EFFECT OF RECYCLING ON FIBRE CHARACTERISTICS OF AGRI-RESIDUE PAPER FROM CHEMICAL PULP

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Thesis

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CERTIFICATE

Certified that this thesis work titled **"EFFECT OF RECYCLING ON FIBRE CHARACTERISTICS OF AGRI-RESIDUE PAPER FROM CHEMICAL PULP"** which is being submitted by Mr. Parmod Kumar, in fulfillment of the requirements for the award of the degree of **Doctor of Philosophy-Chemical Engineering** of Thaper Institute of Engineering and Technology (Deemed University), **Patiala, India**, is a record of candidate"s own work carried out by him under our supervision and guidance. The matter embodied has not been submitted, in part or full, to any other university or institution for award of any degree.

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ABSTRACT

In the present time to meet out the gap between demand and supply of the paper, it has become the prime requirement to recycle the paper prepared from the agri- residue pulp, which is prepared from the fast growing specie available on large scale. The bagasse is the only waste fibrous discharge in huge quantity available from the sugar industries in northern India, which is utilized as a raw material for the production of specialty and other grades of paper in paper industries. So in this Ph.D. programme the efforts have been carried out to recycle the agri-residue based paper and to study the fiber characteristics of paper produced after recycle, to recover the strength loss with the help of blending of long fibered pulp to optimize the strength and other properties of paper with the help of mechanical treatment like beating and refining and the addition of retention aids and other strength improving chemicals for improving the recycling potential of the bagasse based paper for the protection of depletion forests and sustainable ecology in the country.

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NOMENCLATURE

BB	Bleached bamboo pulp
BF	Burst factor
BG	Bagasse pulp
BL	Breaking length (meters)
BS	Bursting strength (kg/cm^2)
CA	Catiofast (Modified Polyethleneimine)
CS	Cationic starch T-25
GE	General electric brightness
N*	Retention aids chemicals (N-7607 and N-7530)
N-7607	Coagulant
N-7530	Flocculent
PAC-2014	Poly aluminium chloride
PV	Photo volt
RP	Radiata pine wood pulp
SN	Sursalone (High molar mass anionic polyacrylamide)
TF	Tear factor (mN)
TRS	Tear strength
TS	Tensile strength of Paper (kN/m)
X	Fortified rosin solution and PAC-2014 for pH control
Y	Soap stone filler

ABBREVIATIONS

A.D. : Air-Dried

IPPTA : Indian Pulp and Paper Technical Association

BSF : British Sheet Former

CA : Catiofast (Modified Polyethylenimine), BASF Ludwigshafen Germany

CS : Cationic Starch T-25

CSF : Canadian Standard Freeness

ISO : International Standards Organisation

MIT : Massachusetts Institute of Technology

O.D. : Oven Dry

PAC : Poly -aluminium Chloride

RH : Relative Humidity

SCAN : Scandinavian Pulp, Paper and Board Testing Committee

°SR : Degree Schopper Reigler

SN : Sursalone (Polyacrylamide), BASF Ludwigshafen Germany

TAPPI : Technical Association of the Pulp and Paper Industry

CHAPTER 1

INTRODUCTION

Due to the fast depletion of forest resources and its impact on ecological balance, the paper industry has turned to fast growing wood species, alternative non-wood fibres and the use of secondary fibre for paper production. The selection of best fibrous raw material, which will be available on sustained basis, appears to be of prime importance and further, the quality of end product will largely depend on the type of fibre and their blends in making the stock. The agri-residues and secondary recycled fibres seem to be the promising raw materials of the future. With this scenario of raw material for paper industry, Government of India encourages the utilization of secondary fibre for paper making by allowing fiscal benefits, which have been allowed for use of bagasse, jute waste, rice and wheat straw if they are used to the extent of 75% in fibre furnish. This invites reinforcement of long fibres, like 6 mm Short Cut Polyester Fibres (SC PSF) in the stock for all those grades of paper wherein the key strength characteristics such as tear, bulk, porosity, folding endurance, stiffness, etc. are very important (Bhuwania et al.1999)

In India, more than 250 mills manufacture various grades of paper using recovered paper, partially or fully in furnish. This figure is increasing day by day. The paper manufactured using recovered paper has also increased significantly which clearly indicates the growth of the sector with time. The world trend on the recycling of recovered paper is also quite encouraging. The growth pattern achieved forecast a bright and challenging future for this segment of paper industry in 21st century (Mahapatra et al. 1999).

The future demand of the raw material for paper manufacture can be met from the proper recycling of the waste paper. In addition to pursuing the ecological balance and saving of raw material, the reduction of power requirement per matric tonne of paper produced is another advantage. But in spite of all the advantages, about 40% of the total paper production in the world was based on the secondary fibre in 2006 (Sixta, 2006). The reasons for such an affair are both social and technical. The social reason is due to improper method of sorting and collection of waste paper, while the technical reason is the deinking of the waste paper and its low fibre strength. Recycled fibres have lower strength and higher drainage resistance than virgin fibres.

Recycling of waste paper involves a series of following steps as mentioned below.

- Waste paper collection and supply
- Defibreing
- Contaminant removal
- Deinking
- Bleaching

These steps are continuously being improved through extensive research and development effort and increasing proportions of recycled fibre are utilized for paper manufacture. Earlier, the bulk of the total recycled fibre was utilized in paperboard manufacture, particularly in the middle layers of multiply boards. However, today nearly 35% of the recycled fibre is utilized in newsprint, tissue, packaging and other grades of fine paper.

In spite of so many advantages of waste paper recycling, its present recovery in India is lower compared to world around. Some of the reasons for this are as follows:

a) Improper and unorganized method of waste paper gradation at the time of collection.
b) The paper industry mainly depends on the imported waste paper. Proper attention has not been given to indigenous waste paper due to its low strength and other reasons like shives and brightness etc.
c) Waste paper is generally used for manufacturing the low grades of papers. Very little efforts have been made to make high quality papers from the waste paper.
d) The recycling of waste paper has never been taken seriously. The paper industry does not have a good guiding force to streamline the process technology for effective utilization of waste paper. No worth mentioning research work has been carried out to develop an indigenous process technology suitable to Indian waste paper equipment and environment.

While looking for increased utilization of recycled fibre, there are technical bottlenecks limiting its use. Most important of them are being the reduction in strength and other desirable properties of fibre during recycling. Recycling of chemical pulps made from agri-residues is very limited due to short fibre and low strengths. A very little information is available on the characteristics of recycled agri - residue pulps. More efforts have not been made to improve the characteristics of the recycled pulp. But more pulp will be produced from agri - residue, which needs to be recycled for economic and environment reasons. Therefore, an attempt has been made to study the recycling of agri-residue pulps for their characteristics and explore the possibility of improving its properties. The objectives of the present work are to study the effect of recycling on the characteristics of agri-residue pulp (bagasse) and improvement of strength properties of recycled pulp.

CHAPTER 2

LITERATURE REVIEW

There is increasing use of recycled pulps by Indian industry in the present day context of scarcity of conventional wood and bamboo-based inputs for paper-making. Though both mechanical and chemical factors in the paper making process affect the drainage / retention, the chemical aspects of retention are more important as the use of chemistry does not require capital and chemistry is easier to apply than rebuilding or modifying a paper machine system.

2.1 Characteristics of recycled paper

Paper recycling causes major changes in the strength and optical properties of pulps. In general, recycling tends to decrease tensile strength, burst strength, and folding endurance while increasing tear resistance, stiffness, light scattering, and opacity. However, the magnitude of change upon recycling is different for different types of pulps (kraft, sulfite, mechanical, etc.). Pulp recycling potential – the ability to retain physical properties after recycling - depends on its pulping and papermaking history. Chemical pulps exhibit pronounced changes, while mechanical pulps remain relatively insensitive to recycling (Bangji Cao, et al. 1998). The effects of recycling on the strength of paper can be evaluated in terms of the degree of ‘paper making potential’ initially extracted from the fibre. High yield mechanical pulps undergo relatively little processing compared with virgin fibres and consequently their papermaking potential is low. Property losses of these fibres with recycling are small. On the other hand, a refined, bleached chemical pulp has maximum amount of paper making potential generated, and recycling losses with this type of pulp are much more severe. These effects can be understood in terms of basic structure of the fibre. It was reported that, at higher pulp yields pulp swell ability after recycling was almost completely recovered. At lower yields, increasing irreversibility was observed. Therefore, Scallan and Tigerstrom suggested that the strength loss upon recycling was a feature of low yield pulps. The removal of lignin and hemicellulose in a chemical pulp leaves porous and flexible fibre, which swell, fibrillate and bond very effectively. These fibres undergo irreversible collapse when they are dried and thus their bonding ability decrease with recycling. Mechanical wood pulp fibres have much less porous structure and are less able to swell and bond. They do not collapse on drying, thus their bonding potential is not greatly affected on recycling (Phipps, 1994).

Chemical pulps fibres are known to 'hornify' on drying. The term ‘hornification’ can be defined as the decrease in water retention value (WRV). But hornification is today used as a "descriptive term for the physical and chemical changes that occur to pulp fibre during drying, principally shrinkage and formation of internal hydrogen bonds. Some of these effects are irreversible. It is also known that drying causes an irreversible loss in fibre swelling i.e. a loss in the physical expansion of the fibre cell (Scallan, 1978).

The fibre shrinkage occurs in two different phases; in the first phase the shrinkage is caused by the dewatering of large intra-fibre cell wall pores. The removal of pore water causes mainly the tangentially oriented inter lamellae pores to close or to tighten. This causes mainly shrinkage orthogonal to the lamellar plane, hence, fibre shrink in this phase by flattening. It is called the shrinkage I. The second phase of shrinkage starts in the final phase of drying, when tightly bound water leaves the microstructure of the fibre. Cell wall pores have closed already and the remaining water, which is more or less tightly bound, is situated in the non-crystalline domains of cellulose. The removal of this water causes the late shrinkage, seen different to the shrinkage I, in the direction of the fibre width. It is called as shrinkage -II (Wise and Paulapuro, 1999).

The loss of intrinsic fibre properties such as bonding capacity, flexibility and swelling potential during papermaking is associated with the phenomena of irreversible hardening or 'hornification' during drying. An essential feature of recycling is repeated drying and rewetting-disintegrating of the paper sheet. During drying, hydrogen bonds are formed between cellulose chains in the cell wall and part of these bonds remains unbroken upon rewetting. In the literature, the extent of hornification has been reported to be dependent upon the type of raw material and the method of pulping used. Strength reductions as high as 30% for paper burst and 35% for tensile have been reported for dried versus un-dried pulp. A linear relationship has been observed between the decrease in burst and the amount of drying, expressed as a percentage of solids of the partially dried pulp. Similarly, in recycling experiments, there is a progressive reduction in tensile strength with each cycle up to about 6 cycles. Horn (1975) observed that the tearing strength decreased with subsequent cycles.

Fibre breakage as well as hornification influences the strength properties of recycled paper. The cause of strength losses with drying and recycling has generally been attributed to a structural change in the cell wall due to irreversible bonding of cellulose surfaces. The fibrils aggregate into larger units (strings) on drying, which reduce the area accessible to water and formed a stiffer structure. Further hornification in dissolving grade pulps to the amorphous face of cellulose change from the pseudo-soft to the glassy state with drying.

Bangji Cao et al. (1998) studied the effects of hemicellulose (principally pentosans and especially xylan) and lignin on recycled pulp quality and observed that the amount of pentosans in the pulps played a crucial role in their recycling potential with the pulp recyclability improving with higher pentosan content. This effect was observed in both low-yield chemical pulps and ultra high – yield chemi-mechanical pulps. Lignin content did not significantly affect the recycling potential of the pulp. The possible reason for this could be the presence of xylan molecules in between cellulose microfibrils which prevent neighbouring microfibrils from developing close associations with each other during drying. By doing so, the xylan helps to preserve much of the fibre’s wet flexibility, which is crucial if the fibre is to maintain its papermaking properties when it is recycled. The hemicellulose material in pulp fibres is mainly responsible for hornification with drying. Thus, the phenomenon is greatest with hemicellulose rich pulps. This does not conflict with other evidence, since the hemi cellulose at the fibril surfaces would serve to draw the fibril together with drying to form a stiffer structure.

It has been reported that the speed and temperature of the drying can affect hornification and if the drying is not uniform, the hornification takes place at an average dry solids content of 60– 65%. Generally, hornification increases markedly with drying below 70–75% dry solids. When a pulp was ion exchanged to contain a single low valency species such as sodium, the bonding and the strength of the sheet improved. It should be possible to use this concept in the reverse manner – that is, incorporation of high valency cations in the wet pulp before drying to prevent hornification. Thus, trivalent cations such as Al^{3+}, Cr^{3+}, and Fe^{3+} should provide the best protection against hornification followed by divalent ions such as Ca^{2+} and Mg^{2+}, with monovalent ions such as Na^{+} and Li^{+} offering the least protection. It has been observed that when $Al_2(SO_4)_3$ is present, hornification is inhibited to some extent .

Previous workers have reported that the different responses for mechanical and chemical pulp arise from the relative amount of lignin present in the fibres. The swelling behaviors of never-dried and recycled pulps were compared as a function of yield. It was shown that, at higher pulp yields, pulp swell ability after recycling was almost completely recovered. At lower yields, increasing irreversibility was observed. It was experimentally observed that the strength loss upon recycling was a feature of low-yield pulps. The common explanation for this behavior is that removal of the lignin-hemicellulose gel provides an opportunity for greater intermolecular mobility and contact with the carbohydrate component. On the other hand, if there is enough lignin present, the composite lignin- carbohydrate cell structure is rigid enough to resist collapse from surface tension upon drying.

Paper is a randomly bonded network of cellulose fibres whose tensile strength is controlled by both fibre strength and bond strength. Page has described a mechanism for the tensile failure of paper in terms of these two controlling parameters. Qualitatively, the relationship states that the strength of weakly bonded paper is controlled by factors associated with bonding strength, while, in stronger papers, fibre strength is more important. Page used two assumptions for this theory.

The firs assumption in Page’s theory concerns stress distribution in a paper strip at the instant of tensile failure. During straining, the load is distributed across progressively fewer fibres along a line of potential rupture due to bond failure at the fibre ends. Bonds continue to fail in the rupture zone, and the remaining fibres take more of the sheet load until they are lying in the direction of loading and reach their rupture strain. At this point, complete failure of t6he paper occurs. This is express as follows:

$$T = n_f Zc /(n_f + n_p) \qquad \text{(a)}$$

Where:

n_f = number of fibres crossing the rupture zone that take the load at failure and than break.

n_p = number of fibres crossing the rupture zone that pullout intact due to point bond breakage and therefore carry no load at failure.

T = tensile strength of the paper strip in breaking length, and

Zc = finite-span tensile strength of the paper strip in breaking length, if no bond breaking had occurred.

Sheet formation is uniform, so that the number of fibres crossing the rupture line is not appreciably lower than the number that cross any line traversing the paper perpendicular to the strain direction. Some scientists measured the tensile strength of hand sheets at different beating degrees and recorded the percentage of fibres that broke at failure. The data which generates the straight line between breaking length (km) and percent broken fibres at failure supports the first assumption of the Page's equation, which is further represented by the following,

$$T = 8\, n_f Zc/9(n_f + n_p) \qquad \text{(b)}$$

Equation (a) is a linear relationship in which:

$T = 0$, where $n_f/(n_f + n_p) = 0$ and

$T = 8Zc / 9$, where $n_f/(n_f + n_p) = 1$.

Second Assumption

Page's second assumption relates the number of fibres that fail at the instant of rupture and the number that are pulled intact. This is expressed as follows,

$$n_p/n_f = \text{function}\,(f,B) \qquad \text{(c)}$$

Where,

f = mean fibre strength, dynes, and

B = mean force in dynes, applied along the fibre axis and cross the rupture line required to pull a fibre from a sheet.

B depends on the relative bonded area of the sheet (RBA), the bond strength per unit area, and the fibre length. According to Van den Akker, the fibre strength for random sheets is represented by Eq.d:

$$f = 8/3(A\rho g Z) \qquad \text{(d)}$$

Where:

A = average fibre cross section,

ρ = density of fibrous material, and

g = acceleration due to gravity.

Assuming that all fibre-to-fibre bonds act cooperatively along a length of fibre, B is represented by Eq. (e):

$$B = bP9\,(L/4)\,(RBA) \qquad \text{(e)}$$

Where:

b = bond strength per unit area.

P = perimeter of the fibre cross section,

L = fibre length (L/4 is mean pulled length), and

RBA = relative bonded area of the sheet.

The above equations can be manipulated to obtain Page's equation for the tensile strength of paper:

$$1/T = 9/8Z + 12A\rho g/bPL\,(RBA) \qquad \text{(f: Page Equation)}$$

In theory, Page equation (e) establishes a relationship between certain fibre properties (viz., fibre length, fibre coarseness, fibre perimeter, zero-span tensile strength), a paper property (relative bonded area), and a fibre-to-fibre interaction (bond strength per unit area).

Reformulation of the Page Equation

Page maintains that the following equation is a satisfactory representation of well-bonded sheets, such as conventional packaging papers and printing and writing papers. This equation is the basis of the MAPPS computer simulation program, which predicts the properties of paper based on fibre and process variables. The current validated database for this program is based on the properties of virgin fibres. The Page equation can be reformulated as follows:

$$1/T = 9/8Z + 12gC/PLbRBA \qquad \text{(g)}$$

Where:

T = tensile breaking length, km,

Z = zero-span breaking length, km,

C = fibre coarseness, mg/100m,

P = fibre perimeter, mm,

L = fibre length, (weight average),

b = fibre-fibre bond strength, dynes/cm^2,

RBA = relative bonded area, %, and

g = gravitational constant.

The work presented by Darcy Clark and A. Jones showed that the best representation of fibre length is weight-average fibre length, which is compatible with the measurement of coarseness. Fibre coarseness and perimeter can be measured using well-established microscopic techniques. RBA can be calculated from the scattering coefficient of the sheets:

$$RBA = [S_0 - S]/S_0 \qquad \text{(h)}$$

Where,

S_0 = the scattering coefficient of an unbonded sheet, and

S = the scattering coefficient of a paper sheet.

Substituting Eq. (h) into Eq. (g) and rearranging them lead to a relationship between the tensile properties of the sheet scattering coefficient:

$$[1/T - 9/8Z]^{-1} = b/\gamma - \{b/\gamma S_0\}\, S \qquad \text{(i)}$$

Where:

We refer to the left side of Eq. (i) as the Page Parameter. Fibre-fibre bond strength and the value of S_0 for individual pulps can be calculated from a plot of the Page Parameter vs. the scattering coefficient.

Despite the acceptance of this explanation by many workers, there is some inconsistency with regard to the role of lignin on the recycling behavior of pulp. Some workers studied the effects of recycling of three loblolly pine kraft pulps. Two of them were unbleached pulps with 46% and 60% yields. Their Klason lignin contents were 16.2%, 4.8%, and 0.2%, respectively. It was found that the percentage loss of strength properties with recycling did not correlate well with the gradual removal of lignin content in the pulps.

Hsieh et al. (1998) studied the strength and drainage characteristics after recycling kraft pulps and treated with and without chlorine. The yields of three regular kraft pulps, without any chlorine treatment, were 47%, 55%, and 59%. In another case the initial yield of kraft pulp observed were 52%, 58% and 63%. It was found that in the case of regular kraft pulps, without any chlorine treatment, the strength loss after recycling increased with decreased yield. However, this trend was less pronounced for the chlorine – treated pulps, which suffered less strength loss at a given level of pulp yield. It is known that chlorine treatment is more selective in removing lignin and preserving hemicellulose than the conventional kraft pulping process. Hence, as the yields were decreased via chlorine treatment, lignin was selectively removed, and the hemicellulose content was maintained at a relatively high level. This may have contributed to the difference in recycling response between the two series of pulps, thus suggesting that lignin and hemicellulose contents in pulps may influence the recycling behavior differently.

There is some speculation in the literature regarding the role of hemicellulose in the re-formation of paper. It was reported by some workers that the loss of wet plasticity was related to the formation of ordered regions within the fibre. Hemicellulose may be partly involved in the formation of this new ordered region. Thereby, the hemicellulose would become inaccessible and unable to contribute to the hydrogen bonding in remaking of paper. Eastwood and Clarke (1977) expressed a similar opinion. It was suggested that "hornification" takes place, for the main part, with in the hemicellulosic material of the fibres because of the degree of swelling and mobility of the molecules. Beyond these speculations, there has been little effort to understand the role of hemicellulose on recycling. Moreover, in past studies, the effects of lignin and hemicellulose were frequently mixed, since lignin and hemicellulose are removed with relatively low selectively in the common commercial chemical pulping process. Bangji Cao, et al. (1998) studied the effects of lignin and hemicellulose and evaluate their relative importance in influencing pulp recycling potential in terms of strength property losses.

Recycled pulp has been used in the manufacture of various grades of paper and board for many years. Worldwide, more than one third of the paper produced is made from recycled pulp. In fact, pulp and papermaking is one of the important industries in India categorized as a "Core Sector Industry" and there have been continuous growth in this industry to supply ever- increasing demand for a variety of paper products. Waste paper is being used as an important raw material for pulp and papermaking by all segments of the industry. There is increasing use of recycled pulp by Indian industry in the present day context of scarcity of conventional wood and bamboo-based inputs for papermaking. However, there is a limitation in paper recycling. With each recycle, the quality of pulp deteriorates as the recycled fibres have higher drainage resistance and lower strength than virgin fibres due to its exposures to repeated pulping and drying processes. Water removal is an important aspect, which is affected mainly by machine design, speed and stock quality. Long fibreed pulps from softwoods give very good machine run ability followed by short fibred pulps from various hardwood species. Recycled pulps pose drain ability problems and limit the speed of paper machine, which has a direct impact on the final production.

2.2 Features of commercial pulps

Most market chemical pulps are dried to approximately 85% to 90% solids. When economical, market pulps are also sold in wet laps dewatered to approximately 45%

solids. Integrated mills use never-dried fibres in their papermaking operation, resorting to dry-wet lap pulps during the occasional pulp mill outage. The physical properties and the response to refining of never dried, wet lapped and once-dried fibres are different. Therefore, papermakers have to adjust operating conditions to compensate for these differences.

Although never–dried and once-dried fibres are chemically similar, they differ greatly in their physical properties. Never-dried fibre contains much more water per unit dry mass than those of dried fibres after rewetting. Being more swollen, the never-dried walls are more flexible or conformable. In contrast, the walls of dried (and rewetted) fibres are stiff. Significant changes in the papermaking properties of fibres occur with water removal as the walls become progressively more rigid and less conformable.

Dried fibres can be made more conformable by mechanical treatment, such as beating or refining, which flexes fibres repeatedly in water. Unfortunately, this requires considerable expenditure of energy. Moreover, refining of fibres introduces undesirable effects such as fibre shortening and the production of fines, which increase the drainage resistance of the pulp. Furthermore, the changes brought about by drying are not entirely reversible. The photomicrographs of never-dried fibres fibrillate to a much greater extent than once-dried fibres. It is noticed that at a given level of refining energy, the swelling or WRV (water retention value) in dried fibres remains lower than in never-dried fibres.

Clearly, what distinguishes never-dried fibres from dried ones at any beating or refining level is fibre swelling and the resultant conformability of the fibre wall. Both factors greatly influence papermaking and sheet properties. The higher conformability and fibrillation of never-dried fibres translate to lower refining cost to achieve a given tensile strength. Energy is required to dry pulps. The drying process stiffens fibres, and refining restores only a portion of fibre conformability. Therefore, pulp should only be dried if storage, transport, or use of wet pulps is uneconomical or impractical.

The mechanical properties of fibres as well as their ability to swell are diminished after they have been exposed to the pulping and drying conditions imposed during the paper making cycle. The reduction in swelling and loss of fibre flexibility after drying reduces the strength potential of recovered fibres. The extent and reversibility of the reduction is dependent on the original pulp type and on the papermaking process. Contamination and age degradation also contribute to the reduced strength of recycled fibre.

The presently known methods of improving drainage or restoring some or all the strengths of recycled fibres may be grouped into seven generalized categories: mechanical treatment, chemical additives, fractionation, blending, chemical treatments, enzymatic treatments and paper machine modifications. Paper strength properties are largely a function of fibre length and inter fibre bonding. Inter fibre-bonding increases with specific surface area by fibrillations and the presence of materials that facilitate surface interactions.

Now-a-days, the use of waste furnish and the closure of back water systems have led to increasing demand on many wet ends, resulting in poorer retention, slower drainage, and reduced strengths. Consequently, the need of wet end chemicals for functional and processing aids has become progressively more and more important.

Cellulose paper is very vulnerable to water since it contains many hydroxyl groups; therefore, sizing becomes a necessary process for many paper grades. Rosin soap size has been the most widely used sizing agent since the sizing techniques were developed in 1807, because the material is fairly inexpensive and abundant and the sizing process is easy to operate. However, this sizing agent can now be applied only in an acidic pH range since alum has always been the predominant mordant of choice in industry and it is not effective at elevated pH due to its chemical characteristics.

The twin phenomena of drainage and retention are so intimately related that it is normally impossible to alter one of these parameters without affecting the other, and frequently when the drainage is improved the retention falls. There are two ways in which retention is customarily expressed, either as 1) first- pass retention, or 2) total or overall retention.

First pass retention is defined in terms of the amount of head box solids retained on the wire, and is normally expressed in terms of percentage retained. Total or overall retention is calculated from the mass of the paper leaving the machine and the amount of stock used, and it is again usually expressed as a percentage of the solids content of the stock that appears as product. The use of recycled fibre, in paper making furnish, for more and more demanding grades has set new targets for the treatment process. Development efforts have been largely directed to equipment and processes to produce cleaner fibre, and less attention has been paid to the development of fibre characteristics. However, the key to developing the desired properties is based on the bonding ability of fibre and great attention is paid to this feature when processing virgin fibre. Whenever the fibre passes through the papermaking process, swelling and bonding ability is reduced. Every reuse weakens the fibre, causes irreversibility change and thus reduces fibre potential.

Recycled fibre is often used as filler and low bonding ability is counteracted by using chemical binders, which binds furnish components with low bonding ability to the paper web. By upgrading fibre potential during slushing, screening and cleaning, the amounts of fines and fibrils needed for a good fibre bonding is reduced. These stages regenerate swelling and bonding ability to some extent but not enough, and therefore, more intensive treatment–refining–is needed. Since the fibre potential of recycled fibre is not comparable to that of virgin fibre, the demands- on the refining process, conditions, equipment, fillings and other factors affecting the refining results are of a different nature.

Correctly chosen, moderate low consistency refining improves the bonding ability of recycled fibre. It also brings the low requirements for chemical binders and the possibility of increasing the amount of recycled fibre in furnish. To understand the papermaking potential of recycled fibre it is useful to look at the history of those fibres. Many paper and board grades are made of virgin fibre. This fibre passes through the paper making process, and the product is converted for various purposes.

For information-newspapers, magazines, books, leaflets, advertisements; for goods–bags and boxes, the reusable material is collected for further use in papermaking and some countries have a long history in the reuse. The collected paper contains impurities and harmful foreign materials; which must either be removed or made non-visible. If clean enough, recycled fibre can be used for thin, high quality papers. Dirtier fibre is used for lower grades or hidden in between top and bottom layers in case of heavier multilayer board grades. Recycled fibre does not differ significantly from virgin fibre since it originates from used virgin fibre. Recycled fibres enter the stock preparation process either in wet or in dry form. Previous refining and drying stages have also had an impact on those fibres. As a result of earlier treatment, recycled fibre is not always suitable for papermaking. It has a great extent to lose its bonding ability and stock preparation is required as it is for virgin fibre. The best way to develop bonding ability is by moderate low consistency refining which is also able to straighten curly and kinky fibres. Today, there are several reasons for refining recycled fibre and the old maxim ‘Once refined fibre should not be refined any more’ must be reconsidered. However, recycled fibre is more sensitive to errors in refining than virgin fibre. It has been weakening and undergone irreversible change into the fibre. If not refined in a correct way the result can be disastrous. Undesirable effects increased drainage resistance and major reduction in fibre length and tearing strength can be avoided by selecting refining equipment and conditions correctly.

The development of the fibre length and coarseness with refining was observed to decrease with refining. However, it has been reported that the changes in the length-weighted fibre length did not correlate with changes in the number of long fibres per unit mass, indicating that the length-weighted fibre length was not accurately tracking the reduction in fibre length with refining. This is mainly because its value is affected by the production of fines during refining. It was found that only a relatively poor fit between the theory and experiments could be obtained using the measured values of fibre length and coarseness. This is because these measured values are affected by the presence of fines generated during refining. A better fit with the Page equation was actually obtained by assuming no change in coarseness and fibre length for the refined pulps (Page D. H., 1985). The major source of improvement in the tensile strength of the sheets was an increase in their relative bonded area.

Low consistency refining has long been used to improve the tensile strength of paper, but the mechanisms through which refining produces these improvements are still a topic of current research. The term “refining of chemical pulps” means the mechanical treatment of chemical pulp fibres with aim of making them more suitable for papermaking (Hietanen, and Ebeling 1990). Refining process modifies the pulp properties by imposing cyclic deformation on fibres and they are in most cases imparted through bars on rotating surfaces. More efforts have been tried in understanding the action of refiners on fibres. According to Hietanen and Ebeling, (1990), the primary efforts of refining are the creation of new surfaces, the creation of new particles and structural changes to the fibres. The major changes in fibre morphology that occur with refining have been thoroughly reviewed by Page (1989).

The primary means of characterizing the action of a refiner is through the specific energy that is put into the pulp. However, it is now widely recognized that specific energy alone is not always sufficient to characterize the outcome of refining and at least one additional parameter is required. Thus, it was proposed that the mechanical action of a refiner should be described by two basic variables i.e. the number of impacts imposed per unit mass of pulp (N) and the intensity of each impact, (I). The C- factor theory (Kerekes, 1990) provides a means of calculating N and I from the net power of the refiner and the pulp flow through the refiner and its usefulness in characterizing a wide range of refiners. The equivalent refining action between refiners is expected when both the N and I of each refiner are equal (Kerekes, et al, 1993).

2.3 Effect of retention aids

The economics of the papermaking operations is determined by the value of the overall retention of fibre fines and chemicals; whereas the ease of operation of the wet–end is profoundly affected by the value of the first-pass retention. This first - pass retention should be regarded as being composed of two components, the long fibre retention and the fine retention. Since long fibres can be efficiently filtered first by the wire and also by the forming paper web, long fibre retention values are normally very high and approach 100%. On the other hand, the fines are those particles that escape filtration by the wire or the forming web, and it is the retention of these materials which really determines the wet- end behavior of the system as a whole; frequently fines retention are in the range 30–70%. The lowest value of fines retention that can be tolerated depends, amongst other things, on the water and solid losses from the machine. If it is imagined that the papermaking machine is completely closed up, i.e. that the only water and solids losses are those of water lost in the driers, which is only a small proportion of the total in the system, and the solid being reeled up at the dry end, then the fines content will not continuously increase.

Even the subdivision of retention indicated above is insufficient to describe in detail the chemical behavior of the wet-end. In particular, in the fines retention needs to be subdivision further. There can be a number of such subdivisions depending on the type of furnish used, but typically it may need to divide fines retention into pulp fines retention, filler fines retention and size fines retention, since to study first - pass retention alone may well be inadequate.

In order to have an over simple model upon which to hang consideration of retention and drainage, consider the sheet as an assembly of parallel cylindrical pore running from the top face to the bottom face to the sheet, and the fines as spherical particles of dimensions smaller than the diameter of the cylindrical pores. Drainage will be most rapid when the pores have as large a pore diameter as possible. For a given weight this would be when the sheet was as thick as possible. The retention of fines with the pores has the effect of obstructing flow in the pores and reducing it. So to keep good drainage in a sheet with high fines retention then the sheet must be as open as possible, at least until the sheet reaches the press section on the paper machine. As the sheet is compressed the pore radii are effectively reduced (Michael and Darren 1994).

Recently, it has been reported that mechanical pre-treatment consisting of compressive impact and shear action (Hobart mixer) before the refining on recycled fibres, e.g. old corrugated containers, results in large improvements in strength properties after laboratory refining without use of synthetic polymers and without causing drainage problems for the pre-treated fibres.

Good retention is paramount for a clean and trouble-free wet-end in papermaking. The optimum retention of fines and fillers is of technical and economic importance. The zeta potential has been postulated to be the controlling parameter. Considerable work has been reported in literature on effect of zeta potential on drainage, filler and fines retention, sizing, paper strength and paper machine performance. White water solids build–up and severe losses decrease with increased first pass retention. Limited studies have been carried out earlier on zeta potential or retention/drainage of recycled pulps (Bhardwaj et al. 2003). Enzymes in combination with polymeric flocculants have also been tried to enhance freeness of recycled fibres that translates to improvement in drainage. (Bhardwaj et al.1995).

Though both mechanical and chemical factors in the papermaking process affect the drainage/retention, the emphasis in recent past, has been on the chemical aspects of retention. The use of chemistry does not require capital and chemistry is easier to apply than rebuilding or modifying a paper machine system. Recent trends of employing different types of additives have been reported to be quite effective in improving the machine run ability (Nishi K. Bhardwaj, 2003).

However, there is a strong need for more quantitative understanding of the effects of different wet-end chemicals in controlling zeta potential to improve retention in drainage of secondary fibres, which could result in higher production rates and improved quality. Such information is of immense importance to Indian industry; particularly to small and medium scale paper mills where relatively obsolete machinery with relatively lower speeds are being used for papermaking due to economic constraints.

The need of wet-end chemicals for functional and processing aid has become progressively more and more important with the use of increasing recycled pulp in furnish, recent high–speed paper machine trends and closure of backwater systems. A growing desire for increased productivity, better environment and competitiveness from mills using recycled fibres has placed a premium on the analysis of drainage performance by addition of chemicals. To use the wet-end chemicals in paper mills, it is important to assess and optimize the process with different kinds of pulps in the laboratory. Some wet study, some wet-end chemicals have been evaluated particularly for their effect on zeta potential of pulp to control and improve retention and drainage of recycled pulps. A substantial gain in the drainage rate could be used in various ways – to improve the speed of the paper machine, to achieve greater dilution in the head box or to use low-grade papers more extensively as a source of recycled pulp.

There are a wide variety of agro-based materials that can be utilized for pulp production. Straw and bagasse are current primary sources for agro-based pulp production in China, Mexico, and India, respectively, although the supplies of bamboo are rapidly dwindling in India. Bagasse is the fibrous residue left over after the crushing and extraction of sugarcane, (Saccharum officinarum) for sucrose production. Bagasse is readily available and easily accessible in many tropical and subtropical countries in the world and is often very abundant in countries without supplies of wood resources. Bagasse is produced as a residue, but not utilized in paper making in the south –eastern United States (primarily Louisiana) and Hawaii.

An important advantage with bagasse is that there are usually very few problems associated with collecting the fibrous resource; the costs of collection, processing, and washing are borne by sugar mill. However, the bagasse must be properly depithed and stored to produce high quality pulps.

Mechanical and chemical pulps have been prepared from bagasse and a variety of paper products contain bagasse pulps. However, mechanical bagasse pulps generally exhibit inferior strength properties. The high energy cost and inferior pulp quality render mechanical pulps less attractive, particularly for bagasse. This is inspite of the obvious advantages of higher yields and less pollution.

2.4 Effect of polyacrylamide in recycling of paper

It has been reported that adsorption of the cationic polyacrylamide onto fibres or fines increases substantially after beating. After drying, however, it decreases to the level of unbeaten pulp. Simple recycling of unbeaten pulp caused little change in cationic polyacrylamide adsorption. Cationic polyacrylamide adsorption onto beaten pulp decreased in the early stages of recycling and then increased, probably due to the oxidation of the pulp fibre in the inner cell wall during multiple recycling. Secondary fines generated during the first beating process showed cationic polyacrylamide adsorption twice as great as that of primary fines. Cationic polyacrylamide adsorption onto the secondary fines that were newly generated from the recycled pulp fibres decreased with recycling.

Various polymers have been used for many years in paper manufacture to promote retention and increase strength. Since cellulosic fibres and most fillers are negatively charged, cationic polymers are used to a large extent in papermaking, To be effective, these polymers need to be absorbed on fibres, fines and fillers. Obviously, an understanding of the adsorption behavior of the polymers is essential for the understanding of their effectiveness in papermaking (Lee and Joo, 2000). The adsorption behavior of cationic polymers predominantly determined by the charge interaction with anionic fibre surface and the adsorption of polymers onto fibre increased with the hydrodynamic surface area (Lindstrom, et al. 1974). For instance, it has been shown that the adsorption of cationic starches onto cellulosic fibres increases with increasing content of carboxyl groups on the fibres (Marton and Marton 1976), and that cationic starches are preferentially adsorbed on cellulosic fines that have a larger surface area (Marton, 1980).

2.5 Effect of fungal treatment

In recent years, the advantages of using fungal treatment prior to mechanical refining of wood have been demonstrated. Considerable energy savings and enhancement in strength properties of aspen and pine pulps were realized by the use of the white rot fungus ceriporiopsis subvermispora. Further studies demonstrated that this fungus provided even greater benefits for biomechanical pulping of two agro based materials, kenaf and jute. Attempts to produce a strong biomechanical pulp from bagasse with the white rot fungus phanerochaete cbrysosporium proved unsuccessful. It was necessary to treat with sodium hydroxide to obtainable pulp, which should be then bleached chemimechnical pulp (BCMP). P. chrysosporium has been shown to be inferior to C. subrermispora for biomechanical pulping of wood, and clearly P. chrysosporium is not viable for pulp production from bagasse (Pablo Bustamante 1999).

The fibrous elements of bamboo (Dendrocalamus strictus) pulp are similar to those of cereal fibrous straw, sugar cane and other grasses. Bamboo fibres vary markedly in fibre length typically 1.4 to 4.3 mm, average 2.7mm long and 6.8 to 27.3, average 14 micrometers in width. Wide thin walled pitted fibres can vary between 2.8 and 3.2 mm in length and 20 to 40 micrometers in width. Parenchyma cells are up to 0.25 mm long by 65 micrometers wide whilst vessel elements can be up to 100 micrometers wide (Kenneth N. et al. 1995).

Enzymes applications have been proposed for pulp and paper manufacture to enhance pulp bleaching, pulp refining, deinking, cellulose purification, deposit control, and papermaking. For mechanical pulping, wood fibres are separated and refined using mechanical actions that are energy intensive and lead to some damage of the fibres. Consequently, alternative approaches are sought to minimize these deleterious effects.

The cellulase component cellobiohydrolase I, from Trichoderma reesei, has been reported to enhance mechanical pulp refining by reducing energy consumption, apparently as the result of selective action on crystalline cellulose. However, when a crude cellulase preparation was evaluated in the fibre processing pilot plant, more energy was required to achieve a target of freeness (drainage property of the pulp, which is an indicator of pulp refining) during secondary refining. This undesirable effect was apparently due to a higher loss of pulp fines after the inner stage treatment of the pulp with enzyme. Subsequent work in the laboratories showed that cellulase treatment of a long fibre rich fraction of a mechanical pulp increased its retention of untreated fines during papermaking, thus improving the tensile and burst strength of the resultant sheets. However, this effect was observed in relatively pure long fibre fraction isolated using laboratory scale equipment.

