the addition of filler. The value of print through of 0.75 for blank got reduced by about 33% at filler level of 26.2%. The total fiber rising area (TRA), another important printing property measured using fibre rising tester (FRT) got increased with addition of filler. Upto filler addition level from 7.9 to 26.2% the increase in TRA was not steep (of level of about 9%). But further addition gave abnormally high rising area (to the extent of about 30%). This indicated that probably filler addition level beyond 26 % for blend of bamboo and hard wood pulps in the ratio 20:80 may lead to serious linting problem in offset printing. Addition of cationic starch gave reduction in TRA value. The polarity treated method of filler addition also gave better effect.

Evaluation of paper samples from 25 different Indian Pulp and Paper mills revealed that there is wide variation in formation index values. Deterioration in formation also caused drop in sizing degree, retention of filler. The bonding properties (tensile index, burst index) are also adversely affected with deterioration in formation. The extent of difference observed in tensile index ranged 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% respectively.

ACKNOWLEDGEMENTS

The management of Central Pulp and Paper Research Institute is thankful to Sh. R. Vardhan, Vice President (Corporate R&D) BILT and Dr. Ashok Kumar, GM (Manufacturing) Star Paper Mills Saharanpur for their co-operation and technical discussion during the course of investigation on this project.

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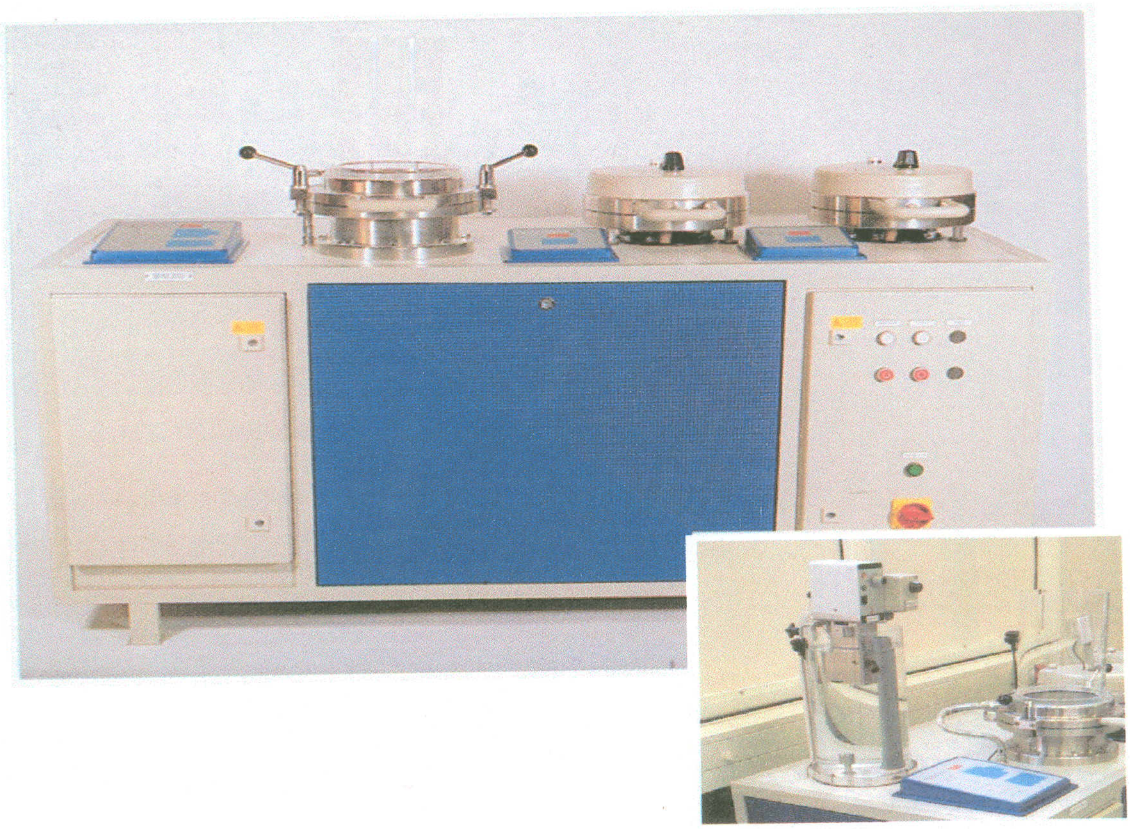
Chapter 1 Filler Loading in Different Indigenous Pulps

Chapter 3 Common Deficiencies In Paper Manufactured By Indian Mills

Chapter 4 Fillers In Paper Making (Review)

INFRASTRUCTURE CREATED

For carrying out the study on the filler retention of pulps accurately, a semi automatic sheet making machine (Haage Rapid-Koethen sheet former) was procured.



The salient features of the former are as under;

Sheet size: 200mm diameter

Sheet forming: Programmable as follow

- water volume 0 - 10 liters
- mixing time 0 - 999 sec
- Settling time 0 - 999 sec
- Drainage time 0 - 999 sec
- Suction time 0 - 999 sec

Pressing/drying: Programmable as follow

- Drying temperature 85 - 150°C
- Drying time 120 - 999 sec

Hand sheet making: **Up to 40 handsheets per hour**

CHAPTER 1

FILLER LOADING IN DIFFERENT INDIGENOUS PULPS

1. INTRODUCTION

Over the years, fillers have become an increasing important component of paper making furnishes. The reasons for this development are obvious. Conventional filler pigments are considerably cheaper than cellulosic fibres. At the same time, they improve some of the important end use properties of many paper grades. The result of this is that the papermaker generally tries to maximize the filler content in such grades in which fillers can be used. Filler is incorporated into paper either or both of the following reasons

- To improve process economics, since filler is considerably cheaper than fibre.
- To modify the technical properties of paper.

The prices of fillers are 3.5 to 10 times lower than the price of cellulose fibres. A variety of fillers in the amounts varying from 3 to 20% by weight are used in most kinds of papers to decrease production cost or to impart specific sheet properties. Most filled papers are produced for printing and writing sector and it would be impossible to make either SC magazine paper of acceptable printability or Bible paper of sufficient opacity without filling. One non-printing grade where filling is essential is cigarette paper, which contains PCC filler to control the burning rate. Not all-technical properties are improved by filling. Those, which get improved generally are opacity, brightness, gloss, stability, smoothness, porosity and printability. Those which are generally worsened include strength (due to interference of the filler with inter fibre bonding), size demand (due to adsorption of size on the filler surface), abrasion and dusting of these, the strength quantum is particularly important, since it ultimately limits the level at which filler can be incorporated in the sheet.

There are two major headaches being faced by today's papermakers. The first is the ever increasing cost of the raw materials, particularly virgin fibre, and second is the energy costs associated with turning their raw material into saleable products. Recent research has highlighted several approaches by which these problems can be diminished, The most attractive proposition is to increase the filler loading of the paper. Increasing the filler loading of paper is of interest not only in terms of reduction in raw material cost, but also, as stated before in consideration of energy costs. There are two areas where saving can be made. Firstly in refining, as filler does not need to be refined, and secondly in steam consumption. Increased filler levels will produce sheets that drain faster and dry more easily on the paper machine, thereby leading to less steam consumption while in the dryers.

Unfortunately it is not possible simply to substitute large amounts of low cost filler for the expensive fibre, because of both technical and process problems. However, recent technical developments have shown these difficulties can be overcome.

Conventional approaches to achieve filler increase without problems are to optimize papermaking process and to enhance bonding, Which are:

- Pulp selection for strength properties, for example, it may be necessary to increase the percentage of long fibre component of paper furnish.
- Optimization of refining to increase strength, to enhance those product properties that are likely to be degraded by addition of filler.
- Use of different size press additives and technology to improve surface properties and reduce picking and dusting.
- Wet end addition of strength aids to increase the level of bonding.
- Use of pre-flocculation techniques to agglomerate the filler into a spongy mass to lower specific surface area, to minimize the debonding effect of higher specific surface area fillers.
- Use of pre-adsorbed additives on the filler surface to enhance the bonding on the fibre surface.

Commonly and commercial fillers available are talc, china clay, diatomaceous silica, calcium carbonate, titanium dioxide, aluminosilicate, hydrated aluminum oxide, zinc sulphide and calcium sulphate. The general properties, availability and use of the various fillers are described elsewhere (1). The properties of commonly used fillers are given in Table 1. Clay and calcium carbonate are most widely used in many countries. In India, soapstone (Talc) is the main filler used for papermaking. Talc is a hydrated magnesium silicate 3 $MgO.4SiO_2.H_2O$.

The particles are very thin platelets, possessing the unusual characteristics of having one hydrophillic surface and one hydrophobic.

Presently the maximum amount of filler used by Indian mills in cultural papers is upto 15%,except few mills. Filler loading around 30% or even more is being practiced in wood free papers in developed countries using mainly wood pulps. It would be of interest to examine the behaviour of increased level of filler on the papers from indigenous papermaking raw materials so that possibility of increasing it could be explored. The objective of the project is to develop a more effective economical approach to use fillers with benefit in bottom line cost and clean papermaking.

2. EXPERIMENTAL MEHTODS FOR PULP EVALUATION:

2.1 Pulps used:

Hypo bleached soda cooked wheat straw pulp.
Hypo bleached soda cooked bagasse pulp.
Hypo bleached kraft bamboo pulp.
Hypo bleached eucalypt kraft pulp.
Bleached softwood Kraft pulp (imported)

2.2 Beating:

In all the cases beating was carried out in PFI mill to freeness level 300 ± 50 ml CSF under the following conditions according to ISO DP 5269.

Pulp charge (g.o.d.)	30
Stock concentration (%, w/w)	10
Load (N/cm)	17.7
Relative speed (m/s)	6.0

2.3 Specific Surface area and Swollen volume :

Specific surface area and swollen volume were measured by permeability method using Pulmac apparatus. In this a pulp pad is formed and held between two movable screens so that the density can be varied. The permeability of the pad was measured at different bed densities by measuring the flow through the pad and drop across the pad. The permeability is the rate for unit pressure drop, bed mass, bed area and liquid viscosity. A linear plot $(KC^2)^{1/3}$ against C, where K is the bed density and C the permeability, gives estimates of the specific surface and swollen volume of pulp fibres.

2.4 Sheet making ::

Handsheets were prepared in accordance with ISO DP 5269 /2method. To minimize loss of fines during sheet preparation, a **Rapid -Kothen sheet making machine** with a backwater recirculation system was used. The first few sheets were rejected and the remaining sheets prepared using the backwater from the earlier sheets. Talc, China clay and GCC (ground $CaCO_3$) were used as filler. The following approaches were tried:

- Cationic starch of charge density 176.6 μ.eq/g (1% on pulp basis) or dual component retention aid (Hydrocol) comprising of 0.2% hydrocol polymer Percol 47 (Cationic polyacrylamide resin charge density 1200 μ.eq/g) and 0.2% Hydrocol pigment (charge density negative 60.2 μ.eq/g)) was used as retention aid.
- Pre flocculated filler: The filler was dispersed in water to prepare a slurry. To this slurry 0.1% anionic flocculent (Percol 155) was added followed by1% cationic starch. The pre-flocculated filler thus obtained was added to pulp slurry.
- Polarity treatment to filler and pulp: The filler was pre flocculated with anionic polymer (0.1% Percol 155, Anonic polyacrylamide resin charge density 2925 μ.eq/g)) and pulp was treated with 1% cationic starch separately. Both filler and pulp were mixed together.

2.5 Handsheets testing:

Handsheets were conditioned at temperature 27±1°C and relative humidity 65±2% before testing. Tests were made according to the following methods:

Apparent density	-	ISO R-438
Tensile index	-	ISO 1924
Tear index	-	ISO 1974
Sp. Scattering coefficient	-	SCAN C 2769
Brightness	-	ISO 2470

Ash content - ISO 2144

2.6 Wet web strength testing :

Wet web strength characteristics of the pulps were evaluated as per SCAN -M : 18 X.

3.0 RESULTS AND DISCUSSION

3.1 FILLER RETENTION CAPABILITY OF DIFFERENT PULPS:

In a sheet, mechanical entrapment and electrokinetic interactions (3,4,9) retain filler. The characteristics of the different fillers used in this study are recorded in Table II.The strength properties of the pulps used in the studies are given in Table III showed that these pulps were reasonally stronger . In general the average dimensions for most of the fibres, fibrils and fillers fall in the range given in Table IV. The Paper network structure generally contains 50% or more void space. The fibres form the framework and filler particles are not of enoughly large dimensions to cause major spatial disruption. The filler particles are, however, similar in scale to fibrils and fibre debris and therefore can strongly influence their behaviors. In the present laboratory studies it was found that in the absence of any retention additive soap stone filler retention was lowest in the case of softwood pulp and highest for wheat straw pulp. The retention capability of eucalypt and bagasse pulps for this filler was however comparable but interestingly higher than softwood pulp and bamboo pulp. The retention of filler in bamboo pulp is lower than that of wheat straw, bagasse and eucalypt pulps. The filler retention capability is not improved by making stronger pulp by changing the bleaching sequence as observed for CEHH and D/CEHD bleached eucalypt pulps (Fig.1) The lower filler retention in the case of softwood and bamboo pulp was probably due to relatively more porous mat formed by their fibres due to which only relatively large sized material had chance to be held up in the fibre structure of the mat. The smaller particles and fines which are generally in the size range of 0.001 to 1μm get filtered out from the sheet. Few of such small particles however could get entrapped in the fibrillar network extending from fibres and also in their lumens as white water drains away during sheet formation. On the other hand wheat straw, bagasse and eucalypt pulps formed relatively a closer sheet matrix which enabled them to retain higher amount of filler. Secondly these pulps had high amount of fines which could co-flocculate with filler to form bigger particles thus helping in better retention. The specific surface area and swollen volume of the pulp samples measured by permeability method were higher for bagasse and wheat straw pulp than other pulps (Table V). The higher the specific surface area the slower the water will be drained from the sheet during its formation. Swollen volume which is the volume of the fibre plus water associated with fibres in the fibre mat and is the volume unavailable for fluid flow, the higher values of it for wheat straw and bagasse pulps may also be factor responsible for higher retention of fillers in them. The trend of retention of china clay and GCC is similar to soapstone, however, the retention of talc as filler is relatively more than china clay and calcium carbonate(Table VI). Special care is therefore needed in increasing the filler content in a sheet.

