STUDY OF CHEMI-MECHANICAL PULPING OF EUCALYPTUS PULP

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
PULP AND PAPER ENGINEERING

By

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CANDIDATES DECLARATION

I here by declare that work which is being presented in dissertation thesis entitled " **Study of chemi-mechanical pulping of Eucalyptus pulp**" in the partial fulfillment of the requirement for the award of degree of Master of Engineering in Pulp and Paper Technology from Institute of Paper Technology, Saharanpur is an authentic record of my own work carried out during the period from July 1994 to March 1995, under the guidance of Dr. M.C. Bansal, Professor and Dr. S.P. Singh, Lecturer.

The matter presented in this dissertation report has not submitted by me for the award of any other degree.

Vishal Garg

(VISHAL GARG)

This is to certify that the above statement made by the candidate is true to the best of our knowledge.

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ABSTRACT

Mechanical pulping produces some desirable properties with in the pulp, which are very useful in many grades of papers. This also gives pulp with higher yield at relatively lower cost. Chemi refiner mechanical pulping (CRPM) of Eucalyptus chips was tried using different chemical composition in preimpregnation stages for different time and temperatures. The results indicated that preimprignation at 6% NaOH, under atmospheric condition for 24 hours followed by heating for 2 hours at 80°C temperature gave better results. The chips were refined in Sprout Waldran Laboratory Refiner with single rotating disc of 12 inches diameter and it was observed that 4 pass refining with decreasing clearance gave better results. The pulp was evaluated for strength and optical properties for optimizing the above parameters.

The (CRMP) was bleached by single stage Hydrogen Peroxide bleaching and brightness up to 50% was obtained. It was also observed that brightness enhancement also takes place using H_2O_2 in preimprignation stage by which one stage of bleaching after refining can be reduce to obtain final brightness of pulp.

The work was extended to Bagasse CRMP and strength and optical properties of Bagasse pulp make under different preimpregnation and refining were studied. It was again observed that a CRMP pulp made with 6% NaOH under atmospheric condition for 24 hours soaking followed by 2 hours heating at 80°C temperature, gives better results. From the results obtained, it is evident that Chemi-Refiner Mechanical pulp so obtained from Eucalyptus and Bagasse are suitable for supplementing the newsprint manufacturer.

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CONTENTS

CHAPTER - 1

1. INTRODUCTION

There are two main types of pulping processes - Chemical and Mechanical, or a combination of two to produce different types of pulps. The choice of pulping processes depands upon the wood species and the end application for the pulp produced.

Chemical pulping dissolves out the lignin which binds the cellulose fibers together. The pulp thus formed consist of individual fibers which are rendered flexible due to lignin removal. Chemical pulp produce strong dense papers. Chemical pulp can be used in unbleached state for such liner board, wrapper or beg papers or they can be bleached to substantially high brightness.

Mechanical pulp has certain desirable properties, which make it useful in many grade of papers. These properties arise from the fact that essentially all the constituents of the wood are retained in the pulp. It is composed of mainly fiber bundles and fiber fragments with some whole individual fibers. Properties of pulps are of, small average particle length, a relatively stiff fiber which prevent packing and therefore leads to give a sheet of paper with high bulk and good opacity.

The bulkiness gives a cushioning effect in sheets due to fiber tends to regain its shape when compressed and released. This property plus the fact that mechanical pulp absorbs the ink easily, rapidly and uniformly gives paper an excellent printability. Mechanical pulps are relatively low in cost because of its high yield (almost 100%) and thus make it advantageous but also has lower strength and lack of permanence and does not develop appreciable strength during beating.

The main reason for the use of mechanical pulp is its lower cost. This factor plus its excellent printing characteristics has made it the chief constituent of newsprint and other printing papers. The first mechanical pulps was produced by grinding softwood. However now, a number of processes are available to produce mechanical pulp with various types of raw materials. These pulps are now extensively used to substitute chemical pulps, to different extents, depending upon the end product.

As the softwood for producing mechanical pulps is not easily available, there has been an intensive search for alternative raw materials and processes for the production of the inexpensive cultural papers and newsprint in India. The attempts have been directed towards utilizing the hard woods, which are available in tropical and subtropical regions, natural forests and plantations. Hardwood due to shorter fiber length, produce a very weak pulp by direct mechanical reduction and chemical pretreatment results in significant improvement in pulp properties. Mix dense hardwood are used in Japan for newsprint and their utilization involves mainly either a cold caustic or a hot sodium sulfite pretreatment.

Chips from hardwood require chemical treatment prior to refining when subjected to ultra high yield mechanical pulping. A proper treatment will soften the wood, and thereby support a fiber separation without severe damage in the refiner. Hardwood comprise a very heterogeneous group, and different species respond differently to chemical treatment.

Two processes are available for making chemi-mechanical pulps:

1. Cold soda pulping
2. Sulfite pulping

Cold soda pulping is more suitable due to its applicability to various species of hardwoods. The limitation in sulfite processes is its being unsaturability for deep coloured hardwoods though the strength properties and initial brightness are better.

In addition, Sodium hydroxide in combination with hydrogen per oxide has been used, mainly to produce pulp with higher initial brightness, reduce darkening of chips, which is caused due to the high temperature and alkaline conditions prevailing during preheating and refining.

The main aim of our study is to investigate the possibility for in impregnation with sodium hydroxide and hydrogen peroxide prior to refining, and the effect of various parameters involved during impregnation.