Carbohydrate–degrading enzymes are only one of the classes of enzymes produced by microorganisms for the degradation of wood. Other microbial enzymes known to modify non-carbohydrate components, including lignin and minor wall constituents, could also be expected to alter pulping and papermaking. Lignin - degrading or lignin - modifying enzymes, such as laccase, lignin peroxidase, manganese peroxidase, and particularly the laccase – mediator system, have already shown promise for applications in pulp delignification and bleaching. It has also been suggested that proteinases, which attack the protein concentrated in the primary wall of wood fibres, may enhance fibre separation during mechanical processing, even though this protein is a minor structural component of wood. Similarly, other component of the primary wall, such as pectins and xyloglucans, may warrant consideration. Furthermore, a recent report indicated that the removal of lipid extractives from mechanical pulp fibres could improve fibre bonding to increase tensile strength.

2.6 Techniques for enhancing the strength of recycled fibres

Recycled fibres have lower strength and higher drainage resistance than virgin fibres, which limit the paper quality and speed at which the paper machine can operate. The mechanical properties of fibre as well as their ability to swell are diminished after they have been exposed to the pulping and drying conditions imposed during the paper making cycle. The reduction in swelling and the loss of fibre flexibility after drying reduces the strength potential of recovered fibres. The extent and reversibility of the reduction is dependent on the original pulp type and on the paper making process. Contamination and age degradation also contribute to the reduced strength of the recycled fibre .The methods of improving drainage or restoring some or all of the strength of recycled fibres can be classified in to seven categories: mechanical treatment, chemical additives, fractionation, blending, chemical treatments, enzymatic treatments and paper machine modifications.

Strength loss generally can be regained by refining. Unfortunately, this usually reduces drainage and production capacity. Increased refining also limits the amount of strength that can be regained by refining in future cycles. High-shear-field (HSF) treatment, in a pulp consistency range of 10-20%, can be used to produce an effect similar to refining. During HSF treatment the fibre wall structure is modified by the brushing and bending action, which increases the bonding area. The HSF treatment produces less fines than refining and this results in less freeness loss (Chase, 1975).

The use of chemical additives, which improve the strength properties without changing the repulping requirement, can provide an alternative method to refining. The resins often used are anionic polymers, which facilitate hydrogen bonding and strong electrostatic bonds between fibres and fines. These resins improve the dry strength of paper by increasing both the strength and the area of the interfibre bonds (Ganpati et al., 1991)

Treatment of wastepaper with sodium hydroxide increases the freeness and the strength properties of recycled fibre. Sodium hydroxide treatment promotes fibre swelling, thereby increasing fibre flexibility and surface conformability. The alkali treatment helps to swell the secondary fibre, which increases the surface area available for bonding. A NaOH treatment at 10% pulp consistency for 30 min. at 70 ^{0}C is typical of conditions commonly used; (Ganpati et al. 1991).

Oxygen-alkali delignification has recently been studied as a means of improving strength properties in old corrugated container recycled pulp (De Ruvo et al., 1986). The delignification treatment was found to improve the bonding and strength characteristics, probably because of softening, swelling, and lignin removal. The strength improvement in the fibre is especially noticeable in the higher burst value and strain-to-failure value at a given drainage rate.

A combination of alkali and HSF treatment may be a better alternative to obtain high product quality from secondary fibre. The strength properties of the recycled paper obtained by the combination of alkali and HSF treatment are higher than those obtained by refining and, in some cases, are comparable with the virgin pulp. This treatment offers a potentially valuable, practical method of increasing the use of secondary fibre in boxboard as well as corrugating medium (Ganpati, et al. 1991).

The blending of high yield recycle pulp with kraft recycle pulp can also lead to improvement in strength properties. This area can offer attractive option in terms of economic advantages. It is important that initial study be conducted to find optimum blending proportion of recycled high yield and Kraft pulps and examine possible combination with refining as HSF treatment, chemical addition, alkali treatment or oxygen alkali treatment for improved pulp qualities.

CHAPTER 3

EXPERIMENTAL

The experiments were performed at Research and Development Centre, Ballarpur Industries Limited (Unit Shree Gopal) Yamunanagar. The bleached bagasse pulp used in the present study was procured from Century Paper Mill, Lalkua, Nainital (Uttaranchal). The bagasse pulp was produced in continuous digester and bleaching sequences CD – EOD were used for blending with the bagasse pulp.

Pulping of bagasse:

Cooking type	:	Direct
Bath ratio	:	1: 3
Cooking temperature	:	168-170 ºC
Active alkali charged in bagasse cooking	:	12 %,
White liquor sulphidity	:	18 %
Pulp Yield (BD)	:	50 %
Kappa No.	:	13

Bleaching Specification of Bagasse pulp

Unbleached pulp pH	:	8
Brightness	:	35 %
Viscosity	:	25 cp
Kappa No.	:	13

Bleaching at C/D stage

Inlet pH	:	2
Outlet pH	:	2.5
Brightness (% PV)	:	65
Kappa No.	:	4

Bleaching at alkaline extraction stage

Inlet pH	:	9

Outlet pH : 8.5
Brightness : 70
Kappa No. : 02

Bleaching of Dioxide pulp

Inlet pH : 2.0-5.0
Outlet pH : 7.0
Brightness : 86.76
Viscosity (cp) : 20
Free ClO_2 (ppm) : 300

Bleaching conditions of different stages:

S. No.	Stage	Units	C/D	E/O	D
1	Chemical charged	%	3.0/0.2	2.0/1.5	0.4
2	Retention time	Minutes	45	90	150
3	Temperature	ºC	27	60-65	75-80

Characteristics of pulp at stock preparation section:

S.No.	Parameters	Units	Values
1	Consistency	%	3.5%
2	Freeness	CSF	605
3	pH	pH	7
4	Brightness	% PV	88
5	Free ClO_2	ppm	100(max.)
6	Ash	%	0.87

The long fibreed bamboo pulp was used for blending with the bagasse pulp. Some quantity of long fibreed bleached radiata pine wood pulp was also used for blending with the bleached bagasse pulp. The bagasse pulp was screened and cleaned using the centri-cleaner for the removal of dirt and contaminant particles, which may affect the strength properties of the standard paper sheet. After screening and cleaning of the bagasse pulp, its fibre classification was carried out in the Bauer-NcNett fibre classifier as per TAPPI standard **(T 233 sm–53)**. The results of fibre classification of bagasse pulp are as follows:

Mesh Size of Screen	+ 20	-20 + 30	-30 + 50	-50 + 100	-100 + 200
Percentage retention of bleached bagasse pulp at 605 ml CSF	13.31	19.56	15.42	19.87	31.84

The brightness, opacity, smoothness, porosity and stiffness of the different pulps were determined and the results obtained are as follows:

1. Bleached Bagasse Pulp

Brightness	(% PV)	: 88
Opacity	(%)	: 91
Gurley Porosity	(sec. /100ml air)	: 90
Smoothness	(sec./50ml air)	: 48 / 55
Stiffness	(°Taber)	: 4.0 / 2.0

2. Bleached Radiata Pine Wood Pulp

Brightness	(% PV)	: 93.4
Opacity	(%)	: 77.5
Porosity	(sec./100ml air)	: 1.98
Bulk	(cm^3/gm)	: 1.74

3. Bleached Bamboo Pulp

Brightness	(% PV)	: 85.5
Opacity	(%)	: 89.0
Porosity	(sec. /100ml air)	: 2.78

Characteristics: The chemicals used as retention aids were tested for their specific properties. The various properties are as follows:

1. Modified polyethyleneimine - Catiofast

Colour : colourless aqueous solution
Ionic charge : cationic
Density at 20 °C : 1070 kg/m^3
Viscosity (Brookfield) : 1500 mPa.s
pH : 8

2. Anionic polyacrylamide – Polymin AE 75 (high molar mass Sursalone)

Density at 25 °C : 1040 kg/m^3
pH (1% solution in distilled water) : 7

Ionic charge : anionic
Viscosity at 20 °C (Brookfield) : 1300 mPa.s

Experiments were performed to study the effect of recycling on the characteristics of bleached bagasse pulp and improvement of properties of recycled pulp. The experiments have been categorized into three sections as follows:

Section 1	Recycling experiments without addition of chemicals.
Section 2	Recycling experiments with the addition of chemicals. (Fortified rosin size 1.2%, ecorite PAC 2014, soap stone filler 15%) and retention aids (anionic polyacrylamide and Modified Polyethyleneimine).
Section 3	Recycling experiments with the addition of chemicals (Fortified rosin size 1.2%, ecorite PAC 2014, soap stone filler) and retention aids (N-7607 and N 7530) in the presence of starch.

3.1 Study of strength properties due to recycling of bagasse paper sheet without adding chemicals

The bleached bagasse pulp was screened in the 20mesh screen. The screened pulp was centri-cleaned four times using the centri-cleaner in the laboratory for the removal of dirt and contaminants from the pulp. About 360 gm O.D. pulp was charged in the valley beater for the disintegration. The pulp was disintegrated in the valley beater without applying load for about 30 minutes. Before the start of beating, the consistency of the pulp was maintained as per the TAPPI standard **(T 200 m–60)** and the pH and temperature of the pulp were noted. The standard load was applied on the beater for the commencement of the beating of the pulp. The beaten pulp samples were collected after constant time intervals and each sample was marked with its identity. The CSF of each pulp sample was evaluated as per the TAPPI standard **(T 227m– 58)**. The standard paper sheets of 60 gram per square meter were prepared as per the TAPPI standard on British sheet former without adding additives or any chemicals to it. The standard paper sheets were pressed for 7 minutes at 50 psi gauge pressure in the hydraulic paper sheet press. The paper sheets were kept in the drying rings after pressing. Drying rings containing the paper sheets were kept in the conditioned room at 23 °C and 50% relative humidity for about 48 hours as per the TAPPI standard **(T402m–49).** The moisture content of paper sheet was evaluated after conditioning at standard temperature and relative humidity. These paper sheets were tested for average caliper, bulk, basis weight, brightness, porosity and smoothness. After testing the surface and optical properties, the tensile strength in terms of breaking length, burst factor, tear factor, and double folds were tested for each CSF of the beaten pulp samples.

The standard paper sheets were kept in other laboratory for 20 days for aging purpose. After 20 days aging, the paper sheets of various categories of different CSF were reslushed in the hydrapulper separately. The pulps were kept in the different marked containers to avoid mixing of pulps.

For making the first recycled paper sheet, the pulp was disintegrated by the high-speed disintegrator for about 20 minutes and the pulp was screened to remove the fibre flocs. The first recycled standard paper sheets were prepared on the British sheet former after evaluating the CSF of the various re-slushed pulps. These standard paper sheets were again pressed in the hydraulic press and dried in the conditioned room. The first recycled standard paper sheets were again tested for strength, optical and surface properties. These recycled standard paper sheets were made and their surface and strength properties were evaluated at each recycled stage up to fifth recycled stage. After the fifth recycle, it was observed that the further recycling of these paper sheet is difficult due to its very low strength and rough texture of the sixth recycled paper sheet. The standard paper sheets made for various CSF were tested for strength, optical and surface properties.

3.2 Study of recycling of bleached bagasse paper sheet by adding fortified rosin size 1.2%, Ecorite PAC 2014, soap stone filler 15% and retention aids (anionic polyacrylamide and modified polyethyleneimine)

The standard paper sheets of 60 gm/m^2 basis weight were prepared by adding 1.2% fortified rosin size, and ecorite PAC 2014 to control the pH of the pulp admixture at 5.0 ± 0.5. The soap stone filler was also added. The quantity of soap stone filler added was 15% of the quantity of oven-dried pulp. The anionic polyacrylamide and modified polyethyleneimine retention aids chemicals were also added in the varying doses for maintaining the good retention. When the strength properties of the first recycled paper sheets were evaluated, a heavy reduction in the strength properties was noticed. To improve the strength properties of the paper, the bleached beaten radiata pine wood pulp was blended in different proportions of 10, 20, and 30%. The improvement in strength properties of paper was evaluated for different CSF of pulp. It was noticed from the results that more fresh pulp blending would be needed for further recycling after the first recycle. The fresh beaten bleached bagasse pulp or the long fibreed pulp was blended with the beaten recycled pulp after the first recycled stage.

3.3 Study of recycling of bleached bagasse paper sheet at different CSF by adding fortified rosin size 1.2%, Ecorite PAC 2014, soap stone filler 15% and retention aids N*(N–7607 and N–7530) in presence of starch

For the study of strength improving chemicals, the cationic starch of different doses was used in making the standard paper sheet at different CSF pulp samples. The standard paper sheets of 60 gm/m^2 basis weight were prepared by adding 1.2% fortified rosin size and ecorite PAC 2014 to control the pH of the pulp admixture at 5.0 ± 0.5. The soap stone filler was also added. The quantity of soap stone filler added was 15% of the quantity of oven- dried pulp.

The cationic starch in the standard paper sheet was added in different doses to observe the effect in strength development in the standard paper sheet. The cationic starch added was 0.5%, 0.7%, and 1.0% of the total quantity of the oven-dried pulp. For maintaining the good retention of chemicals in the paper sheet the retention aids chemicals N* [N-7607 (0.1%) coagulant and N–7530 (0.25%) flocculent] were added in the admixture.

3.4 List of equipments used

In the present study, experiments were performed in the laboratory using the following equipments and instruments:

1) Defibreator
2) British sheet former
3) Standard paper sheet drying rings
4) Hydraulic sheet press
5) CSF tester
6) Agitator
7) Disintegrator
8) Valley beater (Valley Iron Works Co. Applenton, U.S.A.)
9) Stop watch

10) Digital weighing balance
11) Laboratory oven
12) Hydra-pulper
13) 20 mesh screen
14) Centri-cleaner battery
15) Bauer-McNett Fibre classifier
16) Electric furnace
17) Electric iron
18) Water bath
19) High speed agitator
20) Laboratory glass wares
21) Tensile strength tester
22) Burst strength tester
23) Elmendorf tear strength tester
24) Micrometer for the measurement of caliper of the paper
25) Double fold tester
26) Photo volt brightness tester
27) Electronic platform weighing balance
28) Paper sample cutter
29) Color touch – 30 (Brightness tester) Technidyne Corporation New Albany Indiana (U.S.A.)

3.5 List of chemicals used

Modified polyethyleneimine (Catiofast, 67056 Ludwigshafen / Germany)

Cationic starch – T 25 (Bharat Starch and Chemicals Limited, Yamunanagar)

Coagulent (N - 7607) (Ondeo Nalco India Limited, 20-A, Park Street, Kolkata)

Fortified rosin size (IVAX, Chemicals Pvt. Ltd., Hyderabad)

Floculant (N – 7530) (Ondeo Nalco India Limited, 20-A, Park Street, Kolkata)

Poly-aluminium chloride (Ecorite PAC- 2014) (Grasim Industries Ltd., Nagda, M.P.)

Soap stone filler (Abhay Talc Calakoti Compound, Rampur Road, Haldwani, Uttaranchal)

Anionic polyacrylamide (Sursalone (polymin AE75), 67056 Ludwigshafen / Germany)

3.6 TAPPI standard test methods used in laboratory experiments

1.	Laboratory Processing of Pulp (Beater- Method)	T	200 m – 60
2.	Forming Hand Sheet for Physical Tests of Pulp	T	205 m – 60
3.	Physical Testing of Pulp Hand sheets	T	220 m – 60
4.	Drainage Time and Drainage Factor of Pulp	T	221 m – 51
5.	Freeness of Pulp	T	227 m – 58
6.	Cupriethylenediamine Disperse Viscosity of Pulp	T	230 sm – 50
7.	Fibre Length of Pulp by Classification	T	233 sm – 53
8.	Conditioning Paper and Paperboard for Testing	T	402 m – 49
9.	Bursting Strength of Paper and Paperboard	T	403 m – 53
10.	Tensile Breaking Strength of Paper and Paperboard	T	404 m - 50*
11.	Basis Weight of Paper and Paperboard	T	410 m - 45*
12.	Thickness and Density of Paper	T	411 m – 44
13.	Moisture in Paper and Paperboard	T	412 m – 53
14.	Ash in Paper	T	413 m – 58
15.	Internal Tearing Resistance of Paper	T	414 m - 49
16.	Folding Endurance of Paper	T	423 m - 50
17.	Opacity of Paper	T	425 m – 60
18.	Bulking Thickness of Paper and Paperboard	T	426 m - 46
19.	Brightness of Paper and Paperboard	T	452 m - 58

CHAPTER 4

RESULTS AND DISCUSSION

Experiments were performed to study the effect of recycling on the characteristic of bagasse pulp and improvement of strength properties of recycled paper. Experiments were carried out to study the strength properties of paper due to recycling of bagasse paper without the addition of chemicals and retention aids. The effect of addition of chemicals (fortified rosin size 1.2%, PAC 2014, soap stone filler and retention aids (anionic polyacrylamide and modified polyethyleneimine) for the improvement in the strength properties of paper sheet was studied. The effect of cationic starch and retention aids (N–7607 and N–7530) for the improvement of strength properties of paper sheet was also studied. The experiments were performed at varying CSF of pulp samples for the improvement of strength properties of paper sheet.

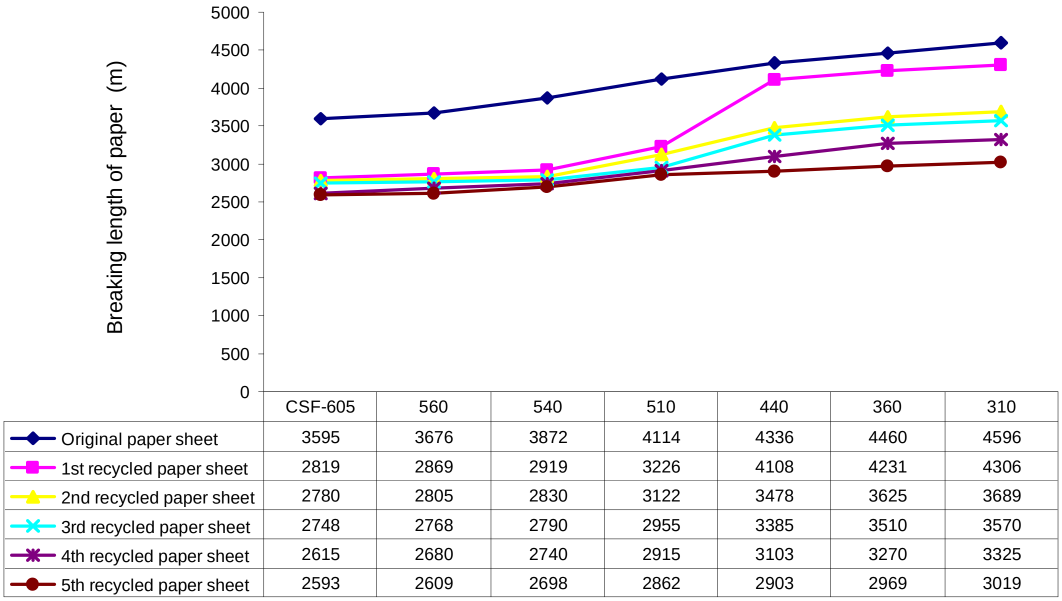
SECTION-A

4.1 Effect on breaking length with varying CSF

Experiments were performed to study the breaking length of paper sheet for bleached bagasse pulp at different CSF. The breaking length of paper sheet was evaluated after each recycle of paper sheet. The breaking length of original paper sheet and subsequent recycles (up to 5 recycles) was evaluated. The results are shown in **Fig. 4.1.** It can be noticed from **Fig. 4.1** that at high CSF pulp the paper sheet has low breaking length. It can be further noticed from **Fig. 4.1** that there is a decrease in breaking length of paper sheet with an increase in the number of recycles at constant CSF.

The CSF of pulp indicates the beat-ability of a pulp sample i.e. the lower CSF of the pulp implies more beating of the pulp. The specific surface area of fibre increases with the increase in extent of beating. The increase in surface area of the fibre leads to strong fibre bonding which ultimately enhances the strength property of paper made from the pulp.

The increase in breaking length of paper sheet with a decrease in CSF was observed up to a certain value of CSF. The strength properties of paper start decreasing with the decrease in CSF beyond the optimum value of CSF. This is due to poor fibre to fibre bonding.



	CSF-605	560	540	510	440	360	310
Original paper sheet	3595	3676	3872	4114	4336	4460	4596
1st recycled paper sheet	2819	2869	2919	3226	4108	4231	4306
2nd recycled paper sheet	2780	2805	2830	3122	3478	3625	3689
3rd recycled paper sheet	2748	2768	2790	2955	3385	3510	3570
4th recycled paper sheet	2615	2680	2740	2915	3103	3270	3325
5th recycled paper sheet	2593	2609	2698	2862	2903	2969	3019

FIG. 4.1 Breaking length of pure bleached bagasse paper sheet at various CSF for different recycled stages.

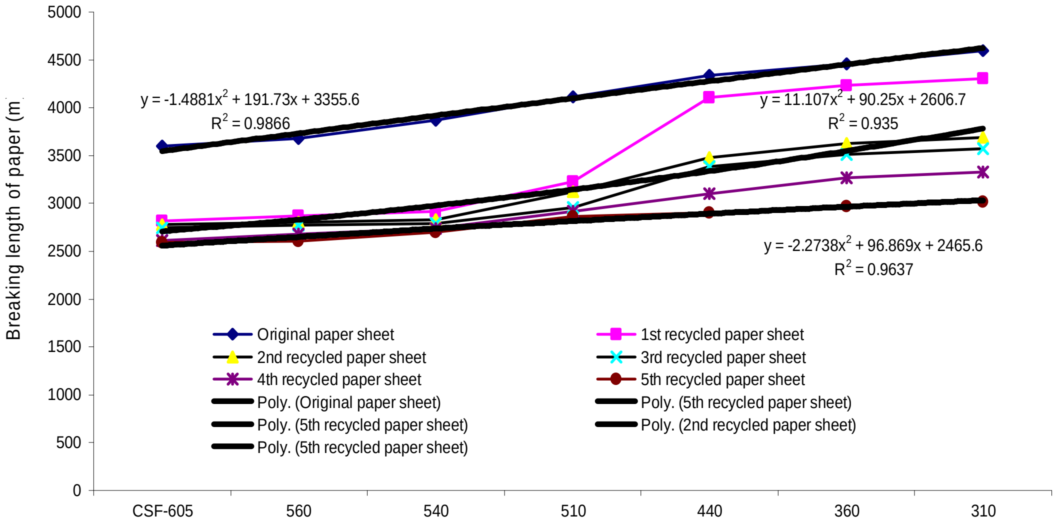


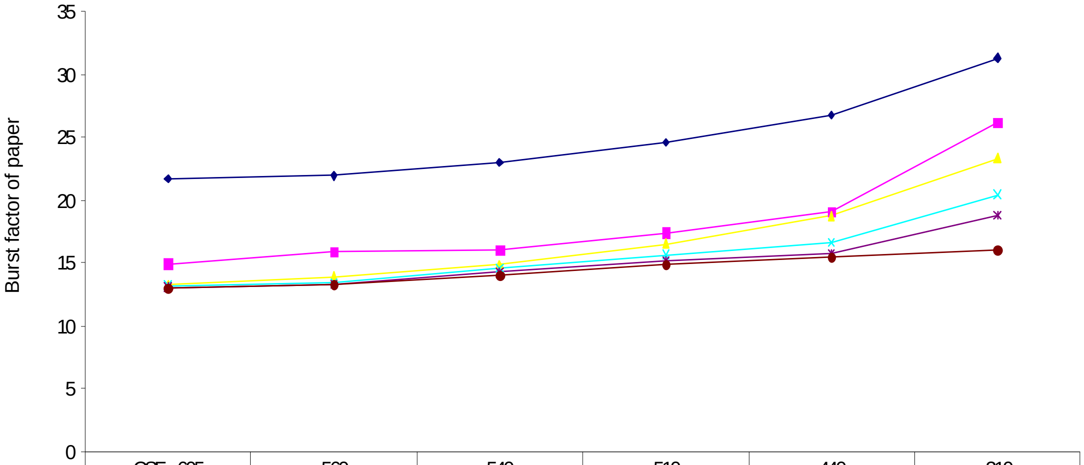
Fig. 1 A. Statistical graph of breaking length of pure bleached bagasse paper sheet at various CSF for different recycled stages.

4.2 Effect on burst factor with varying CSF

Experiments were performed to study the burst factor of paper sheet with the varying CSF. All the six experiments were performed at different CSF and the results are plotted in **Fig. 4.2.** It can be observed from **Fig. 4.2** that with an increase in the beating of the bleached bagasse pulp, the burst factor of the paper sheet increases. The decrease in pulp CSF leads to an increase in burst factor of paper sheet. At 605 ml CSF the burst factor of bleached bagasse paper is 21.69. In case of more beating of bleached bagasse pulp, the burst factor improves up to 31.33 at 310 ml CSF. More beating or refining of pulp increases the specific surface area of the pulp fibre, which result in high burst factor of the paper sheet. The hornification in fibre reduces the capacity of bond formation among the fibres during the drying period of paper sheet at the different recycling stages.

4.3 Effect on tear factor with varying CSF

Experiments were performed to study the tear factor of the paper sheet of bleached bagasse pulp with varying CSF. *It can be observed from **Fig. 4.3** that with a decrease in CSF of the pulp, the tear factor of the paper sheet increases. As the specific surface area of the fibre increases due to the beating effects on the fibre, it leads to strong bonding of the fibres resulting in increased tear factor of paper sheet. It can be further noticed from **Fig. 4.3** that when the paper sheet is recycled, the tear factor starts decreasing for a particular value of CSF. Due to increased recycle of paper, the hornification of the pulp fibre takes place during the drying process of paper sheet. It causes less bonding among the fibres and the recycled paper sheet becomes bulkier as compared to the original paper sheet. It results in a decrease in strength properties of the recycled paper leading to a lower value of breaking length, burst and tear factor of paper sheet.



	CSF - 605	560	540	510	440	310
◆ Oringinal paper sheet	21.69	21.97	23.03	24.63	26.82	31.33
■ 1st recycled paper	14.98	15.96	16.07	17.45	19.15	26.15
▲ 2nd recyled paper	13.35	13.96	14.93	16.56	18.77	23.37
× 3rd recycled paper	13.23	13.51	14.62	15.68	16.63	20.47
✱ 4th recycled paper	13.07	13.36	14.28	15.16	15.76	18.83
● 5th recycled paper	12.98	13.34	14.04	14.88	15.46	16.06

Fig. 4.2: Burst factor of pure bleached bagasse paper sheet at vairous CSF for different recycled stages.

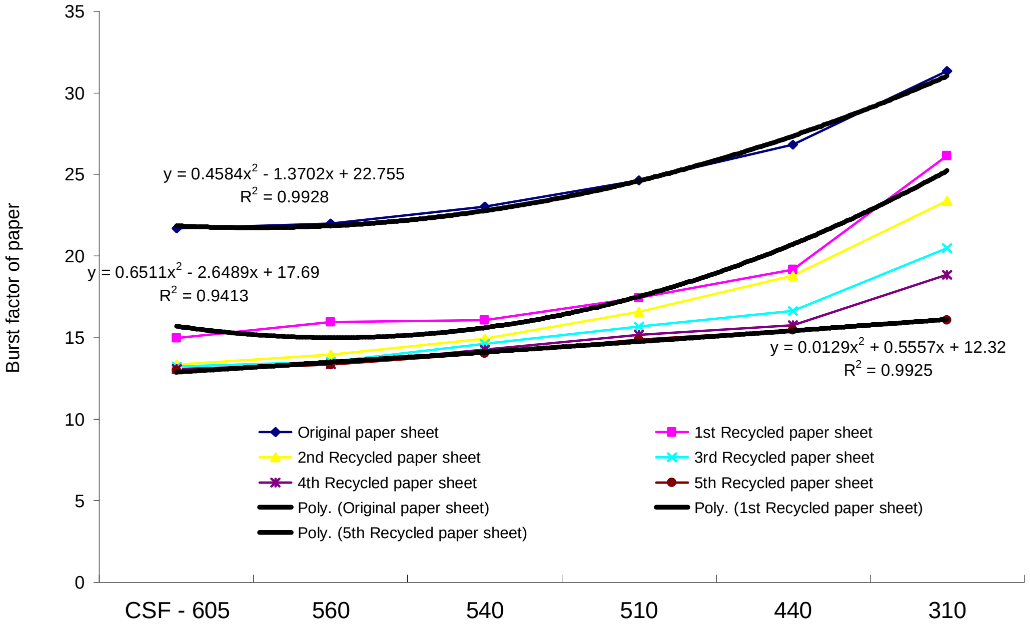
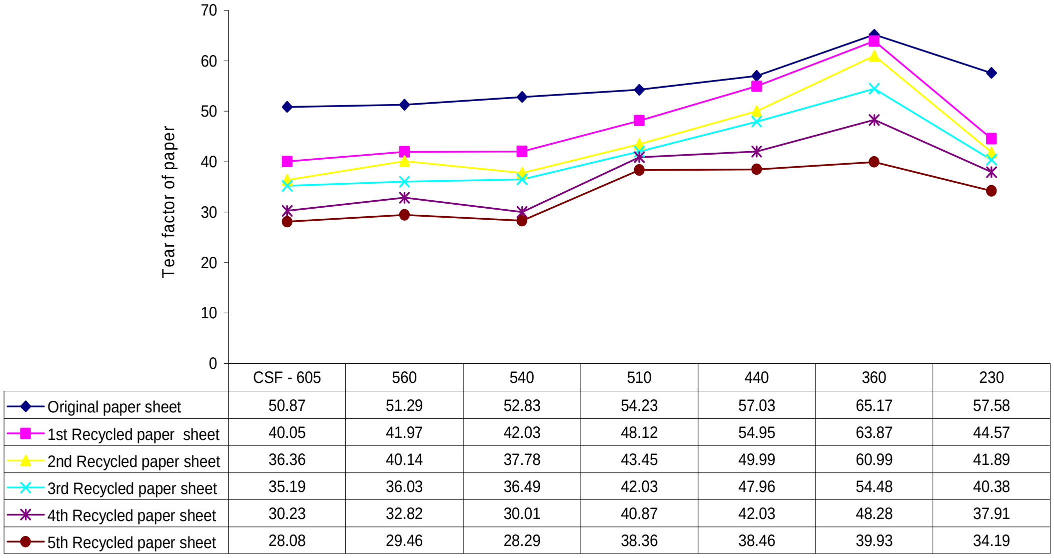


Fig. 2 A: Statistical graph of burst factor of pure bleached bagasse paper sheet at various CSF for different recycled stages.



	CSF - 605	560	540	510	440	360	230
◆ Original paper sheet	50.87	51.29	52.83	54.23	57.03	65.17	57.58
■ 1st Recycled paper sheet	40.05	41.97	42.03	48.12	54.95	63.87	44.57
▲ 2nd Recycled paper sheet	36.36	40.14	37.78	43.45	49.99	60.99	41.89
× 3rd Recycled paper sheet	35.19	36.03	36.49	42.03	47.96	54.48	40.38
✳ 4th Recycled paper sheet	30.23	32.82	30.01	40.87	42.03	48.28	37.91
● 5th Recycled paper sheet	28.08	29.46	28.29	38.36	38.46	39.93	34.19

Fig. 4.3: Tear factor of pure bleached bagasse paper sheet at various CSF for different recycled stages.

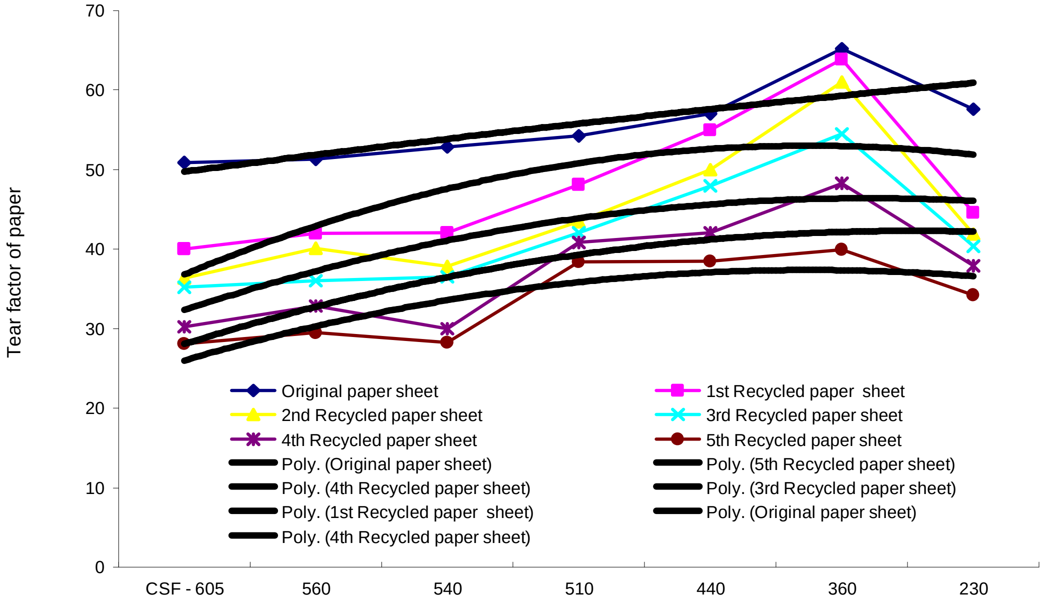


Fig. 3 A : Statistical graph of tear factor of pure bleached bagasse paper sheet at various CSF for different recycled stages.

SECTION B

4.4 Effect of addition of chemicals on breaking length

Experiments were performed to study the effect of chemicals on the breaking length of paper sheet of bleached bagasse pulp. The following sets of experiments were performed with different doses of chemicals:

1. Experiment 1- In the first experiment, breaking length of the original paper sheet without the addition of chemical was evaluated.
2. Experiment 2- In the next experiment, fortified rosin size (1.2%) was added to control the absorbency of water in the paper. Poly-aluminium chloride (PAC) was added to control the pH of the admixture at 5.0 ± 0.5. The breaking length of the paper sheet was evaluated.
3. Experiment 3- Fortified rosin size (1.2%) was added to control the absorbency of water in the paper, poly-aluminium chloride (PAC) was added to control the pH of the admixture at 5.0 ± 0.5. Further, 15% soapstone powder (filler) was added and the breaking length of the paper sheet was evaluated.
4. Experiment 4- Fortified rosin size (1.2%) was added to control the absorbency of water in the paper. Poly-aluminium chloride (PAC) was added to control the pH of the admixture at 5.0 ± 0.5. Soapstone (15%) powder (filler) was added and the breaking length of the paper sheet was evaluated. Anionic polyacrylamide and modified polyethyleneimine were added in the pulp in varying doses to improve the paper sheet consolidation. In experiment 4, anionic polyacrylamide (0.3%) and modified polyethyleneimine (0.04%) were added. The breaking length of paper sheet was evaluated by testing in laboratory for strength properties.
5. Experiment 5- In experiment 5, the doses of anionic polyacrylamide and modified polyethyleneimine were changed while keeping the doses of other chemicals same as in experiment 4. Anionic polyacrylamide (0.4%) and modified polyethyleneimine (0.05%) were added.
6. Experiment 6- In experiment 6, anionic polyacrylamide (0.5%) and modified polyethyleneimine (0.08%) were added keeping the doses of other chemicals same as in experiment 4.

The composition of the pulp for the different experiments has been summarized in **Table 4.1.**

TABLE 4.1

The composition of pulp for different experiments

Expt. No.	**Bagasse Pulp (%)**	**Rosin size (%)**	**PAC**	**Filler (%)**	**Anionic polyacrylamide (%)**	**Modified polyethyleneimine (%)**
1	100	nil	nil	nil	nil	nil
2	100	1.2	yes	nil	nil	nil
3	100	1.2	yes	15	nil	nil
4	100	1.2	yes	15	0.3	0.04
5	100	1.2	yes	15	0.4	0.05
6	100	1.2	yes	15	0.5	0.08

All the six experiments were performed at different CSF and the results are plotted in **Fig. 4.4**. The following conclusions can be drawn from **Fig. 4.4**.

1. When an increase in the beating of the bleached bagasse pulp, the breaking length of the paper sheet increases up to a CSF of 230 ml. The breaking length of the paper sheet decreases after the optimum value of CSF.
2. The breaking length of the paper sheet is found to decrease with the addition of fortified rosin size and PAC. This trend was observed at all the values of CSF.
3. The breaking length of the paper sheet further decreases with the addition of the soapstone powder (filler). This trend was observed at all the values of CSF.
4. There is an enhancement in breaking length of the paper sheet by addition of anionic polyacrylamide and modified polyethyleneimine. The degree of enhancement is different at various CSF. The maximum increase in breaking length was observed at 310 ml CSF.
5. Three set of experiments were performed to study the effect of the retention aids

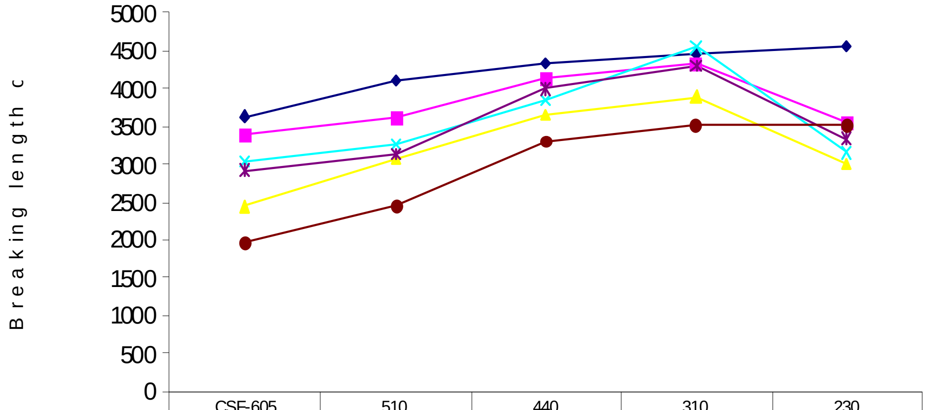
anionic polyacrylamide and modified polyethyleneimine. It can be noticed that lower dose of anionic polyacrylamide (0.3%) and modified polyethyleneimine (0.04%) were effective at higher CSF (605, 510, 440 ml) while more dose of anionic polyacrylamide (0.5%) and modified polyethyleneimine (0.08%) were effective at lower CSF (310 and 230 ml).

6. The maximum improvement in breaking length was observed at CSF 310 ml. It is recommended for the paper mills to use this combination of anionic polyacrylamide (0.3%) and modified polyethyleneimine (0.04%) to maintain the beating degree at 310 ml CSF to get the maximum strength of paper sheet.

4.5 Effect of addition of chemicals on burst factor

Experiments were performed to study the effect of chemicals on the burst factor of paper sheet prepared from bleached bagasse pulp. The six set of experiments mentioned under section 4.4 were performed and the results are plotted in **Fig. 4.5.** The following conclusions can be drawn from **Fig. 4.5 :**

1. The burst factor of original paper was found to increase with a decrease in CSF.
2. The significant effect of fortified rosin size and poly-aluminium chloride was observed on burst factor.
3. The burst factor of the paper sheet was found to decrease with the addition of the soap stone powder (filler). This trend was observed at all the values of CSF.
4. A significant increase in the burst factor was observed with the addition of 0.5% anionic polyacrylamide and 0.08% modified polyethyleneimine at lower values of CSF when compared with (100% BG, X+Y) composition of the pulp slurry. It implies that the high dose of retention aids was more effective at lower CSF.



	CSF-605	510	440	310	230
100%BG, No chemicals added	3635.86	4114.29	4336.04	4463.25	4572.76
100%BG, X	3388.52	3621.15	4130.77	4341.85	3547.68
100%BG, X+Y	2437.48	3056.41	3653.04	3887.69	2998.61
100%BG, X+Y+0.3%SN+0.04%CA	3045.31	3264.39	3843.11	4540.72	3152.25
100%BG, X+Y+0.4%SN+0.05%CA	2921.04	3141.77	3995.07	4296.31	3340.41
100%BG, X+Y+0.5%SN+0.08%CA	1967.02	2451.28	3305.06	3515.35	3512.56

Fig. 4.4: Breaking length vs. CSF of original paper sheet prepared from bleached bagasse pulp by the addition of sizing chemicals, soap stone filler, varying doses of anionic polyacrylamide and modified polyethyleneimine.