3.2 EFFECT ON THE PAPER PROPERTIES DUE TO INCREASED FILLER CONTENT (TALC)

3.2.1 APPARENT DENSITY

Softwood, bamboo and eucalypt pulps indicated continuos increase in the apparent density with the increase in filler content (Fig.2). This may be due to the higher specific gravity of fillers. The specific gravity values for most of the fillers are in the range of 2.5 to 3 g/cm^3 which is relatively quite higher than that of cellulosic fibres which is around 1 g/cm^3 (5). In the case of bagasse and wheat straw pulps after the initial increase upto the filler level of around 17 percent there was a slight drop in the density. This drop for these pulps at higher filler loading could be probably due to prevention of the formation of fibre to fibre-bonds. The fibres become stiffer & slightly increase the bulk. However it needs more investigations.

3.2.2 TENSILE STRENGTH:

Tensile strength is one of the most important properties in papermaking. The behavior of different pulps with increase in the filler content is depicted in Fig.3.All pulps had shown a drop in tensile strength when filler level was increased . The tensile drop is lower at the low filler level, while it is quite sharp at higher filler levels. This could be probably due to the reason that at lower filler dose the filler try to settle between the contact area of fibres in the beginning and then it settles on other sites i.e. imperfections on the fibre walls. At the higher dosage however the filler gets diffused into the lumen of the fibres which causes sharp drop due to lowering in the collapse tendency resulting in lower degree of fibre bonding. The particle size distribution and the specific gravity of fillers are important characteristics for fibre bond interference (6,7,8).

At 15% filler level the percent drop in the tensile strength observed for softwood, bamboo, eucalypt, baggasse and wheat straw pulps was 25, 18 ,18, 21 and 22 percent respectively.

3.2.3 TEARING STRENGTH:

Increase in the filler content in the paper made from all the five pulps caused constant reduction in the tearing strength (Fig.4). The drop was relatively lesser in the case of softwood pulp and higher in bamboo pulp as compared to the other pulps of eucalypt, bagasse and wheat straw which showed almost the same extent of drop. For softwood pulp the reduction in tearing strength was about 7% when 20% filler was added whereas for other pulps reduction to the extent of 10% was noticed. The drop in the tearing strength in the case of bamboo at this filler level was about 15%. This drop in the tearing strength could be due to interference of filler particles with the bonding of fibres as the tearing strength of paper depends upon fibre length and bonding.

3.2.4 SCATTERING CO-EFFICIENT

This is an important property for printing grade paper as it affects opacity and hence print show through. The effect of filler on the Sp.Scatt. of different pulps is shown in (Fig.5). The improvement in Sp.scatt. Co-eff. with increased filler content was highest in the case of bagasse pulp and least in the case of eucalypt pulp. As bagasse fibres have tendency to collapse more easily than eucalypt fibres the effect of filler in preventing fibre bonding and creating new fibre air interfaces become more apparent in the case of bagasse. The new interfaces increase the Sp.scatt. Co-eff. The improvement in the Sp.scatt. co-eff. for softwood and wheat straw pulps was found to be in between the corresponding values for bagasse and eucalypt pulps. The behaviour of bamboo pulp is similar to eucalypt pulp. A drop in the Sp.Scatt. co-eff. was observed in all the pulps as the amount of filler increased beyond 28% level. This may be due to the fact that at higher filler level more pigment to pigment interfaces are formed rather than pigment to fibre interfaces. The former interfaces have lesser ability to scatter light. At higher dosage levels the pigment particles may agglomerate which means more particles coming closer together and forming optical contact, which will not scatter light, and cause reduction in specific scattering coefficient.

3.3 IMPROVING THE FILLER RETENTION:

The above findings indicated that increasing the soapstone (Talc) content had relatively more adverse effect on the tearing strength properties of straw pulps than those of wood pulps did. Changing the filler from talc to china clay or calcium carbonate it was observed that these fillers were retained relatively lower than talc . Relative improvement in the value of scattering coefficient due to addition of calcium carbonate was higher by 4-14 m^2/kg than talc and china clay (Tables VII to XI)

3.3.1. WET END ADDITION OF APPROPRIATE STRENGTH AND RETENTION AID:

Presently retention aid systems available fell into two basic categories (10,11).

- Single component system.
- Dual Component system.

The latter can be further subdivided into

- dual polymer system
- micro particle system

Although single component systems are by no means dead, the main emphasis in present papermaking system is on dual component system. Specific combinations utilized might include.

- Low molecular weights highly cationic polymers (Polyamines) and prior to HMW anionic acrylamide.
- Low molecular weight non-ionic phenolic resin, added before HMW nonionic polyethylene oxide.

particles have a very high charge density and probably don't "bridge" fines like a traditional high molecular weight flocculent. The very high anionic surface likely act as a "super coagulant" between cationic sites or fines, collapsing them into electrostatically attracted soft flocs smaller in size than traditional flocs.

This higher retention is due to reduction in the anionic forces between fibres and filler particles. In water, cellulosic fibres and fines are negatively charged because of the ionization of the their carboxyl groups. The filler particles are also negatively charged. The negative charges present both on the fibres and the filler particles produce repulsive ionic forces, which are stronger than attractive vander wall's forces thus preventing particles of similar charges coming together and coagulating. With the addition of either cationic starch or hydrocol the anionic repulsive forces amongst fibre and filler get neutralized. The additives introduce counter ions (i.e. cations) which break the electrical double layer on the surface of fibres; fines and fillers thus cause better retention. For all the studied pulps the drop in strength property tensile strength and tearing strength was lesser when filler was used alongwith hydrocol as retention aid than cationic starch. Calcium carbonate as filler caused lesser drop in strength properties than talc and china clay. The Sp.scatt. Co-eff. Improved appreciably when calcium carbonate alongwith hydrocol was used. The increase was more than that observed for talc and china clay. This indicated that improvement in opacity of these pulps could be expected appreciably when $CaCO_3$ alongwith hydrocol is used as retention aid.

3.3.2 PRE FLOCCULATION OF FILLER

Another approach tried to improve the filler retention was preparing and using pre flocculated filler. Pre flocculation is treating the filler particles with a chemical modifier which causes them to flocculate, prior to the paper stock There are some commercially pre flocculated systems available namely 'Hylode' developed by English Clays Lowering Pochin and Co Ltd.(15.16) and "Snowfloc' developed by Blue circle PLC. The latter system enables chalk (Calcium carbonate) to be used in Rosin -alum system.(17). In the present study , the filler was dispersed in water to prepare a slurry of about 40% solid content and to this slurry 0.1% anionic flocculent (Percol 155)was added followed by 1% cationic starch. The pre flocculated filler thus obtained was added to pulp slurry. It was observed that pre flocculated filler gave slightly better retention than starch alone. The effect on the strength characteristics was comparable for both the cases. The effect on filler retention was relatively lower than observed in the case of hydrocol. Similar trend was observed for talc, china clay and calcium carbonate for all the pulps studied (tables II to VI).Pre flocculated filler gave relatively lower Specific scattering co efficient than starch addition and hydrocol addition.

3.3.3 USING PRE ADSORBED ADDITIVES ON THE FILLER SURFACE TO ENHANCE BONDING ON THE FIBRE SURFACE

Another approach tried was to create a such system where filler itself takes part in bonding process so that the more it is added the better the paper. for this to achieve the combination of pre flocculation and cationic starch treatment was tried. The filler was treated with anionic polymer (0.1% Percol 155) and subsequently added to the pulp that had been treated with cationic starch (1%). It was observed that this method led to better retention (about 0.5 to 3%)than the other methods tried. The effect on the strength was comparable to that observed for hydrocol system, the best considered earlier. The results were better than starch and pre flocculated system. This is probably due to different charges (polarity) between fibres and filler which led to fibre/filler bonding which took out the normal debonding effect of filler.

3.3.4 WET WEB STRENGTH CHARACTERISTICS

When the wet web is removed from the paper machine wire the fibre structure should be sufficiently consolidated to be able to overcome the adhesion to the wire and to withstand severe mechanical stress exerted in it between the couch and the first press in open draw. Wet web strength is best explained by taking into consideration tensile strength as well as stretch i.e. TEA absorption as extensibility of the fibre mat at higher moisture content is strongly affected by the curvature and flexibility of the fibres. In all the pulps studied it was observed that the addition of filler caused drop in the wet web TEA index values. Talc caused higher drop than china clay and calcium carbonate. The pre adsorbed additive on filler surface technique (Polarity treated filler) caused lesser drop in the wet web tensile energy absorption than the other methods. Wet web TEA index of about 35 mJ/g is sufficient for open draw medium speed paper machine.

3.3.5 EFFECT OF PARTICLE SIZE (OF TALC) ON THE FILLER RETENTION AND SOME PAPER CHARACTERSTICS OF EUCALYPT PULP.

The dependence of filler retention on particle size is shown in Fig.7 The smaller particles are retained relatively lower than larger particles. The particle size distribution study of the filler in different areas of papermaking Fig.8 indicated that filler retained and circulating within the paper making system is much finer than original raw material feed (Ref 18) .This highlights one of the papermaking most untraceable processing difficulty that Improved filler retention stands out as one of the most critical requirements to enable increase filler content in the paper.

Fig 9 shows tensile strength at 40% weight filler loading level for eucalypt pulp for talc of different particle sizes. It can be seen that the larger particle size (> 5μm) has lesser disruption effect on the tensile strength than that finer particles. This is probably due of the attachment of small filler particles to fibrils thus preventing collapse and consolidation on drying.

Fig 10 shows relationship between the light scattering coefficient and particle size of talc. The maximum scattering is around 0.6μ. Although there appears a simple relationship between filler particle size and light scattering for a filler but it is not always true as anything which influence the void structure of the sheet or the filler will have significant effect.

Fig11 shows porosity as function of filler particle size. The porosity of paper increases with increase in particle size of filler. Thus is probably due that the coarse particles increase the void spaces of the sheet hence improves porosity.

3.3.6 EFFECT OF CHANGING THE REFINING ON THE IMPROVEMENT OFFILLER RETENTION IN EUCALYPT PULP

To check the effect of refining on filler retention, eucalypt pulp as such and devoid of fines was studied at different levels of filler addition. It was observed that the pulp devoid of fines could retain more filler (2 to 4%) tables IX &.XII This was probably due to reason that the pulp fibres get better fibrillated on refining in the absence of primary fines which in turn caused better retention of filler. The trend of filler retention in different cases was same as reported earlier.

3.3.7 EFFECT OF INCREASED FILLER LOADING ON THE PRINTING CHARACTERISTICS

To observe the effect of increased filler loading on the printing characteristics, handsheets prepared using blend of 20% bleached bamboo and 80% bleached eucalypt pulp refined to freeness level of 350 - 400 CSF, loaded with talc as filler under the different conditions described earlier were studied for different printing characteristics. The sheets were sized using 0.8 % dispersed rosin along with Poly aluminum chloride and alum (ratio 50:50) at pH 6.2. These sheets were calendered using laboratory calender under hard nip and soft nip configuration at 10 bar pressure and 90^{o}C temperature. Print density and print through parameters were evaluated after printing using IGT printability tester. (AIC 2-5 model).

Printing density curve parameters i.e. Contact factor m and Saturation density (19) were evaluated . It was observed that contact factor (m) and saturation density are improved with the addition of filler. Contact factor got improved from 0.42 to 0.53 and saturation density got increased from 1.23 to 1.51 (Table XIII). Soft nip calendering gave better improvement than hard nip calendering. The print through tendency got reduced with the addition of filler. The value of print through of 0.75 for blank got reduced by about 33% at filler level of 26.2%. Fiber rising characteristics were evaluated using Fiber rising tester (FRT). In this the surface of the paper is treated with pre-selected volume of water and after the water application the paper is rapidly dried with an IR heater. This effects simulates the conditions of offset printing . The paper surface is examined for structural changes using a vedio camera.

It was observed that the total fiber rising area (TRA) increased with addition of filler. Upto filler addition level from 7.9 to 26.2% the increase was not steep(of level of about 9%). But further addition gave abnormally high rising area (to the extent of about 30%). This indicated that probably filler addition level beyond 26 % for blend of bamboo and hard wood pulps in the ratio 20:80 may lead to serious linting problem in offset printing. Addition of cationic starch gave reduction in TRA value. The polarity treated method of filler addition also gave better effect.

4. CONCLUSIONS:

- The present studies on laboratory scale revealed that in the absence of any retention aid, the amount of filler retained was highest for wheat straw pulp and lowest for softwood pulp. Eucalypt and baggasse pulps had comparable filler retention capability and it was higher than softwood pulp. The retention of filler in bamboo pulp is lower than wheat straw, baggasse and eucalypt pulps but higher than softwood pulp. Specific surface area and swollen volume were higher for wheat straw and baggasse pulps than other pulps. The filler retention capability is not improved by making stronger pulp by changing the bleaching sequence as observed for CEHH and D/CEHD bleached eucalypt pulps .

- With the increase in filler content, softwood and eucalypt pulps showed continuous increase in the apparent density. Whereas in the case of baggasse and wheat straw pulps after an increase upto certain filler level a slight drop was observed.

- At 15% filler level in the sheet the percent drop in the tensile strength observed for softwood, bamboo, eucalypt, baggasse and wheat straw pulps was 25,18 ,18,21 and 22 percent respectively. With increase in filler content the relative drop in the tearing strength was lowest in the case of softwood pulp.

- The improvement in the Sp. scatt. Co-eff. with increased filler content was highest in the case of baggasse pulp and least in the case of eucalypt pulp. The effect on the improvement of Sp.scatt. Co-eff. for softwood and wheat straw pulps was somewhere between baggasse, eucalypt and bamboo pulps..

- Ground Calcium carbonate (GCC) as filler had relatively better retention than china clay but lower than talc.

- Coarser particles of talc are retained better than finer ones. the larger particle size (> 5μm) has lesser disruption effect on the tensile strength than finer particles. The porosity is

relatively more improved with coarser particles, whereas reverse has been observed for the specific scattering coefficient for eucalypt pulp.

- The retention of filler in these pulps can be improved by use of dual component retention aids or pre flocculation of fillers or using pre adsorbed additive technique on the filler surface to enhance bonding on the fibre surface.

- Pre flocculated filler gave better retention than starch alone. The effect on the strength characteristics was comparable for both these. The effect on filler retention was relatively lower than observed for hydrocol.

- Using pre adsorbed additive technique on the filler surface gave better retention (about 0.5 to 3%)than the other methods tried. The effect on strength was comparable to that observed for hydrocol system.

- Addition of filler caused drop in the wet web TEA index values. Talc caused higher drop than china clay and calcium carbonate. Using pre adsorbed additive on filler surface technique (Polarity treated filler) caused lesser drop in the wet web tensile energy absorption than the other methods.