In the present study the effect of various chemical pretreatments, namely NaOH, NaOH + Na_2SO_3 and NaOH + H_2O_2 have been studied; on the various properties of chemi-mechanical pulps produced from Eucalyptus and alternative raw materials like Bagasse.

CHAPTER - 2

2. LITERATURE REVIEW

Mechanical pulps are produced by two different processes- Grinding and Refining.

In the grinding process, debarked logs are forced against a revolving grinding stone which grinds the fibers off the log and also separate them from the matrix. In the refining process, wood chips are fed between two metal discs with at least one of them rotating. The wood fibers are separated by the action of grooves and bars on the surface of the two discs.

These two type of mechanical pulping are significantly different: The ground wood pulp has a higher content of fine material due to abrasive action, while the refiner pulp has a smaller content of fine material and long fiber tends to be more ribbon like.

A typical flow sheet of refiner pulping process has shown in Fig-1(1). The wood chips are screened to remove objectionable large over size chips which can create nonuniform feeding problem. In some cases fine saw dust is also removed because it does not produce a good pulp quality. The screened chips are washed to remove any dirt, sand or grit in order to reduce the wear of the refiner plates. The chips are refined normally in a two stage system and in some cases chemicals are also added to chips in order to improve pulp quality (CRMP).

2.1, History and introduction of ground wood pulping

In about 1838-1840, Friedrich Killer (1) of Hainchin Saxony pressed a piece of wood against an old tool grinder stone, using water as a lubricant. The abraded material fell on a clothe, which absorbed the water and left the fibers off with a knife and pressed it and had his first ground wood paper. In 1844 he develop a large equipment for about 100 kg groundwood pulp (1).

The pulp quality obtained is dependent upon the operating conditions in ground wood mill, the wood species and the quality of wood being used. The operating variables in the stone ground wood mill are stone surface, stone speed, grinding pressure, power input, energy consumption, production, temperature of grinding, freeness and wood variables. They all are interrelated and can not be completely isolated for individual study. The principle operating variables are stone ground wood and grinding pressure. Normally a 50-60 grit stone is used for newsprint and for printing papers the grit of 80-100 is used. Increasing the grinding pressure increases the production and power input to the grinder, and decreases the energy consumption per ton of paper. This increase the freeness, reduces the strength and increase the shive content.

The wood variables:

For Softwood

Wood density is more important especially when wood is purchased in volume for pulping, since it influences the weight of wood per cord. Lower density wood are preferred for mechanical pulping because they usually produce stronger and long fiber pulp. Some typical groundwood pulping characteristics of North American softwood are shown in Table-1.

For Hardwood

Poplar and Cotton wood which are low in density can be ground to produce an acceptable pulp for ground wood and other printing papers. **However denser hard wood produce pulp with a high fine content and consequently have lower strength have as shown in Table-2.** The availability of hardwood, like Eucalyptus, has increased over the years in India and thus has drawn our attention for more work in this area.

2.2, History and introduction of refining process

The first application of refining chips was developed by Arne Asplund in 1931 (1), when chips were refined at an elevated temperature and pressure to produce coarse dark fibers. This material was used to produce a board. After 1950s that work was further developed for paper making pulps. The initial work was done at atmospheric pressure, and process became known as Refiner mechanical pulping (RMP).

In mid 1960s, development work was started on Thermo mechanical pulping (TMP), which involved a pressurized first stage refining at an elevated temperature followed by a second refining stage at atmospheric pressure. The resultant pulp was stronger than RMP, contained fewer shives and had lower bulk (1). The search for high yield and high quality pulps lead to the development of a number of modified TMP processes which included the chemical treatment too. By the end of 1984, there were 181 TMP and modified TMP processes around the world, producing pulp for wide variety of end uses (2).

The main mechanical pulping processes which have received general acceptance, are as follows:

SGW, (Stone groundwood):
Almost self-explanatory, commonly called stone ground wood pulping. It is obtained by rubbing the wood logs against stone-rolls under atmospheric pressure.

PGW, (Pressurized groundwood pulping):
Logs are ground under pressure at temperature over 100°C. More heat is generated in this case and thus proper temperature maintenance with water sprays is important.

RMP, (Refiner mechanical pulping):
Atmospheric refining with no pretreatment, in the refiner. Chips are fed at proper consistency for better temperature control and pulp quality.

TRMP, (Thermo refiner mechanical pulping):
Chips are presteamed at a temperature over 100°C and then refined at atmospheric pressure. Presteaming helps in softening of chips and thus quality of refined chips is better.

TMP, (Thermo mechanical pulping):
Chips are steamed and primarily refined at elevated temperature, which is normally followed by a second stage atmospheric refining. Pulp quality is improved over TRMP pulp.

PTMP, (Tendom or Pressure/ Pressure thermomechanical pulping):
Similar to TMP except that both primary and secondary stages of refining are carried out under pressurized condition for improve quality.

PRMP, (Pressure refined mechanical pulping):
Similar to PTMP except for the fact that the chips are not presteamed at an elevated temperature prior to refining which is customary for TMP and PTMP systems.

CMP, (Chemical mechanical pulping):
Chips are presteamed with a chemical at an elevated temperature prior to atmospheric refining to produce a pulp yield at over 80%.