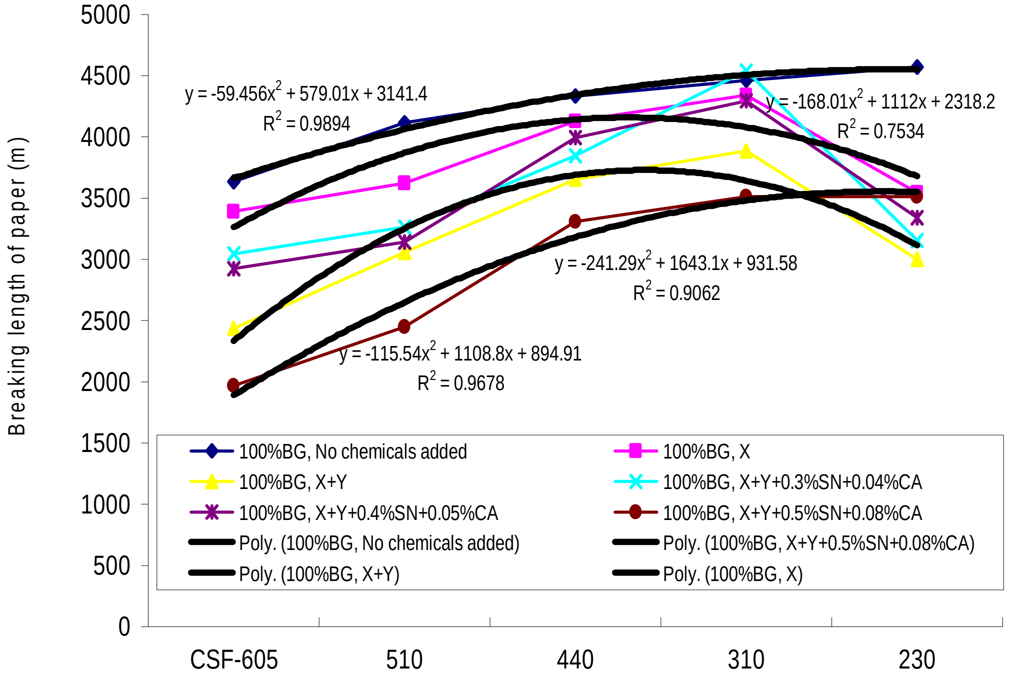
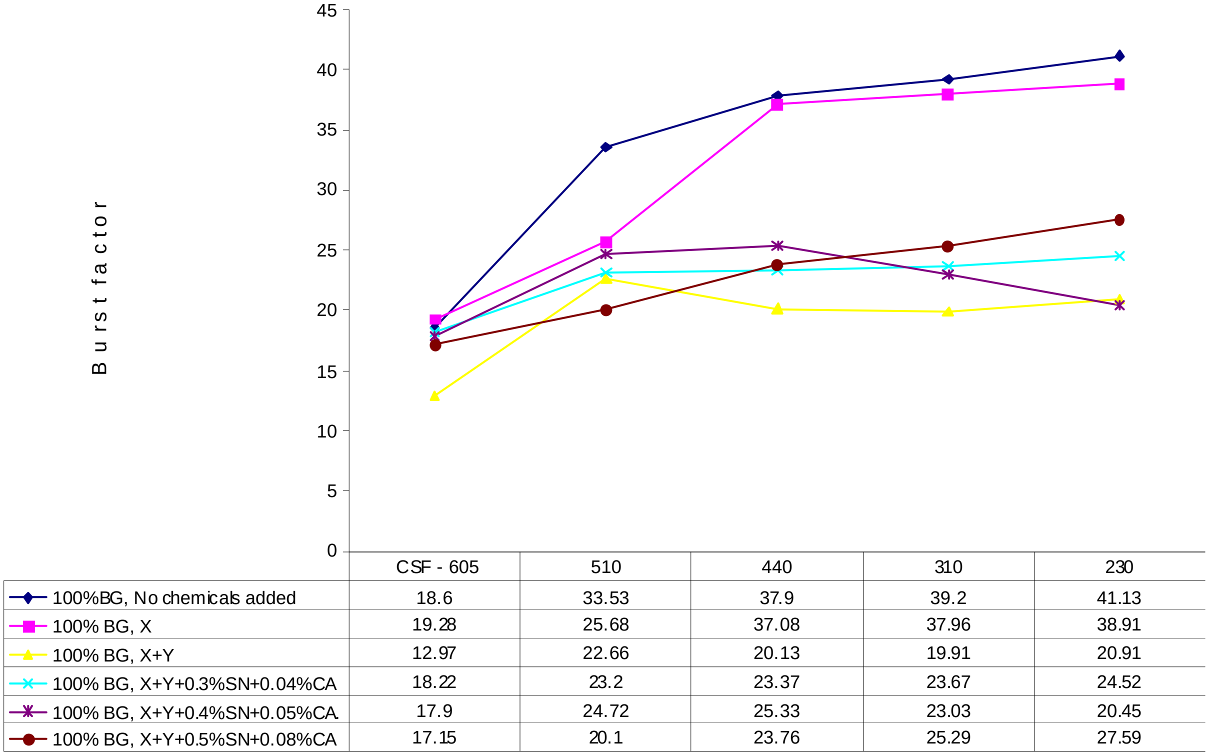


Fig. 4 A: Statistical graph of breaking length vs. CSF of original paper sheet prepared from bleached bagasse pulp by the addition of sizing chemicals, soap stone filler, varying doses of anionic polyacrylamide and modified polyethyleneimine.



	CSF - 605	510	440	310	230
◆ 100%BG, No chemicals added	18.6	33.53	37.9	39.2	41.13
■ 100% BG, X	19.28	25.68	37.08	37.96	38.91
▲ 100% BG, X+Y	12.97	22.66	20.13	19.91	20.91
× 100% BG, X+Y+0.3%SN+0.04%CA	18.22	23.2	23.37	23.67	24.52
✱ 100% BG, X+Y+0.4%SN+0.05%CA.	17.9	24.72	25.33	23.03	20.45
● 100% BG, X+Y+0.5%SN+0.08%CA	17.15	20.1	23.76	25.29	27.59

Fig. 4.5: Burst factor vs. CSF, of original paper sheet prepared from bleached bagasse pulp by the addition of sizing chemicals, soap stone filler, varying doses of polyacrylamide (SN) and polyethyleneimine (CA).

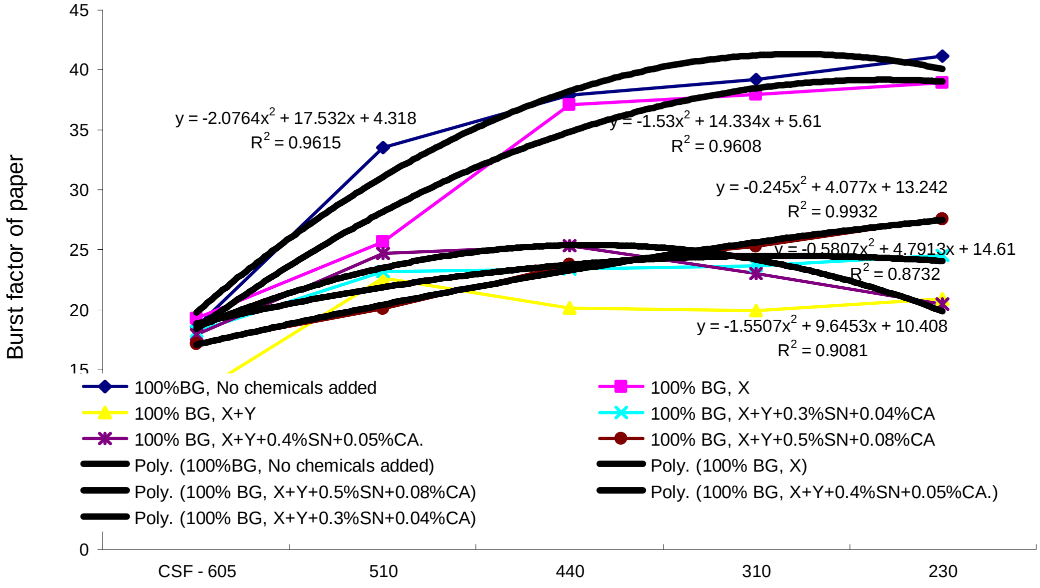


Fig. 5 A: Statistical graph of Burst factor vs. CSF, of original paper sheet prepared from bleached bagasse pulp by the addition of sizing chemicals, soap stone filler, varying doses of sursalone and catiofast.

4.6 Effect of addition of chemicals on tear factor

Experiments were performed to study the effect of chemicals on the tear factor of paper sheet of bleached bagasse pulp. The six set of experiments mentioned under section 4.4 were performed and the results are plotted in **Fig. 4.6.** The following conclusions can be drawn from **Fig. 4.6**:

1. A gradual increase in tear factor of the original paper sheet was noticed with a decrease in CSF except at 230ml CSF.
2. A significant effect of fortified rosin size was observed on tear factor of the paper sheet was observed.
3. A significant increase in tear factor of the paper sheet by the addition of anionic polyacrylamide and modified polyethyleneimine was observed at lower values of CSF (440 and 310 ml) except on 230 ml CSF.

4.7 Effect of addition of chemicals on breaking length after the first recycles

Experiments were performed to study the effect of chemicals on the breaking length of paper sheet of bleached bagasse pulp. The following sets of experiments were performed with different doses of chemicals:

Experiment 1 - In the first experiment, breaking length of the first recycled paper sheet without the addition of chemical was evaluated.

Experiment 2 - In the next experiment, fortified rosin size (1.2%) was added to control the absorbency of water in the paper. Poly-aluminium chloride was added to control the pH of the admixture at 5.0 ± 0.5. The breaking length of the paper sheet was evaluated.

Experiment 3 - Fortified rosin size (1.2%) was added to control the absorbency of water in the paper. Poly-aluminium chloride (PAC) was added to control the pH of the admixture at 5.0 ± 0.5. Further, 15% soapstone powder (filler) was added and the breaking length of the paper sheet was evaluated.

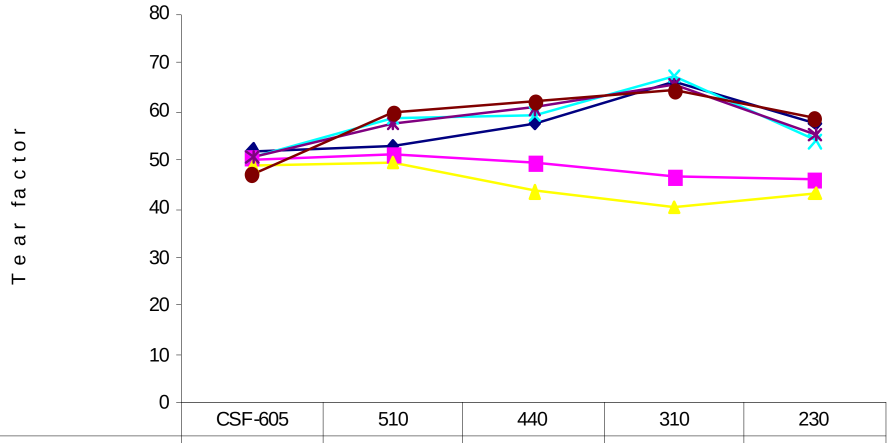
Experiment 4 - Fortified rosin size (1.2%) was added to control the absorbency of water in the paper. Poly-aluminium chloride (PAC) was added to control the pH of the admixture at 5.0 ± 0.5. Soapstone powder (filler) was added and the breaking length of the paper sheet was evaluated. Anionic polyacrylamide and modified polyethyleneimine were added in the pulp in varying doses to improve the paper sheet consolidation. In experiment 4, anionic polyacrylamide (0.3%) and modified polyethyleneimine (0.04%) were added. The breaking length of paper sheet was evaluated by testing in laboratory for strength properties.

Experiment 5 - In experiment 5, the doses of anionic polyacrylamide and modified polyethyleneimine were changed while keeping the doses of other chemicals same as in experiment 4, anionic polyacrylamide (0.4%) and modified polyethyleneimine (0.05%) were added.

Experiment 6 - In experiment 6, anionic polyacrylamide (0.5%) and modified polyethyleneimine (0.08%) were added keeping the doses of other chemicals same as in experiment 4.

All the six experiments were performed at different CSF. The composition of the pulp for the six experiments mentioned above is summarized in **Table 4.1** and the results are plotted in **Fig. 4.7.** The following conclusions can be drawn from **Fig. 4.7**:

1. With an increase in the beating of the bleached bagasse pulp, the breaking length of the paper sheet increases up to 310 ml CSF. The breaking length of the paper sheet decreases after the optimum value of CSF.
2. The breaking length of the paper sheet is found to decrease with the addition of fortified rosin size and PAC. This trend was observed at all the values of CSF.
3. The breaking length of the paper sheet further decreases with the addition of filler and this trend was observed at all the values of CSF.
4. It is observed that the addition of 0.3% anionic polyacrylamide and 0.04% modified polyethyleneimine resulted in improvement of breaking length up to 310 ml CSF. But at 310 ml CSF, 0.4% anionic polyacrylamide and 0.05% modified polyethyleneimine is more effective.



	CSF-605	510	440	310	230
100%BG, No chemicals added	51.97	52.72	57.37	66.19	57.58
100% BG, X	50.25	51.38	49.19	46.58	45.79
100% BG, X+Y	48.57	49.32	43.36	40.27	43.03
100% BG, X+Y+0.3%SN+0.04%CA	50.67	58.54	59.4	67.09	53.77
100% BG, X+Y+0.4%SN+0.05%CA	50.68	57.38	60.55	65.34	54.97
100% BG, X+Y+0.5%SN+0.08%CA	47.27	59.62	61.91	64.19	58.79

Fig. 4.6: Tear factor vs. CSF, of paper sheet prepared from bleached bagasse pulp by the addition of sizing chemicals, soapstone filler and varying doses of anionic polyacrylamide and modified polyethyleneimine.

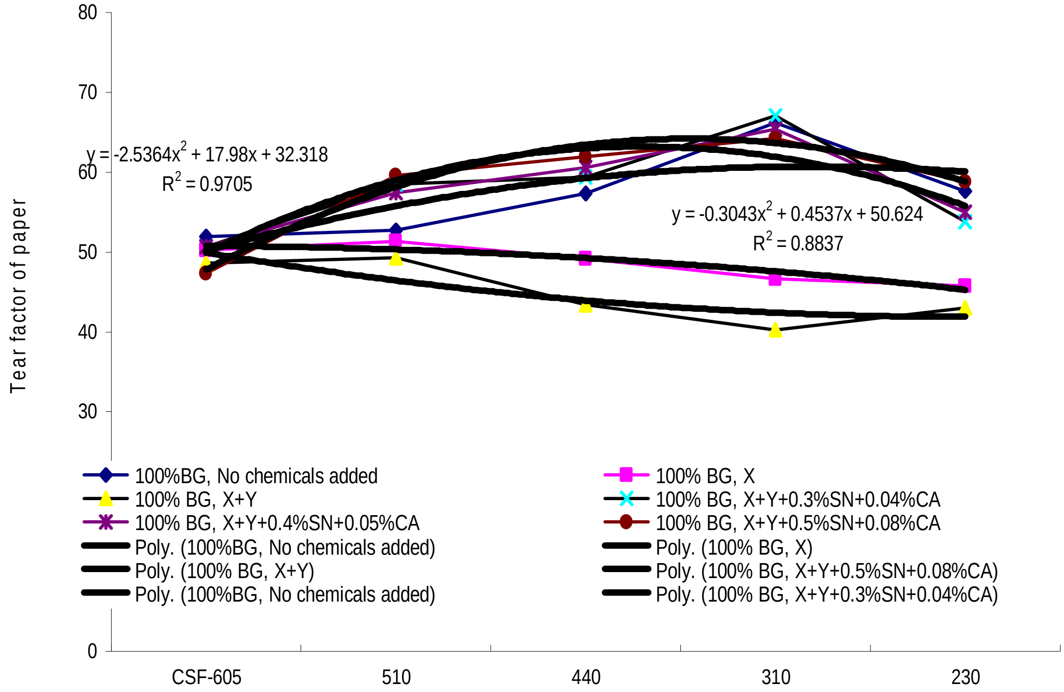
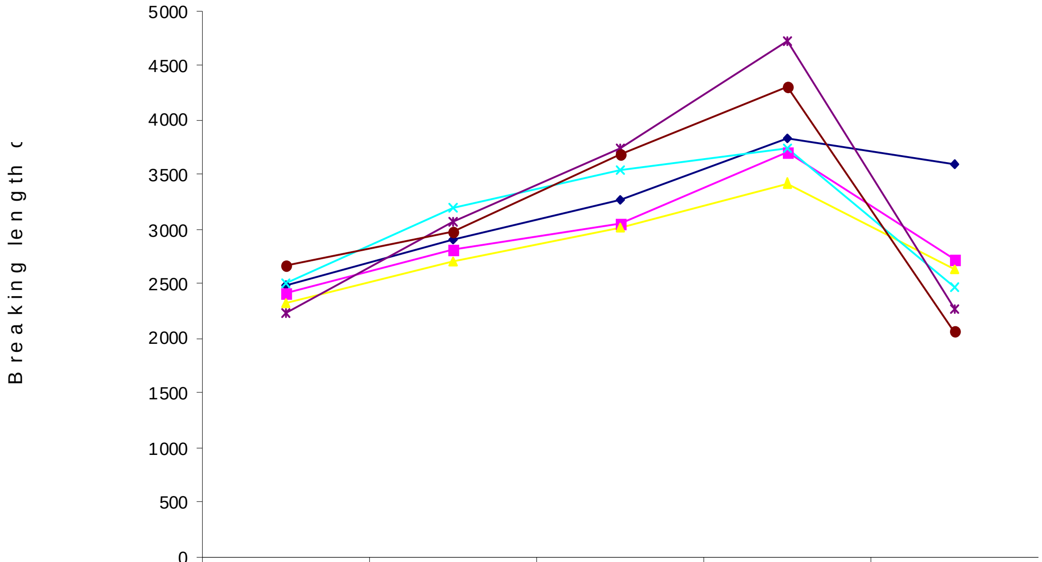


Fig. 6 A: Statistical graph of tear factor vs. CSF, of paper sheet prepared from bleached bagasse pulp by the addition of sizing chemicals, soap stone filler and varying doses of anionic polyacrylamide and modified polyethyleneimine.



	CSF - 605	510	440	310	230
◆ 100% BG, No chemicals added	2490.71	2904.81	3272.17	3839.19	3601.27
■ 100% BG, X	2416.11	2822.01	3057.66	3703.84	2725.94
▲ 100% BG, X+Y	2318.91	2704.71	3009.24	3423.79	2631.31
× 100% BG, X+Y+0.3%SN+0.04%CA	2512.81	3190.81	3547.61	3746.83	2472.92
✱ 100% BG, X+Y+0.4%SN+0.05%CA	2236.19	3073.43	3745.98	4719.24	2270.69
● 100% BG, X+Y+0.5%SN+0.08%CA	2668.75	2973.89	3695.14	4300.72	2057.59

Fig. 4.7: Breaking length vs. CSF, of first recycled paper sheet prepared from bleached bagasse pulp by adding sizing chemicals, soap stone filler, and varying doses of polyacrylamide(SN) and polyethyleneimine(CA).

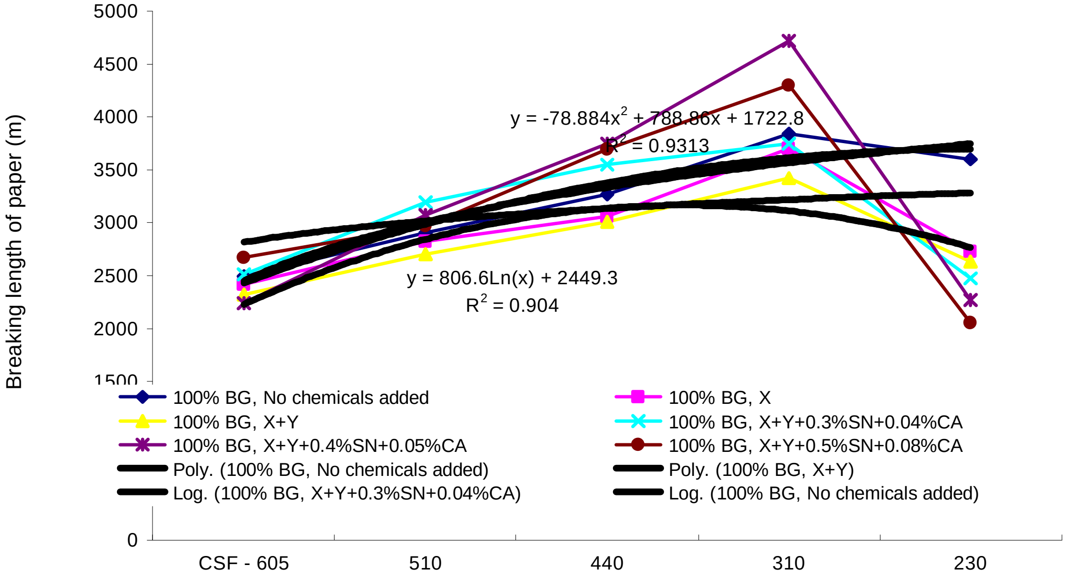


Fig. 7 A: Statistical graph of breaking length vs. CSF, of first recycled paper sheet prepared from bleached bagasse pulp by adding sizing chemicals, soap stone filler, and varying doses of sursalone and catiofast.

4.8 Effect of addition of chemicals on burst factor after first recycle of paper

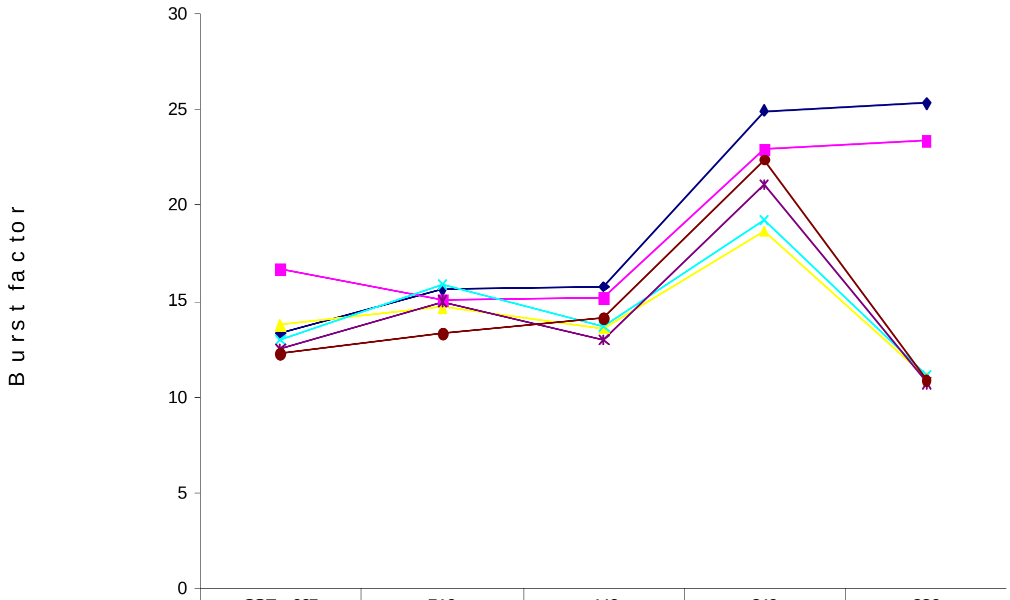
Experiments were performed to study the effect of chemicals on the burst factor of paper sheet of bleached bagasse pulp. The six set of experiments mentioned under section 4.7 were performed and the results are plotted in **Fig. 4.8.** The following conclusions can be drawn from **Fig. 4.8:**

1. The burst factor of first recycle paper was found to increase with a decrease in CSF.
2. No significant effect of fortified rosin and poly-aluminium chloride was observed on the burst factor.
3. The burst factor of the paper sheet was found to decrease with the addition of the soap stone powder (filler). This trend was observed at all the values of CSF but more reduction in burst factor was observed at 230 ml CSF.
4. The burst factor was found to increase by 19.82% at 310 ml CSF when compared with (100%BG, X+Y) with the addition of 0.5% anionic polyacrylamide and 0.08% modified polyethyleneimine at lower values of CSF. It implies that the high dose of retention aids was more effective at 310 ml CSF. But at 230 ml CSF the high dose of anionic polyacrylamide and modified polyethyleneimine is not effective.

4.9 Effect of addition of chemicals on tear factor after first recycle of paper

The six set of experiments mentioned under section 4.7 were performed for evaluation of the tear factor and the results are plotted in **Fig. 4.9**. The following conclusions can be drawn from **Fig. 4.9**:

1. The tear factor of first recycle paper sheet increases with the decrease in CSF.
2. The concentration of retention aids (0.3% anionic polyacrylamide and 0.4% modified polyethyleneimine) is more effective, to make up the loss of tear factor at all the values of CSF except 230 ml CSF and the values of (100% BG, X+Y). was compared with (100% BG, 0.3%X+ 0.04% Y).
3. In case of 230 ml CSF, high concentration of retention aids chemicals are effective in comparison to 605, 540, 440, and 310 ml CSF.
4. To recover this reduction of tear factor at 230 ml CSF, other strength improving chemicals may be used.



	CSF - 605	510	440	310	230
100% BG, No chemicals added	13.33	15.57	15.76	24.9	25.28
100% BG, X+No(Y+SN+CA)	16.68	15.06	15.19	22.87	23.33
100% BG, X+Y+No(SN+CA)	13.73	14.65	13.59	18.67	10.96
100% BG, X+Y+0.3%SN+0.04%CA	12.98	15.81	13.65	19.2	11.11
100% BG, X+Y+0.4%SN+0.05%CA	12.47	14.99	12.97	21.07	10.74
100% BG, X+Y+0.5%SN+0.08%CA	12.23	13.31	14.07	22.37	10.91

Fig. 4.8: Burst factor vs. CSF, of first recycled paper sheet prepared from bleached bagasse pulp by the addition of sizing chemicals, soap stone filler, and varying doses of polyacrylamide (SN) and polyethyleneimine (CA).

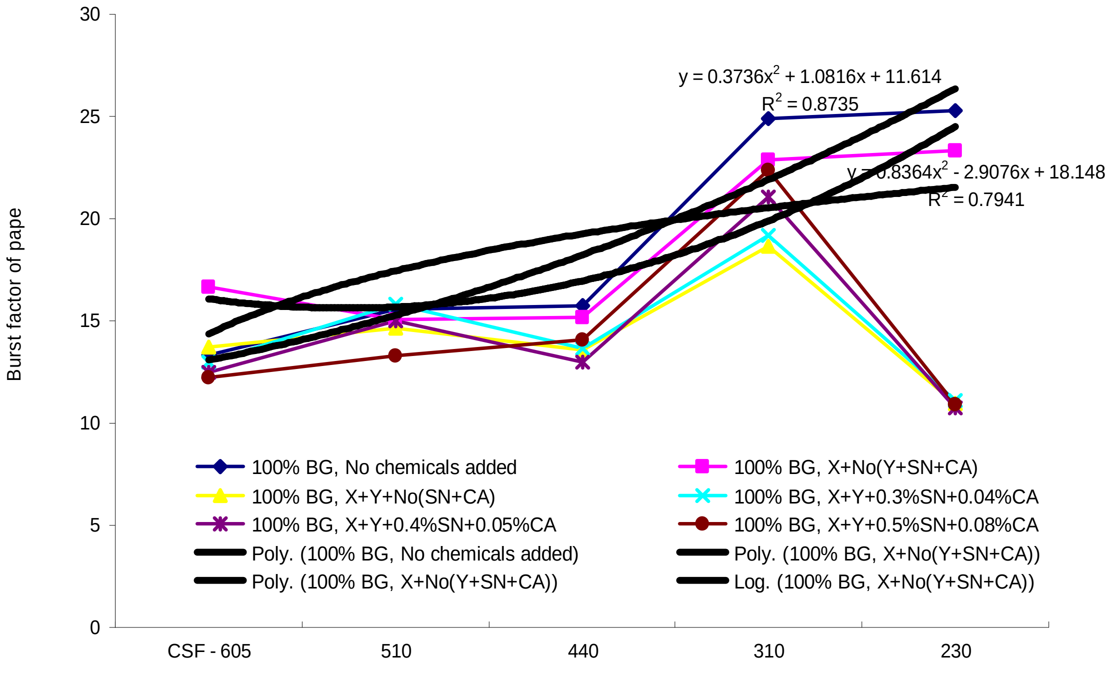
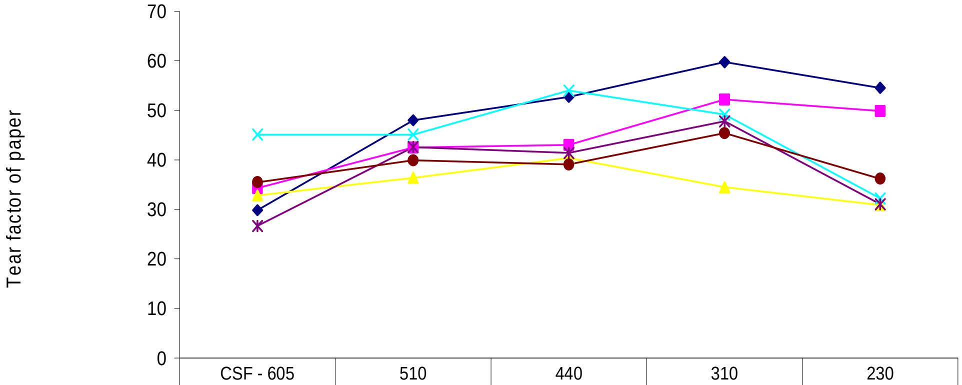


Fig. 8 A: Statistical graph of burst factor vs. CSF, of first recycled paper sheet prepared from bleached bagasse pulp by the addition of sizing chemicals, soap stone filler, and varying doses of sursalone and catiofast.



	CSF - 605	510	440	310	230
◆ 100% BG, No chemicals added	29.84	48.01	52.76	59.76	54.58
■ 100% BG, X+No(Y+SN+CA)	34.29	42.51	43.02	52.21	49.88
▲ 100% BG, X+Y+No(SN+CA)	32.84	36.43	40.41	34.51	30.91
× 100% BG, X+Y+0.3%SN+0.04%CA	45.12	45.12	54.02	49.16	32.23
✳ 100% BG, X+Y+0.4%SN+0.05%CA	26.67	42.62	41.41	47.83	31.07
● 100% BG, X+Y+0.5%SN+0.08%CA	35.48	39.95	39.06	45.44	36.19

Fig. 4.9: Tear factor vs. CSF, of first recycled paper sheet prepared from bleached bagasse pulp blended with bleached bamboo pulp with the addition of sizing chemicals, soap stone filler and varying doses of sursalone and catiofast.

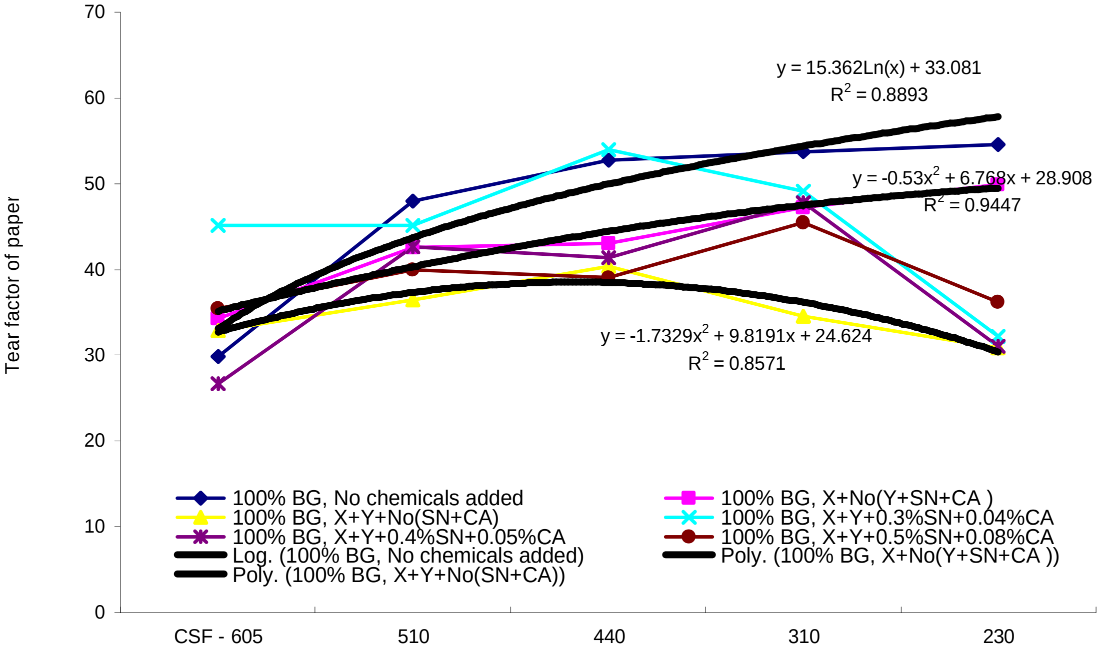


Fig. 9 A: Statistical graph of tear factor vs. CSF, of first recycled paper sheet prepared from bleached bagasse pulp blended with blgd. bamboo pulp with the addition of sizing chemicals, soap stone filler and varying doses of sursalone and catiofast.

4.10 Effect of blending of long fibreed pulp and addition of chemicals on breaking length after the second recycle of paper sheet

The strength properties of first recycled paper decreased to an appreciable extent and it was not fruitful to recycle the paper without adding chemicals and long fibreed pulp in paper making at second recycled stage. Experiments were performed to study the effect of blending of long fibreed pulp and addition of chemicals on the breaking length of paper sheet of bleached bagasse pulp. Total seven experiments were performed after varying the composition of the pulp furnish. Long fibre pulp was added in different proportions to the recycled pulp slurry from the first recycled stage. The CSF of the long fibre pulp was maintained equal to the CSF of the recycled pulp slurry from the first stage to ensure uniform bonding. The different chemicals (fortified rosin size, poly-aluminium chloride, filler, anionic polyacrylamide and modified polyethyleneimine) were added in varying doses to study their effect on the breaking length of the recycled paper sheet. Fortified rosin size was added to control the absorbency of water of the paper sheet. PAC was added to maintain the pH as well as to retain the fortified rosin size on the fibre surface. Soapstone powder was added as filler to increase the opacity of the paper as well as to enhance the brightness and surface properties of the paper sheet. Anionic polyacrylamide and modified polyethyleneimine were added as retention aids. The composition of the pulp for the 7 experiments is tabulated in **Table 4.2.** The experiments were performed at different CSF and the breaking length of the paper sheet was evaluated for all the CSF.

All these seven experiments were performed at different CSF and the results are plotted in **Fig.4.10**. The following conclusions can be drawn from **Fig. 4.10**:

1. The breaking length of paper sheet increases with the decrease in the CSF.
2. There is an increase in breaking length due to the blending of long fibre pulp and addition of anionic polyacrylamide (0.3%) and modified polyethyleneimine (0.04%) as retention aids.
3. With an increase in amount of retention aids dosing (anionic polyacrylamide (0.5%) and modified polyethyleneimine (0.08%) and keeping the other parameters same, an improvement in the breaking length is observed. It implies that the increased doses of retention aids are beneficial in this case.
4. An increase in breaking length is observed in experiment no.3 (20% blending of long fibreed pulp and addition of anionic polyacrylamide (0.3%) and modified

polyethyleneimine (0.04%) retention aids while keeping other parameters same.

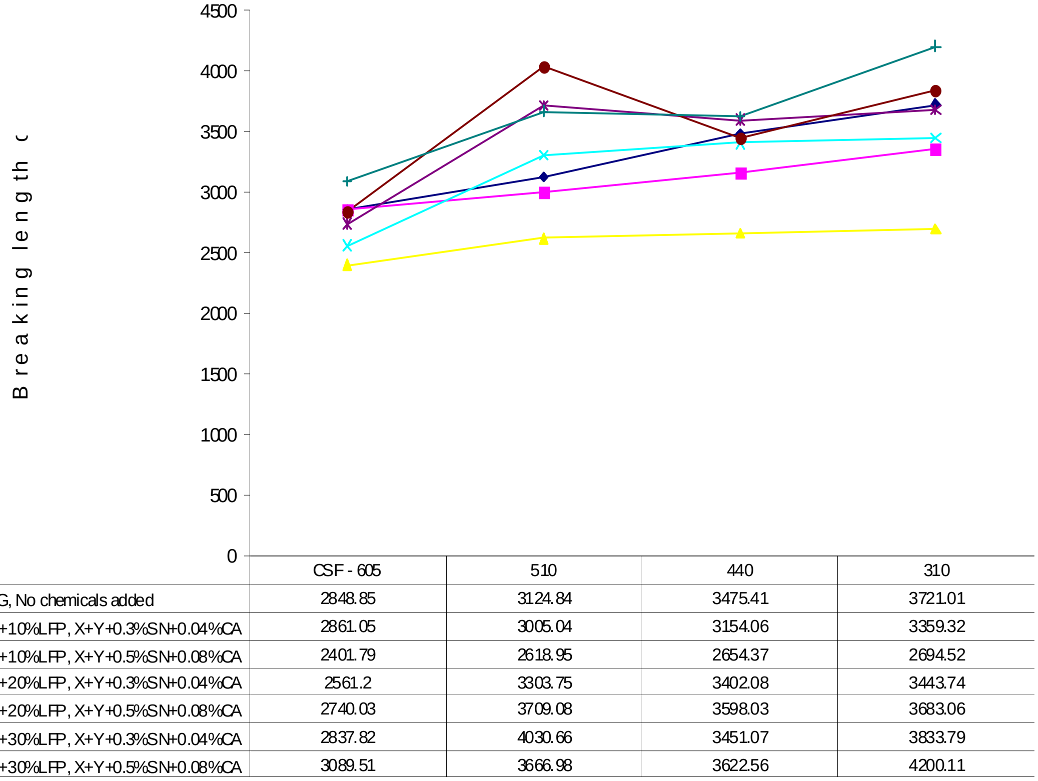
5. A further improvement in breaking length was observed in experiment 4 (by increasing the retention aids (anionic polyacrylamide (0.5%) and modified polyethyleneimine (0.08%)).
6. Generally the breaking length of the paper sheet increases with a decrease in CSF. But it can be noticed from **Fig. 4.10** that the breaking length obtained at 510 ml CSF (experiment no. 5) is almost equal to breaking length at 310 ml CSF. This effect is due to the increase in blending of the long fibre pulp and addition of retention aids.
7. The breaking length of the second recycled paper sheet was found to be maximum at 310 ml CSF (experiment no. 6) in case of 30% blending of long fibre and addition of retention aids (anionic polyacrylamide 0.5% and modified polyethyleneimine 0.08%). The breaking length obtained in experiment no.6 at 310 ml CSF is more than the breaking length obtained at 510 ml CSF in experiment no. 5.