- The filler retention is also improved by adopting refining which improves fibrillation of fibres as indicated by studying the eucalypt pulp devoid of primary fines

- Filler addition in blend of bamboo and eucalypt pulp (20:80) resulted in the printing characteristics improvement. The print contact factor got improved from 0.42 to 0.53 and print saturation density got increased from 1.23 to 1.51 . Soft nip calendering gave better improvement than hard nip calendering. The print through tendency got reduced with the addition of filler. The value of print through of 0.75 for blank got reduced by about 33% at filler level of 26.2%.

- The total fiber rising area (TRA) which is indicative of smooth printing press runnability increased with addition of filler. Upto filler addition level from 7.9 to 26.2% the increase was not steep(of level of about 9%). But further addition gave abnormally high rising area (to the extent of about 30%). This indicated that probably filler addition level beyond 26 % for blend of bamboo and hard wood pulps in the ratio 20:80 may lead to serious linting problem in offset printing. Addition of cationic starch gave reduction in TRA value. The polarity treated method of filler addition also gave better effect.

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TABLE 1: Properties of commonly used fillers (Ref. 2)

Name	Formula	Comp-osition	Refrac-tive Index	Scatt.Co-eff. (100Sp) Sp in m^2/g	Brightness (%)	Specific Gravity (g/cc)	Particle Size (micron)	Particle Shape	Abrasiveness mg	Nonvolatile At 105^0C %	pH
Clays											
Filler	$AL_2O_3.2SiO_2.2H_2O$	46 % SiO_2 39% $AL_2O_3.13H_2O$	1.57	9.5-11.5	78-90	2.58	0.2-2	PLATELETS	1-17	99.5	6.6
Coating	$AL_2O_3.2SiO_2.2H_2O$	46 % SiO_2 39% $AL_2O_3.13H_7O$	1.57	14	85-90	2.58	0.2-2	Platelets	1-6	99.6	7.0
High white	$AL_2O_3.2SiO_2.2H_2O$	46 % SiO_2 39% $AL_2O_3.13H_2O$	1.57	7-17	90-95	2.58	0.2-2.	Platelets	1-6	99.6	6.3-7.5
Calcined	$AL_2O_3.2SiO_2.2H_2O$	51 % SiO_2 40% $AL_2O_3.13H_2O$	1.60	-	90-95	2.63	0.7-1.5	Platelets	15-30	99	6.0
Calcium carbonate											
Natural	$CaCO_3$	96% $CaCO_3$	1.59	17-24	80-95	2.65	0.7-3	Rounded	3-15	-	-
Ppt rrhombs	$CaCO_3$	98.6% $CaCO_3$	1.60	28-36	95-100	2.65	0.3.3	Rhombohedral	2-9	-	8.9
Ppt needles	$CaCO_3$	-	-	30	95-100	=	0.3-3	Acicular	-	-	-
Raffold	$CaCO_3$ $Mg(OH)_2$	65% $CaCO_3$ 35%$Mg(OH)_2$	1.53	19	92-94	2.50	1-2	-	5-12	-	-
Sulphate											
Pearl filler	$CaSO_4$	98.0 %$CaSO_4$	-	-	93.9	2.8-3.0	10	Acicular	6-10	99.75	9.0
Barium sulphate											
Baryts	$BaSO_4$	97 %$BaSO_4$	1.64	7.8	98.0	4.3-4.4	1-2	Acicular	3-4	99.83	9.0
Blanc fixe	$BaSO_4$	98.8%$BaSO_4$	1.64	14.3	93.3	4.4	0.5	Acicular	1-2	100	-
Silicates											
Ppted	SiO_2	78% SiO_2 5% CaO	1.45	25.4	96.5	2.08	0.1-3	Spherical	5-13	91.9	9.7
Silico aluminate	Al_2O_3 SiO_2	68%SiO_2 12% Al_2O_3 9% Na_2O	1.55	22.4	97-100	2.10	0.1-3	Spherical	10-15	88.9	10.2
Dia. Silica	SiO_2	92% SiO_2	1.47	29-40	69-83	2.0	0.5-4	Diatoms	59-64	97.0	-
Talc	$3MgO.4SiO_2.H_2O$	62% SiO_2 32%MgO 5% H_2O	1.57	-	85-90	2.7	1.5-10	Platelets	3-5	-	9.2
Aluminum trihydrate	$Al_2O_33H_2O$	65% Al_2O_3 34% H_2O	-	25.8-29	97-100	2.4	0.5-0.5	Platelet	3-5	99.44	9.5
Zinc sulphide	ZnS	95%Zns	2.37	-	98	4.0	0.3	Spherical	12	-	8.5
Anatase	TiO_2	98% TiO_2	2.55	43-51	98-100	3.9	015-0.3	Spherical	10-30	99.3	8.3
Rutile	TiO_2	90-95% TiO_2	2.76	54-68	98-100	4.2	0.15-0.3	Spherical	10-30	99.0	6.5

TABLE II - CHARACTERISTICS OF THE DIFFERENT FILLERS USED

Characteristics	Filler Type		
	Talc	China clay	GCC
Brightness (% ISO)	92.9	87.5	94.0
Refractive Index	1.57	1.57	1.59
Particle Size (passing 300 mesh sieve)	100	99.9	99.9
Sp. Gravity	2.70	2.58	2.65
Particle charge	Negative	Negative	Positive

TABLE III –STRENGTH CHARACTERISTICS OF DIFFERENT PULPS

(1) Wheat straw Pulp

PFI (Rev.)	Freeness CSF (ml)	Apparent Density (g/cm^3)	Burst Index ($kPa.m^2/g$)	Tensile Index (N.m/g)	Tear Index ($mN.m^2/g$)	Porosity Bendtsen (ml/min.)	Sp. Scatt. Coeff. (m^2/kg)
0	410	0.70	2.0	36.5	4.7	75	38.9
500	230	0.81	3.15	42.0	4.0	20	32.8
2000	130	0.82	3.25	49.5	3.0	15	26.5

(2) Bagasse Pulp

PFI (Rev.)	Freeness CSF (ml)	Apparent Density (g/cm^3)	Burst Index ($kPa.m^2/g$)	Tensile Index (N.m/g)	Tear Index ($mN.m^2/g$)	Porosity Bendtsen (ml/min.)	Sp. Scatt. Coeff. (m^2/kg)
0	480	0.71	2.05	38.5	5.10	90	32.0
500	420	0.85	3.20	42.0	5.00	75	31.0
1000	350	0.90	3.80	48.0	4.90	60	30.6
2000	200	0.92	4.20	52.5	4.50	20	29.5

Con.

(3) Eucalypt Pulp CEHH

PFI (Rev.)	Freeness CSF (ml)	Apparent Density (g/cm^3)	Burst Index ($kPa.m^2/g$)	Tensile Index (N.m/g)	Tear Index ($mN.m^2/g$)	Porosity Bendtsen (ml/min.)	Sp. Scatt. Coeff. (m^2/kg)
0	580	0.60	1.20	37.0	3.5	>3000	43.3
1000	520	0.66	2.20	50.0	5.0	2600	42.3
2000	460	0.73	4.00	59.0	5.6	1400	41.4
3000	340	0.78	4.60	65.0	5.8	450	39.7
4000	180	0.80	4.70	70.0	5.5	90	35.4

Eucalypt Pulp D/CEHD

PFI (Rev.)	Freeness CSF (ml)	Apparent Density (g/cm^3)	Burst Index ($kPa.m^2/g$)	Tensile Index (N.m/g)	Tear Index ($mN.m^2/g$)	Porosity Bendtsen (ml/min.)	Sp. Scatt. Coeff. (m^2/kg)
0	660	0.67	1.50	47.0	4.50	>3000	41.3
1000	550	0.74	3.20	60.0	5.50	2200	40.3
2000	490	0.78	4.50	69.0	5.80	1100	38.4
4000	350	0.82	6.00	75.0	6.85	420	37.7
6000	180	0.84	6.20	78.0	6.95	100	34.4

Con.

(4) Softwood Imported

PFI (Rev.)	Freeness CSF (ml)	Apparent Density (g/cm^3)	Burst Index ($kPa.m^2/g$)	Tensile Index (N.m/g)	Tear Index ($mN.m^2/g$)	Porosity Bendtsen (ml/min.)	Sp. Scatt. Coeff. (m^2/kg)
0	745	0.43	0.70	13.5	11.7	>3000	27.8
2000	700	0.58	3.50	49.0	24.0	>3000	20.7
4000	560	0.66	4.75	61.0	19.8	1700	19.1
6000	445	0.69	5.00	70.0	16.6	800	17.0
8000	270	0.71	5.60	73.0	14.3	280	15.9
10000	200	0.72	6.10	77.0	13.0	45	16.0

(5) Bamboo Pulp

PFI (Rev.)	Freeness CSF (ml)	Apparent Density (g/cm^3)	Burst Index ($kPa.m^2/g$)	Tensile Index (N.m/g)	Tear Index ($mN.m^2/g$)	Porosity Bendtsen (ml/min.)	Sp. Scatt. Coeff. (m^2/kg)
0	695	0.56	0.85	22.0	10.4	> 3000	39.6
1000	635	0.62	2.6	39.0	11.8	2030	39.0
2000	575	0.63	3.1	47.0	11.5	550	38.4
3000	470	0.67	3.65	53.0	9.5	400	36.6
4000	245	0.70	4.7	63.0	7.0	250	22.3

TABLE – IV GENERAL CHARACTERISTICS OF THE DIFFERENT PULPS

Component	"Length"	"Width"
Fibres	0.5-2 mm	5-50 μm
Fibrils	100-500 μm	0.2-0.5 μm
Fiber debris	50-100 μm	5-50 μm
Fillers	0.2-15 μm	0.1-10 μm

TABLE V -SPECIFIC SURFACE AREA AND SPECIFIC VOLUME OF THE DIFFERENT PULPS

Pulp	Specific surface area cm^2/g	Specific volume cm^3/g
Wheat straw	31030	3.77
Bagasse	37980	3.94
Eucalyptus	26040	3.43
Softwood	18930	3.07
Bamboo	20980	3.25

TABLE VI -FILLER RETENTION AT 40% FILLER LOADING FOR DIFFERENT PULPS

Pulp	Filler	Retention (%)
Wheat straw	Talc	63
	China clay	40
	GCC	48
Bagasse		
	Talc	56
	China clay	38
	GCC	45
Eucalypt (CEHH)		
	Talc	58
	China clay	37
	GCC	46
Eucalypt (D/CEHD)		
	Talc	59
	China clay	36
	GCC	47
Bamboo		
	Talc	52
	China clay	35
	GCC	43
Softwood		
	Talc	44
	China clay	25
	GCC	32

TABLE VII -PROPERTIES OF WHEAT STRAW PULP IN THE PRESENCE OF DIFFERENT TYPES OF FILLERS (AMOUNT ADDED 40%) AND RETENTION TREATMENTS.

Pulp with	*Wet Web TEA Index* At 20 % solid ***(mJ/g)***	*Apparent density* ***(g/cm²)***	*Tensile Index* ***(N.m/g)***	*Tear Index* ***(m.N.m²/g)***	*Sp.Scatt. Co-eff.* ***(m²/kg)***	*Ash* ***%***
Blank	41.3	0.81	42.0	4.00	32.8	4.1
Talc	26.9	0.90	30.0	3.40	36.2	25.2
Talc + starch	29.1	0.90	33.5	3.50	37.6	25.9
Talc + hydrocol	31.4	0.90	36.5	3.60	38.0	26.2
Pre flocculated talc	35.8	0.90	35.0	3.50	36.4	25.8
Polarity treated talc	37.8	0.88	38.5	3.80	38.6	26.4
China clay	29.5	0.89	33.0	3.65	34.4	16.0
China clay + starch	31.5	0.89	35.0	3.60	35.4	17.9
China clay + hydrocol	34.8	0.90	36.5	3.70	36.8	22.9
Pre flocculated clay	36.5	0.89	35.5	3.65	35.8	20.6
Polarity treated clay	38.5	0.89	37.5	3.80	37.4	23.3
$CaCO_3$	31.7	0.84	35.0	3.55	43.1	18.8
$CaCO_3$ + starch	33.9	0.83	36.5	3.65	44.3	19.9
$CaCO_3$ + hydrocol	35.2	0.84	38.0	3.70	45.4	20.9
Pre flocculated$CaCO_3$	38.4	0.84	37.0	3.60	43.0	21.9
Polarity treated $CaCO_3$	39.5	0.85	39.5	3.85	46.2	23.2

TABLE VIII -PROPERTIES OF BAGASSE PULP IN THE PRESENCE OF DIFFERENT TYPES OF FILLERS (AMOUNT ADDED 40%) AND RETENTION TREATMENTS.

Pulp with	*Wet Web TEA Index* At 20 % solid ***(mJ/g)***	*Apparent density* ***(g/cm^2)***	*Tensile Index* ***(N.m/g)***	*Tear Index* ***(m.N.m^2/g)***	*Sp.Scatt. Co-eff.* ***(m^2/kg)***	*Ash* ***%***
Blank	30.0	0.90	48.0	4.90	30.6	0.5
Talc	20.6	0.87	24.5	2.80	41.7	20.8
Talc + starch	21.8	0.85	26.5	3.10	42.0	23.1
Talc + hydrocol	22.3	0.86	29.5	3.25	44.6	26.0
Pre flocculated talc	23.1	0.86	28.5	3.10	38.5	24.8
Polarity treated talc	23.6	0.85	30.5	3.40	44.9	26.6
China clay	22.0	0.84	26.5	3.60	32.0	15.2
China clay + starch	23.3	0.85	27.5	3.70	33.5	18.2
China clay + hydrocol	24.4	0.84	29.0	3.80	34.5	19.6
Pre flocculated clay	25.2	0.85	28.5	3.75	32.8	18.7
Polarity treated clay	26.6	0.85	31.5	4.00	34.7	20.6
$CaCO_3$	24.7	0.86	27.5	3.15	44.7	18.0
$CaCO_3$ + starch	25.2	0.87	28.5	3.25	47.9	25.4
$CaCO_3$ + hydrocol	25.6	0.88	29.5	3.40	49.0	29.0
Prefloculated$CaCO_3$	26.2	0.84	28.0	3.10	45.7	26.2
Polarity treated $CaCO_3$	26.9	0.85	31.0	3.50	49.5	29.8

TABLE IX -PROPERTIES OF CEHH EUCALYPT PULP IN THE PRESENCE OF DIFFERENT TYPES OF FILLERS (AMOUNT ADDED 40%) AND RETENTION TREATMENTS.