CTMP, (Chemithermomechanical pulping):
A chemical is added to the chips either prior to or during the presteaming of the chips with first stage refining at an elevated temperature of over 100°C and any subsequent refining at atmospheric pressure. Retention time and pressure in the presteaming device is normally such that the yields are in the plus 90% range.

CRMP, (Chemirefiner mechanical pulping):
Chemical pretreatment of the chips with yield of plus 90% .

TMCP, (Thermomechanical chemi-pulping):
Pressurized first stage refining at an elevated temperature of treated chips. The fiber so obtained are then chemically treated or after the subsequent stages.

2.3, Behaviour of raw materials with CRMP Processes

C.K. Textor (3) showed that direct reduction of hardwood chips produced a very low strength filler type of pulp, and a chemical pretreatment with cold soda produced a significantly stronger pulp for less refining energy. The physical and optical properties of pulps produced varied widely depending upon the wood species.

There are mainly two types of chemical pretreatment :

1. Impregnation with either Sodium hydroxide (NaOH)
2. Combination of Sodium hydroxide and Sodium Sulfite (Na_2SO_3)
3. Sodium hydroxide and Hydrogen peroxide (H_2O_2)

2.3.1. Cold soda

Cold soda pulp from Eucalyptus has been produced in Australia since 1957 (4). In initial stages, the chips (1.2-1.6 cm. in length) were soaked in a batch operation for a period of 2 hours at 30°C, in solution of sodium hydroxide of sufficient strength, so as to absorb around 6% NaOH, on an OD basis. The treated chips were pressed and after two stages of refining, the resultant pulp was washed and then bleached at 12% consistency using 1.7% NaOH and 4.5% available chlorine as hypochlorite. After bleaching, the pulp was acidified with sufficient H_2SO_4 acid to bring the pH down to 3.3 before washing at 99% efficiency on vacuum washer. The bleaching increased the brightness from 40-60%. The pH of bleaching was adjusted to 6.5 and refining stage reduces the freeness to 75 ml, CSF. The total energy requirement was 53 hp/ODMT, of which 48 hp/ODMT was for refining only.

The early work (4) showed the superiority of cold soda pulp over alkaline ground wood pulp with respect to strength and energy consumption Table-3.

Table-3, Cold soda vs alkaline groundwood

	Cold soda	Alkaline groundwood
NaOH absorbed (%)	6.55	-
Energy hpd/t	50.60	85.50
Freeness, CSF	142.00	68.00
Burst Index	2.19	0.77
Tear Index	4.53	1.97

However, the cold soda pulp has a significantly lower opacity, ie. 85-88, compared to 96-98 of alkaline ground wood pulp (5).

2.3.2. NaOH and Na_2SO_3

In 1966, Combine Locks (1) installed a slightly modified system, They soaked their poplar chips for 30 minutes at atmospheric pressure at 77-80°C and had a comparable pickup of sodium hydroxide and sodium sulfite. Treated chips were pressed and refined into two stages at atmospheric pressure. The final pulp freeness was 160 ml,CSF and it was used in many grade of papers, including 26 pound directory where furnish was:

CRMP	55%
Spruce stone groundwood pulp	15%
Sulfite	30%

Leask (6) showed that an alkaline impregnation of poplar white Birch and Willow chips produced a significant improvement in physical characteristics compared to direct reduction of chips . The amount of NaOH absorbed affected the energy requirement and physical characteristics of the pulps, while the Na_2SO_3 mainly affected the pulp brightness.

Allan et (7) discussed the refining Aspen, Birch and Maple chips with and with out mild chemical treatment, using NaOH and Na_2SO_3. The NaOH improves the bonding efficiency of the available fiber surface and increase the L-factor, indicating less failure across the cell wall.

Eriksen and Oksum (8) have discussed the production of chemical pulp from (Bentula verrucosa). Their main conclusion were

1. Chemical must be uniformly distributed through every chip.
2. Impregnation in a screw press give a rapid and satisfactory penetration.
3. Refining at 100°C and atmospheric pressure gives good result.
4. The refining temperature should be kept at,or just below the glass transition point of the treated wood.

2.3.3. NaOH and H_2O_2

Some mills in the USA are treating hardwood chips with an alkaline peroxide solution prior to refining. The chemical pretreatment consist of 4-8% NaOH and 2-4% H_2O_2 for 90 minutes. at 40°C. It is possible to produce a strong pulp, at a high brightness because the bleaching ability of the peroxide allows the higher level of caustic to be used in the pretreatment. The alkali content improves the pulp strength while reducing the pulp yield and the energy required to reach a given freeness. The Table -4, compares the result obtained on Poplar and Maple chips using severe caustic sodium sulfite treatment and caustic peroxide treatment (1).

The physical and optical properties of CRMP pulp varies, widely depending upon the characteristics of individual species. The results from Table-5 (9), show that caustic pretreatment produce a significantly stronger pulp for less refining energy but pulp brightness is lower and the best response was from Aspen, White Birch, Cotton wood and Yellow poplar. The pulp yield was 83-92% for hot sulfite. Work done by Allan etc. indicated that the strength properties of original Green wood may have an important bearing on the level of chemical pretreatment and specific energy required, Datas are shown in Table-6 (10).

Cold caustic pulping of Eucalyptus produces a significantly stronger pulp that obtained by grinding alkaline impregnated billets for substantially lower energy input, Table-7. Also young trees required more energy than lower density matured pulp, but young trees pulp is much stronger, Table-8 (11).