4.11 Effect of blending of long fibreed pulp and addition of chemicals on burst factor after the second recycled of paper sheet

A total of 11 experiments were performed by varying the composition of the pulp. Long fibre pulp was added in different proportions to the recycled pulp slurry from the first recycled stage. The CSF of the long fibre pulp was maintained equal to the CSF of the recycled slurry from the first stage to ensure uniform bonding. The different chemicals (fortified rosin size, poly-aluminium chloride, filler, anionic polyacrylamide and modified polyethyleneimine) were added in varying doses to study their effect on the burst factor of the recycled paper sheet. Fortified rosin size was added to control the absorbency of water of the paper sheet. Poly aluminium chloride was added to maintain the pH as well as to retain the fortified rosin size on the fibre surfaces. Soapstone powder was added as filler to increase the opacity of the paper as well as to enhance the brightness and surface properties of the paper sheet. Anionic polyacrylamide and modified polyethyleneimine were added as retention aids (**Fig. 4.11**). The composition of the pulp for the 11 experiments is tabulated in **Table 4.3.** The experiments were performed at different CSF. The burst factor of the paper sheet was evaluated for all the 11 experiments and the results are plotted in **Fig. 4.11.**

TABLE 4.2
The effect on breaking length of blending of long fibreed pulp and addition of chemicals after second recycle of paper

Expt. No.	Bagasse pulp (%)	Long fibre pulp (%)	Rosin size (%)	PAC	Filler (%)	Anionic polyacrylamide (%)	Modified polyethyleneimine (%)
1	100	nil	nil	nil	nil	nil	nil
2	90	10	1.2	yes	15	0.3	0.04
3	90	10	1.2	yes	15	0.5	0.08
4	80	20	1.2	yes	15	0.3	0.04
5	80	20	1.2	yes	15	0.5	0.08
6	70	30	1.2	yes	15	0.3	0.04
7	70	30	1.2	yes	15	0.5	0.08



	CSF - 605	510	440	310
◆ 100%BG, No chemicals added	2848.85	3124.84	3475.41	3721.01
■ 90%BG+10%LFP, X+Y+0.3%SN+0.04%CA	2861.05	3005.04	3154.06	3359.32
▲ 90%BG+10%LFP, X+Y+0.5%SN+0.08%CA	2401.79	2618.95	2654.37	2694.52
× 80%BG+20%LFP, X+Y+0.3%SN+0.04%CA	2561.2	3303.75	3402.08	3443.74
✳ 80%BG+20%LFP, X+Y+0.5%SN+0.08%CA	2740.03	3709.08	3598.03	3683.06
● 70%BG+30%LFP, X+Y+0.3%SN+0.04%CA	2837.82	4030.66	3451.07	3833.79
+ 70%BG+30%LFP, X+Y+0.5%SN+0.08%CA	3089.51	3666.98	3622.56	4200.11

Fig. 4.10: B. L. vs. CSF, of 2nd recycled paper sheet prepared from blending the blgd. radiata pine wood pulp with blgd. bagasse pulp, by adding sizing chemicals, soap stone filler, and varying doses of polyacrylamide (SN) and polyethyleneimine (CA).

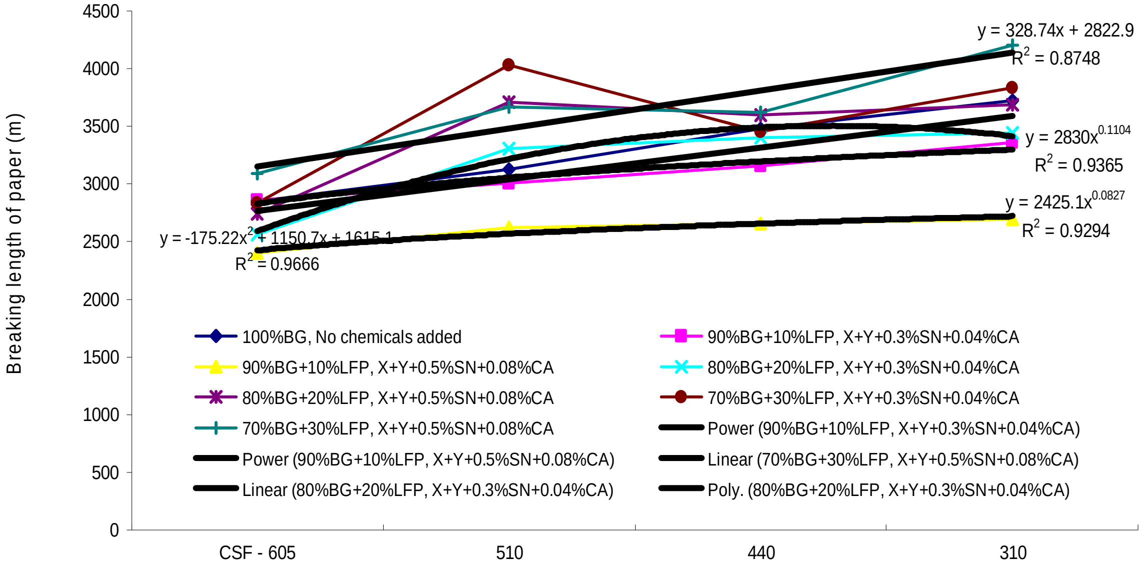
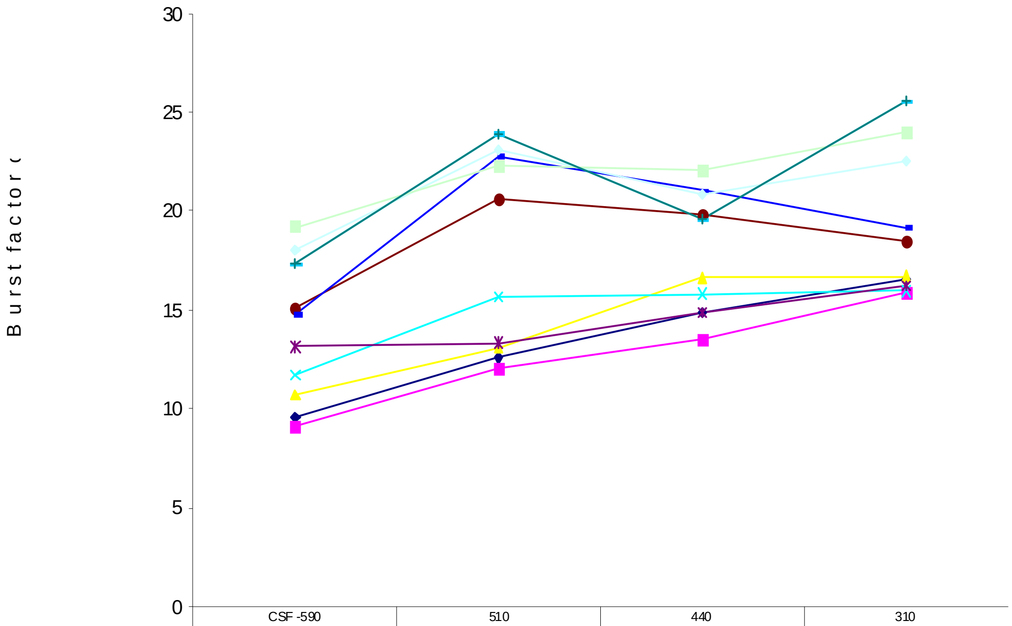


Fig. 4.10 A: Statistical graph of breaking length vs. CSF, of 2nd recycled paper sheet prepared from blending the blgd. radiata pine wood pulp with blgd. bagasse pulp, by adding sizing chemicals, soap stone filler, and varying doses of SN and CA.

TABLE 4.3

The effect of long fibreed pulp and addition of chemicals on burst factor of second recycle of paper sheet

Expt. No.	Bagasse (%)	Long fibre pulp (%)	Rosin size (%)	PAC	Filler (%)	Anionic polyacrylamide (%)	Modified polyethyleneimine (%)
1	100	nil	nil	nil	nil	nil	nil
2	100	nil	1.2	yes	15	nil	nil
3	90	10	1.2	yes	15	0.3	0.04
4	90	10	1.2	yes	15	0.4	0.05
5	90	10	1.2	yes	15	0.5	0.08
6	80	20	1.2	yes	15	0.3	0.04
7	80	20	1.2	yes	15	0.4	0.05
8	80	20	1.2	yes	15	0.5	0.08
9	70	30	1.2	yes	15	0.3	0.04
10	70	30	1.2	yes	15	0.4	0.05
11	70	30	1.2	yes	15	0.5	0.08



	CSF -590	510	440	310
100% BG, No chemicals added	9.53	12.55	14.83	16.57
100% BG, X+Y	9.07	11.97	13.46	15.84
90%BG+10%LFP, X+Y+0.3%SN+0.04%CA	10.71	13.07	16.61	16.71
90%BG+10%LFP, X+Y+0.4%SN+0.05%CA	11.67	15.66	15.81	15.93
90%BG+10%LFP, X+Y+0.4%SN+0.05%CA	13.11	13.32	14.83	16.21
80%BG+20%LFP, X+Y+0.3%SN+0.04%CA	15.11	20.55	19.81	18.51
80%BG+20%LFP, X+Y+0.4%SN+0.05%CA	14.79	22.81	21.01	19.18
80%BG+20%LFP, X+Y+0.5%SN+0.08%CA	17.33	23.91	19.58	25.55
70%BG+30%LFP, X+Y+0.3%SN+0.04%CA	18.04	23.11	20.83	22.51
70%BG+30%LFP, X+Y+0.4%SN+0.05%CA	19.17	22.25	22.03	23.95
70%BG+30%LFP, X+Y+0.5%SN+0.08%CA	17.33	23.91	19.58	25.55

Fig. 4.11: Burst factor vs. CSF, of paper sheet prepared from blending of bleached radiata pine wood pulp with bleached bagasse pulp, adding sizing chemicals, soap stone filler and varying doses of polyacrylamide (SN) and polyethyleneimine(CA).

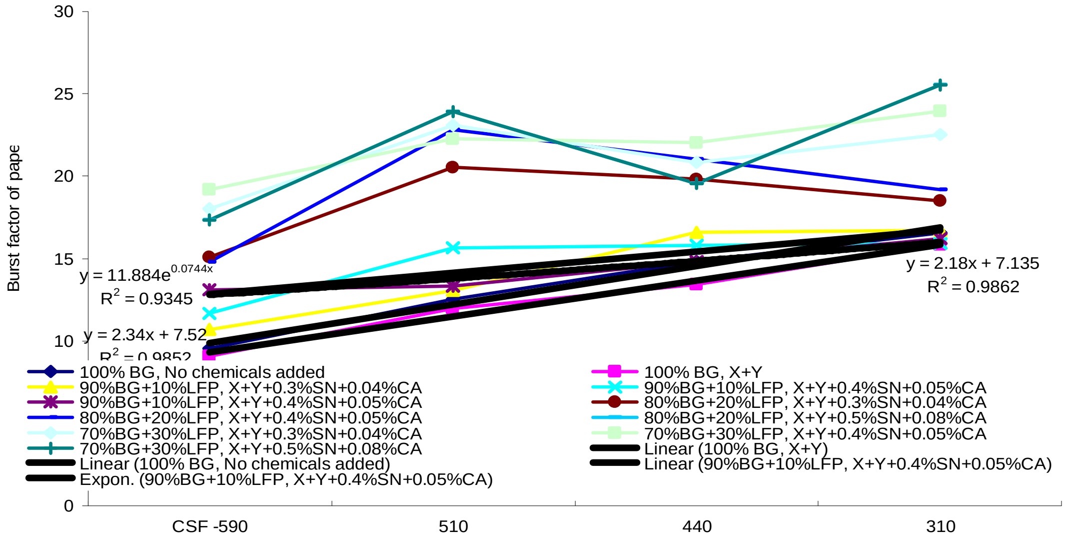


Fig. 11 A: Statistical graph of burst factor vs. CSF, of paper sheet prepared from blending of bleached radiata pine wood pulp with bleached bagasse pulp, adding sizing chemicals, soap stone filler and varying doses of SN and CA.

The following conclusions can be drawn from **Fig. 4.11**:

1. The burst factor increases as the CSF of the pulp decrease from 605 to 310 ml.
2. A decrease (4.4 to 9.2%) in burst factor is observed at each stage of CSF when 1.2% fortified rosin size and poly-aluminium chloride 2014 and 15% soap stone filler are added in the pulp.
3. An increase (15.3%) in burst factor was observed due to the blending of long Fibreed pulp.

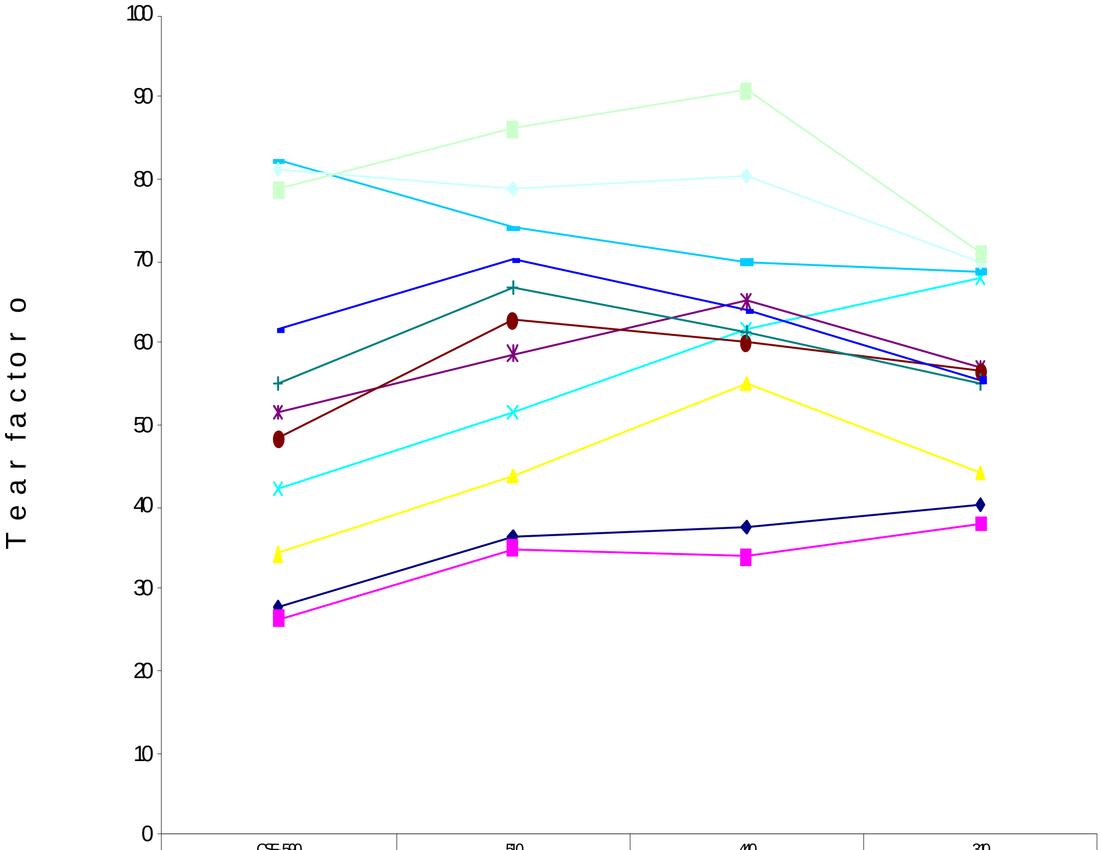
4.12 Effect of blending of long fibreed pulp and addition of chemicals on tear factor after second recycled of paper sheet

The tear factor of the paper sheet was evaluated for all the experiments and the results are plotted in **Fig. 4.12**.

TABLE 4.4

The effect of long fibreed pulp and addition of chemicals on tear factor in second recycle of paper sheet

Expt. No.	Bagasse (%)	Long Fibre pulp (%)	Rosin size (%)	PAC	Filler (%)	Anionic polyacrylamide (%)	Modified polyethyleneimine (%)
1	100	nil	nil	nil	nil	nil	nil
2	100	nil	1.2	yes	15	nil	nil
3	90	10	1.2	yes	15	0.3	0.04
4	90	10	1.2	yes	15	0.4	0.05
5	90	10	1.2	yes	15	0.5	0.08
6	80	20	1.2	yes	15	0.3	0.04
7	80	20	1.2	yes	15	0.4	0.05
8	80	20	1.2	yes	15	0.5	0.08
9	70	30	1.2	yes	15	0.3	0.04
10	70	30	1.2	yes	15	0.4	0.05
11	70	30	1.2	yes	15	0.5	0.08



	CSF-590	510	440	310
100% BG, No chemicals added	27.66	36.43	37.54	40.17
100% BG, X+Y+No(SN+CA)	26.37	34.97	33.97	38.04
90% BG+10% LFP, X+Y+0.3% SN+0.04% CA	34.31	43.87	55.06	44.09
90% BG+10% LFP, X+Y+0.4% SN+0.05% CA	42.16	51.49	61.59	67.97
90% BG+10% LFP, X+Y+0.5% SN+0.08% CA	51.68	58.77	65.02	57.03
80% BG+20% LFP, X+Y+0.3% SN+0.04% CA	48.54	62.77	59.98	56.67
80% BG+20% LFP, X+Y+0.4% SN+0.05% CA	54.98	66.78	61.39	55.26
80% BG+20% LFP, X+Y+0.5% SN+0.08% CA	61.58	70.03	63.97	55.65
70% BG+30% LFP, X+Y+0.3% SN+0.4% CA	82.27	74.01	69.94	68.88
70% BG+30% LFP, X+Y+0.4% SN+0.05% CA	80.97	78.97	80.51	69.74
70% BG+30% LFP, X+Y+0.5% SN+0.08% CA"	78.87	86.09	90.92	70.93

Fig 4.12: T.F. vs CSF, of 2nd recycled paper sheet prepared from blending of blgd. radiata pine wood pulp with blgd. bagasse pulp, adding sizing chemicals, soap stone filler, and varying doses of polyacrylamide (SN) and polyethyleneimine (CA).

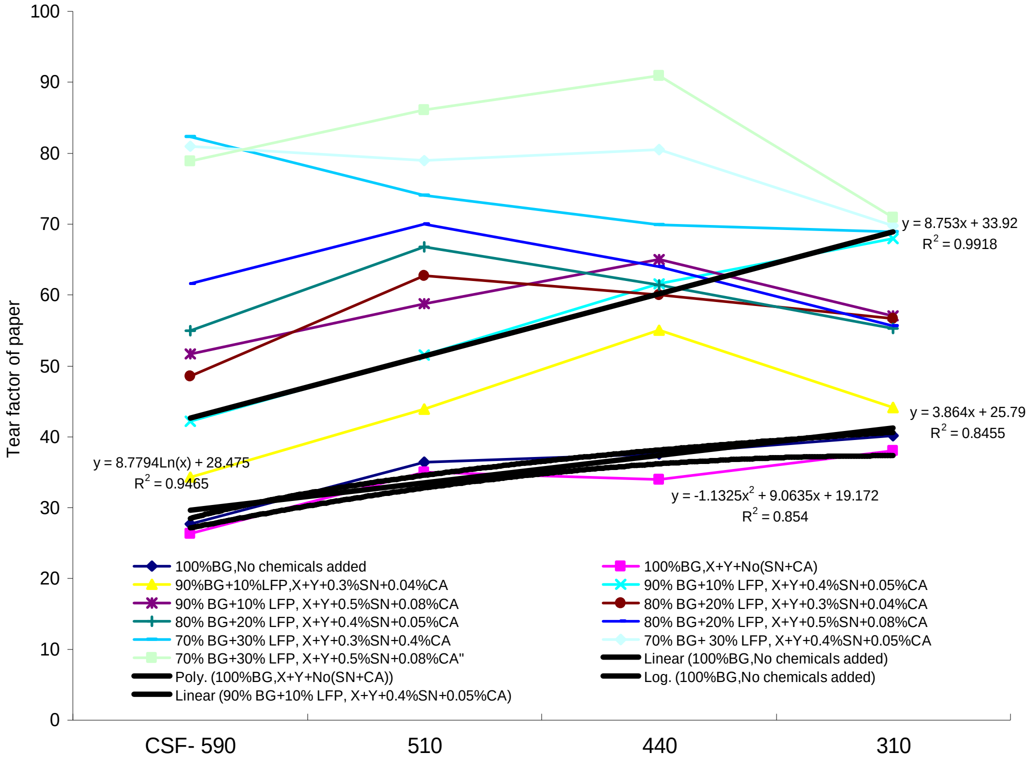


Fig. 12 A : Statistical graph of Tear factor. vs. CSF, of 2nd recycled paper prepared from blending of blgd. radiata pine pulp with blgd. bagasse pulp, adding sizing chemicals, soap stone filler, and varying doses of SN and CA.

The following conclusion can be drawn from **Fig. 4.12**.

1. It is observed that in case of blending of 70% bleached bagasse pulp fibre with 30% bleached bamboo pulp fibre and the addition of sizing and soap stone filler content and retention aids (0.5% anionic polyacrylamide and 0.08% modified polyethyleneimine) chemicals, the tear factor of the paper increase from 590 ml CSF to 440 ml CSF.
2. The tear factor of the paper made as per the above mentioned composition increase slowly from 510 ml to 310 ml CSF of pulp. But due to the addition of sizing and soap stone filler a slight decrease in tear factor was observed at 310 ml CSF, which might be due to the addition of filler in the stock at that beating degree of pulp fibres i.e. at 310 ml CSF.
3. It is also observed that the activity of increasing the dosing of anionic polyacrylamide and modified polyethyleneimine decrease slightly with the decrease in the CSF of the pulp fibres from 590 ml to 310 ml.
4. It is also observed that very slight increase in tear factor occurs due the increase in dosing of retention aids from 0.3% anionic polyacrylamide and 0.4% modified

polyethyleneimine to 0.5% anionic polyacrylamide and 0.08% modified polyethyleneimine content as per the **Fig 4.12**.

4.13 Effect of recycling on brightness and opacity of paper sheet

The ISO brightness and opacity of the original paper sheet first recycle paper and second recycle paper sheet were evaluated with the help of Color Touch-30 Brightness tester (Technidyne Corporation New Albany Indiana U.S.A.). The results for original paper sheet first recycle paper sheet and second recycle paper sheet are tabulated in **Table 4.5, 4.6** and **4.7** respectively. It is observed from the results that there are minor changes in the ISO brightness and opacity of the paper sheet when the paper sheet is recycled from initial state to the first recycled paper sheet. The average ISO brightness of original standard paper sheet is 71.89 and variance 0.42, where as in first recycled paper sheet it is about 72.95 units with the variance of 0.70 units. It was observed that brightness of paper sheet increases due to the addition of soap stone filler and other chemicals at the first and second recycled stage of paper sheet. The ISO opacity of the standard paper sheet also increases in the first recycled paper sheet when some additional chemicals were added while making the first recycled paper sheet. The increase in opacity was observed due to the addition of filler content having the extra brightness. The addition of long fibreed pulp having more brightness is also the reason of increasing the brightness in the case of second recycled paper sheet.

The addition of filler having good brightness is also the reason for an increase in the opacity. In the **Table 4.5**, the minimum opacity of standard paper sheet observed is about 80.1 units, when the first recycled paper sheet is prepared by adding fortified rosin size 1.2% and PAC–2014 solution for controlling the pH 4.5 to 5.5. There is 1.2% reduction in brightness due to the addition of fortified rosin size and PAC–2014 solution. The increase in opacity of first recycled paper observed is due to the addition of anionic polyacrylamide and modified polyethyleneimine chemicals at 230 ml CSF. It can be concluded that the opacity of the paper sheet increases due to the fibre shortening, as the fibre fines retention is more in the paper sheet with the use of retention aids chemicals. The more retention of fibre fines and filler content improves the smoothness and glaze of the paper sheet and reduce the porosity of the resulting paper sheet. Similarly, it can be concluded from the analysis of the results of brightness and opacity of the second recycled paper sheet that the ISO brightness and opacity of paper sheet increases due to the addition of filler and retention aids chemicals. The average ISO brightness and variance of standard paper sheet was observed from 73.81 and 1.09 units. The average ISO opacity and variance was observed 87.51 and 1.98 units (**Table 4.7**).

TABLE 4.5

Optical properties of original paper sheet prepared from bagasse pulp using fortified rosin size, PAC-2014, soap stone filler, anionic polyacrylamide (SN) and modified polyethyleneimine (CA)

S. No.	CSF(ml)	Paper sheet composition	ISO Brightness	ISO. Opacity
1	605	No chemicals added	71.1	79.5
2	”	X	71.8	79.6
3	”	X + Y	71.9	80.0
4	”	X + Y + 0.3% SN + 0.04% CA	72.5	80.0
5	”	X + Y + 0.4% SN + 0.05% CA	72.4	80.3
6	”	X + Y + 0.5% SN + 0.08% CA	72.3	78.7
7	510	X	71.8	80.0
8	”	X + Y	71.6	80.0
9	”	X + Y + 0.3% SN + 0.04% CA	71.8	82.7
10	”	X + Y + 0.4% SN + 0.05% CA	70.8	82.8
11	”	X + Y + 0.5% SN + 0.08% CA	71.9	83.7
12	440	No chemicals added	71.7	83.4
13	”	X	70.9	80.9
14	”	X + Y	71.4	80.4
15	”	X + Y + 0.3% SN + 0.04% CA	71.4	81.7
16	”	X + Y + 0.4% SN + 0.05% CA	71.8	82.3
17	”	X + Y + 0.5% SN + 0.08%CA	72.5	83.0
18	310	No chemicals added	73.3	78.1
19	”	X + Y + 0.3% SN + 0.04% CA	71.7	80.8
20	”	X + Y + 0.4% SN + 0.05% CA	71.4	80.0
21	”	X + Y + 0.5% SN + 0.08% CA	71.8	79.8
22	230	No chemicals added	72.9	80.2
23	”	X	70.6	81.5
24	”	X + Y+ 0.3% SN + 0.04% CA	72.6	84.6
25	”	X + Y + 0.4% SN + 0.05% CA	72.7	83.9
26	”	X + Y + 0.5% SN + 0.08% CA	72.6	85.3

TABLE 4.6

Optical properties of first recycled paper sheet prepared from bleached bagasse pulp using fortified rosin size, PAC- 2014, soap stone filler, anionic polyacrylamide (SN) and modified polyethyleneimine (CA) retention aids

S.No.	CSF (ml)	Paper sheet composition	ISO Brightness	ISO Opacity
1	605	No chemicals added	71.9	80.7
2	”	X	72.8	80.1
3	”	X + Y	72.7	80.8
4	”	X + Y + 0.3% SN + 0.04% CA	73.2	80.8
5	”	X + Y + 0.4% SN + 0.05% CA	73.2	81.5
6	”	X + Y + 0.5% SN + 0.08% CA	73.2	80.8
7	510	X	72.6	81
8	”	X + Y	72.6	85.6
9	”	X + Y + 0.3% SN + 0.04% CA	72.8	84.8
10	”	X + Y + 0.4% SN + 0.05% CA	71.9	85.7
11	”	X + Y + 0.5% SN + 0.08% CA	72.8	89.7
12	440	No chemicals added	72.8	85.3
13	”	X	71.8	82.8
14	”	X + Y	72.5	83.3
15	”	X + Y + 0.3% SN + 0.04% CA	72.1	82.7
16	”	X + Y + 0.4% SN + 0.05% CA	72.7	86.4
17	”	X + Y + 0.5% SN + 0.08%CA	73.4	83.9
18	310	No chemicals added	74.1	61.1
19	”	X + Y + 0.3% SN + 0.04% CA	72.6	82.6
20	”	X + Y + 0.4% SN + 0.05% CA	72.6	81.7
21	”	X + Y + 0.5% SN + 0.08% CA	72.7	80.8
22	230	No chemicals added	73.8	82.9
23	”	X	71.5	83.4
24	”	X + Y+ 0.3% SN + 0.04% CA	74.8	88
25	”	X + Y + 0.4% SN + 0.05% CA	74.8	87.8
26	”	X + Y + 0.5% SN + 0.08% CA	74.3	92.0

TABLE 4.7

Optical properties of second recycled paper sheets prepared from bagasse and long fibreed (rpw) pulp using fortified rosin size, PAC 2014, soap stone filler, anionic polyacrylamide (SN) and modified polyethyleneimine (CA) retention aids

S. No.	CSF (ml)	Paper sheet composition	Chemicals added	ISO Brightness	ISO Opacity
1	605	100% BG + 0% RP	No chemicals added	74.9	86.9
2	”	90% BG + 10% RP	X + Y + 0.5% SN + 0.08% CA	73.8	87.1
3	”	80% BG + 20% RP	X + Y + 0.3% SN + 0.04% CA	74.5	86.6
4	”	70% BG + 30% RP	X + Y + 0.3% SN + 0.04% CA	75.6	84.5
5	510	100% BG + 0% RP	No chemicals added	74.1	88.6
6	”	90% BG + 10%BB	X + Y + 0.4% SN + 0.05% CA	73.6	87.2
7	”	80% BG + 20% RP	X + Y + 0.3% SN + 0.04% CA	73.8	85.8
8	”	70% BG + 30% RP	X + Y + 0.3% SN + 0.04% CA	74.2	84.0
9	440	100% BG + 0% BB	X + Y	71.8	90.1
10	”	90% BG + 10%BB	X + Y + 0.3% SN + 0.04% CA	71.4	92.4
11	”	70% BG + 30% BB	X + Y + 0.5% SN + 0.08% CA	72.4	88.1
12	”	70% BG + 30% BB	X + Y + 0.5% SN + 0.08% CA	73.8	88.5
13	310	100% BG + 0% BB	X + Y	73.8	88.5
14	”	90% BG + 10% BB	X + Y + 0.5% SN + 0.08% CA	74.6	88.8
15	”	80% BG + 20% RP	X + Y + 0.5% SN + 0.08% CA	74.1	87.1
16	”	70% BG + 30% RP	X + Y + 0.5% SN + 0.08% CA	74.7	86.3

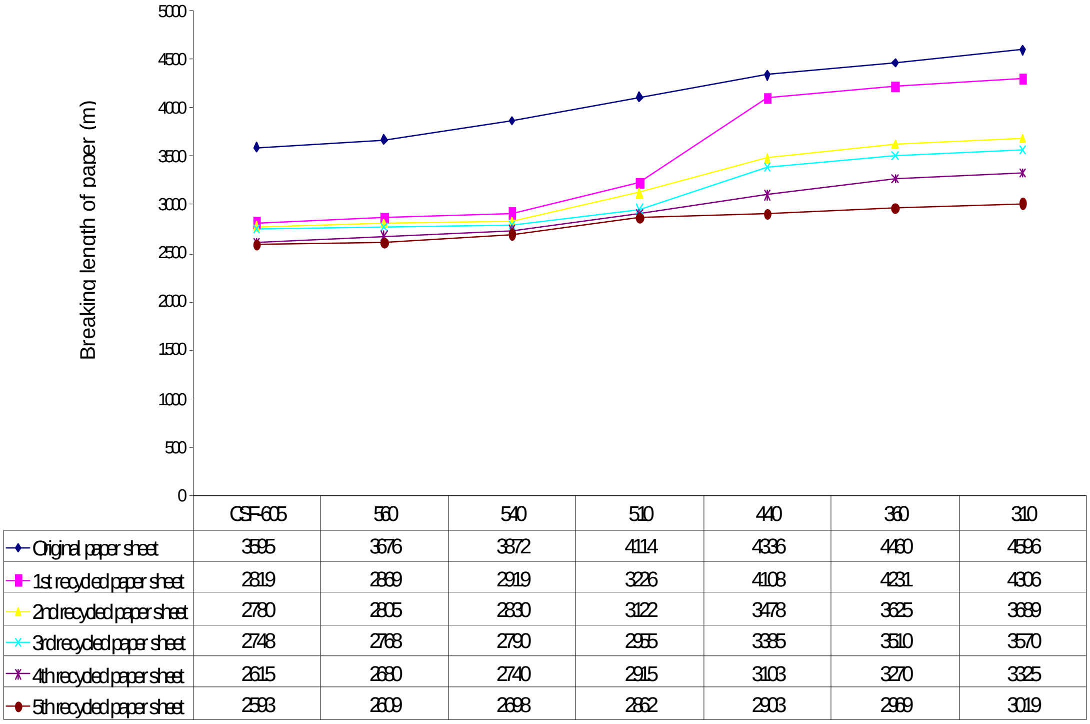
SECTION-C

Effect on strength properties of paper due to blending of fresh bleached bagasse pulp with bamboo pulp using cationic starch T–25

The experiments were performed to study the effect of cationic starch on strength properties of paper. Initially bagasse pulp was blended with fresh bleached bamboo pulp in varying ratios. Cooked starch was added in the admixture. Then coagulant N-7607 was added and 15 seconds were provided for the reaction to take place. Then flocculent N-7530 was added and again 15 seconds were provided for reaction to take place. The standard paper sheets were prepared and strength properties were evaluated. The paper sheets were tested for breaking length, burst factor, tear factor and double folds.

4.14. Study of recycling of paper sheet made by pure bleached bagasse pulp

The paper sheet prepared from the pure bleached bagasse pulp (no chemicals added) was recycled five times. The breaking length of paper sheet was measured after each stage and the results are plotted in **Fig. 4.13**. The results of recycling of paper sheet prepared by pure bleached bagasse pulp at different CSF without using chemicals are tabulated in **Table 4.8**. The breaking length of the original paper sheet has been taken as 100 percent and corresponding decrease in breaking length at each stage was calculated and the results are tabulated in **Table 4.8**. It can be noticed that the maximum loss of breaking length was observed in case of first recycled stage and the loss in breaking length from first to 5th recycled paper sheet is gradual. **Table 4.8** shows that the reduction in breaking length of first recycled sheet is more at high CSF as compared to low CSF. This higher reduction occurs due to the hornification of the fibre, which leads to low bonding capacity at high CSF. At low CSF, the fibres are well-beaten having greater specific surface area and the pulp contains more fibrillated fibres. When the paper sheet is made for 1st recycled stage, the loss of breaking length is less due to the good bonding of well-beaten and fibrillated stock.



	CSF-605	560	540	510	440	360	310
♦ Original paper sheet	3595	3676	3872	4114	4336	4460	4596
■ 1st recycled paper sheet	2819	2869	2919	3226	4108	4231	4306
▲ 2nd recycled paper sheet	2780	2805	2830	3122	3478	3625	3689
× 3rd recycled paper sheet	2748	2768	2790	2955	3385	3510	3570
✱ 4th recycled paper sheet	2615	2680	2740	2915	3103	3270	3325
● 5th recycled paper sheet	2593	2609	2698	2862	2903	2969	3019

Fig. 4.13: Breaking length of pure bleached bagasse paper sheet at various CSF for different recycled stages.

TABLE 4.8

Effect on breaking length of paper due to recycling of paper sheet

CSF →	310	440	510	540	560	590
Breaking length of original paper sheet	100%	100%	100%	100%	100%	100%
First Recycle	93.69	94.74	78.42	75.39	78.05	78.41
Second Recycle	80.27	80.21	75.89	73.09	76.31	77.33
Third Recycle	77.68	78.06	71.83	72.06	75.30	76.43
Fourth Recycle	72.35	71.56	70.86	70.76	72.91	72.74
Fifth Recycle	65.69	66.95	69.57	69.68	70.97	71.13
Loss in breaking length up to 5th Recycle (%)	34.31	33.05	30.43	30.32	29.03	28.87

The only loss occurred in this case is due to the reduction in intrinsic strength of the fibre. The loss in breaking length can be recovered by addition of some strength improving chemicals and retention aids or by blending with long fibreed pulp.

The fortified rosin size, PAC-2014 and retention aids were added to the pure bleached bagasse pulp and the breaking length was measured at different CSF. The results are tabulated in **Table 4.9**. A reduction in breaking length was observed at all CSF. The breaking length of pure bleached bagasse pulp was assigned a value of 100%. A reduction of 1.88% in breaking length was observed at 590 CSF. It can be observed that in case of bleached bagasse pulp without addition of chemicals the breaking length of paper sheet was sufficient. The reduction in breaking length occurred due to the addition of fortified rosin size and poly-aluminium chloride 2014 (X). The further reduction in breaking length was observed by addition of 15% soapstone filler (Y). The reduction in strength properties by the addition of fortified rosin size, PAC-2014 and retention aids can be prevented by blending the pulp with bleached bamboo pulp.

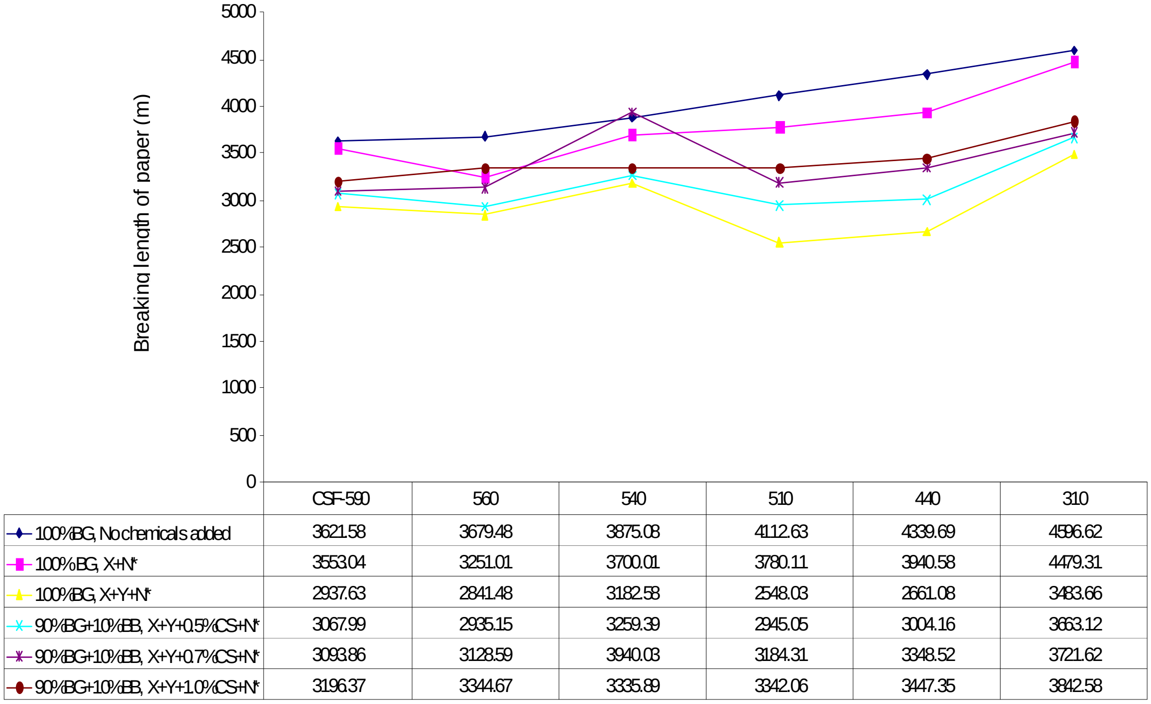
Initially bleached bagasse pulp (pure bleached bagasse pulp, fortified rosin size, PAC-2014, retention aids) was blended with fresh bleached bamboo pulp in varying ratios. The bleached bamboo pulp was mixed with the bleached bagasse pulp in three different proportions i.e. 10% (90% bleached bagasse pulp and 10% bleached bamboo pulp), 20% (80% bleached bagasse pulp and 20% bleached bamboo pulp) and 30 % (70% bleached bagasse pulp and 30% bleached bamboo pulp). Cooked starch was added in the admixture. Then coagulant N-7607 was added and 15 seconds were provided for the reaction to take place. After this, flocculent N-7530 was added and again 15 seconds were provided for reaction to take place. The standard paper sheets were prepared and strength properties were evaluated. The paper sheets were tested for breaking length, burst factor, tear factor and double folds. The effect of addition of cationic starch in further recovery of the strength properties (breaking length, burst factor, tear factor and double folds) was investigated. Three different doses of cationic starch (0.5%, 0.7% and 1 .0%) were studied.

The breaking length of the paper sheet made from 90% bleached bagasse pulp blended with 10% bleached bamboo pulp and different doses of cationic starch were added.