Pulp with	*Wet Web TEA Index* At 20 % solid ***(mJ/g)***	*Apparent density* ***(g/cm²)***	*Tensile Index* ***(N.m/g)***	*Tear Index* ***(m.N.m²/g)***	*Sp.Scatt. Co-eff.* ***(m²/kg)***	*Ash* ***%***
Blank	54.4	0.77	65.0	5.80	39.7	1.6
Talc	48.4	0.81	39.5	5.00	45.0	23.5
Talc + starch	49.2	0.85	43.5	5.20	46.4	24.2
Talc + hydrocol	50.3	0.86	47.5	5.40	47.3	25.6
Pre flocculated talc	51.5	0.82	46.5	5.30	45.6	25.2
Polarity treated talc	53.2	0.88	48.0	5.50	48.8	26.7
China clay	50.9	0.80	44.5	5.00	37.4	14.7
China clay + starch	51.2	0.80	48.5	5.20	46.5	17.6
China clay + hydrocol	52.2	0.84	52.5	5.30	48.4	22.0
Pre flocculated clay	53.3	0.83	51.5	5.35	46.4	21.0
Polarity treated clay	54.8	0.84	53.0	5.40	50.0	23.2
$CaCO_3$	51.2	0.70	46.5	5.10	48.2	18.4
$CaCO_3$ + starch	52.3	0.69	50.5	5.35	49.9	22.4
$CaCO_3$+ hydrocol	54.5	0.69	52.5	5.45	52.2	23.2
Prefloculated$CaCO_3$	56.7	0.71	50.5	5.40	50.3	21.1
Polarity treated $CaCO_3$	57.5	0.71	53.5	5.55	54.5	24.9

TABLE X -PROPERTIES OF SOFTWOOD PULP IN THE PRESENCE OF DIFFERENT TYPES OF FILLERS (AMOUNT ADDED 40%) AND RETENTION TREATMENTS.

Pulp with	*Wet Web TEA Index* At 20 % solid *(mJ/g)*	*Apparent density* *(g/cm^2)*	*Tensile Index* *(N.m/g)*	*Tear Index* *(m.N.m^2/g)*	*Sp.Scatt. Co-eff.* *(m^2/kg)*	*Ash* *%*
Blank	170.0	0.77	72.0	14.3	17.0	0.5
Talc	83.7	0.77	50.0	13.4	29.5	18.1
Talc + starch	84.5	0.80	53.5	13.2	32.1	19.6
Talc + hydrocol	86.5	0.79	50.0	12.7	33.3	20.8
Pre flocculated talc	90.9	0.82	49.0	12.0	30.6	19.4
Polarity treated talc	92.4	0.81	54.0	13.3	36.3	22.2
China clay	89.6	0.75	52.0	13.6	27.5	10.3
China clay + starch	90.2	0.77	54.0	12.0	29.5	11.8
China clay + hydrocol	95.6	0.82	56.5	13.8	30.6	13.8
Pre flocculated clay	96.4	0.80	54.5	12.4	28.1	15.0
Polarity treated clay	99.4	0.81	58.0	13.9	36.0	16.2
$CaCO_3$	99.5	0.70	53.5	13.9	42.2	13.4
$CaCO_3$ + starch	100	0.71	54.0	12.1	43.3	15.8
$CaCO_3$+ hydrocol	102	0.69	56.5	12.9	44.8	17.2
Prefloculated$CaCO_3$	101.5	0.74	54.5	12.8	40.7	16.8
Polarity treated $CaCO_3$	102.7	0.74	56.0	13.3	45.8	17.5

TABLE XI -PROPERTIES OF BAMBOO PULP IN THE PRESENCE OF DIFFERENT TYPES OF FILLERS (AMOUNT ADDED 40%) AND RETENTION TREATMENTS.

Pulp with	Wet Web TEA Index at 20 % solid **(mJ/g)**	Apparent Density **(g/cm)**	Tensile Index **(N.m/g)**	Tear Index **($m.N.m^2/g$)**	Sp. Scatt Co-eff. **(m^2 /kg)**	. Ash **%**
Blank	114.9	0.70	58.0	8.50	35.5	1.4
Talc	78.9	0.74	31.0	7.4	42.2	18.2
Talc + starch	81.3	0.75	36.0	7.70	43.2	22.2
Talc + hydrocol	84.5	0.75	39.5	7.90	44.5	25.8
Pre flocculated talc	85.5	0.76	39.0	7.80	40.7	23.2
Polarity treated talc	87.5	0.76	41.5	7.90	44.6	26.2
China clay	81.2	0.76	36.0	6.90	36.5	14.0
China clay + starch	83.3	0.77	41.0	7.30	38.5	17.7
China clay + hydrocol	84.5	0.78	42.0	7.50	40.5	20.5
Pre flocculated clay	85.6	0.79	40.0	7.45	38.2	19.6
Polarity treated clay	87.6	0.79	41.5	7.40	47.7	21.8
$CaCO_3$	83.2	0.73	48.0	7.00	46.4	17.2
$CaCO_3$ + starch	84.5	0.72	40.5	7.60	47.5	20.2
$CaCO_3$+ hydrocol	86.5	0.73	45.0	7.70	48.2	22.0
Prefloculated$CaCO_3$	87.8	0.70	40.5	7.80	45.4	21.0
Polarity treated $CaCO_3$	89.9	0.70	46.5	7.85	47.5	22.5

TABLE XII -EFFECT OF REFINING EXTENT CHANGE ON THE FILLER RETENTION OF EUCALYPT PULP (REFINING AFTER PRIMARY FINES REMOVAL)

Pulp with	*Wet Web TEA Index* at 20 % solid **(mJ/g)**	*Apparent density* **(g/cm^3)**	*Tensile Index* **(N.m/g)**	*Tear Index* **($m.N.m^2/g$)**	*Sp.Scatt. Co-eff.* **(m^2/kg)**	*Ash* **%**
Blank	60.4	0.75	70.0	6.50	38.4	1.2
Talc	54.4	0.79	45.5	5.70	47.0	25.5
Talc + starch	55.2	0.83	48.5	5.90	48.4	26.2
Talc + hydrocol	56.3	0.84	52.5	6.10	49.3	27.6
Pre flocculated talc	57.3	0.80	51.5	6.00	47.6	27.1
Polarity treated talc	59.3	0.86	53.0	6.20	50.8	28.5
China clay	56.9	0.78	49.5	5.70	39.4	17.7
China clay + starch	57.2	0.78	53.5	5.90	48.5	20.6
China clay + hydrocol	58.2	0.82	57.5	6.00	50.4	25.0
Pre flocculated clay	59.3	0.81	56.5	6.05	48.4	24.0
Polarity treated clay	60.8	0.82	58.0	6.10	52.0	25.2
$CaCO_3$	57.2	0.68	51.5	5.80	50.2	20.4
$CaCO_3$ + starch	58.3	0.67	55.5	6.05	51.9	25.4
$CaCO_3$+ hydrocol	60.5	0.67	57.5	6.15	54.2	26.2
Prefloculated$CaCO_3$	62.7	0.69	55.5	6.10	52.2	24.1
Polarity treated $CaCO_3$	63.5	0.69	58.5	6.25	56.5	28.3

TABLE XIII - PRINTING CHARACTERISTICS OF BLEND OF BAMBOO AND HARDWOOD PULP (20:80) CONTAINING DIFFERENT AMOUNT OF FILLER AFTER HARD NIP AND SOFT NIP CALENDERING.

Filler Addition (%)	Ash, %	Printing characteristics after					
		Hard nip calendering			Soft nip calendering		
		m	**D**	**Print through**	**m**	**D**	**Print through**
Blank	1.3	0.41	1.23	0.75	0.42	1.33	0.68
10	7.9	0.42	1.30	0.63	0.44	1.36	0.65
20	15.4	0.44	1.32	0.60	0.47	1.40	0.62
30	20.4	0.45	1.35	0.58	0.49	1.44	0.57
40	26.2	0.47	1.37	0.50	0.50	1.47	0.55
50	32.3	0.48	1.41	0.47	0.51	1.50	0.52
40+Cat.starch	27.5	0.49	1.40	0.49	0.52	1.48	0.56
40+Hydrocol	28.2	0.49	1.40	0.48	0.52	1.48	0.54
Prefloculation	27.8	0.48	1.39	0.50	0.51	1.49	0.56
Polarity treated talc	29.5	0.49	1.41	0.45	0.53	1.51	0.55

TABLE XIV - FIBER RISING (TOTAL RISING AREA ,TRA) CHARACTERISTICS OF BLEND OF BAMBOO AND HARDWOOD PULP (20:80) CONTAINING DIFFERENT AMOUNT OF FILLER AFTER HARD NIP AND SOFT NIP CALENDERING.

Filler Addition (%)	Ash, %	Printing characteristics after							
		Hard nip calendering				Soft nip calendering			
		Smoothness	Bulk cm^3/g	.Scatt Coeff m^2/kg	TRA mm^2/m^2	Smoothness ml/min	Bulk cm^3/g	.Scatt. Coeff. m^2/kg	TRA mm^2/m^2
Blank	1.3	30	1.19	52.0	1.14	25	1.12	46.3	1.12
10	7.9	25	1.17	52.2	1.95	20	1.10	45.2	1.16
20	15.4	20	1.12	53.8	2.15	15	1.09	47.2	2.00
30	20.4	15	1.10	54.9	2.35	10	1.08	47.8	2.20
40	26.2	15	1.10	55.1	2.55	10	1.07	48.2	2.25
50	32.3	15	1.06	56.1	3.30	10	1.04	48.1	2.90
40+Cat.starch	27.5	15	1.07	55.4	2.30	10	1.05	46.4	2.10
40+Hydrocol	28.2	15	1.06	55.5	2.25	10	1.04	49.7	2.00
Prefloculation	27.8	15	1.03	55.1	2.35	10	1.01	48.3	2.15
Polarity treated talc	29.5	15	1.03	55.7	2.10	10	1.01	49.7	1.90

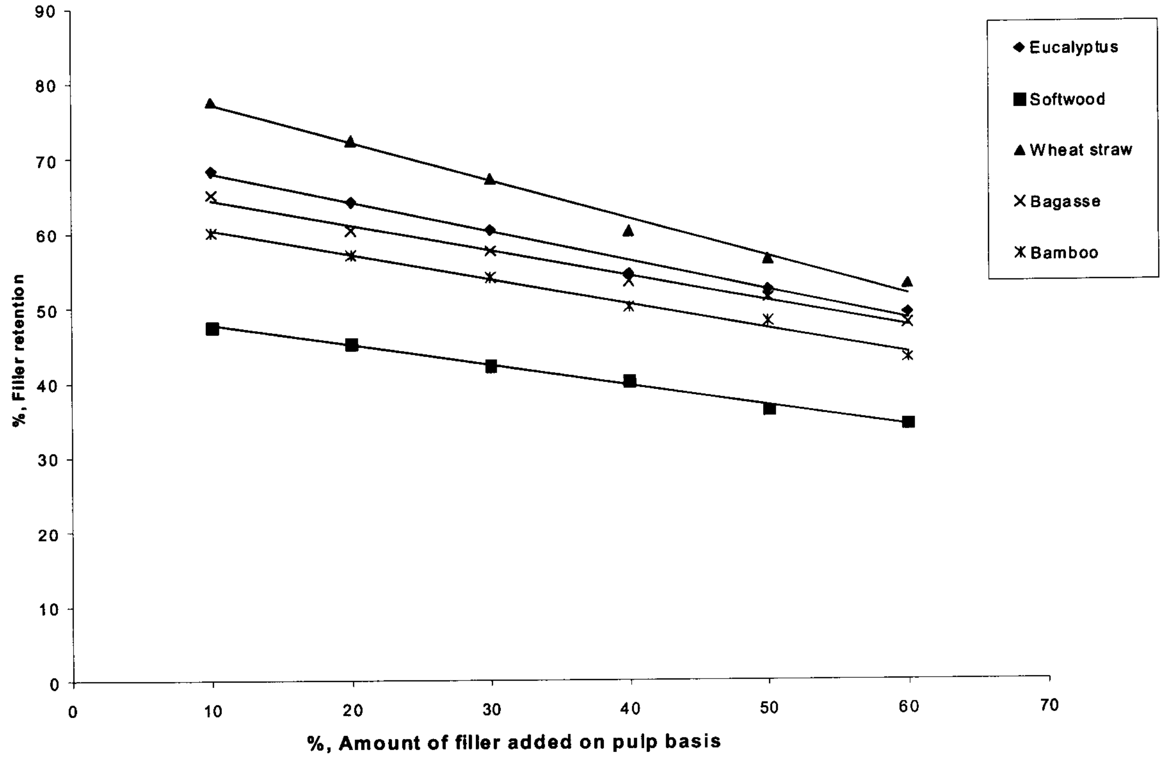

FIG. 1 Filler retention in hand sheets prepared from different pulps

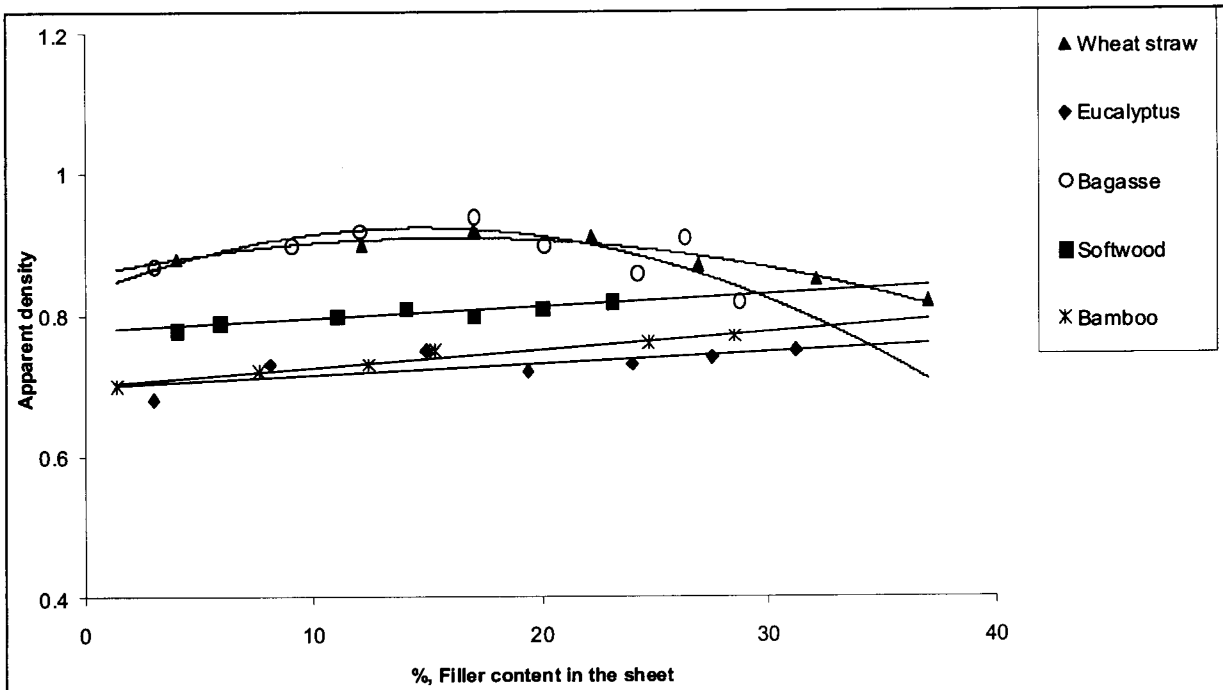

FIG. 2 Effect of filler loading on apparent density of different pulps.