Table-8, Compares the cold soda pulp produced from Eucalyptus globlus from Spain Gmelina Arborera from Nigeria. The Eucalyptus require less energy to reach a freeness of 100 ml, CSF and produce a significantly stronger pulp with lower brightness (12).

The main reason for the use of mechanical pulp is its lower cost. This factor plus its excellent printing characteristics has made it the chief constituent of newsprint and other printing papers, with relatively shorter life.

With the increase in the consumption of printing paper, the demand for the groundwood pulp has also become greater. It has been observed that, although not white in colour as Poplar, Spruce has number of advantages. The wood structure is nearly the same as fiber content is greater (1).

Now, in printing scenario, the softwood supply is not adequate for production of the newsprint required, and there has been considerable activity in the utilization of hardwood to fill the gap. Hardwood due to shorter fiber length, produce a very weak pulp by direct mechanical reduction but the chemical pretreatment results in significant improvement in pulp properties. Mix dense hardwood are used in Japan for newsprint and their utilization involves mainly either a cold caustic or a hot sodium sulfite pretreatment.

Now in the present scenario the raw material availability for manufacture of paper in the country, the conventional raw materials like Bamboo, Hardwoods etc have been depleted to such an extent that they can no longer sustain the production capacity of paper in India.

So trend is towards the use of alternative raw materials like Bagasse and Agriresidues. Sugarcane gives the highest returns in comparison to any other agricultural crop, as all the parts of sugarcane is used in some terms or others. India is the largest sugar cane producer in the world. Bagasse is thus already emerging as the future sustainable fiber for paper industry in India. In India, Tamil Nadu is third largest state for producing sugarcane. Tamil Nadu NewsPrint and Paper Limited (TNPL), in India is the first integrated paper mill to use Bagasse as a raw material for writing, printing and for Newsprint grade (11). The Bagasse mechanical pulp, in TNPL, actually comprises of a Thermo mechanical pulp (TMP) fraction and Chemi mechanical pulp (CMP) fraction in almost equal parts. The TMP fraction provides the opacifing property, which is very sensitive characteristic of newsprint sheet. The CMP fraction provides the strength component of mechanical pulp which dictates machine runnability and sheet properties.

Although the utilization of Bagasse for manufacturer of pulp and paper at commercial scale has been in vogue since last five decades, most of the technological developments have been in the area of depithing and storage i.e. fiber preparation system. However, in area of pulping , the focus has been only to manufacture of newsprint grade pulp for manufacture of bagasse news print. A detailed account of various attempts to produce Bagasse Newsprint has been covered by Dr. Joe Atehison in his various papers (13).

The manufacture of commercially acceptable Newsprint using high percentage of Bagasse in the furnish has not been successful, until recently, when break through eventually was achieved at the TNPL for whom Beloit-SPB process was specifically developed. This mill produced the world's first commercially accepted newsprint in October 1985. The details of the process and the commercial exploitation of this process at TNPL were presented in the International Seminar on Bagasse Newsprint held in Madras in April 6, 1986 (14).

In Table-13, comparison of three Bagasse based newsprint mills that are commercially operating based on various processes are given (14,15). From the comparison, it can be seen that Beloit-SPB process is the only process that does not use any long fiber softwood, but still has commercially acceptable opacity and strength properties.

Properties obtained from mechanical Bagasse pulp and other imported i.e. SGW TMP, CTMP from softwood are given in Tables -17, and 18. The strength properties of mechanical Bagasse pulp are superior to SGW and some what lower than TMP pulp and CTMP pulp (16).

The details of the development of the process and commercial break-through achieved were presented in the TAPPI pulping conference, Toronto, 1986 (14,15).

CHAPTER - 3

3. EXPERIMENTAL PROCEDURE

3.1. Raw material

The raw material used for this study was hardwood Eucalyptus, which is available in tropical region of India. The types of Eucalyptus which are found in India are as follows:

1. Eucalyptus Globulus
2. Eucalyptus Grandis
3. Eucalyptus Teriticonis
4. Eucalyptus Deglupta
5. Eucalyptus Torelliana

The raw material for this study was Eucalyptus grandis and mix. The Eucalyptus chips were obtained from M/S. Star Paper Mills, Saharanpur. The debarked wood was chipped in plate disc chipper to obtain proper size chips.

3.2. Chemical pretreatment

1. In each case a known weight of 650 gram of AD chips were taken.
2. NaOH of known concentration on OD basis, was added to the chips, and a bath ratio of 3:1 was maintained with addition of water.
3. Chips were put for 24 hours soaking time.
4. Soaked chips were heated for 2 hours at 80°C.

5. Liquor was drained and allow the chips to expand in Hydrogen peroxide solution in the second stage.
6. The drained liquor was analysed for residual active alkali to find out the alkali consumed by the chips.

Pretreatment conditions for first stage chemicals (NaOH):

Chemical charge	- 3-6% on OD basis
Impregnation time	- 20-24 hours
Temperature	- 80°C
Heating time	- 2 hours at 80°C

Pretreatment conditions for second stage chemicals (H_2O_2, hypo etc) under atmospheric conditions.