TABLE 4.9

Effect on breaking length of standard paper sheet due to addition of fortified rosin size, poly-aluminium chloride–2014 at different CSF

CSF →	590	560	540	510	440	310
Pure bagasse pulp, no chemicals added (breaking length in meters)	3621.58	3679.48	3875.08	4112.69	4339.69	4596.62
Breaking length expressed in (%)	100%	100%	100%	100%	100%	100%
Reduced breaking length (%) (Pure bagasse pulp with fortified rosin size and poly aluminum chloride 2014 and N* added)	98.12	88.36	95.48	91.91	90.80	.45
Reduction in breaking length (%)	1.88	11.64	4.52	8.09	9.20	2.55



	CSF-590	560	540	510	440	310
◆ 100%BG, No chemicals added	3621.58	3679.48	3875.08	4112.63	4339.69	4596.62
■ 100%BG, X+N*	3553.04	3251.01	3700.01	3780.11	3940.58	4479.31
▲ 100%BG, X+Y+N*	2937.63	2841.48	3182.58	2548.03	2661.08	3483.66
× 90%BG+10%BB, X+Y+0.5%CS+N*	3067.99	2935.15	3259.39	2945.05	3004.16	3663.12
✱ 90%BG+10%BB, X+Y+0.7%CS+N*	3093.86	3128.59	3940.03	3184.31	3348.52	3721.62
● 90%BG+10%BB, X+Y+1.0%CS+N*	3196.37	3344.67	3335.89	3342.06	3447.35	3842.58

Fig. 4.14: Breaking length vs. CSF, of paper prepared from bleached bagasse pulp blended with bamboo pulp with the addition of sizing chemicals, soap stone filler, and cationic starch using retention aids chemicals (N*).

The results are shown in **Fig. 4.14** and **Table 4.10** and a significant improvement in the breaking length at each CSF on addition of cationic starch is observed. Moreover, the improvement in breaking length increased with an increase in the dose of cationic starch from 0.5%, 0.7% and 1.0%. A significant improvement in breaking length was observed on addition of cationic starch in the standard paper sheet (up to 31.16% at 510 ml CSF).

When the blending with the bamboo pulp was increased from 10 to 20% (80% bleached bagasse pulp and 20% bleached bamboo pulp), the improvement in the breaking length was observed (**Table 4.11 and Fig.4.15).** Similar trend in breaking length was obtained when the blending with bamboo pulp was increased from 20 to 30% (**Table 4.12** and **Fig. 4.16**)

It can be noticed that blending of long fibreed bamboo pulp is more effective at 560 ml CSF with 1.0% cationic starch. Higher CSF is suitable for good breaking length recovery by blending with bamboo fibres when the blending of the bamboo pulp is increased from 10 to 30%. It can be noticed that the blending of bleached bamboo pulp gives good result on higher CSF, i.e. 560 ml to 510 ml.

4.15 Effect on burst factor due to addition of cationic starch and pulp blending, rosin size, poly-aluminium chloride, soap stone and retention aids

The effect of blending with bleached bamboo pulp and dose of cationic starch on burst factor was studied. Experiments were performed in the same manner as for breaking length discussed in the previous section. The results obtained for different compositions are as follows:

bleached bagasse pulp	bleached bamboo pulp	cationic starch		
90%	10%	0.5, 0.7, 0.1%	**Fig. 4.17**	**Table 4.13**
80%	20%	0.5, 0.7, 0.1%	**Fig. 4.18**	**Table 4.14**
70%	30%	0.5, 0.7, 0.1%	**Fig. 4.19**	**Table 4.15**

TABLE 4.10

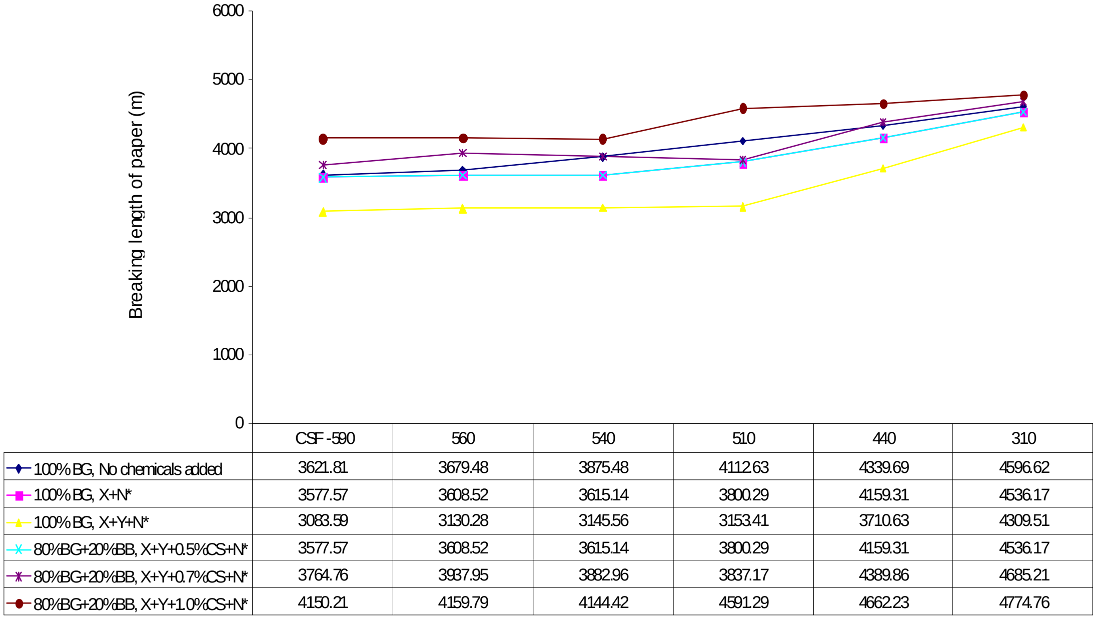
Effect of addition varying doses of cationic starch T-25 on breaking length

CSF →	590	560	540	510	440	310
Breaking length in meters	2937.63	2841.48	3182.58	2548.03	2661.08	3483.66
Breaking length without cationic starch addition	3067.90	2935.15	3259.39	2945.05	3004.16	3663.12
Increase in breaking length expressed in percentage with 0.5%CS addition	4.44	9.72	11.91	22.91	23.76	18.22
Increase in breaking length expressed in percentage with 0.7% CS addition	5.32	10.10	23.80	24.97	25.83	6.83
Increase in breaking length expressed in percentage with 1.0%CS addition	8.80	17.71	4.82	31.16	29.55	10.31

TABLE 4.11

Effect on breaking length due to addition of varying doses of cationic starch in case of 20% blending of bleached bamboo pulp

CSF →	590	560	540	510	440	310
(100%BG, X+N*) Breaking length (m)	3083.59	3130.28	3145.56	3153.41	3710.63	4309.50
(80%BG+20%BB,.X+Y+0.5%CS +N* B.L.(m)	3577.57	3608.52	3615.14	3800.29	4159.31	4536.17
Increase in breaking length (%)	16.02	15.28	14.93	12.05	12.09	5.26
80%BG+20%BB, X+Y+0.7%CS+N*	3764.76	3937.95	3882.96	3837.17	4389.86	4685.21
Increase in breaking length (%)	22.09	25.80	23.44	21.68	18.30	8.72
80%BG+20%BB, X+Y+1.0%CS+N*	4150.21	4159.78	4144.42	4591.29	4662.23	4774.76
Increase in breaking length. (%}	34.59	32.89	31.75	45.60	25.65	10.80



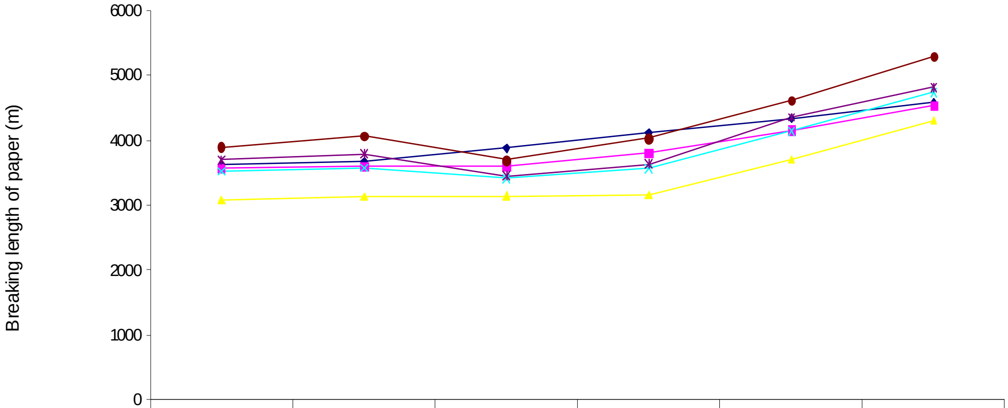
	CSF -590	560	540	510	440	310
◆ 100% BG, No chemicals added	3621.81	3679.48	3875.48	4112.63	4339.69	4596.62
■ 100% BG, X+N*	3577.57	3608.52	3615.14	3800.29	4159.31	4536.17
▲ 100% BG, X+Y+N*	3083.59	3130.28	3145.56	3153.41	3710.63	4309.51
✕ 80%BG+20%BB, X+Y+0.5%CS+N*	3577.57	3608.52	3615.14	3800.29	4159.31	4536.17
✱ 80%BG+20%BB, X+Y+0.7%CS+N*	3764.76	3937.95	3882.96	3837.17	4389.86	4685.21
● 80%BG+20%BB, X+Y+1.0%CS+N*	4150.21	4159.79	4144.42	4591.29	4662.23	4774.76

Fig. 4.15: Breaking length vs. CSF of paper sheet prepared from bleached bagasse pulp, blended with bamboo pulp with the addition of sizing chemicals, soap stone filler, cationic starch and retention aids (N*).

TABLE 4.12

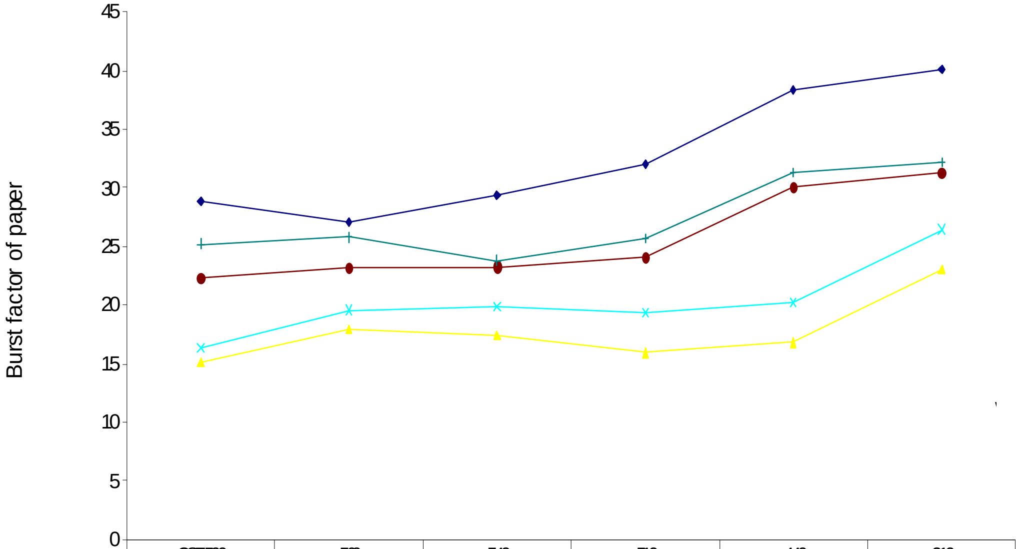
Effect on breaking length of paper sheet due to the addition of varying doses of cationic starch in case of 30% bleached bamboo pulp blending

CSF →	590	560	540	510	440	310
Breaking length in meters →	3083.59	3130.28	3145.56	3153.41	3710.63	4309.50
Increase in breaking length (%) (X+Y+0.5%CS+N*+70%BG+ 30%BB)	14.31	14.08	8.36	13.11	11.50	9.90
Increase in breaking length (%) X+Y+0.7%CS+N*+70%BG+ 30%BB	19.85	5.15	1.36	15.45	17.41	11.83
Increase in breaking length (%) X+Y+1.0%CS+N*+70%BG+ 30%BB	26.54	30.13	17.41	27.94	24.32	22.91



	CSF- 590	560	540	510	440	310
◆ 100% BG, No chemicals added	3621.81	3679.48	3875.08	4112.63	4339.69	4596.62
■ 100% BG, X+N*	3577.57	3608.52	3615.14	3800.29	4159.31	4535.17
▲ 70%BG+30%BB, X+Y+N*	3083.59	3130.28	3145.56	3153.41	3710.63	4309.5
✕ 70%BG+30%BB, X+Y+0.5%CS+N*	3524.99	3570.88	3408.47	3566.78	4137.29	4736.21
✱ 70%BG+30%BB, X+Y+0.7%CS+N*	3695.82	3794.19	3454.66	3639.86	4356.5	4819.44
● 70%BG+30%BB, X+Y+1.0%CS+N*	3901.85	4073.5	3693.35	4034.34	4613.01	5296.64

Fig. 4.16: Breaking length vs. CSF of paper sheet prepared from bleached bagasse pulp, blended with bamboo pulp with the addition of sizing chemicals, soap stone filler, cationic starch and retention aids (N*).



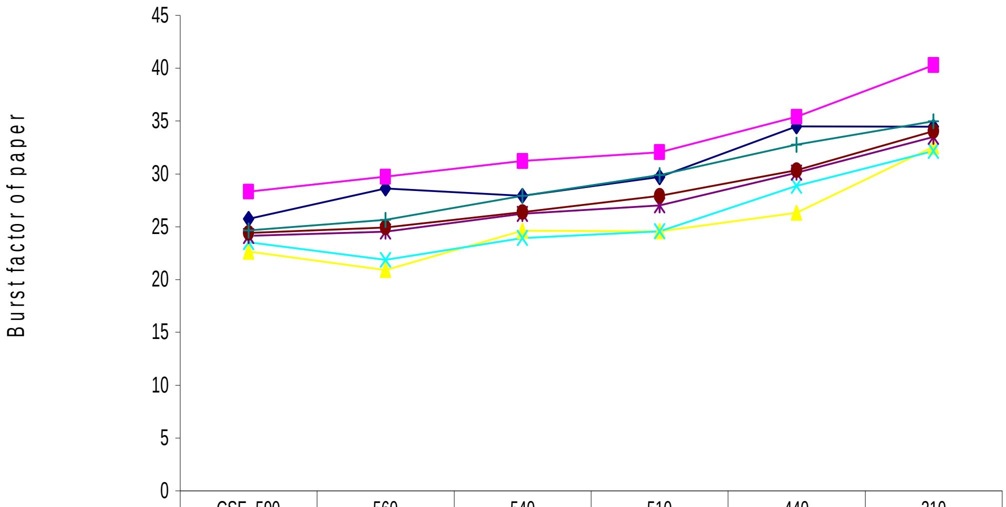
	CSF590	560	540	510	440	310
◆ 100%BG, No chemicals added	28.84	27.04	29.35	32.04	38.35	40.11
▲ 100%BG, X+Y+N*	15.15	17.9	17.42	15.91	16.82	23.03
✕ 90%BG+10%BB, X+Y+N*	16.38	19.57	19.87	19.31	20.17	26.46
● 90%BG+10%BB, X+Y+0.7%CS+N*	22.33	23.16	23.26	24.11	30.11	31.33
+ 90%BG+10%BB, X+Y+1.0%CS+N*	25.23	25.79	23.81	25.64	31.28	32.13

Fig. 4.17: Burst factor vs.CSF of paper sheet prerared by blending of bleached bagasse pulp with bamboo pulp in furnish with the addition of varying doses of cationic starch and retention aids (N*).

TABLE 4.13

Effect on burst factor due to the addition of varying doses of cationic starch at different CSF at 10% bamboo pulp blending

S. No.	Particulars, CSF →	590	560	540	510	440	310
1	Burst factor of pure bleached bagasse pulp (No chemicals added)	28.84	27.04	29.35	32.04	38.35	40.11
2	Effects on B.F. due to addition of fortified rosin size and PAC 2014, and N* in standard paper sheet	28.33	29.73	31.22	32.06	36.74	40.31
3	Variation in burst factor (%)	98.23	109.95	106.37	100.06	95.80	100.5
4	Change in burst factor (%)	-1.77	+9.95	+6.37	+0.06	-4.20	+0.50
5	Burst factor of pure Bagasse paper after addition of 15% soap stone filler and N*	15.15	17.90	17.42	15.91	16.82	23.03
6	Burst factor of paper sheet at (90%BG+10%BB),X+Y+N*	16.38	19.57	19.87	19.31	20.17	26.46
7	Burst factor of paper sheet at pulp composition and chemical (90%BG+10%BB),X+Y+0.5% CS+N*,	20.33	22.46	22.98	22.25	25.12	29.16
8	Increase in burst factor (%)	24.11	14.77	15.65	15.23	24.54	10.20
9	Burst factor of paper sheet at, pulp and chemical composition. (90%BG+10%BB), X+Y+0.7%CS+N*,	22.33	23.16	23.26	24.11	30.11	31.33
10	Increase in burst factor (%)	36.32	18.34	17.06	24.86	49.28	18.41
11	Burst factor of paper sheet at pulp and chemical composition (90%BG+10%BB), X+Y+1.0%CS+N*,	25.23	25.79	23.81	25.64	31.28	32.13
12	Increase in burst factor of paper sheet compared with (S.No.6,) in (%) at pulp and chemical composition (90%BG+10%BB), X+Y+1.0%CS+N*	54.03	31.78	21.67	32.78	55.08	21.43



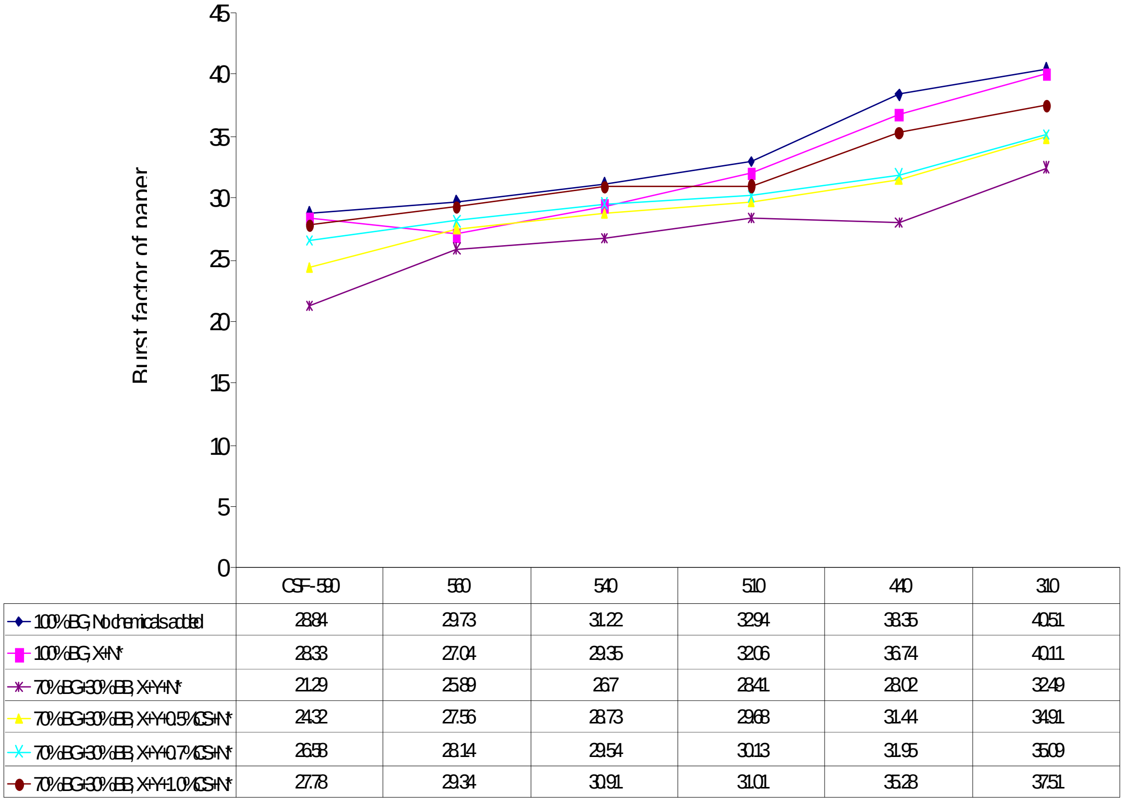
	CSF -590	560	540	510	440	310
◆ 100% BG, No chemicals added	25.73	28.65	27.94	29.69	34.51	34.48
■ 100% BG, X+N*	28.33	29.73	31.22	32.06	35.39	40.31
▲ 100% BG, X+Y+N*	22.65	20.89	24.61	24.57	26.31	32.57
× 80% BG+20% BB, X+Y+N*	23.56	21.87	23.93	24.58	28.87	32.17
✳ 80% BG+20% BB, X+Y+0.5% CS+N*	24.14	24.55	26.22	27.01	30.13	33.51
● 80% BG+20% BB, X+Y+0.7%CS+N*	24.41	24.94	26.38	27.92	30.34	34.04
+ 80% BG+20% BB, X+Y+1.0%CS+N*	24.63	25.65	27.94	29.89	32.77	34.98

Fig. 18: Burst factor vs. CSF,of paper prepared by blending bamboo pulp with blgd. bagasse pulp by the addition of sizing chemicals, soap stone filler & varying doses of cationic starch and retention aids (N*).

TABLE 4.14

Effect on burst factor due to the addition of varying doses of cationic starch at different CSF at 20% bamboo pulp blending

S. No.	Particulars, CSF →	590	560	540	510	440	310
1	Burst factor of pure bleached bagasse pulp (No chemicals added)	25.73	28.65	27.94	29.69	34.51	34.48
2	Effects on B.F. due to addition of fortified rosin size and PAC 2014, and N* in standard paper sheet	28.33	29.73	31.22	32.06	35.39	40.31
3	Variation in burst factor (%)	110.1	103.8	111.7	108.0	102.5	116.9
4	Change in burst factor (%)	10.1	3.8	11.7	8.0	2.5	16.9
5	Burst factor of pure Bagasse paper after addition of 15% soap stone filler and N*	22.65	20.89	24.61	24.57	26.31	32.57
6	Burst factor of paper sheet at (80%BG+20%BB), X+Y+N*	23.56	21.87	23.93	24.58	28.87	32.17
7	Burst factor of paper sheet at pulp composition and chemical (80%BG+20%BB), X+Y+0.5% CS+N*,	24.14	24.55	26.22	27.01	30.13	33.51
8	Increase in burst factor (%)	2.5	12.3	9.6	9.9	4.4	4.2
9	Burst factor of paper sheet at, pulp and chemical composition. (80%BG+20%BB), X+Y+0.7%CS+N*,	24.41	24.94	26.38	27.92	30.34	34.04
10	Increase in burst factor (%)	3.60	14.03	10.24	13.59	5.09	5.81
11	Burst factor of paper sheet at pulp and chemical composition (80%BG+20%BB), X+Y+1.0%CS+N*,	24.63	23.65	27.04	28.89	32.27	34.98
12	Increase in burst factor of paper sheet compared with (S.No.6,) in (%) at pulp and chemical composition (80%BG+20%BB), X+Y+1.0%CS+N*	9.2	31.9	16.8	20.8	19.5	7.2



	CSF-590	560	540	510	440	310
◆ 100% BG, No chemicals added	28.84	29.73	31.22	32.94	38.35	40.51
■ 100% BG, X+N*	28.33	27.04	29.35	32.06	36.74	40.11
✱ 70% BG+30% BB, X+Y+N*	21.29	25.89	26.7	28.41	28.02	32.49
▲ 70% BG+30% BB, X+Y+0.5% CS+N*	24.32	27.56	28.73	29.68	31.44	34.91
✕ 70% BG+30% BB, X+Y+0.7% CS+N*	26.58	28.14	29.54	30.13	31.95	35.09
● 70% BG+30% BB, X+Y+1.0% CS+N*	27.78	29.34	30.91	31.01	35.28	37.51

Fig. 4.19: Burst factor vs. CSF of paper prepared by blending bamboo pulp with bagasse pulp with the addition of sizing chemicals soap stone filler, varying doses of cationic starch and retention aids (N*).

TABLE 4.15

Effect on burst factor due to the addition of varying doses of cationic starch at different CSF at 30% bamboo pulp blending

S. No.	Particulars, CSF →	590	560	540	510	440	310
1	Burst factor of pure bleached bagasse pulp (No chemicals added)	28.84	29.73	31.22	32.94	38.35	40.51
2	Effects on B.F. due to addition of fortified rosin size and PAC 2014, and N* in standard paper sheet	28.33	27.04	29.35	32.06	36.74	40.11
3	Variation in burst factor (%)	98.23	90.95	94.01	97.33	95.80	90.0
4	Change in burst factor (%)	-1.77	-9.05	-5.99	-2.67	-4.20	1.0
5	Burst factor of pure bagasse paper after addition of 15% soap stone filler and N*	21.29	25.89	26.7	28.41	28.02	32.49
6	Burst factor of paper sheet at (70%BG+30%BB), X+Y+N*	16.38	19.57	19.87	19.31	20.17	26.46
7	Burst factor of paper sheet at pulp composition and chemical (70%BG+30%BB), X+Y+0.5% CS+N*,	24.32	27.56	28.73	29.68	31.44	34.91
8	Increase in burst factor (%)	14.23	6.5	7.6	4.5	12.2	7.4
9	Burst factor of paper sheet at, pulp and chemical composition. (70%BG+30%BB), X+Y+0.7%CS+N*,	26.58	28.14	29.54	30.13	31.95	35.09
10	Increase in burst factor (%)	24.85	8.69	10.64	9.57	14.03	8.00
11	Burst factor of paper sheet at pulp and chemical composition (70%BG+30%BB), X+Y+1.0%CS+N*,	27.78	29.34	30.91	31.01	35.28	37.51
12	Increase in burst factor of paper sheet compared with (S.No.6,) in (%) at pulp and chemical composition (70%BG+30%BB), X+Y+1.0%CS+N*	30.48	13.33	8.80	9.15	25.91	15.45

The burst factor of pure bleached bagasse pulp was 38.35 and 40.11 at 440 ml CSF and 310 ml CSF respectively. A 24.54% increase in burst factor (from 20.17 to 25.12) was noticed on addition of 0.5% cationic starch at 440 ml CSF. The increase in burst factor was 49.28% (from 20.17 to 30.11) and 55.08% (from 20.17 to 31.28) on addition of 0.7% and 1.0% cationic starch respectively (**Fig. 4.17** and **Table 4.13**).

It is observed that significant development of the burst factor was observed at 440

CSF with the good texture of paper sheet. This improvement in the paper was noticed due to the addition of cationic starch, which produced the good strength development in the paper sheet.

Similar results were observed from the **Fig 4.18** and **Table 4.14**. The burst factor of pure bleached bagasse pulp in which no chemical was added at 440 ml CSF and 310 ml CSF were 34.51 and 34.48. The burst factor of 28.87 and 32.17 was obtained when the fibre composition was changed by addition of fortified rosin size, PAC 2014, 15% filler and retention aids with 80% bleached bagasse pulp and 20% bleached bamboo pulp. A 14.5% and 2.89% improvement in burst factor was noticed on addition of cationic starch and paper sheets have attained the good quality. It is observed that when the beating increases from 590 ml CSF to 310 ml CSF, a significant improvement in the burst factor was observed and the maximum increase in burst factor observed is about 20.8% at 510 ml CSF.

If the 30% bleached beaten bamboo pulp was blended with the original bleached bagasse pulp, a maximum 12.2% increase in burst factor was observed at 440 ml CSF, if the cationic starch dose was added 0.5%. A 40.46% increase in burst factor was noticed due to the increased beating of the pulp from 590 ml CSF to 310 ml CSF (**Fig. 4.19** and **Table 4.15**). This improvement in burst factor was noticed due to the increase in beating action on the pulp fibres. The increase in specific surface area and fibrillation of the fibres takes place by more beating. The increase in burst factor may be due to the strong inter-fibre bond formation.

4.16 Effect on tear factor of the paper sheet due to blending of 10% bleached bagasse pulp and by addition of cationic starch in the standard paper sheet

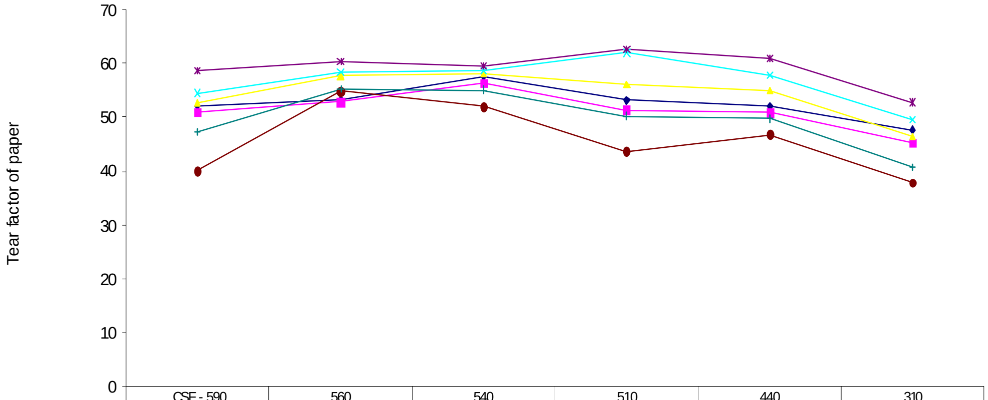
It is observed that due to more beating of pulp the tear factor is increases up to 540 ml CSF, and the increase in tear factor is 10.41%. The increase in tear factor is observed from initial stage to final stage if the cationic starch is mixed from 0.5% to 1.0%. The increase in tear factor is 2.4%. If the strength improving chemicals were increased from 0.5 to 1.0% the increase in tear factor due to cationic starch dose in the paper sheet was not significant. So to increase the tear factor long fibre pulp blending is needed (**Fig. 4.20**). The effect on tear factor due to the blending of bleached bamboo pulp can be studied from **Table 4.16.** The effect of increased dosing of cationic starch on tear factor can be noticed form **Table 4.17**. The maximum tear factor obtained by 30%

blending of bleached bamboo pulp and 1.0% cationic starch is 89.67 at 540 ml CSF (**Table 4.16**).

The effect of cationic starch on tear factor is noticed from **Table 4.17**. It is noticed that the maximum tear factor was obtained at 540 ml CSF with 30% bleached bamboo pulp blending along with 1.0% dose of cationic starch.

To improve the tear strength of the standard paper sheet with the blending of 20% bleached bamboo pulp, maximum improvement in tear factor of the standard paper sheet was observed 57.51% and 10.4% due to the addition of 0.5% cationic starch, and 2.2% due to the addition of 1.0% cationic starch **Fig. 4.21.**

The effect on tear factor is also noticed with blending of 30% long fibreed bleached bamboo pulp. The maximum strength development is noticed about 17.74% at 0.5% mixing of cationic starch. The 21.2% increase in tear factor was noticed at 540 ml CSF due to the blending of 30% bleached bamboo pulp into furnish. The maximum improvement in tear factor was observed due to the beating action on the fibres, improving the tear strength in the paper sheet. The tear strength of the paper sheet decreases due to the excessive beating beyond the limit, as it is clear from the **Fig. 4.22**. The analysis of strength properties of first recycled standard paper sheet was done by blending the fresh bleached bamboo pulp in varying proportions as well as by the addition of varying doses of the cationic starch in the furnish.



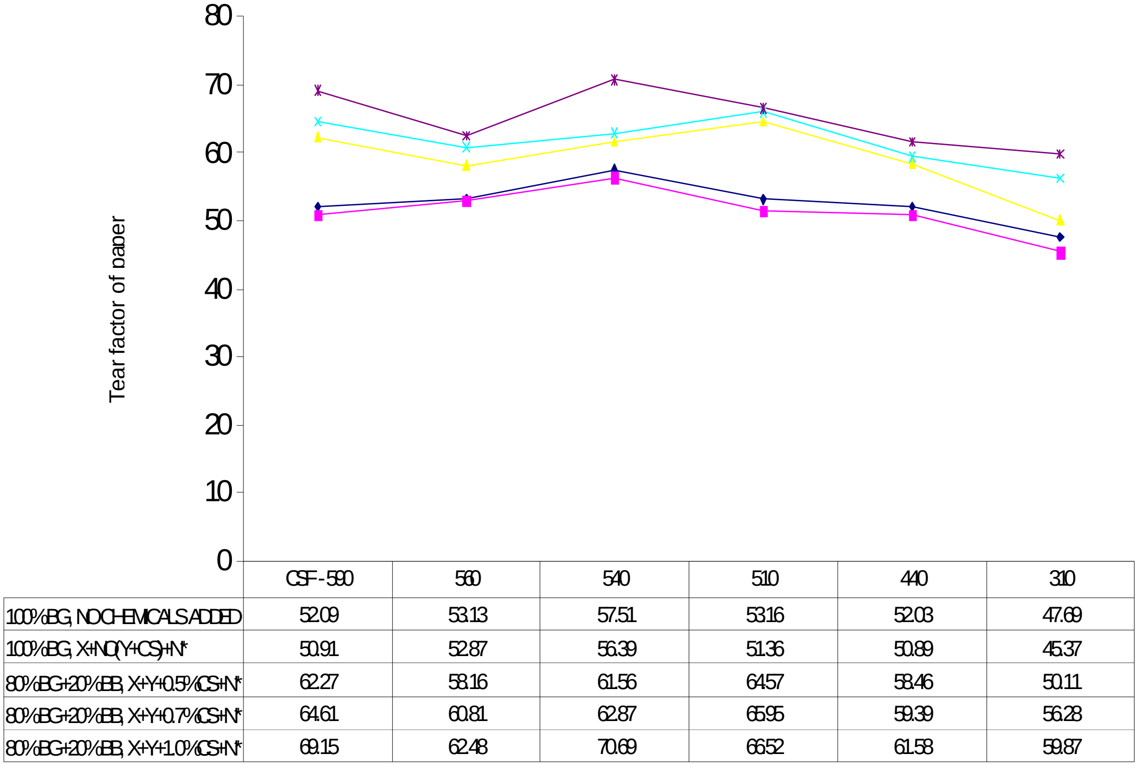
	CSF - 590	560	540	510	440	310
◆ 100% BG, No chemicals added	52.09	53.13	57.51	53.16	52.03	47.69
■ 100% BG, X+No(Y+CS)+N*	50.91	52.87	56.39	51.36	50.89	45.37
● 100% BG, X+Y+N*	40.04	54.85	52.04	43.71	46.82	37.81
+ 90% BG+10% BB, X+Y+N*	47.32	55.26	55.09	50.27	49.72	40.79
▲ 90% BG+10% BB, X+Y+0.5%CS+N*	52.69	57.73	58.14	56.15	55.05	46.43
× 90% BG+10% BB, X+Y+0.7%CS+N*	54.49	58.37	58.75	61.97	57.75	49.59
✱ 90% BG+10% BB, X+Y+1.0%CS+N*	58.67	60.31	59.51	62.72	60.95	52.85

Fig. 4.20: Tear factor vs. CSF of paper prepared by blending of blgd. bamboo pulp with blgd. bagasse pulp with the addition of sizing chemicals, soap stone filler & varying doses of cationic starch and retention aids (N*).