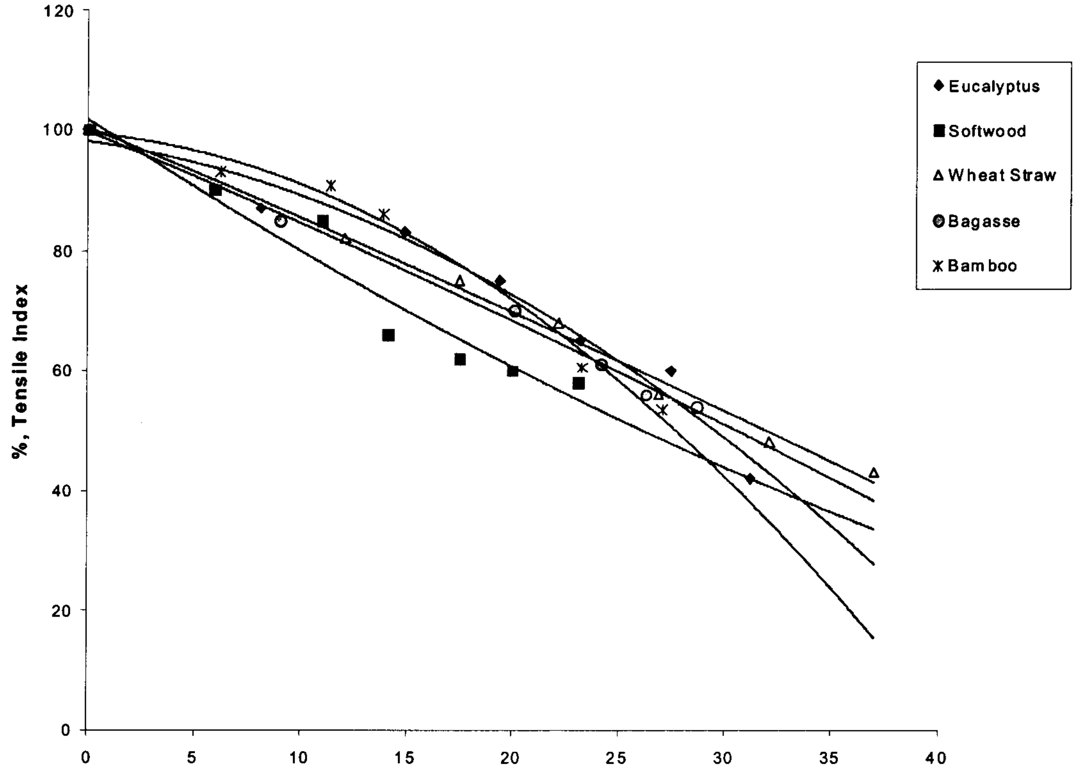

FIG. 3 Effect of filler loading on the Tensile Strength of different pulps.
(Tensile without filler taken as 100 % for each pulp)

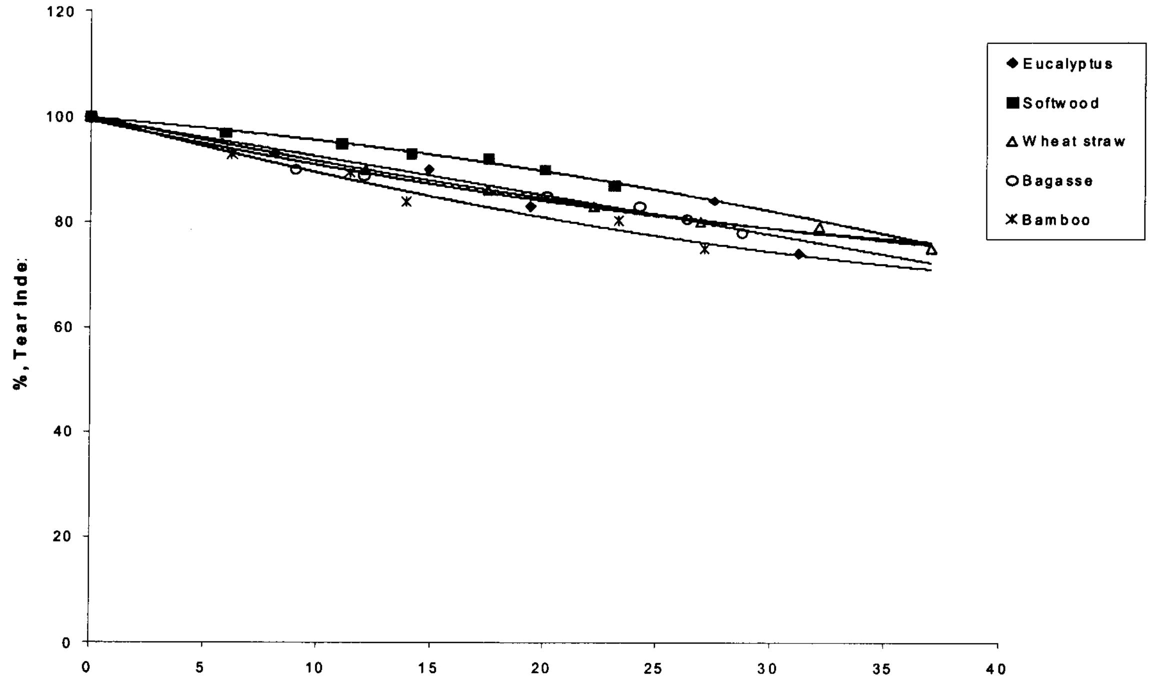

FIG. 4 Effect of filler loading on the Tearing strength of different pulps.
(Tear without filler taken as 100 % for each pulp)

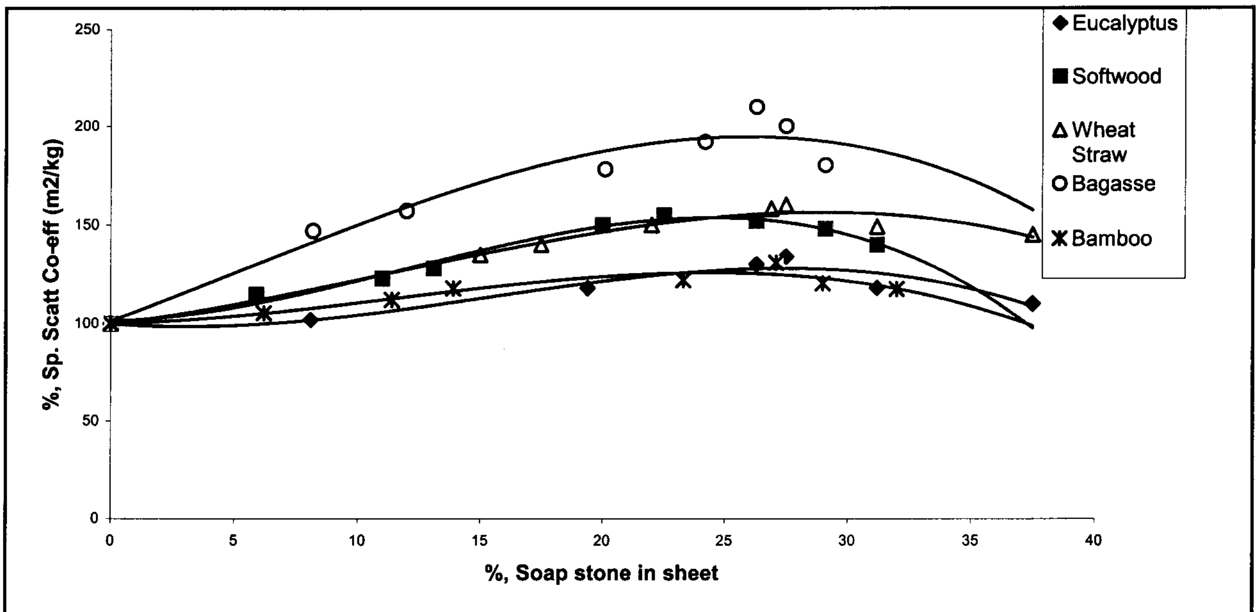

FIG. 5 Effect of filler loading on the Sp. Scatt.Co-eff of different pulps.

Patch

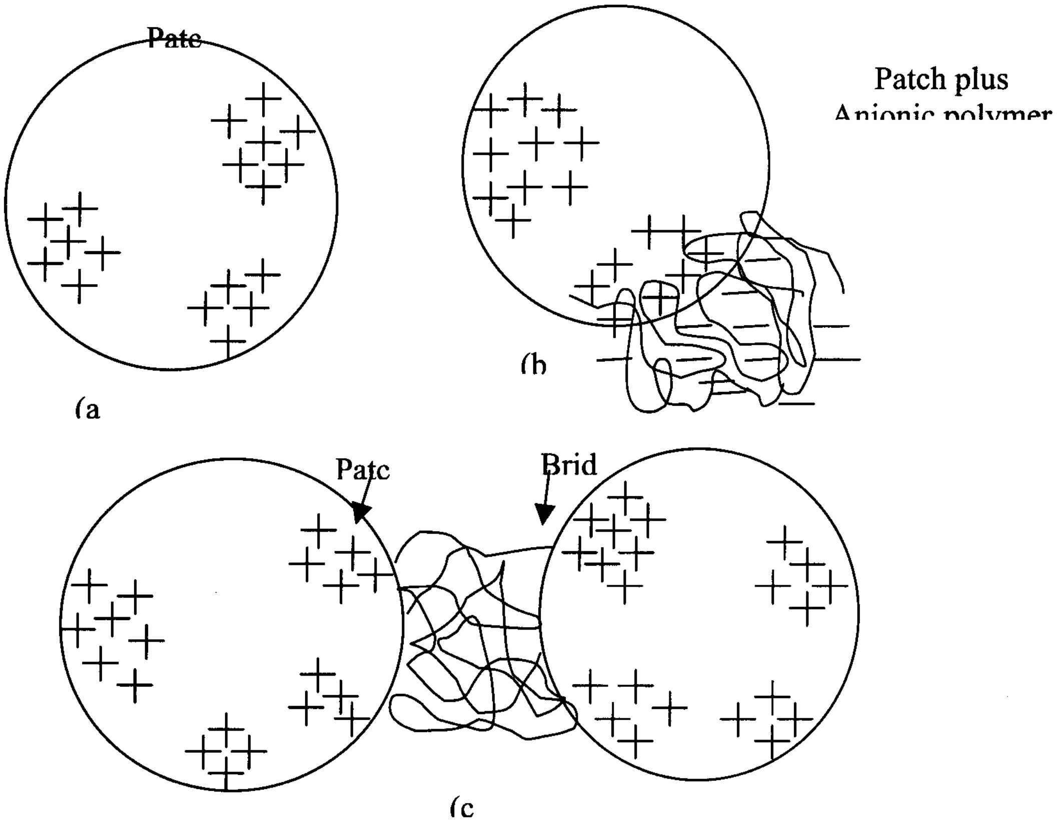

FIG. 6 Patch type

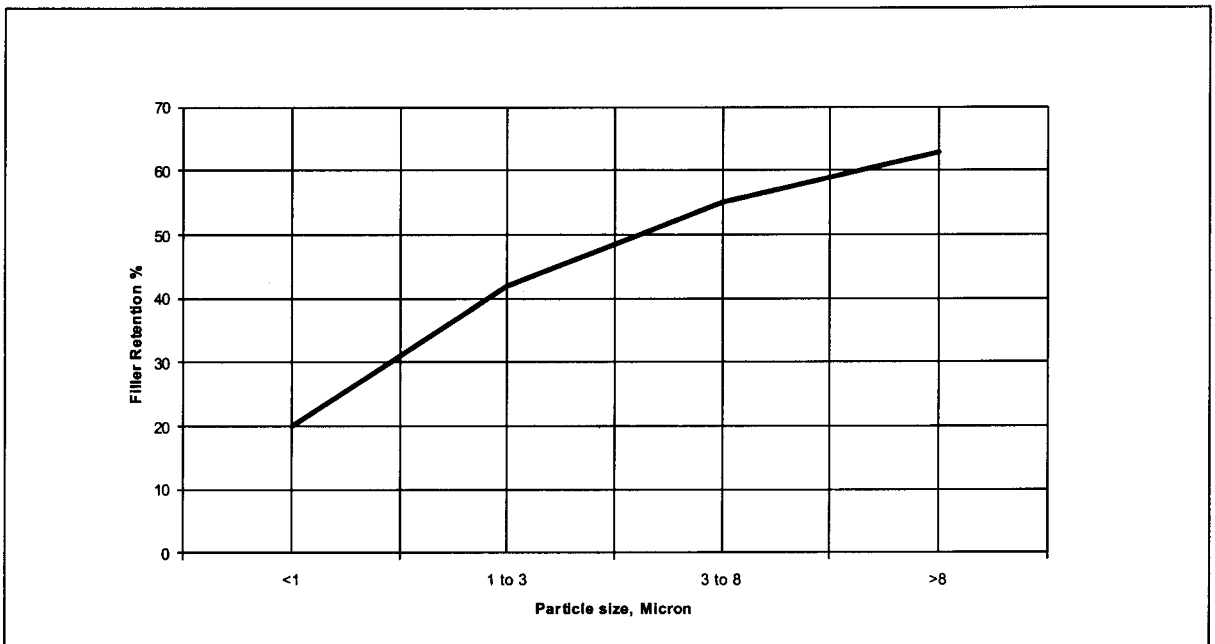

FIG. 7 Effect of particle size on Filler retention in Eucalyptus pulp at 40 % Talc Filler loading