Chemical charge	- 1% on OD basis
Temperature	- 40-45°C
Heating time	- 20-30 minutes

The impregnation was done with the following chemical compositions of wood on OD basis:

1. 5% NaOH + Bleaching with H_2O_2
2. 3% NaOH + 2% Sodium silicate + EDTA + 1% H_2O_2
3. 3% NaOH + 2% Sodium carbonate + EDTA + 1% H_2O_2
4. 3% NaOH + 3% Hypo solution
5. 5% NaOH + 1% H_2O_2
6. 4% NaOH + 2% Sodium sulfite
7. 6% NaOH

8. 8% NaOH

9. 10% NaOH

The effect of impregnation was visible only after refining and sheet making of the pulp so obtained. The effect of these conditions have been indicated in Table-10, 11 and 12, and have been discussed in detail under results and discussion.

3.3. Refining

Sprout Waldron laboratory refiner with single rotating disc of 12 inches diameter was used for the work. The photographs for this refiner is shown in photograph No. 1 & 2. The refiner is connected to a induction motor with V-belt drive, of the following specification:

Type	- AJ200L4R
KW	- 37
Voltage	- 415 volt
RPM.	- 1460
Cosϕ	- 0.85
hp	- 50
Refiner plate no.	- D2 A501 NH
Pulley diameter	- 21 cm. for refiner
	- 36 cm. for motor

For setting zero point in the refiner, water was refined at a rate of 2 lit./minute and plates brought closer and closer till the sound of plates contact was audible.

For every sample chips were refined in four passes at 3-6% consistency.

First pass was at a clearance of 20 thou and 3% consistency.
Second pass was at a clearance of 15 thou and 3-4% consistency.
Third pass was at a clearance of 10 thou and 4-5% consistency.
Fourth pass was at a clearance of 5 thou and 3-4% consistency.

The hot water (50-60°C) was supplied from a water heater , so as to maintain the desired refining temperature.

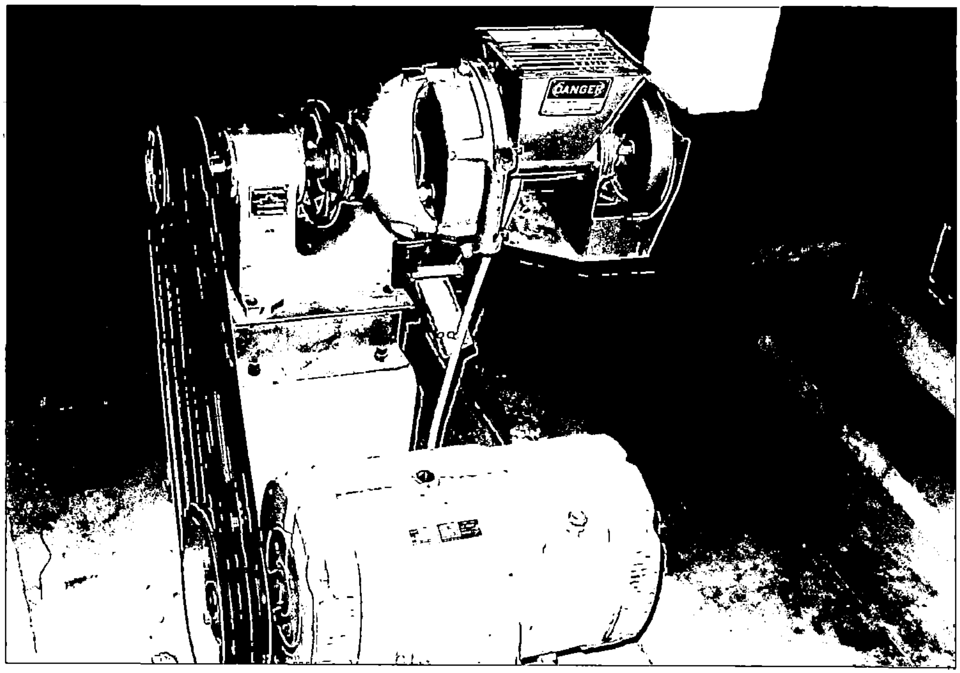
3.4. Pulp evaluation

1. Refined pulp was screened on a laboratory screen and yield was determined by following the usual OD method.

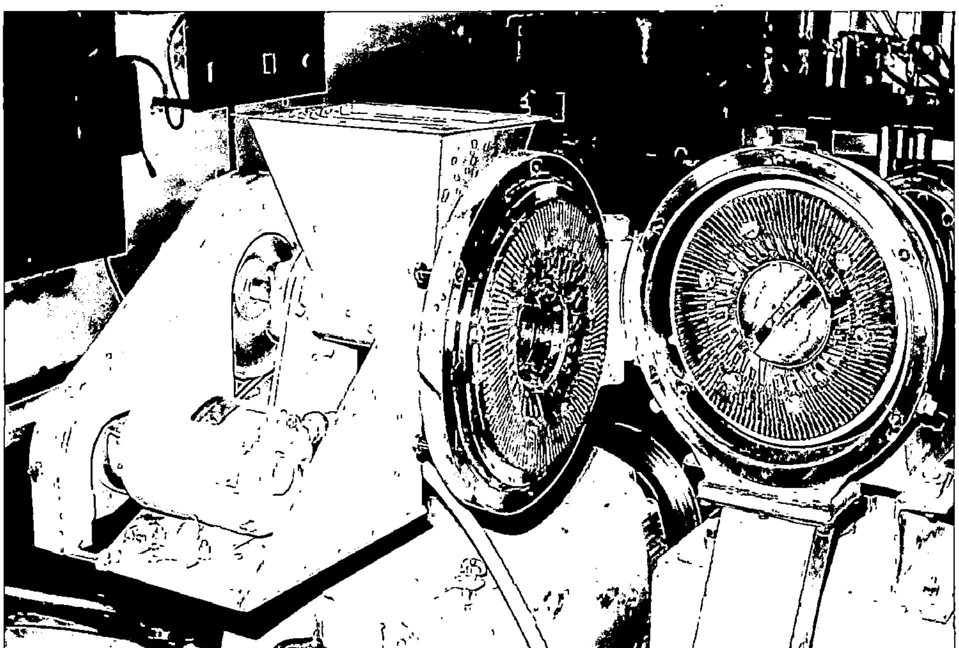
2. Screened pulp was fractioned according to Tappi standard T-233cm-82, in Bauer McNet Classifier using 28, 48, 100 and 200 mesh screens.