TABLE 4.16

Effect on tear factor due to blending of bamboo pulp and addition of cationic starch on original paper sheet

S. No.		CSF→	590	560	540	510	440	310
1	Fibre Composition 90%BG+10%BB	Chem. composition X+Y+N*	47.32	55.26	55.09	50.27	49.72	40.79
2	90%BG+10%BB	X+Y+0.5%CS+N*	52.69	57.73	58.14	56.15	55.05	46.43
3	90%BG+10%BB	X+Y+0.7%CS+N*	54.49	58.37	58.75	61.97	57.75	49.59
4	90%BG+10%BB	X+Y+1.0%CS+N*	58.67	60.31	59.51	62.72	60.95	52.85
5	80%BG+20%BB	X+Y+N*	50.91	52.87	56.39	51.36	50.89	45.37
6	80%BG+20%BB	X+Y+0.5%CS+N*	62.27	58.16	61.56	64.57	58.46	50.11
7	80%BG+20%BB	X+Y+0.7%CS+N*	64.61	61.81	62.87	65.95	59.39	56.28
8	80%BG+20%BB	X+Y+1.0%CS+N*	69.15	62.48	70.69	66.52	61.58	59.87
9	70%BG+30%BB	X+Y+N*	52.01	58.63	63.05	62.90	62.54	57.98
10	70%BG+30%BB	X+Y+0.5%CS+N*	63.86	74.09	75.19	69.61	63.91	61.43
11	70%BG+30%BB	X+Y+0.7%CS+N*	68.34	74.85	76.21	74.46	64.19	64.81
12	70%BG+30%BB	X+Y+1.0%CS+N*	78.41	76.26	89.67	77.04	65.31	65.09



	CSF - 590	560	540	510	440	310
100%BG, NO CHEMICALS ADDED	52.09	53.13	57.51	53.16	52.03	47.69
100%BG, X+NO(Y+CS)+N*	50.91	52.87	56.39	51.36	50.89	45.37
80%BG+20%BB, X+Y+0.5%CS+N*	62.27	58.16	61.56	64.57	58.46	50.11
80%BG+20%BB, X+Y+0.7%CS+N*	64.61	60.81	62.87	65.95	59.39	56.28
80%BG+20%BB, X+Y+1.0%CS+N*	69.15	62.48	70.69	66.52	61.58	59.87

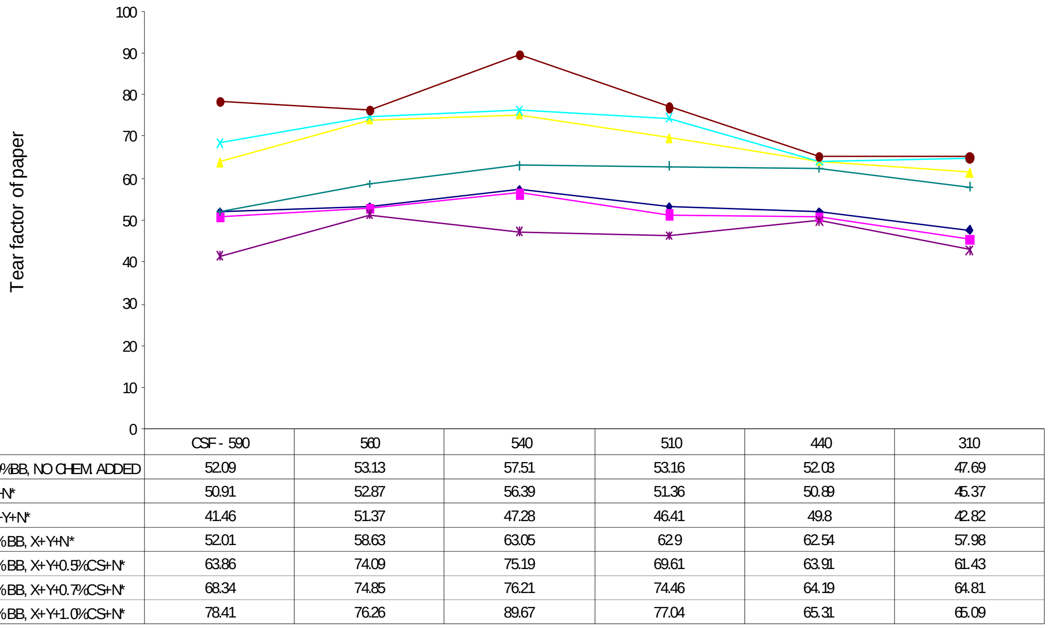
Fig. 4.21: Tear factor vs. CSF, of paper prepared by blending of blgd. bamboo pulp with bagasse pulp with the addition of sizing chemicals, soap stone filler, & varying doses of cationic starch and retention aids (N*)

TABLE 4.17

Effect on tear factor of original paper sheet due to addition of increased blending of

bamboo pulp and varying doses of cationic starch at different CSF (Effect of blending)

S. No.		CSF→	590	560	540	510	440	310
1	Fibre composition 90%BG+10%BB	Chem. composition X+Y+N*	47.32	55.26	55.09	50.27	49.72	40.79
2	90%BG+10%BB	X+Y+0.5%CS+N*	52.69	57.73	58.14	56.15	55.05	46.43
3	80%BG+20%BB	X+Y+0.5%CS+N*	62.27	58.16	61.56	64.57	58.46	50.11
4	70%BG+30%BB	X+Y+0.5%CS+N*	63.86	74.09	75.19	69.61	63.91	61.43
5	80%BG+20%BB	X+Y+N*	50.91	52.87	56.39	51.36	50.89	45.37
6	90%BG+10%BB	X+Y+0.7%CS+N*	54.49	58.37	58.75	61.97	57.75	49.59
7	80%BG+20%BB	X+Y+0.7%CS+N*	64.61	61.81	62.87	65.95	59.39	56.28
8	70%BG+30%BB	X+Y+0.7%CS+N*	68.34	74.85	76.21	74.46	64.19	64.81
9	70%BG+30%BB	X+Y+N*	52.01	58.63	63.05	62.90	62.54	57.98
10	90%BG+10%BB	X+Y+1.0%CS+N*	58.67	60.31	59.51	62.72	60.95	52.85
11	80%BG+20%BB	X+Y+1.0%CS+N*	69.15	62.48	70.69	66.52	61.58	59.87
12	70%BG+30%BB	X+Y+1.0%CS+N*	78.41	76.26	89.67	77.04	65.31	65.09



	CSF - 590	560	540	510	440	310
◆ 100%BG+00%BB, NO CHEM ADDED	52.09	53.13	57.51	53.16	52.03	47.69
■ 100%BG, X+N*	50.91	52.87	56.39	51.36	50.89	45.37
✳ 100%BG, X+Y+N*	41.46	51.37	47.28	46.41	49.8	42.82
+ 70%BG+30%BB, X+Y+N*	52.01	58.63	63.05	62.9	62.54	57.98
▲ 70%BG+30%BB, X+Y+0.5%CS+N*	63.86	74.09	75.19	69.61	63.91	61.43
✕ 70%BG+30%BB, X+Y+0.7%CS+N*	68.34	74.85	76.21	74.46	64.19	64.81
● 70%BG+30%BB, X+Y+1.0%CS+N*	78.41	76.26	89.67	77.04	65.31	65.09

Fig. 4.22: Tear factor vs. CSF, of paper prepared by blending of blgd. bamboo pulp in blgd. bagasse pulp with the addition of sizing chemicals, soap stone filler, varying doses of cationic starch & retention aids (N*)

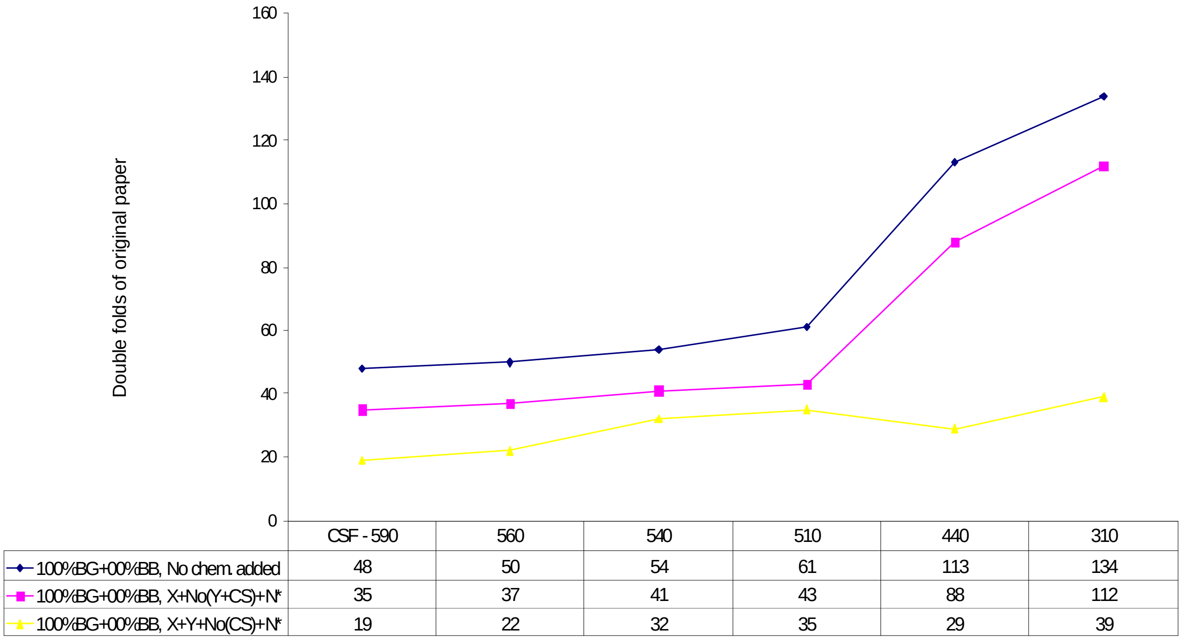
4.17 Effect on double folds of the paper sheet in case of original paper sheet

From the analysis of the results of **Fig. 4.23** and **Fig. 4.24**, the following results are observed. It is observed that there is a significant improvement in double folds of paper due to the beating action on the bagasse fibre. The double folds of paper increase up to the 310 ml CSF of the beaten pulp slurry. It is also noticed that the blending of long fibreed bamboo pulp also imparts a significant increase in double folds of the paper in comparison to the high dosing of cationic starch in paper. To analyze effect of increasing the cationic starch dosing in the paper sheet at various CSF the double folds of its original standard hand sheet has been taken as 100% and the corresponding change in double folds at each stage has been evaluated **(Table 4.18).**

From the analysis of results of the **Table 4.18** the double folds of paper sheet increases by increasing the cationic starch dose in the paper sheets from 0.5% to 1.0%. It was observed from the **Table 4.18**, that when the fibre blending composition (10% bamboo pulp with 90% bagasse pulp) is kept constant and the cationic starch content is increased from 0.5% to 0.7% and 1.0% at 590 ml CSF, the double folds increases as 21, 30, 22 respectively. It was observed that cationic starch is helpful in increasing the double folds of the paper sheet at 310 ml CSF (**Table 4.18**).

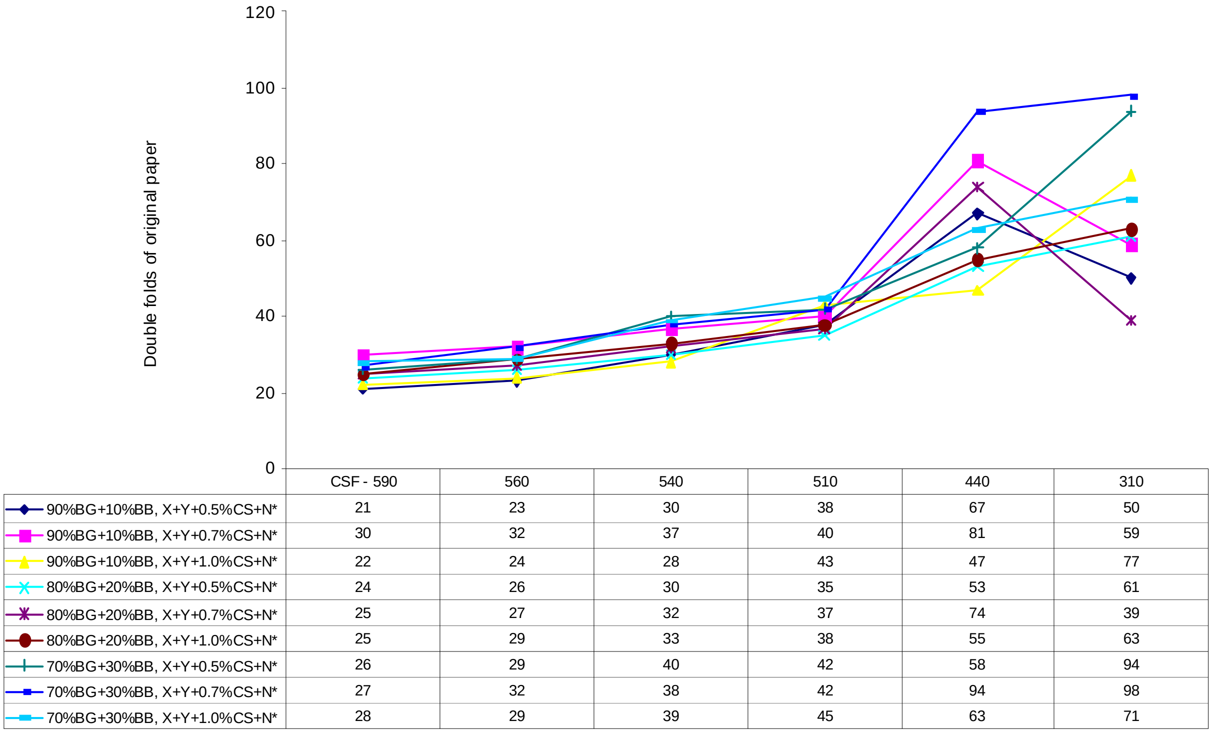
4.18 Effect of blending of long fibreed pulp on double folds of original paper

In case of blending of long fibreed pulp, the effect on double folds was studied by keeping constant the degree of beating and dosing of cationic starch content into the furnish. It was observed that if the blending of long fibreed pulp was increased from 10% to 20% into the furnish the double folds of paper sheet was increased. But if the blending of bamboo pulp was further increased from 20% to 30% the effect on double folds improvement was not significant as in the previous case and the increase in double folds improvement was less. This shows that further improvement in double folds will require much long fibreed pulp. More long fibreed pulp will be needed to maintain the previous performance of double folds



	CSF - 590	560	540	510	440	310
◆ 100%BG+00%BB, No chem. added	48	50	54	61	113	134
■ 100%BG+00%BB, X+No(Y+CS)+N*	35	37	41	43	88	112
▲ 100%BG+00%BB, X+Y+No(CS)+N*	19	22	32	35	29	39

Fig. 4.23: Double folds vs. CSF of original paper prepared by pure bleached baggase pulp with the addition of sizing chemicals, soap stone filler and varying doses of cationic starch and retention aids (N*)



	CSF - 590	560	540	510	440	310
◆ 90%BG+10%BB, X+Y+0.5%CS+N*	21	23	30	38	67	50
■ 90%BG+10%BB, X+Y+0.7%CS+N*	30	32	37	40	81	59
▲ 90%BG+10%BB, X+Y+1.0%CS+N*	22	24	28	43	47	77
× 80%BG+20%BB, X+Y+0.5%CS+N*	24	26	30	35	53	61
✱ 80%BG+20%BB, X+Y+0.7%CS+N*	25	27	32	37	74	39
● 80%BG+20%BB, X+Y+1.0%CS+N*	25	29	33	38	55	63
+ 70%BG+30%BB, X+Y+0.5%CS+N*	26	29	40	42	58	94
■ 70%BG+30%BB, X+Y+0.7%CS+N*	27	32	38	42	94	98
■ 70%BG+30%BB, X+Y+1.0%CS+N*	28	29	39	45	63	71

Fig. 4.24: Double folds vs. CSF of original paper prepared by blending of bleached bamboo pulp with bleached bagasse pulp with addition of sizing chemicals, soap stone filler, varying doses of cationic starch and retention aids (N*)

TABLE 4.18

Effect on double folds of original paper sheet due to blending of bamboo pulp in different ratio and addition of varying doses of cationic starch at different CSF

S. No.		CSF	590	560	540	510	440	310
1	Fibre Composition 100%BG+00%BB	Chemical Double Composition Folds (→)	48	50	54	61	113	134
2	100%BG+00%BB	X+N*	35	37	41	43	88	112
3	100%BG+00%BB	X+Y+N*	19	22	32	35	29	39
4	90%BG+10%BB	(X+Y+N*)	17	21	27	34	48	46
5	90%BG+10%BB	X+Y+0.5%CS+N*	21	23	30	38	67	50
6	80%BG+20%BB	X+Y+0.5%CS+N*	24	26	30	35	53	61
7	70%BG+30%BB	X+Y+0.5%CS+N*	26	29	40	42	58	94
8	90%BG+10%BB	X+Y+0.7%CS+N*	30	32	37	40	81	59
9	80%BG+20%BB	X+Y+0.7%CS+N*	25	27	32	37	74	39
10	70%BG+30%BB	X+Y+0.7%CS+N*	27	32	38	42	94	98
11	90%BG+10%BB	X+Y+1.0%CS+N*	22	24	28	43	47	77
12	80%BG+20%BB	X+Y+1.0%CS+N*	25	29	33	38	55	63
13	70%BG+30%BB	X+Y+1.0%CS+N*	28	29	39	45	63	71

4.19 Effect of beating on double folds

The effect of beating on double folds of paper was studied by keeping the other parameters, like long fibre pulp blending in the bagasse pulp and cationic starch content into the furnish constant.

It was observed that as the beating increases the double folds of paper sheets improve. But there are some variations in the results, which may be due to the cloudiness in the paper sheet. Some good results are observed at low CSF which may be due to good bonding strength of the fibres with the cationic starch as more specific surface area of the fibre remains available due to more beating effects. The good flexibility of paper sheet is available at low CSF pulps because at low CSF the cellulose fibres have good tendency to hold more water in it, due to more fibrillated pulp. The paper sheet contains high density, as more beaten pulp contains more bonding strength among the fibres within the paper sheet. A high CSF, the fibre to fibre bonding remain less and paper sheet contains more void fractions resulting in the porous and bulky paper sheet which produces the less double folds in paper sheet.

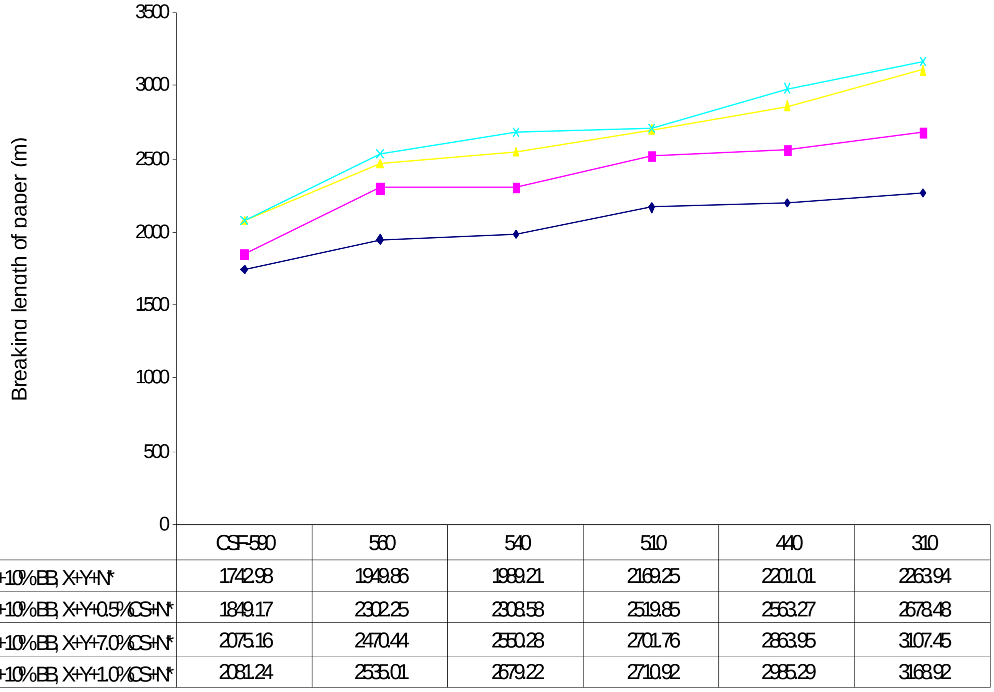
4.20 Effect on breaking length of first recycled paper

If the fibre composition is kept constant and increasing the doses of cationic starch (0.5%), the maximum breaking length was obtained about 2678.48 meters at the 310 ml CSF. If the results of breaking length at 590 ml CSF were compared with 310 ml CSF, it was observed that there is an increase in breaking length (44.85%) which can be further increased due to mixing of 1.0% cationic starch in comparison to other results. The increase in breaking length was observed (18.31%) at 310 ml CSF. The loss in breaking length of original paper sheet and first recycled is about 40.9%. It shows that in recycling process there is much loss in breaking length at this recycling stage which occurred due to low bonding of fibres, which mainly occurs due to the hornification of fibres. The hornification turns the fibres twisted and hard and fibre losses the tendency to hold water to become less flexible. This tendency of fibres reduces the strong hydrogen bond formation among the fibres and the paper ultimately becomes weak.

4.21 Effect of increasing the long fibreed bamboo pulp blending on breaking length in first recycle of paper

The effect of long fibre blending on breaking length of paper sheet is shown in **Fig. 4.25**. The effect on breaking length occurs due to the addition of increased amount of bamboo pulp from 10% to 20%. It was noticed that the improvement in breaking length was observed in each case when the blending the bamboo pulp is increased from 10 to 20%. There is an increase in breaking length from 3168.92 to 3174.88 meters, when the cationic starch dose is increased to 1.0%. It is also noticed from **Fig. 4.25** when the proportion of blending is increased from 10 to 30%, there is also an improvement in the breaking length (3498.59 meters) in the paper sheet. On comparing the results of breaking length the following improvements in the breaking length was noticed as per the **Table 4.19**.

From the analysis of the data of the **Table 4.19,** it is noticed that the improvement in the paper breaking length is more at high CSF, but if the CSF lowers from 590 ml to 330 ml CSF, the effect of blending of bamboo pulp in the furnish has no good effect on the breaking length developments as compared to the CSF 590 ml or 560 ml CSF etc. The reduction in the improvement of the breaking length indicates that at low CSF the short fibre fraction are more in the pulp, which has less development in the breaking length of paper sheet. The breaking length improvement is very low, if the beat-ability of the pulp is increased in the first recycled paper sheet. The maximum breaking length (3174.88 meters) was observed at 310 ml CSF with 20% bleached bamboo pulp blending with 1.0% cationic starch dose at the first recycle stage. It shows that good breaking length at this stage can be obtained with blending of long fibreed pulp along with the dosing of 1.0% cationic starch content **(Fig.4.26).** The maximum breaking length was also obtained (3498.59 meters) at 310 ml CSF with 30% bleached bamboo pulp blending along with 1.0% cationic starch dose in the pulp furnish **(Fig. 4.27).** The improvement in breaking length can also be noticed from **Table 4.19**.



	CSF-590	560	540	510	440	310
◆ 90%BG+10%BB, X+Y+N*	1742.98	1949.86	1989.21	2169.25	2201.01	2263.94
■ 90%BG+10%BB, X+Y+0.5%CS+N*	1849.17	2302.25	2308.58	2519.85	2563.27	2678.48
▲ 90%BG+10%BB, X+Y+7.0%CS+N*	2075.16	2470.44	2550.28	2701.76	2863.95	3107.45
✕ 90%BG+10%BB, X+Y+1.0%CS+N*	2081.24	2535.01	2679.22	2710.92	2985.29	3168.92

Fig. 4.25: Breaking length vs. CSF of first recycled paper prepared by blending of blgd. bamboo pulp with bagasse pulp with the addition of sizing chemicals, soap stone filler, varying doses of cationic starch and retention aids (N*).

TABLE 4.19

Effect on breaking length of first recycle of paper due to blending of long fibre bleached bamboo pulp and addition of varying doses of cationic starch at different CSF

S. No.	Fibre Composition	CSF → Chem. composition	590	560	540	510	440	310
1	90%BG+10%BB	X+Y+N*	742.98	1949.86	1989.21	2169.25	2201.01	2263.94
2	90%BG+10%BB	X+Y+0.5%CS+N*	1849.17	2302.25	2308.58	2519.85	2563.27	2678.48
3	90%BG+10%BB	X+Y+0.5%CS+N*	2075.16	2470.44	2550.28	2701.76	2863.95	3107.45
4	90%BG+10%BB	X+Y+0.5%CS+N*	2081.24	2535.01	2679.22	2710.92	2985.29	3168.92
5	80% BG+20%BB	X+Y+N*	1875.10	1908.03	2179.10	2315.63	2255.71	2229.04
6	80% BG+20%BB	X+Y+0.7%CS+N*	2229.61	2338.63	2506.73	2603.01	2629.94	2647.65
7	80%BG+20%BB	X+Y+0.7%CS+N*	2292.07	2557.21	2598.54	2855.21	2960.07	3117.28
8	80% BG+20%BB	X+Y+0.7%CS+N*	2651.14	2866.41	2883.62	2926.06	3066.25	3174.88
9	70% BG+30%BB	X + Y + N*	2382.32	2529.18	2537.25	2553.47	2762.41	2815.73
10	70% BG+30%BB	X+Y+1.0%CS+N*	2597.03	2690.27	2713.78	2838.63	2957.91	3025.12
11	70% BG+30%BB	X+Y+1.0%CS+N*	2759.87	2798.46	2841.88	2883.09	3126.27	3326.85
12	70%BG+30%BB	X+Y+1.0%CS+N*	2831.09	2861.62	2902.59	3155.63	3168.25	3498.59

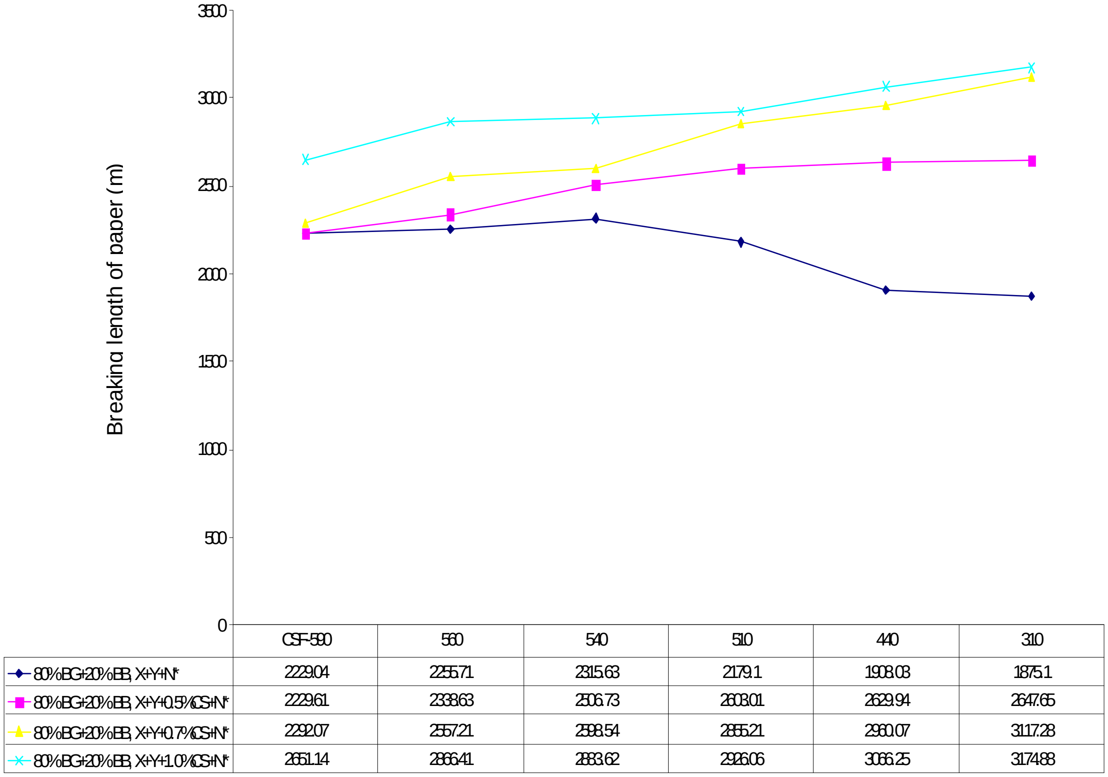
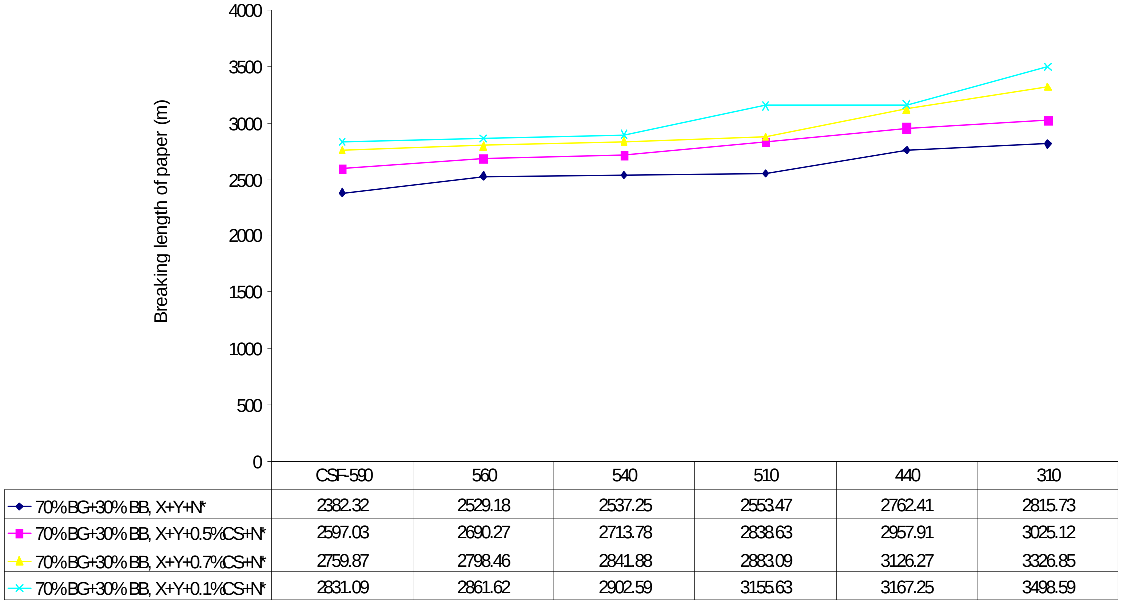


Fig. 4.26: Breaking length vs. CSF, of first recycled paper prepared by blending of blgd. bamboo pulp with bagasse pulp with the addition of sizing chemicals, soap stone filler, varying doses of cationic starch and retention aids (N*).



	CSF-590	560	540	510	440	310
◆ 70% BG+30% BB, X+Y+N*	2382.32	2529.18	2537.25	2553.47	2762.41	2815.73
■ 70% BG+30% BB, X+Y+0.5%CS+N*	2597.03	2690.27	2713.78	2838.63	2957.91	3025.12
▲ 70% BG+30% BB, X+Y+0.7%CS+N*	2759.87	2798.46	2841.88	2883.09	3126.27	3326.85
× 70% BG+30% BB, X+Y+0.1%CS+N*	2831.09	2861.62	2902.59	3155.63	3167.25	3498.59

Fig 4.27: Breaking length vs. CSF of first recycled paper prepared by blending blgd. bamboo pulp with bagasse pulp with the addition of sizing chemicals, soap stone filler, varying doses of cationic starch and retention aids (N*).

4.22 Study of the burst factor

(1) For the case of blending of bamboo pulp.

(a) The burst factor of the paper sheet increases due to the beating, as CSF of pulp decreases from 590 ml to 310 ml, i.e. The burst factor improves from 8.32 to 15.84 with the 10% blending of bleached bamboo pulps in the furnish **(Fig. 4.28).** The maximum burst factor was obtained 21.01 with 10% blending of bleached bamboo pulp along with 1.0% dose of cationic starch.

(b) When the blending of bamboo pulp increased by 20%, there is also a good improvement in burst factor. The burst factor improves from 11.53 to 18.62 when the cationic starch content is kept constant at the value of 0.5%. The change in burst factor was observed from 11.53 to 18.62 when the change in CSF takes place due the beating process from 590 ml to 310 ml CSF **(Fig. 4.29).** When 1.0% cationic starch dose was added along with 20% bleached bamboo pulp blending the maximum burst factor (21.27) was obtained.

(c) There is also an improvement in the burst factor when the blending of bamboo pulp is increased up to 30% and starch content is kept 0.5%. The burst factor is also increases from 14.23 to 20.01 when the CSF changes from 590 to 310 ml due to the beating of pulp **(Fig. 4.30).** A good improvement in burst factor indicates the better recycling potential of the bagasse pulp. The maximum burst factor (22.06) was obtained with the blending of 30% bleached bamboo pulp along with 1.0% cationic starch dose, which indicated that long fibre pulp has little effect on burst factor.

(2) Effect of adding cationic starch

The effect on burst factor may be observed from the **Fig. 4.28, Fig. 4.29**, and **Fig. 4.30**.

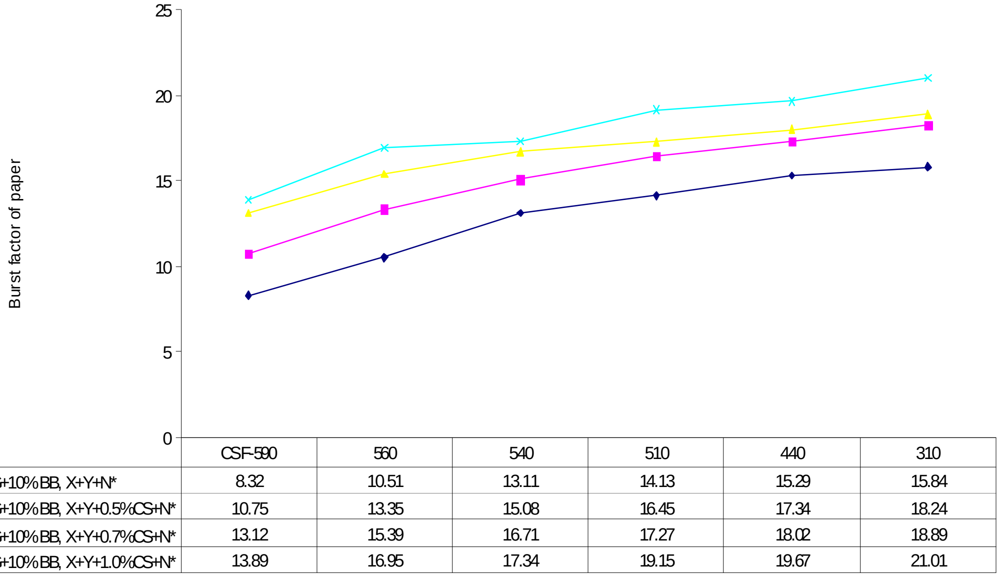
(a) It is observed from the results that there is an improvement in the burst factor at each CSF. The burst factor improvement is there when the cationic starch is added in the increasing order.

(b) The effect of cationic starch on burst factor improvement is more at the 560 ml CSF i.e 26.97% and i.e. 15.19% at 310 ml CSF in case of 10% blending of bamboo pulp **(Fig. 4.28).**

(c) When the bamboo pulp blending is kept at 20% the cationic starch content is increased from 0.5% to 1.0%. The burst factor is increased up to 21.27 at 310 ml CSF **(Fig. 4.29).**

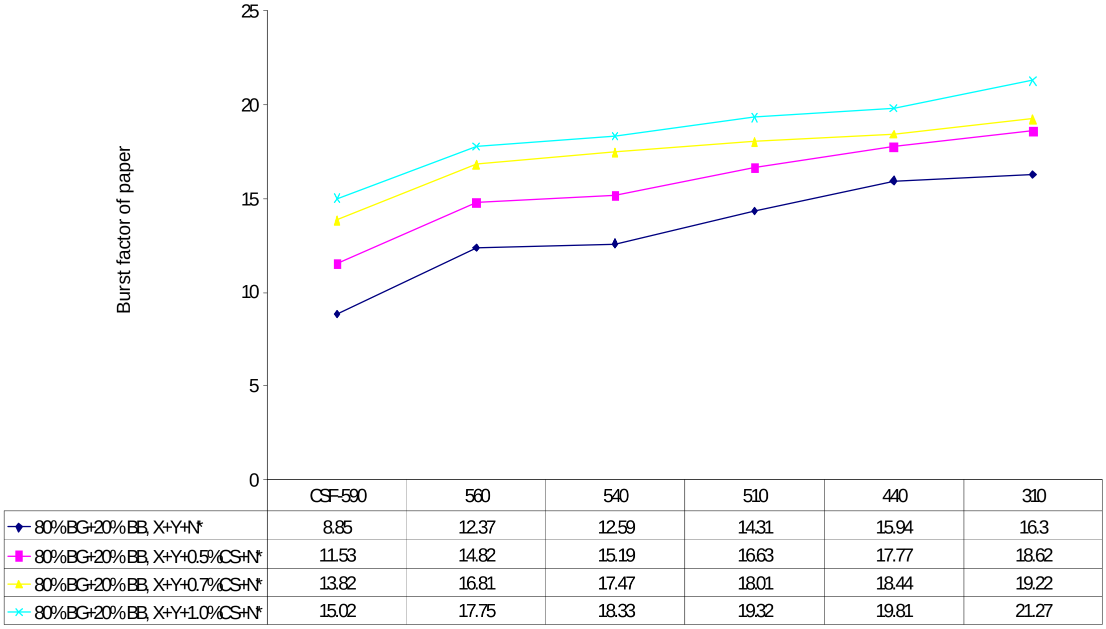
(d) When the bamboo pulp blending is kept at 30% and the cationic starch content increased from 0.5% to 1.0%. The maximum increase in burst factor was observed 22.06 at 310 ml CSF **(Fig. 4.30).**

These results show that when the beating of fibre increases the increase in burst factor progresses slowly, even increasing the addition of cationic starch content into the first recycled paper sheet. It is observed that at low CSF the addition of more cationic starch is less beneficial in comparison to the blending of long fibreed pulps. It is observed from the **Table 4.20** that 1.0% cationic starch dose impart very good in enhancement in the burst factor in paper in comparison to the blending of bamboo pulp.



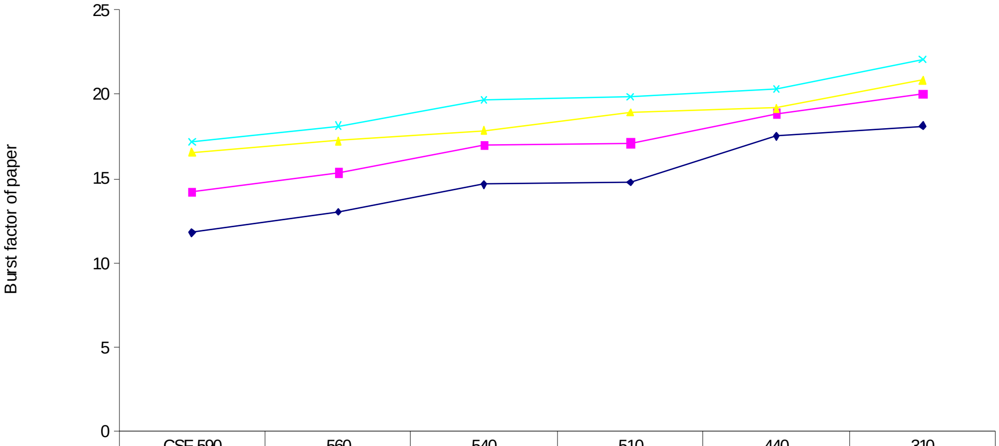
	CSF-590	560	540	510	440	310
◆ 90% BG+10% BB, X+Y+N*	8.32	10.51	13.11	14.13	15.29	15.84
■ 90% BG+10% BB, X+Y+0.5%CS+N*	10.75	13.35	15.08	16.45	17.34	18.24
▲ 90% BG+10% BB, X+Y+0.7%CS+N*	13.12	15.39	16.71	17.27	18.02	18.89
× 90% BG+10% BB, X+Y+1.0%CS+N*	13.89	16.95	17.34	19.15	19.67	21.01

Fig. 4.28: Burst factor vs.CSF, of 1st recycled paper prepared by blending of blgd. bamboo pulp with bagasse pulp with the addition of sizing chemicals, soap stone filler and varying doses of cationic starch and retention aids (N*).



	CSF-590	560	540	510	440	310
◆ 80%BG+20%BB, X+Y+N*	8.85	12.37	12.59	14.31	15.94	16.3
■ 80%BG+20%BB, X+Y+0.5%CS+N*	11.53	14.82	15.19	16.63	17.77	18.62
▲ 80%BG+20%BB, X+Y+0.7%CS+N*	13.82	16.81	17.47	18.01	18.44	19.22
× 80%BG+20%BB, X+Y+1.0%CS+N*	15.02	17.75	18.33	19.32	19.81	21.27

Fig. 4.29: Burst factor vs. CSF of 1st recycled paper prepared by blending of blgd. bamboo pulp with bagasse pulp with the addition of sizing chemicals, soap stone filler, varying doses of cationic starch & retention aids (N*).



	CSF-590	560	540	510	440	310
70% BG+30% BB, X+Y+N*	11.78	13.03	14.65	14.77	17.52	18.15
70% BG+30% BB, X+Y+0.5%CS+N*	14.23	15.37	16.97	17.12	18.87	20.01
70% BG+30% BB, X+Y+0.7%CS+N*	16.57	17.23	17.86	18.92	19.18	20.84
70% BG+30% BB, X+Y+1.0%CS+N*	17.19	18.13	19.66	19.84	20.32	22.06

Fig.4.30: Burst factor vs. CSF of 1st recycled paper sheet prepared by blending of bleached bamboo pulp with bagasse pulp with the addition of sizing chemicals, soap stone filler, varying doses of cationic starch and retention aids (N*).

4.23 Effect on tear factor of the first recycled paper sheet

It is observed that the tear factor of the standard paper sheet improves by the following operations.

(a) Due to blending of bamboo pulp and increasing the beating of the pulp samples.

(b) Due to the increased beating, and dosing of cationic starch content.

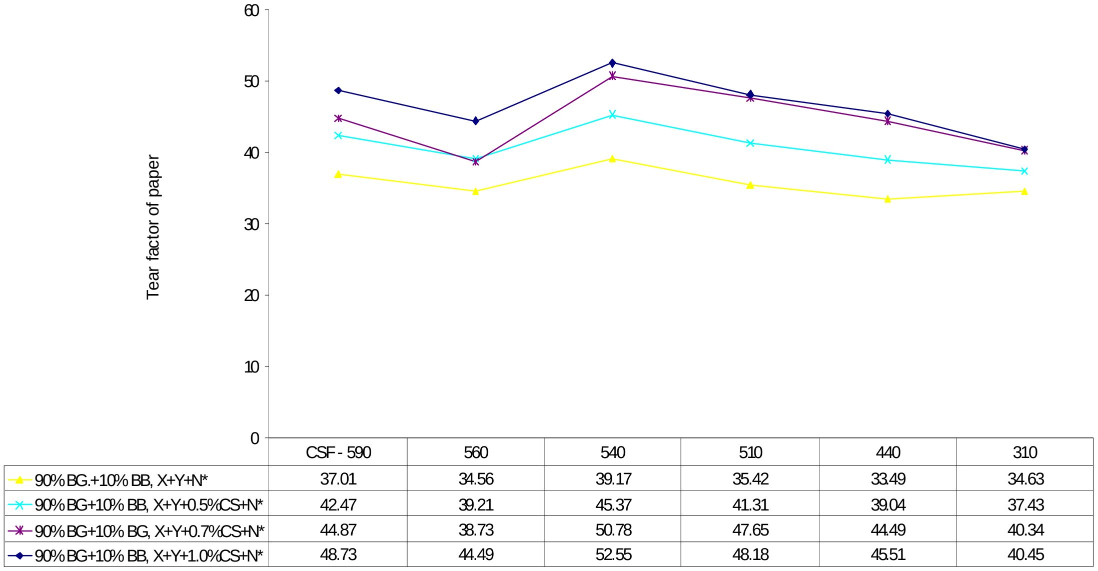
These effects are observed by the analysis of results of the **Fig. 4.31, Fig. 4.32**, and **Fig. 4.33**,

(a) The paper sheet was prepared by blending 10% bamboo pulp with 90% bleached bagasse pulp and addition of 0.5% cationic starch. It is observed that the tear factor of the paper sheet improves from 42.47 to 45.37, when the CSF of the pulp changes from 590 to 540 ml. If more beating of pulp is carried out the tear factor reduces from 45.37 to 37.43 at 310 ml CSF. The tear factor further improves to 52.55 form 45.37 at 540 ml CSF when the starch content is increased from 0.5% to 1.0% and the increase is 15.83% **(Fig. 4.31)**.