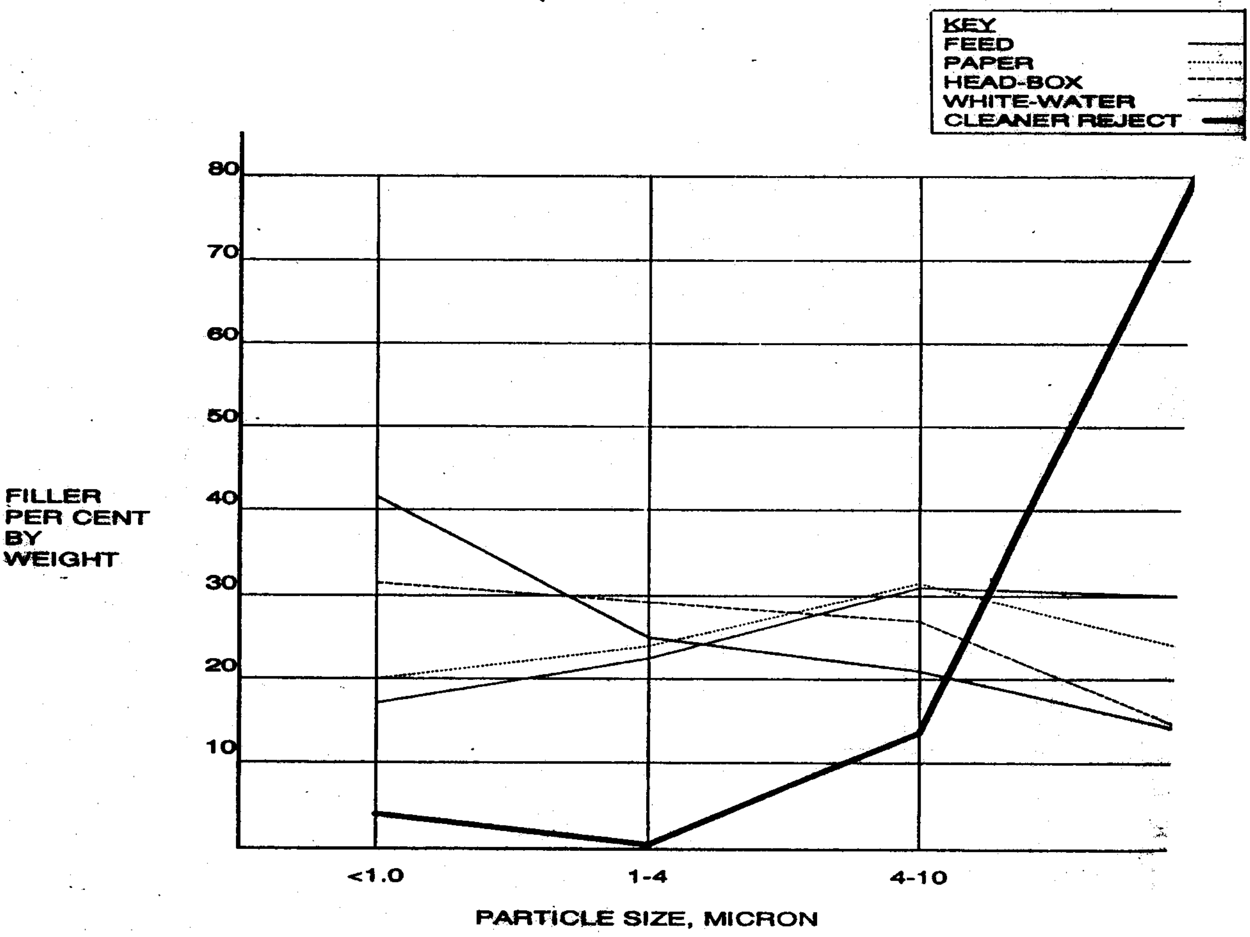

FIG 8. Filler retained and circulating within the paper

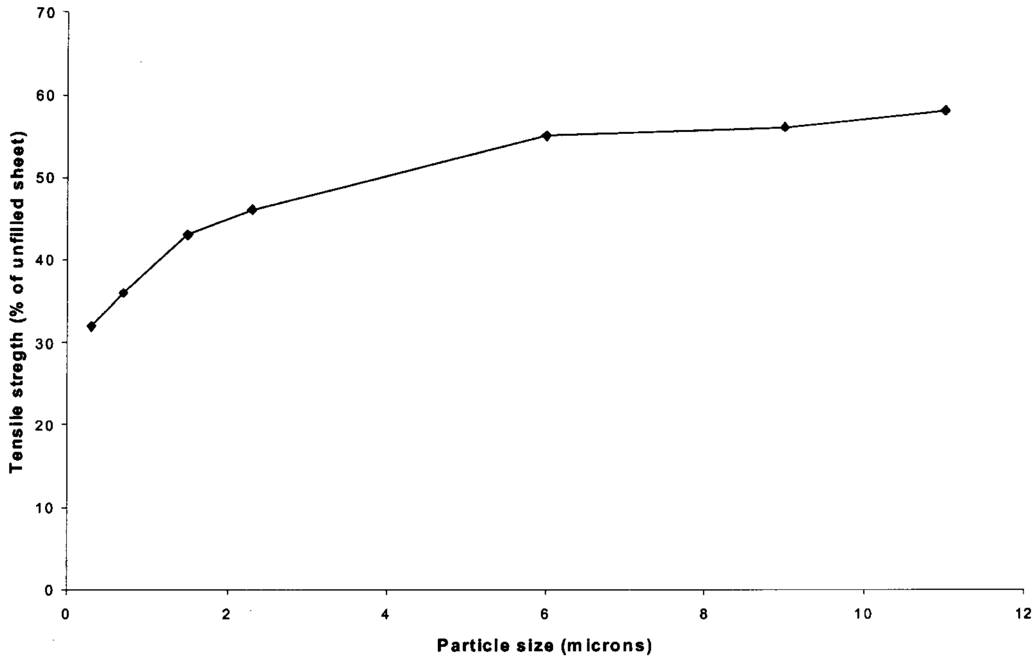

Fig. 9- Effect of particle size (Talc) on Tensile strength of eucalypt pulp at 40 % addition level

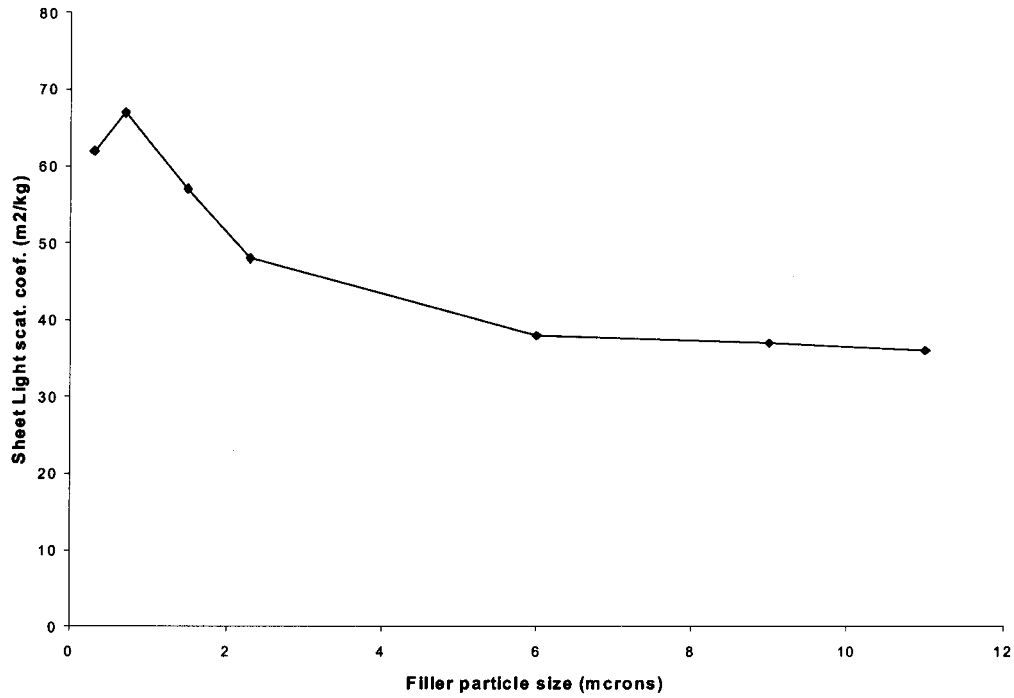

Fig.10- Effect of particle size (Talc) on Sheet Light Scattering Coefficient at 40 % addition level

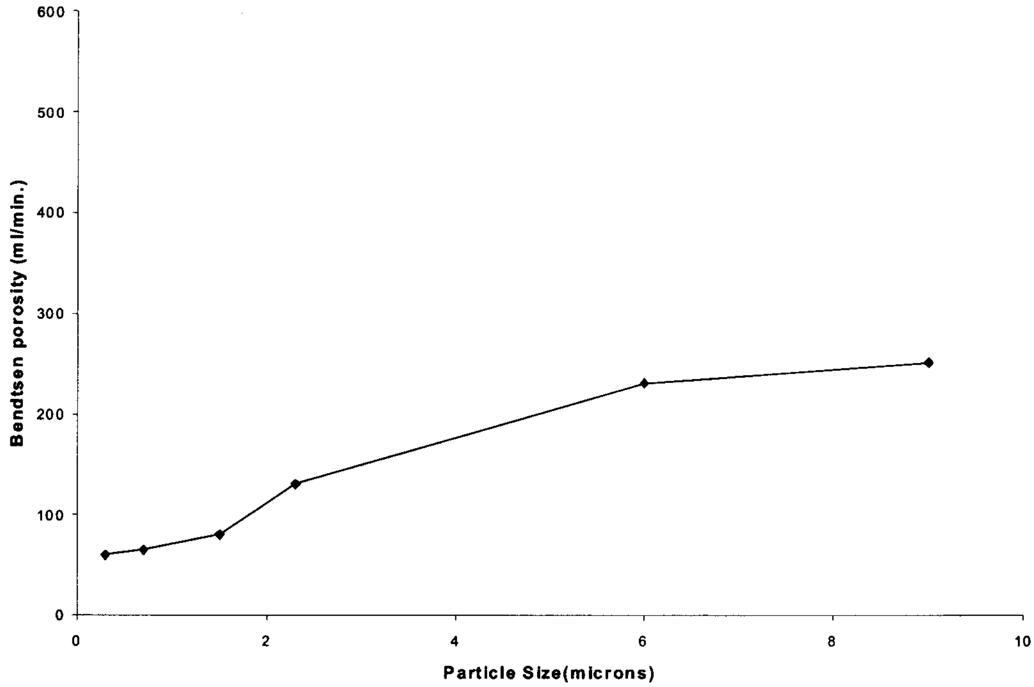

Fig.11- Effect of particle size (Talc) on porosity of Eucalypt pulp at 40% addition level

CHAPTER 2

SURFACE CHARGE OF DIFFERENT FILLERS AND PULPS

1. INTRODUCTION:

Surface charge plays an important role in controlling the performance of fillers, retention aid, sizes, wet and dry strength resins in papermaking. When a papermaking fibre is put into water, it becomes negatively charge. This is due to acid group that is either naturally present in wood or subsequently introduced in pulping and bleaching treatments.

Carboxylic acid groups	-	$COO^- H+$
Sulphonic acid groups	-	$SO_3^- H+$

Cellulosic fibres are negatively charged due to presence of acidic groups which either originate from cell wall constituents or are introduced during pulping or bleaching of fibres. The ionizable groups on cellulosic fibres may be carboxyl group, sulphonic acid groups, phenolic groups or hydroxyl groups. Under normal papermaking conditions, however, the carboxyl and sulphonic acid groups are the major contributors to the fibre ion exchange capacity. The carboxyl groups either originate in the non-cellulosic components in the wood itself or are created during impregnation, pulping or bleaching operations. Sulphonic acid groups are introduced with the sulphite treatment during chemi thermomechanical pulping or during sulphite pulping. In native wood most of the carboxyl groups come from the uronic acid residues (1.2). Both in softwood and hardwoods they are present ad 4-O methyl α-D-glucopyranosyl uronic acid bound to the xylan in hardwood or arabinoxylan in softwood. In addition, each xylan chain contains probably one α-D-galactopyranosyluronic acid group (2). In native wood these groups are esterified and lactonized to various degrees in different wood species (3) and these esters are then hydrolyzed to various extent in the pulping and bleaching operations. The rest of the carboxyl groups in native wood are present in the pectic substances localized to the middle lamella. An additional source of carboxyl groups in the fatty acids and resin acids is the extractives. The major contributors of acidic groups in Kraft pulps are the glucuronic acid residues on the xylan remaining in the pulp or carboxyl groups in the residual lignin.

Fibre charge is one of the controlling factors for the retention of fillers in pulps. The surface charge density of fibres has also been reported to the contributing factor in developing the tensile strength of low-density paper structure (4,5). The amount of charge on the fibre depends on the pulping, bleaching, and processing methods, pH and electrolyte concentrations in the surrounding water. Wood pulps have been studied for surface charge by different researchers (6,7,8,9,10) using different methods. The surface charge reported for different pulps using different methods is given in Table I. Results show wide variation. No relevant information is available for the surface charge of indigenous pulps especially non wood pulps.

Different methods have been reported for determining the charge on cellulosic fibres. In some methods elctrokinetic potential produced by the charged surface is recommended to be measured indirectly using microelectrophoresis, streaming current or electrosomosis techinque (11). Other methods include titration techniques – potentiometric (9) conductometric (12) and colloidal (13). All these methods have certain advantages but none are perfect. Strazelin (14) reviewed the merits of all these methods and concluded that the microelectrophoresis procedure provides the most reliable data. However this method may also give an incorrect value as in case of wood pulp it is not possible to define exactly where zeta potential lies in relation to the surface of fibre, as the later is not ideally smooth but covered with fibrillar projections thus making the assumption that plane of shear at the surface coincides with surface is doubtful.

As the papermaking furnishes is a suspension of charged particles – fibres, fibre fines, filler particles and ubiquities 'Anionic trash'. Added to this suspension are a number of ionic functional additive for example internal size, retention aid & starch. Controlling the interaction of each of these with the furnish component is crucial to efficient and effective filler retention. To understand better the retention mechanism surface charge of different types of fillers and pulps was determined.