   For this firstly, washing and brushing was done to screen to ensure that screens are free from fibers. Water was turned on to just over flow the tanks at the rate of 11.355 l/min.. On completion the motor was started and on obtaining steady state condition, flow was turned off and a specimen of 10 gm od was poured to the first tank. After 20 minutes all fibers were rinsed from all the four compartments and dried at 105°C.

3. The freeness for screened pulp was about CSF 500-550 ml, to reduce the freeness pulp was beaten in vally beater up to the



PHOTOGRAPH NO-1, SPROUT WALDRON REFINER



PHOTOGRAPH NO-2, REFINER PLATE PATTERN

freeness of CSF 200-250 ml.

4. Pulp was fractioned in Bauer McNet classifier with the same screens as per in step second of classification of fibers.
5. Hand sheets were prepared on British sheet former with open system with no back water system.

6. Hand sheets were pressed under standard condition of 5 psi for 5 min. and drying conditions were 26-27°C temperature and 63-65% humidity, according to SCAN standard.

7. Pulp after screening was bleached for peroxide single stage bleaching with constant temperature. The conditions maintained for single stage peroxide bleaching were:

Percentage of H_2O_2 charge	- 1% on OD basis
Percentage of NaOH charge	- 0.8% on OD basis
Time	- 2 hours
Temperature	- 70°C
pH (final)	- 9.4
Consistency	- 10%

This bleaching was done only for first composition.

8. The physical properties were tested according to SCAN, ISO, and Tappi standards.

The strength properties were tested for the following properties:

(i) Tear strength was tested according to T414 om-88.

(ii) Tensile strength was tested according to T404 cm-92.

The optical properties were tested for following properties:

(i) Brightness was according to ISO2470 and T525, using Techni Bright micro TB-1C instrument (based on diffuse illumination with 0° view).

(ii) Scattering coefficient and absorption coefficient were tested according to standard ISO2469, using following equations:

k/s = related to reflectivity

R_∞ = at 457 nm wave length

$k/s = (1 - R_\infty)^2 / 2 R_\infty$

k = Absorption coefficient (m^2/kg)

s = Scattering coefficient (m^2/kg)

$s = [R_\infty / w(1 - R_\infty^2)] . \ln [R_\infty(1 - R_0 R_\infty)/(R_\infty - R_0)]$

$k = (k/s).s$

Opacity = R_0/R_∞, (R_0 and R_∞ are on FMY filter)

9. Concentration of residual alkali was evaluated in the residual liquor obtained after pretreatment stage. The following titration were done to evaluate residual alkali and Hydrogen peroxide:

(i) Titration for NaOH

- First a sample of 25 ml residual alkali was taken.
- Addition of 25 ml Barium chloride and dilute it to 250 ml.
- Sample was put for 24 hour for precipitation.
- Addition of phenofthalene indicator.
- Titration was done with 0.05N HCl.

% of NaOH = (HCl consumed X 0.05)X40 /2.50

CHAPTER - 4

4. RESULTS AND DISCUSSION

4.1, Results and discussion with Eucalyptus pulp

As seen from Fig-2, the maximum tensile strength was obtained when chips were treated with 6% alkali sodium hydroxide prior to refining, and there was slight reduction in tensile strength when a portion of alkali is substituted with sodium sulfite (4% NaOH + 2% sodium sulfite), However tensile strength was reduced to a very large extent when bleach chemical was also added in pretreatment stage. Nearly same tensile strength was obtained when the chips were treated with 5% NaOH and subsequently bleach with !% H_2O_2 after refining.

Similar behaviour was obtained for tear strength. From Fig- 3, it is clear that maximum tear strength was obtained with 6% alkali, and a slight reduction was observed when some portion of alkali is substituted with sodium sulfite (4% NaOH + 2% sodium sulfite). Tear strength also reduce to very large extent when some bleaching chemical is added in pre-impregnation stage. Same strength was obtained, when chips were treated with 5% NaOH and bleaching is done after refining.

It may be mentioned here that both the tensile and tear strength are much lower than the reported values in the literature for same raw material. We may have to study the affect of refiner plate pattern for finding out the above reasons. In this work, we are not able to get the required freeness after refining, which should be around 250- 350 ml CSF.

The effect of chemical pretreatment on brightness of pulp is shown in Fig.4, Addition of bleach chemical in pretreatment stage generally improves the final brightness of the pulp. An abnormal behaviour was observed with the sample treated with 3% NaOH and 3% Calcium hypochlorite. The pulp became progressively darker during refining stage.

The brightness of the pulp was nearly same for bleach chemical included in pretreatment or used as a subsequent stage after refining.