TABLE 4.20

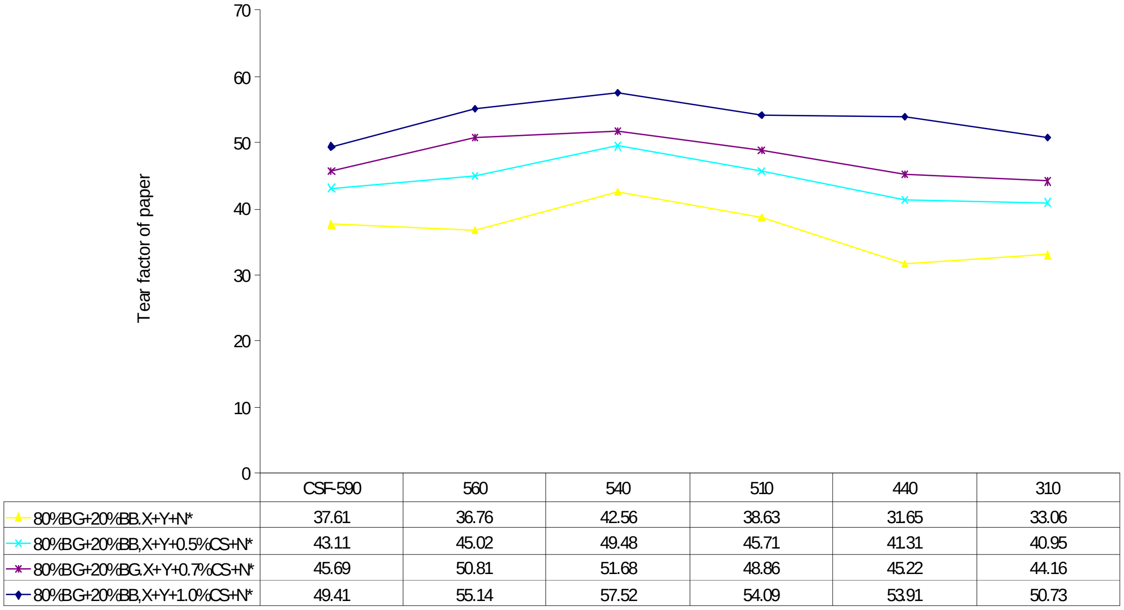
Effect on burst factor of first recycle of paper due to blending of long fibre bleached bamboo pulp and addition of varying doses of cationic starch at different CSF

S. No.		CSF →	590	560	540	510	440	310
1	Fibre composition 90%BG+10%BB	Chem. composition X + Y + N*	8.32	10.51	13.11	14.13	15.29	15.84
2	90%BG+10%BB	X+Y+0.5%CS+N*	10.75	13.35	15.08	16.45	17.34	18.24
3	90%BG+10%BB	X+Y+0.7%CS+N*	13.12	15.39	16.71	17.27	18.02	18.89
4	90%BG+10%BB	X+Y+1.0%CS+N*	13.89	16.95	17.34	19.15	19.67	21.01
5	80% BG+20%BB	X+Y+N*	8.85	12.37	12.59	14.31	15.94	16.30
6	80% BG+20%BB	X+Y+0.5%CS+N*	11.53	14.82	15.19	16.63	17.77	18.62
7	80%BG+20%BB	X+Y+0.7%CS+N*	13.82	16.81	17.47	18.01	18.44	19.22
8	80% BG+20%BB	X+Y+1.0%CS+N*	15.02	17.75	18.33	19.32	19.81	21.27
9	70% BG+30%BB	X + Y + N*	11.78	13.03	14.65	14.77	17.52	18.15
10	70% BG+30%BB	X+Y+0.5%CS+N*	14.23	15.37	16.97	17.12	18.87	20.01
11	70% BG+30%BB	X+Y+0.7%CS+N*	16.57	17.23	17.86	18.92	19.18	20.84
12	70%BG+30%BB	X+Y+1.0%CS+N*	17.19	18.13	19.66	19.84	20.32	22.06



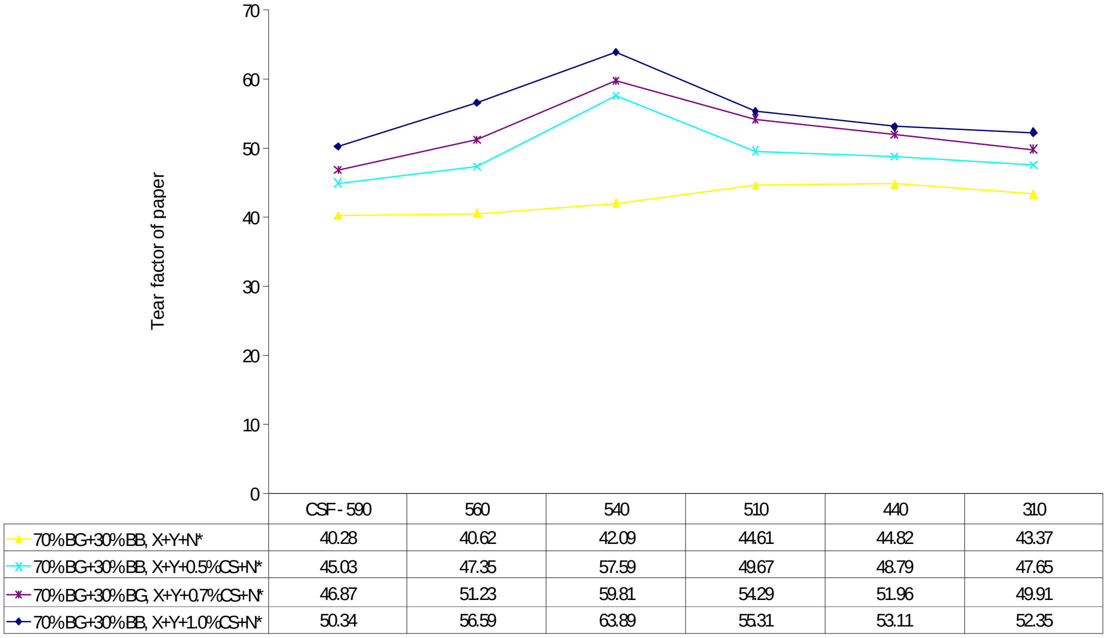
	CSF - 590	560	540	510	440	310
▲ 90% BG.+10% BB, X+Y+N*	37.01	34.56	39.17	35.42	33.49	34.63
✕ 90% BG+10% BB, X+Y+0.5%CS+N*	42.47	39.21	45.37	41.31	39.04	37.43
✱ 90% BG+10% BG, X+Y+0.7%CS+N*	44.87	38.73	50.78	47.65	44.49	40.34
◆ 90% BG+10% BB, X+Y+1.0%CS+N*	48.73	44.49	52.55	48.18	45.51	40.45

Fig. 4.31: Tear factor vs. CSF of 1st recycled paper prepared by blending of blgd. bamboo pulp with bagasse pulp with the addition of sizing chemicals, soap stone filler, & varying doses of cationic starch & retention aids (N*).



	CSF-590	560	540	510	440	310
▲ 80%BG+20%BB.X+Y+N*	37.61	36.76	42.56	38.63	31.65	33.06
× 80%BG+20%BB,X+Y+0.5%CS+N*	43.11	45.02	49.48	45.71	41.31	40.95
✳ 80%BG+20%BG.X+Y+0.7%CS+N*	45.69	50.81	51.68	48.86	45.22	44.16
◆ 80%BG+20%BB,X+Y+1.0%CS+N*	49.41	55.14	57.52	54.09	53.91	50.73

Fig. 4.32: Tear factor vs. CSF, of 1st recycled paper prepared by blending bleached bamboo pulp with bagasse pulp by addition of varying doses of cationic starch and retention aids (N*).).



	CSF - 590	560	540	510	440	310
▲ 70%BG+30%BB, X+Y+N*	40.28	40.62	42.09	44.61	44.82	43.37
× 70%BG+30%BB, X+Y+0.5%CS+N*	45.03	47.35	57.59	49.67	48.79	47.65
✳ 70%BG+30%BG, X+Y+0.7%CS+N*	46.87	51.23	59.81	54.29	51.96	49.91
◆ 70%BG+30%BB, X+Y+1.0%CS+N*	50.34	56.59	63.89	55.31	53.11	52.35

Fig. 4.33: Tear factor vs. CSF of 1st recycled paper prepared by blending of blgd. bamboo pulp with bagasse pulp with addition of sizing chemicals, soap stone filler & varying doses of cationic starch & retention aids (N*).

(b) From the analysis of the data of tear factor the maximum tear development is obtained at 540 ml CSF, but it can be further increased by increasing dosing of cationic starch and by blending of bamboo pulp. The higher tear factor (i.e. 63.89) may be achieved by the 30% blending of bamboo pulp with 1.0% cationic starch dose at first recycled stage (**Fig. 4.33**).

(c) The addition of cationic starch in the paper sheet shows good strength developments (70.33%) at 440 ml CSF, but in some cases the variable results are found which may be due to the variation in the pH or due to the zeta potential of the pulp, which affects the effectiveness of the cationic starch in the strength development of the paper sheet in different cases.

(d) The tear factor of the paper increases due to the blending of long fibreed pulp effectively in comparison to the starch content, but if the pH and other factor are maintained properly the cationic starch also show good strength development in the paper sheet.

(e) From **Table 4.21**, it can be noticed that good tear factor development was obtained at 540 ml CSF and the maximum tear factor (63.89) was obtained by 30% blending of bleached bamboo pulp along with 1.0% cationic starch dose.

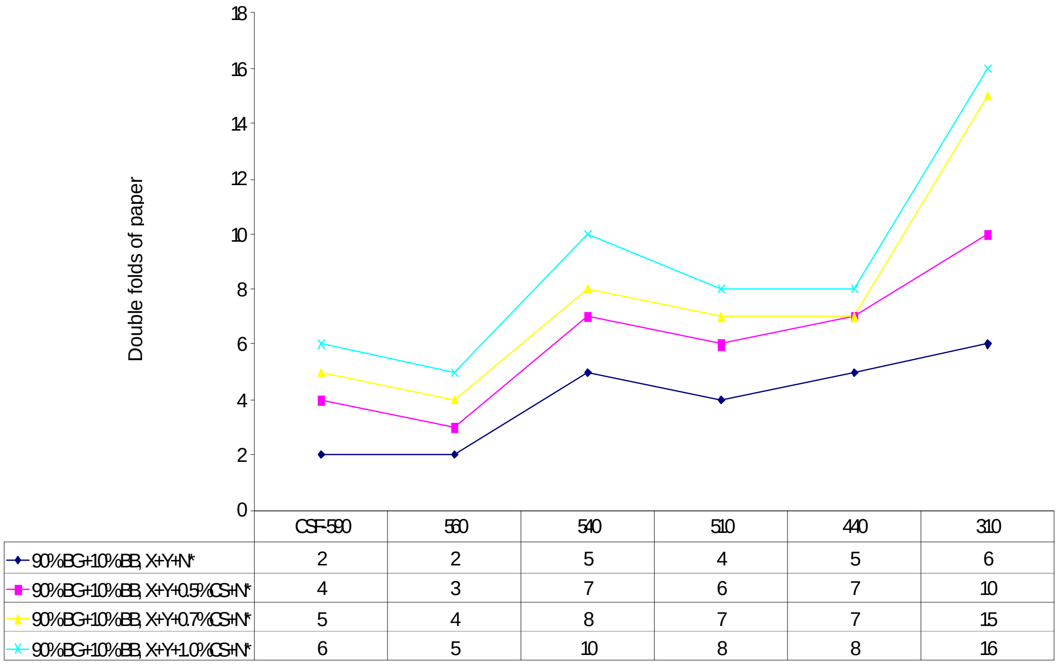
4.24 Effect on double folds of the paper sheet in case of first recycled paper

From the analysis of the results of **Fig. 4.34, Fig. 4.35,** and **Fig. 4.36**, the following results are observed. It is noticed that the double folds of first recycled paper sheet improves from 2 to 6 folds when the CSF of the pulp decrease from 590 ml CSF to 310 ml CSF due the mechanical treatment of fibres in the beating process. Moreover a considerable improvement in double folds is also noticed due to the increased dosing of cationic starch at 310 ml CSF. The increase in double folds at low CSF is more which may be due the strong bonding among the increased surface area of the good beaten fibres. The double folds of its original standard hand sheets have been tabulated and the corresponding change in double folds at each stage has been observed **(Table 4.22).** Analysis of results of the **Table 4.22** for the double folds of paper sheet on the basis increasing the cationic starch dose in the paper sheets from 0.5% to 1.0% are shown in the **Table 4.22**.

TABLE 4.21

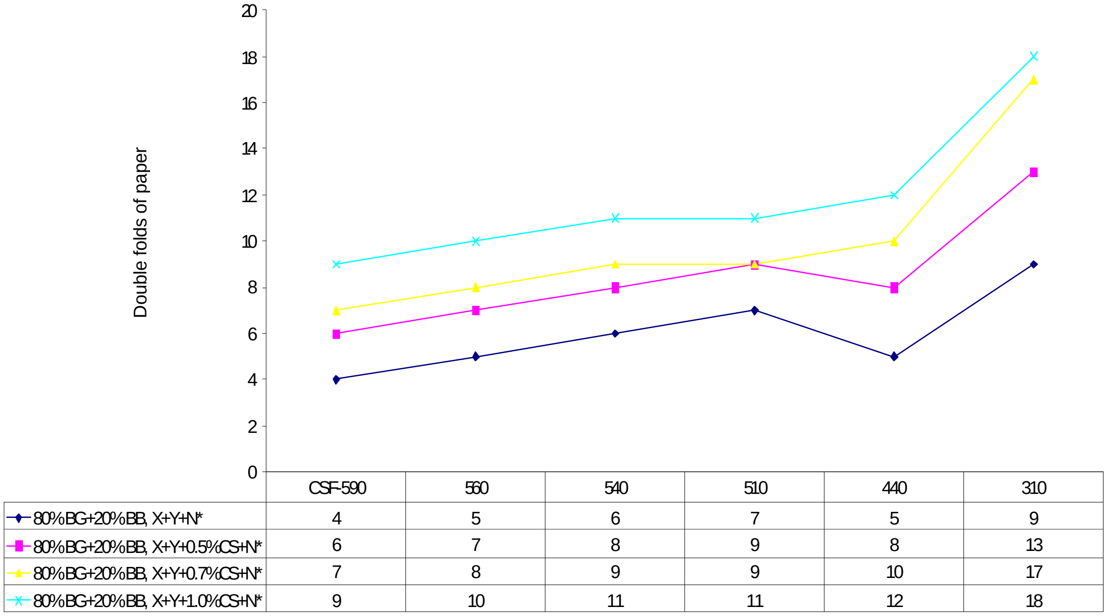
Effect on tear factor of first recycle of paper due to blending of long fibre bleached bamboo pulp and addition of varying doses of cationic starch at different CSF

S. No.		CSF →	590	560	540	510	440	310
1	Fibre composition 90%BG+10%BB	Chem. composition X + Y + N*	37.01	34.56	39.17	35.42	33.49	34.63
2	90%BG+10%BB	X+Y+0.5%CS+N*	42.47	39.21	45.37	41.31	39.04	37.43
3	90%BG+10%BB	X+Y+0.5%CS+N*	44.87	38.73	50.78	47.65	44.49	40.34
4	90%BG+10%BB	X+Y+0.5%CS+N*	48.73	44.49	52.55	48.18	45.51	40.45
5	80% BG+20%BB	X+Y+N*	37.61	36.76	42.56	38.63	31.65	33.06
6	80%BG+20%BB	X+Y+0.7%CS+N*	43.11	45.02	49.48	45.71	41.31	40.95
7	80%BG+20%BB	X+Y+0.7%CS+N*	45.69	50.81	51.68	48.86	45.22	44.16
8	80%BG+20%BB	X+Y+0.7%CS+N*	49.41	55.14	57.52	54.09	53.91	50.73
9	70% BG+30%BB	X + Y + N*	40.28	40.62	42.09	44.61	44.82	43.37
10	70%BG+30%BB	X+Y+1.0%CS+N*	45.03	47.35	57.59	49.67	48.79	47.65
11	70%BG+30%BB	X+Y+1.0%CS+N*	46.87	51.23	59.81	54.29	51.96	49.91
12	70%BG+30%BB	X+Y+1.0%CS+N*	50.34	56.59	63.89	55.31	53.11	52.35



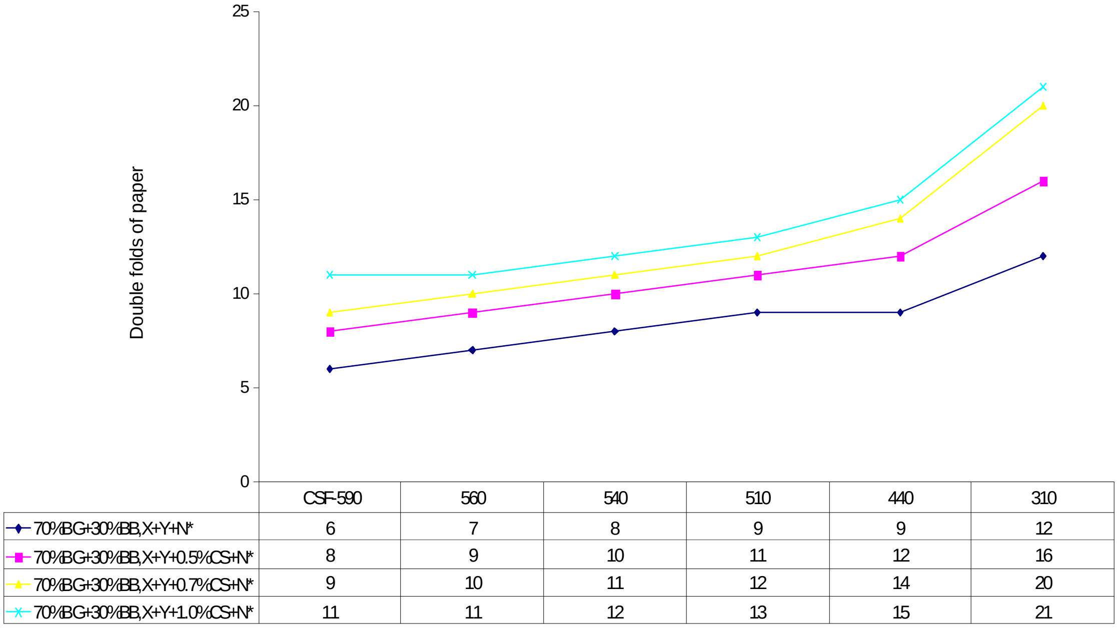
	CSF-590	560	540	510	440	310
◆ 90%BG+10%BB, X+Y+N*	2	2	5	4	5	6
■ 90%BG+10%BB, X+Y+0.5%CS+N*	4	3	7	6	7	10
▲ 90%BG+10%BB, X+Y+0.7%CS+N*	5	4	8	7	7	15
× 90%BG+10%BB, X+Y+1.0%CS+N*	6	5	10	8	8	16

Fig. 4.34: Double folds vs. CSF of 1st recycled paper prepared by blending of blgd. bamboo pulp with bagasse pulp with addition of sizing chemicals, soap stone filler, & varying doses of cationic starch & retention aids (N*)



	CSF-590	560	540	510	440	310
80%BG+20%BB, X+Y+N*	4	5	6	7	5	9
80%BG+20%BB, X+Y+0.5%CS+N*	6	7	8	9	8	13
80%BG+20%BB, X+Y+0.7%CS+N*	7	8	9	9	10	17
80%BG+20%BB, X+Y+1.0%CS+N*	9	10	11	11	12	18

Fig. 4.35: Double folds vs. CSF of 1st recycled paper prepared by blending of bleached bamboo pulp with bleached bagasse pulp with addition of sizing chemicals, soapstone filler & varying doses of cationic starch & retention aids (N*)



	CSF-590	560	540	510	440	310
70%BG+30%BB,X+Y+N*	6	7	8	9	9	12
70%BG+30%BB,X+Y+0.5%CS+N*	8	9	10	11	12	16
70%BG+30%BB,X+Y+0.7%CS+N*	9	10	11	12	14	20
70%BG+30%BB,X+Y+1.0%CS+N*	11	11	12	13	15	21

Fig. 4.36: Double folds vs. CSF of first recycled paper sheet prepared from blending of bleached bamboo pulp with bagasse pulp in various ratios with addition of cationic starch in varying doses and retention aids (N*).

It was observed from the **Table 4.22**, that when the fibre blending composition is kept constant and the cationic starch dose has been increased from 0.5% to 0.7% and 1.0% there is an increase in the double folds at 590 ml CSF and the double fold increases as 4, 5, 6 respectively, when 10% blending of bamboo pulp is carried out with 90% bagasse pulp. It was observed that cationic starch is helpful in increasing the double folds of the paper sheet as per the results shown in **Table 4.22.** The improvement in double folds was noticed as 10, 15, and 16 when the dosing of cationic starch was increased as 0.5%, 0.7% and 1.0% respectively (**310 ml CSF**).

4.25 Effect of blending of long fibreed pulp

In case of blending of long fibreed pulp, the effect on double folds was studied keeping the degree of beating and dosing of cationic starch content constant into the furnish. It was observed that due to blending of long fibreed pulp in furnish, the double folds of paper sheet was increased if the blending of long fibreed pulp was increased from 10% to 20%. But if the blending of bamboo pulp was further increased from 20% to 30% the effect on double folds improvement was not much as in the previous case and the increase in double folds improvement was less. This shows that further improvement in double folds will need much long fibreed pulp. More long fibreed pulp will be needed to maintain the previous performance of double folds.

TABLE 4.22

Effect on double folds of first recycle of paper due to blending of long fibre bleached bamboo pulp in different proportions and addition of varying doses of cationic starch at different CSF

S. No.	Fibre composition	Chem. composition CSF in ml (→)	590	560	540	510	440	310
1	90%BG+10%BB	X+Y+0.N*	2	2	5	4	5	6
2	90%BG+10%BB	X+Y+0.5%CS+N*	4	3	7	6	7	10
3	90% BG+10%BB	X+Y+0.7%CS+N*	5	4	8	7	7	15
4	90%BG+10%BB	X+Y+1.0%CS+N*	6	5	10	8	8	16
5	80%BG+20%BB	X+Y+0.N*	4	5	6	7	5	9
6	80%BG+20%BB	X+Y+0.5%CS+N*	6	7	8	9	8	13
7	80% BG+20%BB	X+Y+0.7%CS+N*	7	8	9	9	10	17
8	80%BG+20%BB	X+Y+1.0%CS+N*	9	10	11	11	12	18
9	70%BG+30%BB	X+Y+0.N*	6	7	8	9	9	12
10	70%BG+30%BB	X+Y+0.5%CS+N*	8	9	10	11	12	16
11	70%BG+30%BB	X+Y+0.7%CS+N*	9	10	11	12	14	20
12	70%BG+30%BB	X+Y+1.0%CS+N*	11	11	12	13	15	21

4.26 Effect of beating on double folds

For observing the performance of double folds of paper sheet with respect to the beating of pulp and other parameters like long fibre blending with the bagasse pulp and increased dosing of cationic starch content was kept constant into the furnish.

It was observed that as the beating increases the double fold of paper sheet improves, but there are some variations in the results, which may be due to the cloudiness in the paper sheet. Some good results are observed at low CSF which may be due to bonding strength of the fibres with the cationic starch as more specific surface area of the fibre is available due to more beating effects. The good flexibility in paper sheet is available at low CSF pulp because at low CSF the cellulose fibres have good tendency to hold more water content in it. Due to more fibrillated pulp, the paper sheet possesses high density, as more beaten pulp contains more bonding strength among the fibres with in the paper sheet. Whereas at high CSF, the fibre to fibre bonding remain less and paper sheet contains more void fractions and resulting the porous and bulky paper sheet which produces the less double folds in paper sheet. The maximum double folds of standard paper sheet was obtained 21 at 310 ml CSF with 30% bleached bamboo pulp blending and 1.0% dosing of cationic starch (**Table 4.22**).

4.27 Effect on breaking length of second recycled paper sheet

(1) Analysis of results of second recycled paper sheet

The second recycled paper sheets were prepared by blending the 50% fresh beaten pulp mixture of pulp containing 70% bleached bagasse and 30% bleached bamboo pulp i.e. (70% BG + 30% BB pulps) by beating it up to the same extent as per the samples available for making the second recycled paper sheets. The fresh pulp was blended in the recycled pulp as this pulp was become too weak after re-slushing after the first recycled stage. As in further processing the cationic starch imparted the bad effect on the strength properties of paper after the first recycle of these paper sheets. So 50% fresh pulp (containing the mixture of 70% bleached bagasse pulp and 30% bleached, bamboo pulp) was blended in the second recycled paper sheets.

The effect on breaking length was analyzed on the basis of

(1) Previous fibre composition present in the sheet.
(2) Blending of fresh pulp (containing mixture of 70% fresh bleached bagasse pulp and 30% fresh bleached bamboo pulp) after beating it up to the same extent of the in which this pulp to be blending.
(3) Addition of cationic starch T-25 in making the standard sheet in varying doses

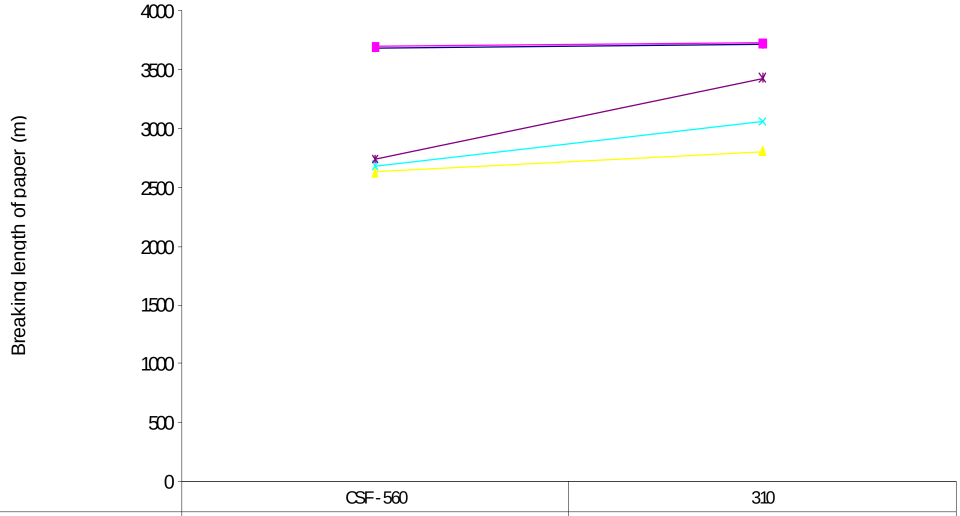
(as mentioned in the table).

(4) On the basis of beating extent of the previous pulp from which the recycled paper sheets were made.

After the evaluation of test results of breaking length, the results were analyzed and plotted in the **Fig. 4.37** and **Fig. 4.38**.

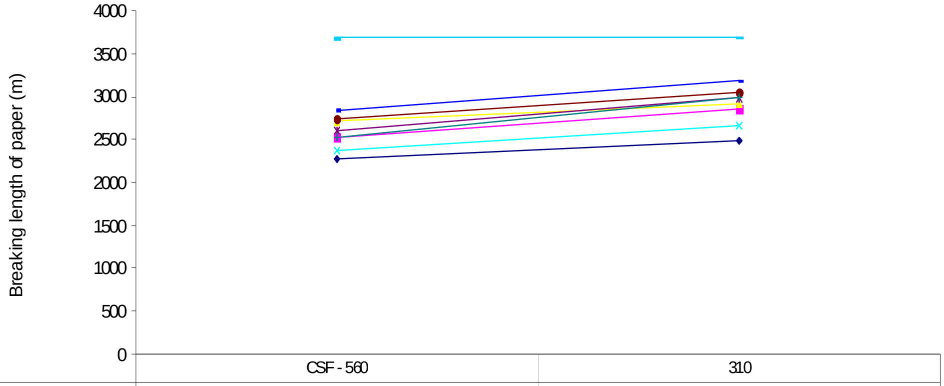
From the **Table 4.23**, it was observed that when 50% fresh beaten pulp was blended in the re-slushed pulp after the first recycle of paper sheet and the standard laboratory sheet was prepared without mixing any chemical in it. The breaking length of second recycled paper sheet was obtained 3687.57 meters at 560 ml CSF and 3721.39 meters at 310 ml CSF. Moreover when the second recycled paper sheet were prepared from the first recycled paper sheet with the dosing of cationic starch in it after re-slushing and by adding 50% fresh pulp on the O.D. basis. The breaking length of second recycled paper sheet was recorded 2493.67 m on 560 ml CSF and 2294.91m on 310 ml CSF. These paper sheets were having about 32.38% and –38.33% reduced breaking length at 590 ml, and 310 ml CSF respectively **Table 4.23**, this decrease in breaking length was quite significant.

Effect of cationic starch on second recycled paper sheet prepared by blending the 50% fresh pulp in the pure bleached bagasse re-slushed pulp from the first recycled paper sheets. A 2.04% increase in breaking length was observed, when the cationic starch dosing was increased from 0.7 to 1.0% on 560 ml CSF. Similarly at 310 ml CSF the (9.09%) improvement in the breaking length was observed when the dose of cationic was content increased from 0.5% to 0.7%. Further at 310 ml CSF when the dose of cationic starch content was increased from 0.7% to 1.0%. A 12.09% increase in breaking length was observed at 310 ml CSF, which is the good sign of the recycle-ability of the paper sheet due to the addition of the cationic starch content. As per the detailed analysis of the data of **Table 4.23,** it was observed that good strength development in the breaking length of paper was observed 3687.57 meters at 560 ml CSF. Whereas at 310 ml CSF the improvement in the breaking length was observed 16.0%, when the standard paper sheet was prepared from the pulp having the fibre composition of first recycled paper sheet with the blending of fresh pulp (having composition 70% bagasse pulp plus 30% bamboo pulp, 1.0% cationic starch along with other chemicals as per the previous paper sheet). The minimum improvement was observed in the paper prepared under the conditions given at the serial no.4 in the **Table 4.23**.



	CSF - 560	310
◆ 100%BG+0%BB+(50%FP), No chamical.	3687.57	3721.39
■ 90%BG+10%BB+(50%FP), No chemical	3695.87	3732.29
▲ 100%BG+0%BB+(50%FP), X+Y+0.5%CS+N*	2629.34	2806.33
× 100%BG+0%BB+(50%FP), X+Y+0.7%CS+N*	2684.75	3061.38
✳ 100%BG+0%BB+(50%FP), X+Y+1.0%CS+N*	2739.53	3431.73

Fig.4.37: Breaking length vs. CSF, of second recycled paper prepared from blending of bleached bamboo pulp in bagasse pulp adding 50% fresh pulp, sizing chemicals, soap stone filler, cationic starch and retention aids (N*).



	CSF - 560	310
◆ 90%BG+10%BB+(50%FP),X+Y+0.5%CS+N*	2271.01	2489.81
■ 90%BG+10%BB+(50%FP),X+Y+0.7%CS+N*	2529.87	2852.73
▲ 90%BG+10%BB+(50%FP),X+Y+1.0%CS+N*	2712.61	2914.16
× 80%BG+20%BB+(50%FP),X+Y+0.5%CS+N*	2371.01	2665.43
✳ 80%BG+20%BB+(50%FP),X+Y+0.7%CS+N*	2607.58	2984.71
● 80%BG+20%BB+(50%FP),X+Y+1.0%CS+N*	2739.53	3048.54
+ 70%BG+30%BB+(50%FP),X+Y+0.5%CS+N*	2527.87	2991.18
▬ 70%BG+30%BB+(50%FP),X+Y+0.7%CS+N*	2842.76	3184.78
▬ 70%BG+30%BB+(50%FP),X+Y+1.0%CS+N*	3687.57	3694.31

Fig. 4.38: Breaking length vs. CSF of 2nd recycled paper prepared from blending of bleached bamboo pulp with bleached bagasse pulp adding fresh pulp, sizing chemical, soap stone filler, cationic starch, and retention aids (N*).

TABLE 4.23

Effect on breaking length of second recycled paper due to increased blending of 50% fresh bleached bamboo pulp and varying doses of cationic starch.

S. No.	Fibre composition	Chemical composition CSF in ml (→)	Breaking length of paper sheet (m) at (CSF-560) (↓)	Gain in breaking length at (CSF-510) (↓)	Improved breaking length at (CSF-310) (↓)	Gain in breaking length (%) (↓)
1	100%BG+00%BB+50%FP	No Chemical added	3687.57		3721.39	
2	100%BG+00%BB+50%FP	X+Y+N*	2493.67	-32.38	2294.91	-38.33
3	100%BG+00%BB+50%FP	X+Y+0.5%CS+N*	2629.34		2806.	
4	100%BG+00%BB+50%FP	X+Y+0.7%CS+N*	2684.75	2.11	3061.38	9.09
5	100%BG+00%BB+50%FP	X+Y+1.0%CS+N*	2739.53	2.04	3431.73	12.09
6	90% BG+10%BB+50% FP	X+Y+0.5%CS+N*	2271.01		2489.81	
7	90% BG+10%BB +50% FP	X+Y+0.7%CS+N*	2529.87	11.4	2852.73	14.58
8	90%BG+10%BB+50%FP	X+Y+1.0%CS+N*	2712.61	7.22	2914.16	2.15
9	80%BG+20%BB+50%FP	X+Y+0.5%CS+N*	2371.01		2665.43	
10	80% BG+20%BB+50%FP	X+Y+0.7%CS+N*	2607.58	9.98	2984.71	11.18
11	80%BG+20%BB+50%FP	X+Y+1.0%CS+N*	2739.53	5.06	3048.54	15.54
12	70%BG+30%BB+50%FP	X+Y+0.5%CS+N*	2527.87		2991.18	
13	70%BG+30%BB+50%FP	X+Y+0.7%CS+N*	2842.76	12.46	3184.78	6.47
14	70%BG+30%BB+50%FP	X+Y+1.0%CS+N*	3687.57	29.12	3694..31	16.0

These results show the maximum strength development in the paper sheet prepared, as per the conditions given in the **Table 4.23** at serial no.14. It was observed from the analysis of the data at s. no.14 in the **Table 4.23** that the breaking length increases from 3687.57 meters to 3694.31 meters due to the increase in beating degree from 560 ml to 310 ml CSF.

4.28 Effect of cationic starch addition on the breaking length of the paper sheet

In the second recycle of the paper sheet the cationic starch improves the breaking length effectively as per the results tabulated in the **Table 4.23.**

It is observed that as the long fibre blending is carried out at 560 ml CSF the increase in breaking length is less in comparison to the increase in breaking length at 310 ml CSF. But some exceptions are observed in this case at 560 ml CSF. The maximum improvement in breaking length was observed at 1.0% cationic starch dosing, at with 30% long fibreed pulp blending at 560 ml CSF. It takes place because at 310 ml CSF, the intrinsic strength of the fibre decreases due to the more beating treatment on the fibres, and the pulp becomes weak due to the more mechanical treatment of fibre in the beater as well as in the disintegrator at the time of re-slushing of the paper sheet prior to make the second recycled paper sheet.

4.29 Effect of blending of long fibreed pulp in the second recycled paper sheet

It is observed from the **Table 4.23** that long fibreed pulp is beneficial in increasing the breaking length of the paper sheet. It was observed from the **Table 4.24** that the improvement in the breaking length is 2.11% at 560 ml CSF.

The standard paper sheet was prepared by increasing the dose of cationic starch from 0.5% to 0.7% with the blending of 50% fresh pulp in furnish of first recycled paper sheet initially prepared from pure bleached bagasse pulp. The breaking length improves from 2629.34 meters to 2684.75 meters (s. no. 1 and 2 in **Table 4.24).** Similarly at 310 ml CSF this improvement (9.09%) is quite significant, when blending of 30% bleached bamboo pulp was carried out along with 1.0% dosing of cationic starch at 560 ml CSF and 310 ml CSF. The corresponding increase in breaking length was observed 29.72% and 16.0% respectively. It can be concluded from the above results that the higher dosing of cationic starch is helpful when the long fibre pulp is more in furnish.

The **Table 4.25** shows that the increase in breaking length 6.62% with 0.5% dosing of cationic starch content with 30% blending of bleached bamboo pulp, and 12.22% increase at 310 ml CSF. The **Table 4.26** shows that the increase in breaking length 9.02% with 0.7% dosing of cationic starch and 30% blending of bleached bamboo pulp into the furnish. It clearly indicates that the improvement in the breaking length of paper is 6.7% due to the 30% blending of bleached bamboo pulp 560 ml CSF (**Fig. 4.38**).

TABLE 4.24
Effect on breaking length of second recycled paper due to blending of bleached bamboo pulp and addition of varying doses of cationic starch

S. No.	Fibre composition	Chemical composition	The breaking length in (m) at (CSF-560)	Gain in breaking length in (m) due to addition of cationic starch at (CSF–560)	Breaking length in (m) at (CSF-310)	Gain in breaking length due to addition of doses of cationic starch at (CSF–310) (%)
1	100% BG + 00% BB +50% FP	X + Y + 0.5% CS + N*	2629.34	-	2806.00	-
2	100% BG + 00% BB +50% FP	X + Y + 0.7% CS + N*	2684.75	2.11	3061.38	9.09
3	100% BG + 00% BB +50% FP	X + Y + 1.0% CS + N*	2739.53	2.04	3431.73	12.09
4	90% BG + 10% BB + 50% FP	X + Y + 0.5% CS + N*	2271.01	-	2489.81	-
5	90% BG + 10% BB + 50% FP	X + Y + 0.7% CS + N*	2529.87	11.4	2852.73	14.58
6	90% BG + 10% BB + 50% FP	X + Y + 1.0% CS + N*	2712.61	7.22	2914.16	2.15
7	80% BG + 20% BB + 50% FP	X + Y + 0.5% CS + N*	2371.01	-	2665.43	-
8	80% BG + 20% BB + 50% FP	X + Y + 0.7% CS + N*	2607.58	9.98	2984.71	11.18
9	80% BG + 20% BB + 50% FP	X + Y + 1.0% CS + N*	2739.53	5.06	3048.54	2.14
10	70% BG + 30% BB + 50% FP	X + Y + 0.5% CS + N*	2527.87	-	2991.18	-
11	70% BG + 30% BB + 50% FP	X + Y + 0.7% CS + N*	2842.76	12.46	3184.78	6.47
12	70% BG + 30% BB + 50% FP	X + Y + 1.0% CS + N*	3687.57	29.72	3694..31	16.0

It was observed that with the addition of 1.0% cationic starch the increases in breaking length at 560 ml CSF and 310 ml CSF was 34.61 and 21.18 % respectively (**Table 4.27**). This shows that the starch addition is quite effective on 560 ml CSF due to the good intrinsic strength of the fibres, where as at more beating at 310 ml CSF the intrinsic strength of the fibre is less and the increase in breaking length is 21.18%. Moreover by increasing the dose of cationic starch, there is less improvement in the breaking length. The more addition beyond 1.0% cationic starch creates the problem of drainage on the wire part of the paper sheet making machine. So the increased dosing of cationic starch in the stock reduce drainage rate on the wire part of British sheet former.