2. EXPERIMENTAL:

Following fillers and pulps were tested

2.1 Fillers

Talc (Soapstone)

China Clay

GCC $CaCO_3$

TiO_2 (Rutile)

$Ti0_2$ (Anatase)

Barytes

2.2 Pulps

Bleached softwood (imported)

Bleached eucalypt pulp (imported)

Unbleached eucalypt pulp

CEHH bleached eucalypt pulp

Unbleached bagasse pulp

CEH bleached bagasse pulp

Unbleached bamboo pulp

CEHH bleached bamboo pulp

CEH bleached wheat straw pulp

Unbleached jute pulp

CEH bleached jute pulp

HH bleached cotton linter pulp

2.3 Determination of fibre surface charge

The fibre charge was determined using particle charge detector PCD 02 (Mutek, Germany). The basic set up of the apparatus is shown in Fig.1 Mutek PCD detector comprised of a cylindrical plastic vessel and a vertically reciprocating displacer piston fitted inside. The solution whose charge is to be measured is put into cylindrical vessel; the charged particles in colloidal solution get partially adsorbed on the cylinder and piston surface. When the piston moves up & down a charge is built up depending upon the characteristics of the colloidal solution. Electrodes affixed in the vessel measure the induced streaming potential thus built up.

To measure the fibre charge about 0.5 of pulp was mixed with 10 ml of 0.001 N poly dadmac. A magnetic stirrer stirred this mixture for two hours. During this time, the cationic polyelectrolyte (Poly-dadmac) completely neutralized the anionic charge in the pulp. Since the polydadmac is in excess, an overall cationic charge remained in the mixture. After the reaction time has elapsed, the pulp fibres in the slurry was removed by sieving. The filtrate was put into the cell and titrated with 0.001 N PES-Na (anionic polyelectrolyte) to the end point.

Fibre charge was calculated using formula

$$Q = (V_2 - V_1) \times C \times 1000 / W$$

Where

$(V_2 - V_1)$ = difference between charge of the fresh polydadmac and the charge of the reacted polydadmac i.e amount of charge neutralised by the sample.

C = titration agent cocentration,0.001 N

1000 = conversion factor, to obtain Q in units of micro equi per gram

W = weight of the sample (o.d)

3.0 RESULTS AND DISCUSSION:

The surface charge of different fillers and pulps are recorded in Tables II & III respectively. All fillers and pulps had negative charge. Amongst the fillers studies the highest negative charge was observed for TiO_2 (Anatase) followed by china clay and TiO_2 (Rutile), and Barytes. GCC has slightly positive charge. This indicated that different fillers would behave colloidically different towards pulp fibres in a sheet matrix thus in retention capability.

Data on indigenous mill pulps gave interesting indication that all indigenous pulps had 2 to 3 times higher negative surface charge than imported pulps. Indigenous eucalypt pulp had about double charge than that of imported eucalypt pulp. The probable cause may be the bleaching sequences employed in our mills, which are hypochlorite based. Hypochlorite bleaching generally oxidizes the cellulose with conversion of some hydroxyl groups to carbonyl groups followed by oxidation of carboxyl groups to carboxyl groups and depoloymerization (15,16). The highest negative charge was observed for bagasse pulp followed by rice straws, wheat straw bamboo and jute. The comparatively higher negative charge for straws than wood pulps is probably due to higher amount of hemicelluloses present in such pulps. The higher charge in case of cotton linter pulp, which contains lower hemicelluloses, is probably due to two-stage hypochlorite bleaching. The higher negative charge on all indigenous pulps than imported wood pulps will result in behaving differently towards retention aids, strengthening agents and sizing chemicals. Some of such chemicals, which had been found to be suitable for imported pulps abroad, may not function satisfactorily for indigenous pulps.

4.0 CONCLUSIONS:

- All fillers and pulps have negative charge. The quantum varies from type to type.
- The order of negative charge in fillers is TIO_2 (Anatase)>China clay > TIO_2 (Rutile) > Talc > Barytes. GCC has slightly positive charge.
- Indigenous mill pulps (Hypo bleached) had 2 to 3 times' higher negative charge than imported wood pulps.
- Bagasse pulp had highest negative charge followed by rice straw, wheat straw, bamboo and jute.

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Table – I

Surface charge of different pulps determined by potentiometric titration (S_0) and polyelectrolyte titration (PTC) published in the literature.

Pulp	$-S_0$ (cg^{-1})	- PTC (cg^{-1})
Unbleached E. regnans GW	12.9 (Ref. 6)	-
Unbleached eucalypt GW	11.7 (Ref. 6)	-
Alkaline peroxide bld. Eucalypt GE	14.2 (Ref. 6)	-
Unbleched eucalypt cold soda	17.2 (Ref. 6)	-
Alkaline hypo bld eucalypt Cold soda	22.0 (Ref. 6)	-
Unbld. P. Radiata TMP	8.2 (Ref. 6)	4.8 (Ref.6)
Alkaline peroxide bld. P.radiata TMP	21.8 (Ref. 6)	7.7 – 14.0 (Ref.7)
Bld. P. radiata Kraft	2.3 (Ref. 6) 2.3 to 3.4 (Ref. 8)	3.4 (Ref. 7) 2.0 to 3.7 (Ref. 8)
Bld. Eucalypt Kraft	4.3 (Ref. 6) 4.2 (Ref. 8) 4.5 (Ref.10)	7.94 (Ref. 8)
Unbld. Scot pine (Pinus Sylvestris) sulphate	9.5 (Ref.9)	
Bld Scot pine	2.9 (Ref. 9)	

Table: II Surface charge density of different types of fillers

Filler	Surface charge (μ. eq/g)
Talc (Soap stone)	-3
China Clay	-10
GCC $CaCO_3$	+2
TiO_2 (Rutile)	-8
TIO_2 (ANATASE)	-16
Barytes	-1

Table III Surface Charge density of different types of imported & indigenous pulps

Pulp	Surface charge (Surface charge (-μ. eq/g))
Bleached softwood (imported)	9
Bleached eucalypt pulp (imported)	13
Unbleached eucalypt pulp	23
CEHH bleached eucalypt pulp	29
Unbleached bagasse pulp	26
CEH bleached bagasse pulp	33
Unbleached bamboo pulp	20
CEHH bleached bamboo pulp	24
CEH bleached wheat straw pulp	28
CEH bleached Rice straw pulp	30
Unbleached jute pulp	17
CEH bleached jute pulp	19
HH bleached cotton linter pulp	23

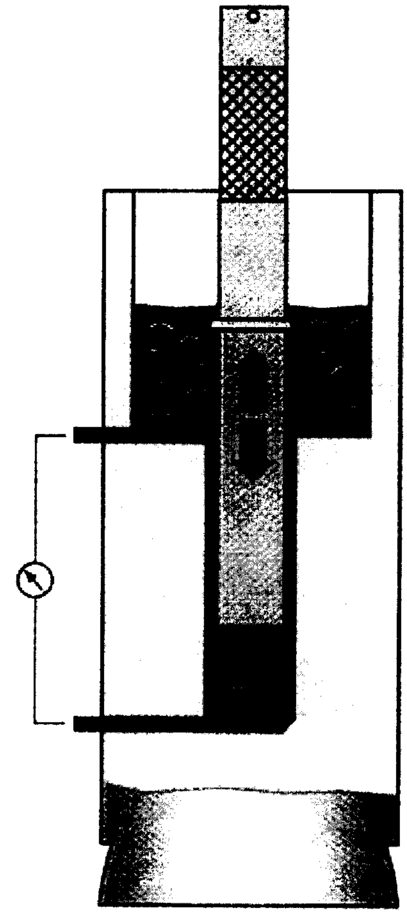

Fig 1. Mutek Particle charge detector.

CHAPTER 3

COMMON DEFIENCIES IN PAPER MANUFACTURED BY INDIAN MILLS

1. INTRODUCTION

To assess the possibilities of improving filler content in commercial papers, the paper samples manufactured by 25 Indian Paper mills were examined in detail. From time to time evaluation of paper samples received in CPPRI, it was observed that the paper produced by many of the Indian mills had wide variation in strength, filler content and optical characteristics though the raw material, its producing method and type of paper machine and there configuration were almost similar. The paper samples were examined in detail for the characteristics viz. formation of sheet matrix, ash content, strength and optical characteristics etc.

3. RESULTS AND DISCUSSION

2.1 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 I to III. 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 II, III). 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 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).

3. EFFECT OF FORMATION ON PAPER CHARACTERISTICS

3.1 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 I, II, III). 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.

3.2 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 II & III). Due to poor formation it is very likely that considerable portion of useful fines are not retained in the sheet.

3.3 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.

4. 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 IV to VII.

4.1 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.m2/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/g and tearing strength 5.20 to 4.70mN.m^2/g. Similar drop was observed for the bagasse and wheat straw pulps also.

4.2 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.

4.3 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.

4.4 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.

4.5 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.

4.6 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.

4.7 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.

4.8 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

$$S = f2\ a/m$$

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.

4.9 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.

5. 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: -

Formation index - 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. Scatt. coefficient	-	SCAN C 2769
Ash content	-	ISO 2144
Cobb	-	ISO 535

6.0 CONCLUSIONS

- 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.

- 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).

- 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.

❖ 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.

❖ 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.

❖ 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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Table I: 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 2	Waste paper Waste paper	40 35 (14.3)	38.5 35.5 (9.1)	1.80 1.50 (16.7)	3.25 2.90 (10.8)	23.4 25.2 (7.7)	36.2 34.4 (5.0)	2.4 2.0 (16.7)	58.7 58.4 2(0.5)	92.1 91.4 2(7.6)	12.1
2	1 2	Waste paper Waste paper	37 30 (19.0)	20.5 15.5 (24.4)	1.05 0.85 (19.0)	3.05 2.75 (9.8)	24.8 27.3 (10.0)	22.1 19.1 (13.6)	6.5 4.5 (30.8)	57.7 57.2 (0.9)	92.6 92.0 (0.7)	12.2
3	1 2	Waste paper Waste paper	30 25 (16.7)	15.5 11.0 (29.0)	.90 .65 (27.8)	2.85 1.65 (42.0)	25.2 28.4 (12.7)	20.4 17.5 (14.2)	8.1 6.6 (18.5)	55.6 55.4 (0.4)	93.8 93.0 (0.9)	11.8
4	1 2	Waste paper Waste paper	35 29 (17.1)	24.5 20.0 (18.3)	1.05 0.85 (19.0)	2.90 1.80 (37.9)	25.4 27.6 (8.7)	35.4 32.0 (9.6)	14.8 13.2 (10.8)	57.1 56.5 (1.1)	93.0 93.6 (0.4)	11.4
5	1 2	Waste paper Waste paper	36 24 (33.3)	23.5 15.0 (36.2)	1.25 0.70 (44.0)	3.50 2.20 (37.1)	18.0 20.2 (12.2)	54.4 44.2 (18.8)	18.2 15.9 (18.7)	59.7 59.2 (0.8)	91.6 92.1 (0.6)	12.6
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 (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 2	Bagasse & bamboo	110 100 (9.1)	49.5 45.5 (8.1)	2.05 1.85 (9.8)	4.50 4.20 (6.7)	20.7 21.9 (5.8)	44.2 39.8 (10.0)	15.2 14.0 (7.9)	77.5 77.0 (0.7)	89.8 89.2 (0.7)	11.0
2	1 2	Hardwood & bamboo	120 91 (24.2)	47.0 30.0 (36.1)	2.30 1.50 (34.8)	6.10 5.10 (16.4)	17.8 18.3 (2.8)	48.2 44.3 (8.1)	14.5 12.6 (13.0)	77.5 76.5 (1.3)	90.2 89.9 (0.3)	13.2
3	1 2	Hardwood & bamboo	140 120 (13.0)	49.5 40.5 (18.2)	3.10 2.65 (11.7)	5.90 5.10 (13.6)	18.8 20.4 (7.9)	42.7 38.9 (8.9)	15.1 13.8 (8.6)	78.9 78.0 (1.1)	91.2 90.5 (0.8)	13.4
4	1 2	Bamboo & hardwood	68 58 (14.7)	28.0 24.5 (12.5)	1.40 1.20 (14.3)	6.20 5.50 (11.3)	18.4 19.1 (3.8)	39.8 37.5 (5.8)	14.5 13.1 (9.7)	77.0 76.5 (0.7)	87.5 87.2 (0.3)	15.5
5	1 2	Bagasse & softwood	120 100 (16.7)	38.5 35.5 (7.8)	2.05 1.75 (14.6)	5.00 4.50 (10.0)	18.6 19.8 (6.5)	37.9 35.4 (6.6)	15.2 13.8 (9.2)	78.5 78.1 (0.5)	90.1 89.8 (0.3)	11.8
6	1 2	Hardwood & bamboo	106 94 (11.3)	42.5 37.0 (12.9)	1.90 1.65 (13.2)	5.80 5.04 (13.1)	17.4 18.6 (6.9)	39.2 36.5 (6.9)	13.5 12.8 (5.2)	78.9 78.0 (1.1)	91.2 90.6 (0.7)	13.1
7	1 2	Hardwood & bamboo	110 100 (9.1)	47.5 42.5 (10.5)	2.85 2.45 (14.0)	5.80 5.50 (5.2)	17.4 18.5 (6.3)	47.5 45.5 (4.20)	15.5 13.9 (10.3)	78.9 78.5 (0.5)	90.5 90.2 (0.3)	12.6
8	1 2	Hardwood & bamboo	95 80 (15.7)	38.5 35.5 (7.8)	2.45 2.10 (14.3)	4.90 4.70 (4.1)	17.6 18.8 (6.8)	46.5 43.5 (6.5)	14.5 13.2 (9.0)	79.9 78.5 (0.5)	90.4 89.8 (0.7)	12.7
9	1 2	Hardwood & bagasse	115 100 (13.0)	46.5 31.0 (33.3)	2.30 2.00 (13.0)	6.10 5.80 (4.90)	17.2 18.9 (9.9)	48.3 46.3 (4.1)	12.6 11.2 (4.1)	78.8 78.5 (0.4)	90.2 89.7 (0.6)	11.8
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.

Table IV: 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 : 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 VI : 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 VII : 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

CHAPTER 4

FILLERS IN PAPER MAKING (REVIEW)

1. INTRODUCTION

Paper fillers are fine, white pigments powders. They are manufactured from natural minerals or synthetically from various raw materials. Every filler material must have certain characteristics, which enhances their use for best filler like

- 100% light reflectance in all wavelengths
- Even particle size, if possible equal to half the wavelength of light close to 0.3U.
- High refractive Index
- Chemically inert
- Opaque-Optimum particle size is important
- Free from deleterious matter/purity

Since most mineral filler are considerably cheaper than fibres, fillers can be loaded in the paper to cut the manufacturing cost & thus improve the process economics. Now-a-days fillers are incorporated into paper

- To reduce the cost of papermaking.
- To modify the certain properties of paper as desired by the manufacturer
- To improve the surface characteristics in case of printing grades.
- To improve brightness, opacity, Whiteness etc.
- To improve colour.
- To increase dimensional stability.
- As an aid to produce special paper quality e.g. controlled rate of burning.