Fig.-4, 5, 6, and 7 show the results with different chemical pretreatment. According to these graphs the scattering, opacity and brightness values are higher when we use Hydrogen peroxide in preimpregnation stages, also there is slight reduction in absorption coefficient. This is because, when we use higher percentage of hydrogen peroxide more fine content is produced, which leads to higher scattering coefficient and also to higher brightness and opacity.

Higher scattering coefficient suggest the higher fine content in the refining stage, which is also supported by the Bauer McNet Classification report given in Table No.- 9. From this table it is clear that substitution of NaOH by Hydrogen peroxide did not result in enough softening of wood chips, which result in greater damage to fiber length. It also reduces the mechanical strength of pulps. Which is also clear from Fig.-2 and Fig.-3. The compositions in which we did not use hydrogen peroxide in preimpregnation stage give better mechanical strength properties.

4.2, Results and discussion with Bagasse Pulp

Based on our observations with Eucalyptus we decided to have some run with Bagasse as raw material too. For this Bagasse was preimpregnated for following chemicals for 24 hours and cooked at atmospheric pressure and at 80°C for two hours.

1. 6% NaOH
2. 4% NaOH
3. 4% NaOH + 2% Na_2SO_3

The preimpregnated Bagasse was passed through the laboratory refiner for different conditions. Again the result of four pass Bagasse pulp was superior than the three pass pulp, based on the hand sheets made in the laboratory. The complete results of Bagasse pulp are shown in Table -14 & 15.

CHAPTER - 5

5. CONCLUSIONS

Table-16, shows the combine results of Bagasse and Eucalyptus pulps and it is evident from the result that 6% NaOH impregnated pulp with both of these raw materials is quite acceptable however more detailed work is needed to examine the effect of other parameters. Also these results are comparable to reported results in Table-17. For more work more plate patterns should be tried in the laboratory refiner, which may give more fibrillation and less cutting action for Bagasse pulp. Based on our result we can conclude following points:

1. More plate patterns are required for this laboratory refiner for better fibrillation and lesser cutting action.

2. On 6% alkali on OD basis we get the best result for both the raw materials, which are comparable to reported one in the text. But replacement of alkali with hydrogen peroxide results in reduced strength properties which also gives higher initial brightness, scattering coefficient and opacity. This results in less consumption of bleaching chemicals in bleaching stages after refining.

3. In this experiment we have not recorded the energy consumed, which is an important factor to calculate power consumed per ton of pulp. The energy consumed with no load and with load may give information, regarding energy consumed in the refining operation only.

CHAPTER - 6

6. REFERENCES

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Table 1. Typical groundwood pulping characteristics of some North American softwoods, compiled from data obtained at the U.S. Forest products laboratory (1).

Species	Density of wood, lb/cu.ft	Stone surface condition	Pressure of wood on stone (psi.)	Energy consumed p/t ofod hp-days	Freeness, ml. Schopper Riegler ml.	Freeness, ml. Canadian stand. ml.	Screen Analysis Retained on 24-mesh	Screen Analysis Passing 150-mesh	Burst index	Tear index	Tensile strength psi.	Breaking length m.	Whiteness (Ives parts blue), %	Brightness (G.E. equivalent), %
Douglas Fir	26	Sharp	24	52	-	110	4.5	46.4	1.0	4.0	-	2500	-	31
Fir														
Subalpine	24	Dull	30	54	330	80	8.6	45.0	1.4	4.9	1890	3400	-	55
Balsam	21	Sharp	20	46	497	-	9.4	44.6	1.4	3.7	1614	3050	65	-
Corkbark	19	Medium sharp	25	71	405	115	19.8	36.0	1.3	5.8	1495	3110	-	59
White	24	Sharp	20	53	423	170	22.5	36.3	1.2	6.9	1327	2610	-	55
Hemlock														
Eastern	24	Fairly dull	25	80	-	-	-	-	1.5	-	2600	-	-	-
Western	25	do	22	50	322	-	4.3	54.5	1.2	4.8	1410	-	-	50
Larch, Eastern														
(Tamarack)	31	Dull	40	58	-	40	5.5	49.0	1.1	5.1	-	3230	-	42
Pine														
Eastern white	19	Sharp	20	57	373	110	16.1	49.2	1.1	4.2	1416	2730	-	56
Jack	25	Medium sharp	28	65	313	83	8.5	45.5	1.2	4.7	1283	2750	-	56
Lodgepole livecut	24	do	20	70	290	-	11.1	47.5	1.5	5.0	1603	2890	-	60
Beetle filled	25	do	20	70	278	-	9.1	53.9	1.4	4.3	1573	2840	-	54
Ponderosa	23	do	20	71	-	115	11.9	30.8	1.3	5.5	-	3080	-	58
Sand	29	do	22	82	-	91	5.0	61.0	1.1	4.7	-	1830	61	-
Southern	29	Fairly dull	32	79	300	-	7.0	55.8	1.3	4.6	1180	-	66	-
Western white														
Healthy	21	Medium sharp	30	70	270	75	13.7	56.2	2.1	5.6	2560	4400	-	55
Pole- blighted	21	do	30	66	255	60	12.8	42.2	1.7	6.0	1926	3560	-	59
Spruce														
Black	25	Sharp	20	52	345	-	2.9	47.4	1.7	4.0	1706	3650	65	55
Engleman														
live-cut	22	Dull	40	71	305	-	13.8	44.8	2.4	6.5	2790	4960	-	56
Beetlekilled	19	Medume sharp	20	79	420	130	13.0	38.8	1.9	5.0	2170	4060	-	56
Sitka	23	Sharp	25	77	250	45	25.8	40.8	2.2	8.5	2040	3710	-	59
White	24	Medume sharp	25	50	460	-	12.7	34.5	1.9	7.2	1926	3530	-	60
White cedar,	19	Dull	27	73	-	95	9.7	47.9	1.5	4.8	-	3280	-	36
Northen														