4.30 Effect of increasing the beating of the stock

The intrinsic strength of the fibres decrease and the increase in breaking length was 21.18%, which is less in comparison to the results of the breaking length at 560 ml CSF.

TABLE 4.25

Effect on breaking length of paper sheet by the addition of 0.5 % cationic starch dosing

S. No.	CSF of pulp of standard paper sheet making (↓)	Paper sheet composition 90%BG+10%BB+50%FP X+Y+0.5%CS+N* Breaking length (m) (↓)	Paper sheet composition 80%BG+20%BB+50%FP X+Y+0.5%CS+N* Breaking length (m) (↓)	Paper sheet composition 70%BG+30%BB+50%FP X+Y+0.5%CS+N* Breaking length (m) (↓)
1	560	2271.00	2371.00	2527.87
2		Increase in breaking length due to long fibreed pulp blending in previous paper sheet (%) (→)	4.40	6.62
3	310	2489.81	2665.43	2991.18
4		Increase in Breaking length in (m) due to previous long fibres pulp blending in the paper sheet (→)	7.05	12.22

TABLE 4.26

Effect on breaking length of paper sheet by the addition of 0.7% cationic starch dosing

S. No.	CSF of pulp at standard sheet making (ml) (↓)	Paper sheet composition 90%BG+10%BB+50%FP X+Y+0.7%CS+N* Breaking length (m) (↓)	Paper sheet composition 80%BG+20%BB+50%FP X+Y+0.7%CS+N* Breaking length (m) (↓)	Paper sheet composition 70%BG+30%BB +50%FP X+Y+0.7%CS+N* Breaking length (m) (↓)
1	560	2529.87	2607.58	2842.76
2		Increase in breaking length in (m) due to previous long fibreed pulp blending in paper sheet (%) (→)	3.07	9.02
3	310	2489.81	2984.71	3184.78
4		Increase in breaking length in (m) due to blending (%) (→)	4.63	6.70

TABLE 4.27

Effect on breaking length of paper sheet by the addition of 1.0% cationic starch dosing

S. No.	CSF of pulp at standard sheet making (↓)	Paper sheet composition 90%BG+10%BB+50%FP X+Y+1.0% CS+N* Breaking length (m) (↓)	Paper sheet composition 80%BG+20%BB +50%FP X+Y+1.0% CS+N* Breaking length (m) (↓)	Paper sheet composition 70%BG+30%BB +50%FP X+Y+1.0% CS+N* Breaking length (m) (↓)
1	560	2712.61	2739.53	3687.57
2		Increase in breaking length due to previous long fibreed pulp blending in paper sheet (%) (→)	0.99	34.61
3	310	2914.16	3048.31	3694.31
4		Percent increase in B.L. due to previous long fibreed pulp blended composition of paper-sheet (→)	4.61	21.18

The effect of increasing the beating of fibres on the breaking length improvement is shown in **Fig. 4.38** at 560 ml and 310 ml CSF.

4.31 Effect on burst factor of the second recycled paper sheet

It is observed from the **Fig. 4.39** that when the chemicals like fortified rosin size, poly- aluminium chloride 2014 and soap stone filler 15% was added in the second recycled paper sheet the burst factor was reduced from 23.08 to 16.73 at 560 ml CSF at the second recycled stage of paper sheet.

It is observed from the **Fig. 4.39** that when the chemicals like fortified rosin size, poly aluminium chloride 2014 and 15% soap stone filler was added in the second recycled paper sheet the burst factor was reduced from 23.08 to 16.73 at 560 ml CSF. Whereas at 310 ml CSF, it reduces from 25.26 to 23.91, as these chemicals reduces the chemical bond strength between the specific surface of the fibres. To reduce this weakening of bond strength, the strength improving chemicals and long fibre blending was used to recover the loss of the paper strength. From the **Fig. 4.40** the following improvement in burst factor were observed due to blending of bleached bamboo pulp and the addition of cationic starch in the varying doses.

4.32 Effect of addition of cationic starch

The effect of addition cationic starch in the second recycled paper sheet, it is observed that the cationic starch is increasing the burst factor of the paper sheet and the increase in burst factor is more at 310 ml CSF and the significant increase in burst factor is observed 19.21% (at the s.no.5 **Table 4.28**). The maximum burst factor was achieved about 28.91 at 310 ml CSF as shown in the table, under the condition of blending and increased beating rate. It shows that cationic starch is good for increasing the burst factor of second recycled paper sheet at 310 ml CSF.

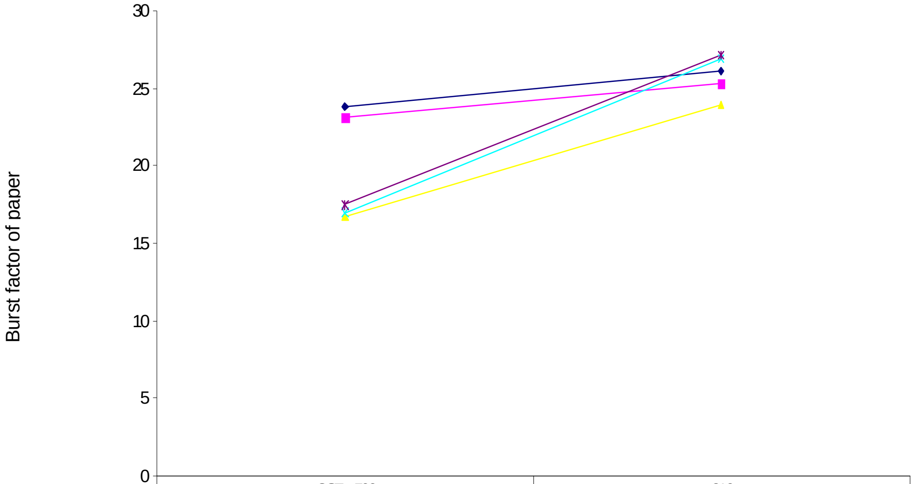
4.33 Effect of beating on burst factor of second recycled paper

From the observation of the **Table 4.28**, it is evident that there is good increase in the burst factor of second recycled paper sheet. The increase in burst factor was observed from 19.21% and 11.79% at s.no.5 and 8. It can be concluded that the degree of beating of the pulp is also a good parameter for obtaining good results of burst factor of second recycled paper sheet.

TABLE 4.28

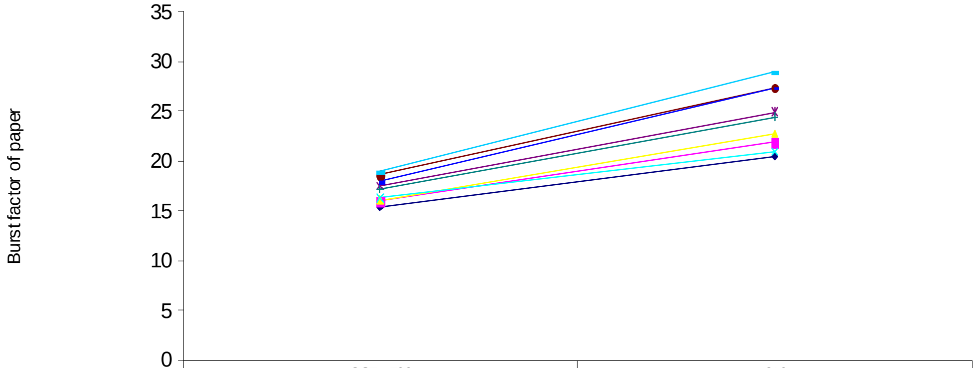
Effect on burst factor of paper sheet due to the blending of bleached bamboo pulp and cationic starch at 560 and 310 CSF

S. No.	Stock composition (↓)	Chemical composition of paper (↓)	The burst factor at (CSF-560) (↓)	Gain in burst factor due to addition of cationic starch at (CSF-560) (%) (↓)	Burst factor at (CSF-310) (↓)	Gain in burst factor due to addition of cationic starch dose at (CSF-310) (%) (↓)
1	90%BG+10% BB+50% FP	X+Y+0.5%CS+N*	15.34		20.51	
2	90%BG+10% BB+50% FP	X+Y+0.7%CS+N*	15.94	3.19	21.85	6.53
3	90%BG+10% BB+50% FP	X+Y+1.0%CS+N*	16.06	0.75	22.73	4.03
4	80%BG+20% BB+50% FP	X+Y+0.5%CS+N*	16.28		20.93	
5	80%BG+20% BB+50% FP	X+Y+0.7%CS+N*	17.48	7.37	24.95	19.21
6	80%BG+20% BB+50% FP	X+Y+1.0%CS+N*	18.56	6.18	22.27	9.30
7	70%BG+30% BB+50% FP	X+Y+0.5%CS+N*	17.16		24.43	
8	70%BG+30% BB+50%FP	X+Y+0.7%CS+N*	17.95	4.60	27.31	11.79
9	70%BG+30% BB+50% FP	X+Y+1.0%CS+N*	18.93	5.45	28.91	5.86



	CSF - 560	310
◆ 90%BG+10%BB+(50%FP), No chemical	23.83	26.12
■ 100%BG+00%BB+(50%FP), No chemical	23.08	25.26
▲ 100%BG+0%BB+(50%FP), X+Y+0.5%CS+N*	16.73	23.91
× 100%BG+0%BB+(50%FP), X+Y+0.7%CS+N*	16.98	26.88
✳ 100%BG+0%BB+(50%FP), X+Y+1.0%CS+N*	17.47	27.11

Fig. 4.39: Burst factor vs. CSF of 2nd recycled paper prepared from blending of bleached bamboo pulp with bleached bagasse pulp adding fresh pulp, sizing chemicals, soap stone filler, cationic starch & retention aids (N*).



	CSF - 560	310
◆ 90%BG+10%BB+(50%FP),X+Y+0.5%CS+N*	15.34	20.51
■ 90%BG+10%BB+(50%FP),X+Y+0.7%CS+N*	15.94	21.85
▲ 90%BG+10%BB+(50%FP),X+Y+1.0%CS+N*	16.06	22.73
× 80%BG+20%BB+(50%FP),X+Y+0.5%CS+N*	16.28	20.93
✳ 80%BG+20%BB+(50%FP),X+Y+0.7%CS+N*	17.48	24.95
● 80%BG+20%BB+(50%FP),X+Y+1.0%CS+N*	18.56	27.27
+ 70%BG+30%BB+(50%FP),X+Y+0.5%CS+N*	17.16	24.43
▪ 70%BG+30%BB+(50%FP),X+Y+0.7%CS+N*	17.95	27.31
▬ 70%BG+30%BB+(50%FP),X+Y+1.0%CS+N*	18.93	28.91

Fig. 4.40: Burst factor vs. CSF of 2nd recycled paper prepared from blending of bleached bamboo pulp with bleached bagasse pulp adding fresh pulp, sizing chemicals, soap stone filler, cationic starch & retention aids (N*).

4.34 Effect on burst factor due to blending of fresh pulp in the admixture of the pulp suspension at the second recycled of paper

The blending of fresh pulp increases the burst factor of paper as tabulated in **Table 4.28**. A significant increase in burst factor was observed (19.9% in comparison of s. no.3 and 5) and minimum observed was about 2.50% {e.g. (6.53-4.03) with comparison of s. no. 2 and 3} at 310 ml CSF.

4.35 Effect on tear factor on second recycled paper

The effect of fresh pulp, addition of varying doses of cationic starch and increased beating effects are tabulated in the **Table 4.29** and **Fig. 4.41**.

It can be observed that when the fibre composition of the paper sheet is kept constant and cationic starch content is increased from 0.5 % to 0.7 %, there is 1.2 % increase in tear factor. The increase was 1.93 % when cationic starch dosing was increased from 0.7 % to 1.0 % at 560 ml CSF. Similarly at 310 ml CSF, the increase in tear factor observed was 12.62 % and 8.74 %. Similarly, the increase in tear factor was observed by changing the composition of the fibres in the paper sheet. An increase in the tear factor was noticed with 80 % bagasse and 20 % bamboo pulp and 50 % fresh pulp was added to make the standard paper sheet. Similarly the fibre composition of the paper sheet was maintained as 70 % bagasse and 30 % bamboo pulp and the 50 % fresh pulp was added for making the standard paper sheets. It was observed that the maximum increase in tear factor was about 12.62 % at 310 CSF (**Table 4.29**). The increase in tear factor was due to the proper ratio of reactants and optimum pH conditions maintained in the admixture of the pulp slurry. These conditions create the better paper sheet consolidation at the wire part of the British sheet former.

4.36 Effect of long fibreed pulp blending on tear factor of second recycled paper sheet

The effect of the long fibre pulp blending into the pulp furnish on tear factor of second recycled paper sheet was studied and the results are tabulated in **Table 4.30** and plotted in **Fig. 4.42**.

The maximum increase in tear factor was observed at 310 ml CSF when the cationic starch dose was 0.5 % and 30 % long fibreed pulp blending along with 70 % bagasse pulp. The maximum tear factor (59.64) was noticed at 560 ml CSF when the long fibre fraction was 30 % bamboo and 70 % bagasse with 1.0 % cationic starch. It was noticed that the maximum tear factor development was achieved in the presence of maximum long fibre content and at the 1.0 % cationic starch addition.

4.37 Effect of beating on tear factor

As per the results tabulated in the **Table 4.30** it can be concluded that the tear factor is more in each case at 560 ml CSF. The tear factor decreases due to more beating if beating degree approaches towards 310 ml CSF. It indicates that the optimum beating lies between the values 560 to 310 ml CSF, after which the tear factor of the paper sheet starts decreasing. So more beating beyond 310 ml CSF is harmful for increasing the tear factor of the paper sheet.

This condition shows that there are so many parameters on which the good sheet consolidation and strength development of the paper sheet depend. To study the effect of blending in standard paper sheet, the paper were prepared from pure bleached bagasse pulp and their tear factors were evaluated as shown in **Fig. 4.41**.

To evaluate the increase in tear factor due to the long fibre pulp blending; into furnish the addition of cationic starch doses have to keep constant. The results of tear factor due the blending are given in the **Table 4.30.** From the analysis of the results of the **Table 4.30**, the maximum increase in tear factor was observed at 310 ml CSF when the cationic starch dose was added 0.5% in case of 30% long fibreed pulp blending along with 70% bagasse pulp. The maximum tear factor (59.64) was noticed at 560 ml CSF when the long fibre fraction was used 30% bamboo and 70% bagasse with 1.0% cationic starch **Fig. 4.42.** From these data it was noticed that the maximum tear factor development was achieved in the presence of maximum long fibre content and at 1.0% cationic starch addition. For the good strength development the other parameters are also responsible for the achievement of the maximum tear factor in the paper sheet.

TABLE 4.29

Effect on tear factor of second recycled paper sheet due to addition of varying doses of cationic starch at 560 ml CSF and 310 ml CSF

S.No.	Fibre composition	Chemical composition	Tear factor at CSF 560	Gain in tear factor due to addition of cationic starch at 560 CSF (%)	Tear factor at CSF 310	Gain in tear factor due to addition of cationic starch at 310 CSF (%)
1	90%BG+10%BB+50% FP	X+Y+0.5%CS+N*	51.21	-	40.32	
2	90%BG+10%BB+50% FP	X+Y+0.7%CS+N*	51.82	1.20	45.41	12.62
3	90%BG+10%BB+50% FP	X+Y+1.0%CS+N*	52.82	1.93	49.38	8.74
4	80%BG+20%BB+50% FP	X+Y+0.5%CS+N*	55.67	-	42.89	-
5	80%BG+20%BB+50% FP	X+Y+0.7%CS+N*	56.28	1.10	46.53	8.49
6	80%BG+20%BB+50% FP	X+Y+1.0%CS+N*	58.23	3.46	50.13	7.74
7	70%BG+30%BB+50% FP	X+Y+0.5%CS+N*	56.84	-	48.34	-
8	70%BG+30%BB+50% FP	X+Y+0.7%CS+N*	57.78	1.65	49.79	3.0
9	70%BG+30%BB+50% FP	X+Y+1.0%CS+N*	59.64.	3.22	52.03	4.5

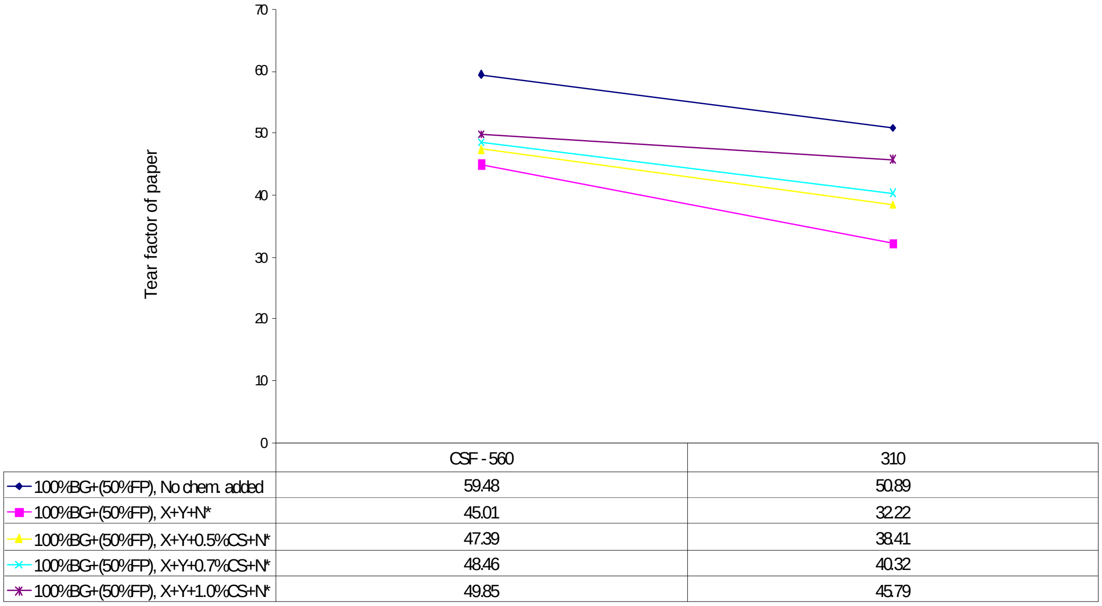
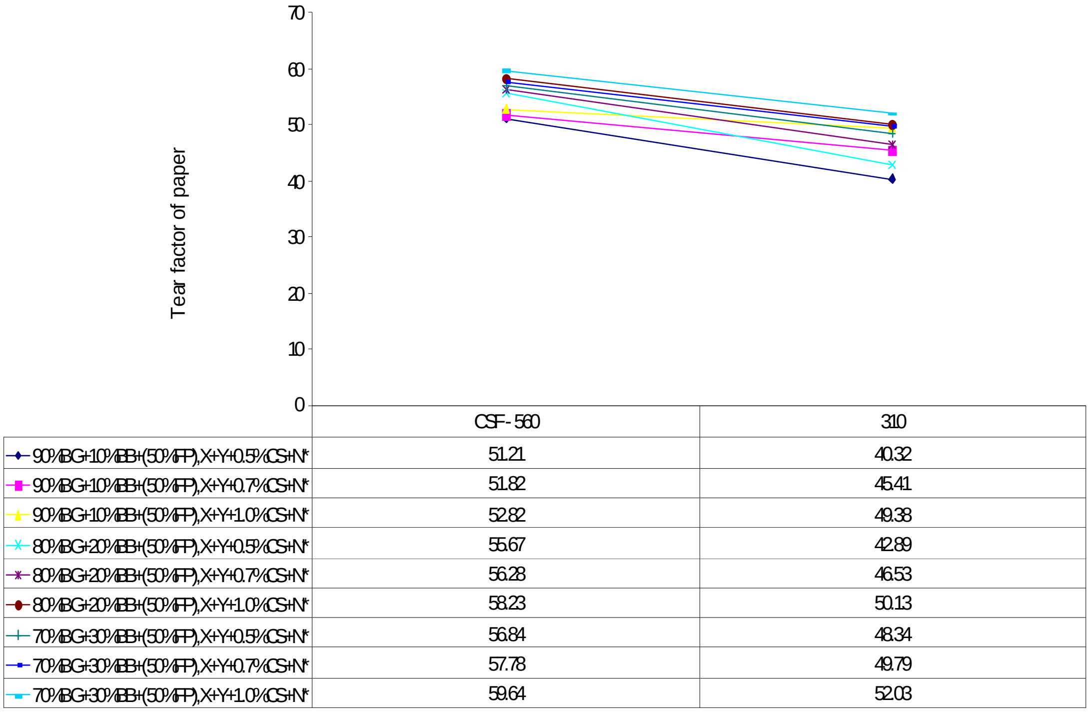


Fig. 4.41: Tear factor vs. CSF of 2nd recycled paper prepared by blending of bleached bamboo pulp with bleached bagasse pulp adding 50% fresh pulp, sizing chemicals, soapstone filler varying doses of cationic starch, and retention aids (N*)

TABLE 4.30

Effect on tear factor due to the increased blending at 560 CSF and 310 CSF

S. No.	Fibre Composition	CSF pulp sample →	560	560	310	310
		Tear factor of paper (Chemical Composition)	Tear factor at 560 CSF	Gain in tear factor due to blending of bleached bamboo pulp (%)	Tear Factor at (CSF 310) CSF	Gain in tear factor due to blending of pulp (%)
1	90%BG+10%BB	X+Y+0.5%CS+N*	51.21	-	40.32	-
2	80%BG+20%BB	X+Y+0.5%CS+N*	55.67	8.71	42.89	6.37
3	70%BG+30%BB	X+Y+0.5%CS+N*	56.84	2.10	48.34	12.71
4	90%BG+10%BB	X+Y+0.7%CS+N*	51.82	-	45.41	-
5	80%BG+20%BB	X+Y+0.7%CS+N*	56.28	8.61	46.53	2.47
6	70%BG+30%BB	X+Y+0.7%CS+N*	57.78	2.66	49.79	7.01
7	90%BG+10%BB	X+Y+1.0%CS+N*	52.82	-	49.38	-
8	80%BG+20%BB	X+Y+1.0%CS+N*	58.23	10.24	50.13	1.52
9	70%BG+30%BB	X+Y+1.0%CS+N*	59.64	2.42	52.03	3.79



	CSF - 560	310
◆ 90%BG+10%BB+(50%FP),X+Y+0.5%CS+N*	51.21	40.32
■ 90%BG+10%BB+(50%FP),X+Y+0.7%CS+N*	51.82	45.41
▲ 90%BG+10%BB+(50%FP),X+Y+1.0%CS+N*	52.82	49.38
× 80%BG+20%BB+(50%FP),X+Y+0.5%CS+N*	55.67	42.89
✱ 80%BG+20%BB+(50%FP),X+Y+0.7%CS+N*	56.28	46.53
● 80%BG+20%BB+(50%FP),X+Y+1.0%CS+N*	58.23	50.13
+ 70%BG+30%BB+(50%FP),X+Y+0.5%CS+N*	56.84	48.34
▪ 70%BG+30%BB+(50%FP),X+Y+0.7%CS+N*	57.78	49.79
▬ 70%BG+30%BB+(50%FP),X+Y+1.0%CS+N*	59.64	52.03

Fig.4.42: Tear factor vs. CSF of 2nd recycled paper prepared by blending of bleached bamboo pulp in bleached bagasse pulp by adding fresh pulp, sizing chemicals, soap stone filler, varying doses of cationic starch & retention aids (N*)

4.38 Effect on double folds of second recycled paper sheet prepared by using bleached bagasse pulp blended with the long fibre bleached bamboo pulp and fresh pulp, at different CSF

Effect of cationic starch T–25

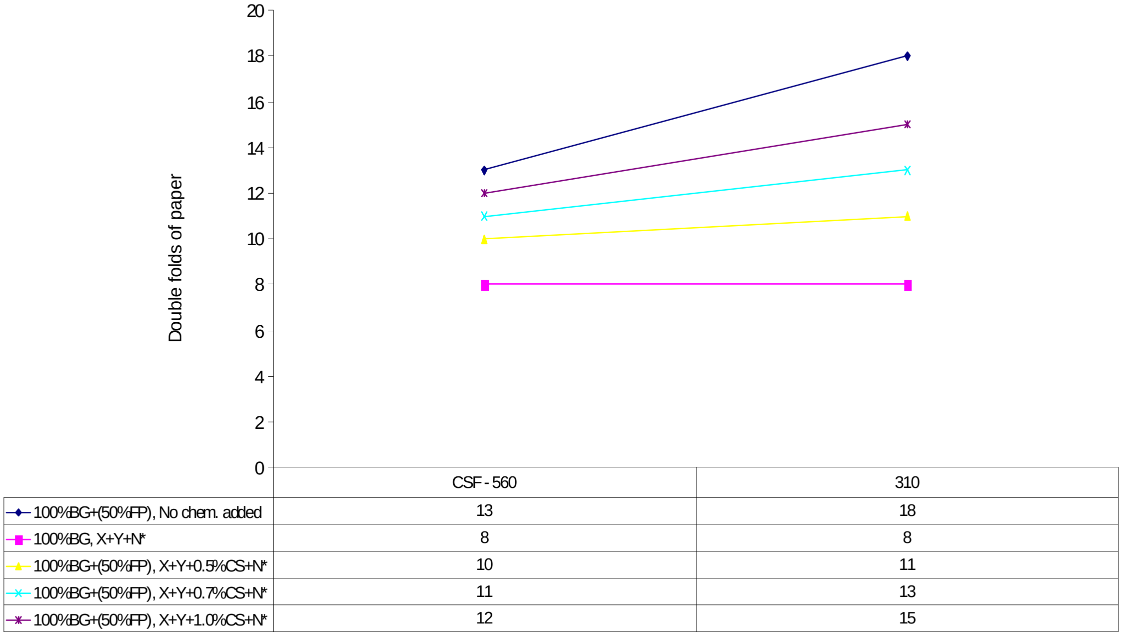
The effect of cationic starch can be studied from **Fig. 4.43** and **Fig. 4.44**. For studying the effect of varying doses of cationic starch, the fibre composition in the paper sheet is kept constant at different CSF like 560 and 310 ml CSF.

It can be observed that as the dose of cationic starch is increased in making the second recycled paper sheet, there is appreciable increase in the double folds of the paper sheet, at 310 ml CSF when 0.7 % cationic starch was mixed in the furnish and the pulp furnish was not containing the bamboo pulp. The fresh pulp was added in the second recycle stage of paper making system as at s. no.3 in **Table 4.32**. This type of same effect was also observed at the s. no.10 of the **Table 4.31.**

At this condition the cationic starch content has shown good double folds strength at both 560 and 310 ml CSF. At this stage the gain in the double folds is 16.67 % when the cationic starch content is only 0.7 %.

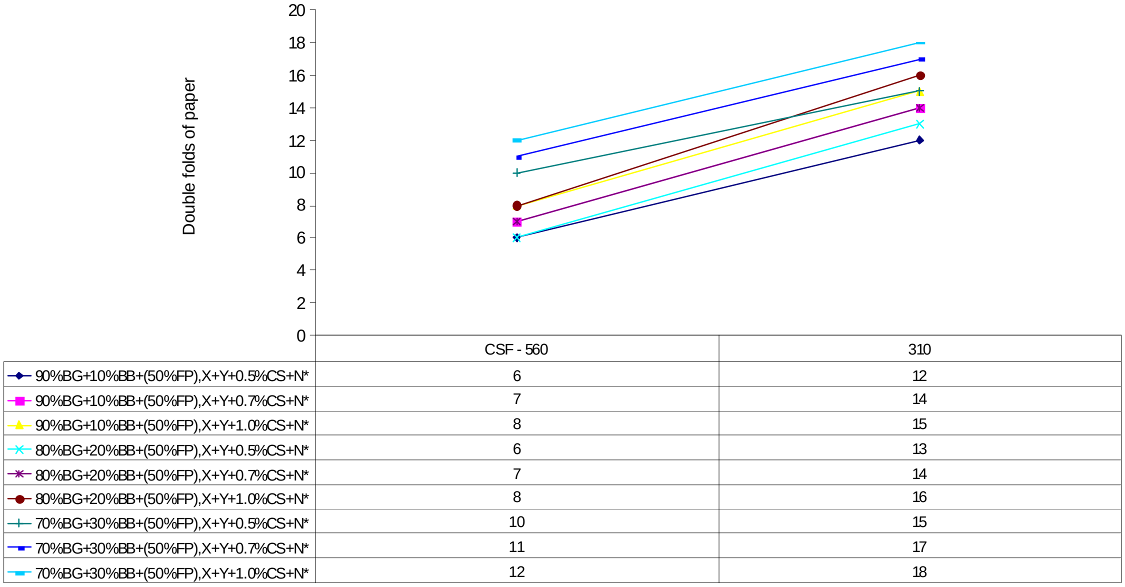
4.39 Effect of blending on double folds of paper sheet due to blending of long fibreed bleached bamboo pulp with bleached bagasse pulp at the second recycle stage of paper

The effect of blending on double folds was studied by keeping the cationic starch content constant at a particular CSF and the results are plotted in **Fig. 4.43** and **Fig. 4.44** and tabulated in **Table 4.32**. It was found that maximum double fold value was 18 (s .no.11, **Table 4.32**) at 310 ml CSF but the increase in blending from 10 to 20 % of the long fibreed pulp or beating of pulp was not showing the good performance. It concludes that good bonding in the fibres was not taking place and the results obtained were not good. Therefore some strength improving chemicals were required for enhancing the double fold of paper sheet.



	CSF - 560	310
100%BG+(50%FP), No chem. added	13	18
100%BG, X+Y+N*	8	8
100%BG+(50%FP), X+Y+0.5%CS+N*	10	11
100%BG+(50%FP), X+Y+0.7%CS+N*	11	13
100%BG+(50%FP), X+Y+1.0%CS+N*	12	15

Fig. 4.43: Double folds vs. CSF of 2nd recycled paper prepared by blending of bleached bamboo pulp in bleached bagasse pulp by adding fresh pulp, sizing chemicals, soap stone filler, varying doses of cationic starch & retention aids (N*).



	CSF - 560	310
90%BG+10%BB+(50%FP),X+Y+0.5%CS+N*	6	12
90%BG+10%BB+(50%FP),X+Y+0.7%CS+N*	7	14
90%BG+10%BB+(50%FP),X+Y+1.0%CS+N*	8	15
80%BG+20%BB+(50%FP),X+Y+0.5%CS+N*	6	13
80%BG+20%BB+(50%FP),X+Y+0.7%CS+N*	7	14
80%BG+20%BB+(50%FP),X+Y+1.0%CS+N*	8	16
70%BG+30%BB+(50%FP),X+Y+0.5%CS+N*	10	15
70%BG+30%BB+(50%FP),X+Y+0.7%CS+N*	11	17
70%BG+30%BB+(50%FP),X+Y+1.0%CS+N*	12	18

Fig. 4.44: Double folds vs. CSF of 2nd recycled paper prepared by blending of bleached bamboo pulp in bleached bagasse pulp and by adding 50% fresh pulp, sizing chemicals, soap stone filler, varying doses of cationic starch & retention aids (N*).

TABLE 4.31

Effect of cationic starch T-25 on double folds of paper sheet

S. No.	Fibre composition	Chemical composition	Double folds of paper at CSF-560	Gain in double folds of paper due to addition of cationic starch at CSF-560 (%)	Gain in double folds of paper at CSF-310	Gain in double folds due to addition of cationic starch at CSF 310 (%)
1	100%BG+00%BB+50%FP	X+Y+N*	8	-	8	-
2	100%BG+00%BB+50%FP	No chem. Added	13	62.5	18	12.50
3	100%BG+00%BB+50%FP	X+Y+0.5%CS+N*	10	-	11	-
4	100%BG+00%BB+50%FP	X+Y+0.7%CS+N*	11	10.00	13	18.20
5	100%BG+00%BB+50%FP	X+Y+1.0%CS+N*	12	9.10	15	15.40
6	90% BG +10%BB+50%FP	X+Y+0.5%CS+N*	06	-	12	-
7	90%BG+10%BB+50%FP	X+Y+0.7%CS+N*	07	16.67	14	16.67
8	90%BG+10%BB+50%FP	X+Y+1.0%CS+N*	08	14.30	15	7.14
9	80%BG+20%BB+50%FP	X+Y+0.5%CS+N*	06	-	13	-
10	80%BG+20%BB+50%FP	X+Y+0.7%CS+N*	07	16.67	14	14.25
11	80%BG+20%BB+50%FP	X+Y+1.0%CS+N*	08	14.30	16	14.28
12	70%BG+30%BB+50%FP	X+Y+0.5%CS+N*	10	-	15	-
13	70%BG+30%BB+50%FP	X+Y+0.7%CS+N*	11	10.00	17	13.33
14	70%BG+30%BB+50%FP	X+Y+1.0%CS+N*	12	9.09	18	5.88

TABLE 4.32

Effect of blending of bleached bamboo pulp with bleached bagasse pulp on double folds in second recycled paper sheet

S. No.	Fibre composition	CSF →	560	560	310	310
		Tear factor of paper (Chemical composition)	Double folds of paper at 560 CSF	Gain in double folds of paper due to blending of pulp (%)	Double folds of paper at 310 CSF	Gain in double folds of paper due to blending of pulp (%)
1	100%BG+00%BB+00%FP	X+Y+N*	8	-	8	-
2	100%BG+00%BB+50%FP	No Chemical added	13	62.5	18	125.0
3	100%BG+00%BB+50%FP	X+Y+0.5%CS+N*	10	-	11	-
4	90%BG+10%BB+50%FP	X+Y+0.5%CS+N*	6	- 40.00	12	9.09
5	80%BG+20%BB+50%FP	X+Y+0.5%CS+N*	6	0.00	13	8.33
6	70%BG+30%BB+50%FP	X+Y+0.5%CS+N*	10	66.67	15	15.38
7	100%BG+00%BB+50%FP	X+Y+0.5%CS+N*	11	-	13	-
8	90%BG+10%BB+50%FP	X+Y+0.7%CS+N*	7	- 36.6	14	7.69
9	80%BG+20%BB+50%FP	X+Y+0.7%CS+N*	7	00.00	14	00.00
10	70%BG+30%BB+50%FP	X+Y+0.7%CS+N*	11	57.14	17	21.43
11	100%BG+00%BB+50%FP	X+Y+1.0%CS+N*	12	- 34.00	18	20.00
12	90%BG+10%BB+50%FP	X+Y+1.0%CS+N*	8	00.00	15	-16.66
13	80%BG+20%BB+50%FP	X+Y+1.0%CS+N*	8	0.00	16	6.67
14	70%BG+30%BB+50%FP	X+Y+1.0%CS+N*	12	50.00	18	12.5

CHAPTER 5

CONCLUSIONS

1. During recycling process of bagasse paper it was observed that the breaking length of paper decreases subsiquently at each recycling stages.The reduction in breaking length at lower CSF (310 ml) is higher i.e. 6.3%,19.73% 22.32%,27.65%,34.31%, on each recycling process.
2. The reduction in breaking length was significant at low CSF. As the reduction in the breaking length of the paper sheet was observed on addition soap stone filler (15%) on the O.D. basis.
3. To recover the reduction of breaking length, the retention aids chemicals were used to Improve the consolidation of paper sheet at the time of paper sheet formation on British Sheet Former. A good recovery of breaking length was observed with the Addition of 0.3% anionic polyacrylamide and 0.04% modified polyethyleneimine Retention aids.
4. Similar improvement was observed in the case of burst factor of the paper sheet.
5. At the higher concentration of these chemicals, a decrease in the strength properties was noticed with respect to the original paper.
6. High dosing of anionic polyacrylamide and modified polyethyleneimine is beneficial at first and second recycle, stage of paper formation.
7. Long fibreed pulp was blended with the recycled pulp of after maintaining the equal CSF followed by beating action of the pulp, resulted the significant increase in the breaking length and burst factor.
8. In the second recycled paper sheet, the breaking length was reduced significantly at low CSF by the addition of fortified rosin size (1.2%), poly-aluminium chloride and 15% soap stone filler. This reduction has been recovered by the addition of 30% long fibreed radiata pine wood pulp and retention aids (anionic polyacrylamide 0.3% and modified polyethyleneimine 0.04%).
9. The recovered breaking length was more than the initial breaking length of the paper sheet.
10. More recycling of paper reduces the strength properties of recycled paper. The

cationic starch along with retention aids N* (Coagulant N–7607 and flocculent N-7530) were added in the pulp. It improves the retention of starch, fillers, and fines in the paper web on the wire part of the paper sheet making machine.

11. A good improvement in the breaking length was observed with the addition 1.0% cationic starch dosing and retention aids. A significant increase in breaking length at 310 ml CSF was also observed with the blending of 20% long fibreed bamboo pulp in the original paper sheet.
12. The improvement in the strength properties of paper indicates that there is very good recycling potential of the bagasse paper. The strength properties of the first recycled paper sheet was very low and these low strength properties were improved by the addition of varying doses of cationic starch and by blending the long fibreed bleached bamboo pulp in the furnish.
13. The maximum breaking length was obtained with 30% blending of the bamboo pulp and 1.0% retention aids. The maximum tear factor was obtained at 540 ml CSF with 30% blending and 1.0% cationic starch dosing and retention aids chemicals.
14. The maximum double folds of first recycled paper sheet were also obtained by 30% blending and 1.0% cationic starch dosing. By observing strength properties of second recycled bagasse paper, the blending of fresh pulp was carried, out to improve the strength properties of second recycled paper sheet. The maximum breaking length was observed with 50% blending of fresh pulp and 1.0% cationic starch dosing at 310 ml CSF.
15. The bagasse pulp can be recycled successfully for number of times for producing the recycled bagasse paper with blending of long fibres up to 30% on O.D. basis. It would help to produce paper from the waste bagasse paper made from the seasonal agri-residue waste from the sugar mills.
16. More experiments are required to be carried to examine the statistical interpretation and through experimental design along with analysis of variance. We can aim to propose for industrial exploitation for the benefit of the industry.

CHAPTER 6

SCOPE FOR FUTURE WORK

1. To investigate the optimum requirement of retention aids, reaction time and at a particular temperature at the time of sheet formation for development of good strength and recycing potential of the paper produced.
2. To improve the recycling potential of bagasse based paper, the study of blending of the long fibreed agri-residue species like saccharum-arundinaceum (moonze) pulp, (khar-saccharum-arundinaceum) sarkanda and ischoemum angustifalium (bhabhar grasses) may be carried out in future plan as these are economic and fast growing species.
3. The study for the improvement of the recycling potential of the bagasse based paper may be carried out by investigating such chemical which may reduce the rate hornification and degradation of fungal attack on the bagasse fibre and other agri-residue pulp fibres.
4. The study of addition the extract of hemicelluloses in the ready made stock at the time of paper sheet formation for improving the recycling potential of the bagasse based paper.
5. The study on different polymers may be carried out to promote the retention fibre fines and other chemicals to enhance the strength properties of paper sheet prepared from the secondary fibres.
6. The study the low consistency refining of the stock for the improvement of the strength, surface and other properties paper may be carried out for the secondary fibre.

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