However use of filler can cause certain undesirable effects in the finished sheet of paper. Those, which are generally worsened, include

- Decrease in the bonding properties of the sheet, resulting in the loss of strength.
- Loss of rigidity, with a marked tendency to become flabby & dusty together with lowered erasing properties.
- Paper may become abrasive on the surface and cause unnecessary wear to printing plates.

Of these the strength factor is particularly important since it ultimately limits the level at which filler can be incorporated in the sheet.

2. IMPORTANT CHARACTERISTICS OF FILLER FOR PAPERMAKING

The following characteristics of filler are important for their use in papermaking

2.1 Particle size

The optical properties of any pigment are strongly affected by the particle size distribution and the degree of agglomeration of the pigment. A narrow particle size distribution promotes good light scattering efficiency which can function with maximum effectiveness only if excessive homoflocculation of the pigment is avoided. The Mie Theory predicts that the maximum scattering of light is obtained by spherical particles one half the wavelength of light or approximately 0.20 to 0.30 μm in diameter. Particles outside this optimum size range scatter light with less efficiency. But the Mie Theory holds true only for spherical particles (plastic pigment, titanium dioxide, etc.) and does not apply to nonspherical particles (clay, talc, precipitated calcium carbonate, etc.). In work performed by Koppelman, it was found that, for platy particles like clay, the optimum opacifying efficiencies were obtained with narrow particle size distributions between 0.70 and 1.5 μm equivalent spherical diameter. Zeller and Gill showed that the optimum particle size for rhombohedral-precipitated calcium carbonates was between 0.40 and 0.50 μm equivalent spherical diameter, and that for scalenohedral-precipitated calcium carbonate was between 0.9 and 1.5 μm equivalent spherical diameter, both with a narrow distribution, respectively. It should be mentioned that these results on particle size optimisation were obtained from laboratory studies under controlled conditions whereas, in a mill situation, unavoidable flocculation of the pigment will occur. This flocculation can be controlled somewhat by optimising the method and order of addition of the pigment with the rest of the paper system. Some pigments have a greater propensity to agglomerate than others. Synthetic silicas are precipitated with a particle size of 0.04 μm and then agglomerate to sizes between 1.0 and 40 μm. Titanium dioxide can agglomerate easily and must be carefully dispersed to maintain its optimum size of 0.20—0.40 μm. Calcined clays are manufactured in such a way that the platelets are fused together forming small, agglomerated structures. Average particle size of different filler types are listed in the table I.

Table I Average particle size of different filler types

Filler types	Average particle size (μm)
Kaolin hydrous	0.2-2.0
Kaolin calcined	0.7-1.5
Ground Calcium Carbonate (GCC)	0.7-3.0
Precipitated Calcium Carbonate (PCC)	0.3-3.0
TiO_2	0.2-0.4
Talc	1.5-10.0
Silica, Silicates	0.1-3.0

2.2Particle shape

Particle shape is a significant factor. When particles deviate from a spherical shape their optimum equivalent spherical diameters may be outside the range predicted by the Mie Theory. Also, the packing orientation of the pigment will greatly influence its alignment within the fibre matrix of the sheet. There are typical particle shapes associated with the different types of pigments. Titanium dioxide, silicas and plastic pigments tend to form spherical particles. The particle shape of precipitated calcium carbonates is controlled through the reaction process, producing three basic crystalline forms, acicular rods or needle-like aragonite crystals, rhombohedral or barrel shaped calcite crystals, and scalenohedral, rosette structures with ellipsoid-shaped calcite crystals. Ground calcium carbonates tend to be irregular in shape. Platy structures, which are long and thin, occur in clays and talcs.

2.3 Specific surface area

The particle size, shape and degree of agglomeration all influence the specific surface area of a pigment. The pigment surface area aids in light scattering and also influences the strength and printing characteristics of the paper. The most common means of measuring the surface area of a pigment is the Brunauer, Emmett, and Teller (BET) nitrogen-adsorption method. Values of specific surface area for different filler pigments are listed in the table II.

Table II Specific Surface Area of different filler types

Filler types	Specific Surface Area (m^2/g)
Kaolin hydrous	10-25
Kaolin calcined	15-25
Ground Calcium Carbonate (GCC)	2-12
Precipitated Calcium Carbonate (PCC)	5-25
TiO_2	7-12
Talc	9-20
Silica, Silicates	45-75

2.4 Effect on paper strength

Filler pigments will tend to cause a reduction in the strength properties of the sheet. In general, the higher the specific surface area the weaker the paper will be at an equal degree of loading. The primary cause for this weakening effect is related to the pigment's interfering with fiber-to-fiber bonding within the sheet.

2.5 Light absorption properties

Light absorption, or, conversely, the light reflectance behaviour, is important to the functionality of the filler pigment. Measurements of reflected light, using a recording spectrophotometer, can reveal differences between pigments in the way they reflect light at different wavelengths. It is easier to meet product specifications on brightness, opacity, or shade when the reflectance spectrum of a pigment approximates a horizontal line between wavelengths of 380 and 700 nm. A reflectance measurement at 380 nm is important to determine how much ultraviolet light is absorbed. This is a problem for both the rutile and anatase forms of titanium dioxide. Anatase titanium dioxides absorb approximately 50% of the light at this wavelength, while the rutile forms absorb approximately 85%. This absorption of ultraviolet light inhibits the effectiveness of fluorescent dyes. Measurements of "brightness" are made at 457nm. At the wavelength of 567 nm (green-yellow light) used in the opacity measurements, a reflectance value can be obtained to represent a pigment's potential opacifying capabilities. Aluminum trihydrates show the best reflectance spectrum, with a nearly horizontal curve throughout the entire spectrum at reflectances of 99% plus. Other filler pigments with high overall reflectance are plastic pigments, sodium silico aluminates, precipitated silicas, and precipitated calcium carbonates. Filler pigments that show a tendency to absorb some ultraviolet light are clays, talc, and ground calcium carbonates. Brightness values of different filler pigments are listed in the table III.

Table III Brightness of different filler types

Filler types	Brightness (%)
Kaolin hydrous	78-90
Kaolin calcined	90-95
Ground Calcium Carbonate (GCC)	80-95
Precipitated Calcium Carbonate (PCC)	95-100
TiO_2	98-100
Talc	85-90
Silica, Silicates	93-99
Aluminum Trihyrdrate	97-100

2.6 Particle charge

The electrostatic charge on a pigment particle plays an important role both in maintaining proper dispersion of the pigment as it is fed to the paper machine and in retaining the particles in the fibre matrix. The non-hydrodynamic forces which affect the behaviour of colloidal particles in general toward each other are of three basic types: van der Waals (always attractive), electrostatic (requires unbalanced electrostatic charge may be attractive or repulsive) and steric (between adsorbed molecules or polymers- usually repulsive if the molecules or polymer is water soluble. The balance between these forces (which each have a characteristic variation with inter-particle distance) determines whether the particles will remain dispersed or flocculate. Zeta potential is a convenient measure of the electrostatic charge on a colloidal particle, which arises from the interaction of the surface of the particle with its solution environment. It is important to point out that the chemical nature of a particle's surface is not given by knowledge of its bulk composition nor is it necessarily consistent from one sample of a given material to the next. It is equally important to take account of the contribution of the solution environment to the zeta potential. The concentration of the potential-determining ion at which the particle has a zeta potential of zero is known as the isoelectric point (IEP). This concentration is generally (but, for heterogeneous surfaces such as those of clays, not always) also the point at which the particle has zero net charge. The presence of other inorganic or organic surface-active agents either as additives to the pigment product (slurry or dry) or to the papermaking system will affect colloidal behaviour of the particles if they are adsorbed on the particle surface. Such agents may modify zeta potential and/or may contribute steric repulsive forces. Low molecular weight polyelectrolytes (polyphosphates, polyacrylates) act as strong dispersants by both strong electrostatic and steric repulsion. Moderate to high molecular weight polymeric papermaking additives (starches, polyacrylamides) may act as dispersants or flocculants depending on the exact method of their use.

2.7 Refractive index

Refractive index is a fundamental property of a pigment that is determined by the chemical composition of the pigment and the arrangement of the atoms in the crystalline structure. This property has a direct influence upon light scattering because light entering the crystalline structure is slowed down and bent or refracted from its normal path a multitude of times inside the structure and, in general, is reflected back out of the particle rather than transmitted. The greater the refractive index of the pigment the more light will be refracted or scattered in the sheet. This aids in opacity development. The refractive indices of different filler types are given in the table IV. The refractive index for cellulose is 1.55, starch is 1.46—1.52, and air is 1.00.

Table IV Refractive Indices of different filler types

Filler types	Refractive Index
Kaolin hydrous	1.56
Kaolin calcined	1.50-1.62
Ground Calcium Carbonate (GCC)	1.58-1.66
TiO^2 Rutile	2.76
TiO_2 Anatase	2.55
Talc	1.57
Silica	1.45
Silicates	1.55
Aluminum Trihydrate	1.57

2.8 Abrasion

Abrasion is an important characteristic of all filler pigments. Highly abrasive pigments will cause excess wear of both paper machine wires and printing plates. Cutter and trimmer knives in the converting area of the mills are also susceptible to excess wear. The abrasiveness of a pigment is principally caused by two factors. The crystalline nature and hardness of the pigment is of importance to the abrasiveness of the pigment (strength of the atomic bonds, spatial arrangement, impurities, etc.), along with its physical properties (size, particle size distribution, shape, surface area, etc.). Impurities such as quartz can cause severe abrasion problems, and larger particles tend to be more abrasive than smaller particles of the same crystalline form. Abrasion caused to the wire by different filler pigments are given in the tableV.

Table V Abrasion caused by different filler types

Filler types	Einlehner (mg wire loss)
Kaolin hydrous	1-6
Kaolin calcined	15-30
Ground Calcium Carbonate (GCC)	3-15
Precipitated Calcium Carbonate (PCC)	2-9
TiO_2	10-30
Talc	3-5
Silica, Silicates	5-13

3. COMMONLY USED FILLER IN PAPERMAKING

In the early days of paper making, filling was simple. Depending upon the local availability, a mineral powder, talc, clay was added to the furnish to achieve high opacity and surface properties or to reduce the cost. Little consideration was given to the characteristics of filler particle as to how they are going to affect the paper quality.

Now-a-days a much wider range of filler grades of different mineralogy or chemical structure and different morphologies is available to most mills at competitive prices. The basic requirements have not changed, but the subtle balance between paper properties and effect of filler has led to much development work to minimize the disadvantages and maximize the benefits.

The correct choice of filler will considerably influence the properties of the finished paper. Some of the commonly used filler in papermaking are discussed below: -

Talc (63% SiO_2, 32% MgO, 5% H_2O)

This filler generally known as soap stone consists of hydrous magnesium silicate in its pure form. It is ideally suited as paper loading because of its inertness and its excellent whiteness, softness and good retention properties. Talc is extremely used as a pitch absorbent both in pulp and paper making process as it collects around pitch particle and prevent them collecting together in large lumps. Because of its hydrophobic nature, the processing of talc in water based dispersion is somewhat tedious. Talc also displays marked affinity to air, which can show up as foaming. Because of the local availability of talc, it is one of the commonly used filler in India.

China clay (39% Al_2O_3, 46% SiO_2, 13% H_2O)

It is most commonly used filler throughout the world. China clay or kaolin clay is formed from the mineral Kaolinite by degradation of alkaline Aluminum silicates.

Clay is a good all round filler for different paper qualities. It is available in various particle size and brightness level. Depending upon how they are processed, filer clays are categorized as Calcined, fractionated, calcined and structured.

Besides these usual clays there are also specialty clays like bentonite and calcined clays.

Calcium carbonate

The most commonly occurring natural $CaCO_3$ is calcite found in limestone. Calcium carbonate filler fall into two categories namely
GCC -Ground calcium carbonate- obtained simply by grinding limestone. Ground calcium carbonate have generally large average particle size and broader particle size distribution.

PCC-Precipitated calcium carbonate-obtained by burning crushed lime sotne in oven at temp around 1000^0C, resulting in the formation of CaO. This CaO is slaked with H_2O to form $Ca(OH)_2$ slurry into which CO_2 gas is introduced to yield PCC.PCC is preferred over GCC because of its fine structure and less abrasion.

Unlike the majority of filler loadings calcium carbonate is not inert to acids with which it reacts. Because of this reason it cannot be used in acid papermaking where it decomposes to give CaO and CO_2. These Ca ions will then compete with Al-moiety of alum for reaction with rosin to form Ca resinates which is a poor sizing material.
It is however stable in water and alkalis. It is necessary, therefore, when using this loading to eliminate acid conditions, otherwise undesirable effects can results with regard to sizing and colouring together with foam formation.

Calcium carbonate is the whitest loading available in the blue end of spectrum, & it is comparable with clay in price range. It may be used in unsized or alkaline sized papers to replace TiO_2.

Titanium dioxide(98% TiO_2)

The high refractive index associated with both forms, namely anatase and rutile, give rise to high value placed on titanium dioxide for use as coating and loading agents.

Titanium dioxide has the property of extreme chemical inertness i.e., acids and alkalis or the common solvents at standard temperature and pressure do not affect it and it is insoluble in H_2O.

High cost of this filler limits its use to only in the manufacture of paper grades that required very high brightness and opacity.

Aluminum Trihydrate (65% Al_2O_3.34%H_2O)

Aluminum trihydrate is used both as filler and in coating to improve whiteness, gloss, smoothness and printability of high quality papers. This pigment is very suitable as an extender of TiO_2.

Aluminum trihydrate is a high brightness filler with small particle size and platelets like shape.

In addition to these filler loading there are some other filler loadings, which are less commonly used. However these are significant because of their local availability in different parts of world. These include gypsum or calcium sulphate, satin white and barium & zinc sulphate.

Calcium sulphate

In recent years the consumption of this filler has declined because it leads to high Ca ion concentration in back water. Although it is still used in coating colours together with clay. In some instances, it is used together with $CaCO_3$ or clay to fill fine papers.

Satin white

It is a synthetic calcium sulfo-aluminate pigment. It is made from lime and alum.

Barium/zinc sulhpate

Barium/zinc sulphate find very limited use in paper industry. Barium sulphate has rather high refractive index (1.64). It is used occasionally in photographic base papers, because of its soft powder structure and higher opacity. $BaSO_4$ use has been largely replaced today by the use of titanium pigments.

Mica

It is an aluminum silicate mineral with an extremely flaky structure. Mica is incorporated in dielectric papers on account of its durability and good insulation properties. Unlike other mineral filler, mica displays strong affinity to pulp fibres.

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