Table-2. Typical groundwood pulping characteristics of some North American hardwood (broad-leaved) species (1)

Species	Density of wood, lb/cu.ft	Stone surface condition	Pressure of wood on stone (psi.)	Energy consumed p/t ofod hp-days	Freeness, ml. Schopper Riegler ml.	Freeness, ml. Canadian stand. ml.	Screen Analysis Retained on 24-mesh	Screen Analysis Passing 150-mesh	Burst index	Tear index	Tensile strength psi.	Breaking length m.	Whiteness (Ives parts blue), %	Brightness (G.E. equivalent), %
Low density species														
Alder, Red	24	Dull	20	97	-	65	0.6	54.1	0.6	3.0	836	1940	-	42
Aspen, Quaking	22	Fairly dull	25	77	435	140	1.7	40.1	1.2	4.0	1122	2220	-	59
Cotton, eastern	23	do	30	68	430	-	1.3	48.9	1.0	3.4	1090	2240	64	-
Willow, Black	24	do	30	67	325	-	1.5	54.0	1.2	3.8	1230	2550	64	-
Yellow poplar	25	do	20	83	433	120	0.7	46.1	0.8	3.4	870	1760	-	63
Higher density species														
Ash, green	34	Fairly dull	30	64	352	-	0.0	74.9	0.7	2.2	716	1700	72	-
Ash, white	34	do	30	51	483	-	0.0	62.8	0.5	2.6	1018	1370	-	62
Beech, American	32	Medium sharp	20	68	343	140	0.0	86.0	0.2	0.7	515	855	-	46
Birch, paper	34	Fairly dull	30	67	475	-	0.1	62.4	0.4	2.0	528	1060	-	52
Birch, yellow	34	Medium sharp	20	68	348	125	0.2	81.8	0.4	0.9	618	1265	-	48
Elm, American	30	Fairly dull	30	78	252	-	0.1	72.8	0.9	3.2	940	2000	52	-
Maple, Red	32	Medium sharp	20	76	270	137	0.0	77.8	0.6	1.6	992	1900	-	50
Maple, sugar	32	Fairly dull	35	75	355	70	0.1	59.7	0.7	2.6	910	1545	-	48
Sugarberry	30	do	30	93	273	-	0.2	72.0	0.8	2.6	906	2100	69	-
Sweetgum	30	Dull	22	69	420	95	0.1	57.5	0.4	2.3	270	580	-	49
Tupelo, Black	31	Dull	30	75	345	50	0.1	62.3	0.7	2.8	630	1330	-	67

Table-4, Comparison of a severe caustic sodium sulfite treatment and the caustic peroxide treatment (1).

Wood species	Poplar		Maple	
NaOH, % on od wood	4.8	4.7	4.9	3.6
Na_2SO_3, % on od wood	6.9	-	4.2	-
H_2O_2, % on od wood	-	1.7	-	1.6
Pulp yield, %	85.0	85.0	-	-
Refining energy, Bhp/adt	38.0	37.0	41.0	40.0
Freeness, CSF	150.0	150.0	115.0	112.0
Bulk	2.15	1.85	2.07	2.22
Burst index	2.2	3.0	1.4	1.3
Tear index	6.9	7.2	4.7	4.0
Brightness	46.0	69.0	33.0	48.0
Scattering coefficient	36.0	34.0	47.0	49.0

Table-5, Composition of Hardwood chemical pretreatment(9).

Wood species	Impregnation Chemical	% Absorbed	Power kwh /odt	freeness CSF	Burst index	Tear index	Tensile	Bulk	Brightness	Opacity
Aspen	-	-	1450	129	0.7	3.7	1600	2.8	57	98
	Na_2SO_3	4.6	931	353	1.0	4.8	2500	2.7	58	92
	NaOH	3.9	716	103	3.3	6.6	5800	1.5	44	92
White birch	-	-	1092	159	0.3	1.2	1200	2.8	49	98
	Na_2SO_3	5.4	877	332	1.2	4.3	3000	2.9	58	94
	NaOH	3.6	573	150	2.9	7.1	5000	2.0	37	93
Soft maple	-	-	1199	129	0.6	2.1	1600	2.8	48	98
	Na_2SO_3	5.4	877	436	0.5	1.9	1400	3.4	64	91
	NaOH	2.9	716	210	1.1	4.1	2600	2.5	46	97
Hard maple	-	-	1289	179	0.4	2.0	1300	3.1	44	98
	Na_2SO_3	4.1	859	435	0.3	2.0	1300	3.6	60	91
	NaOH	2.1	734	139	1.6	3.9	3700	2.3	42	97
Red gum	-	-	877	85	0.2	1.1	1000	2.7	41	91
	Na_2SO_3	5.4	573	181	0.5	2.7	1600	2.9	45	88
	NaOH	3.0	609	80	1.5	4.6	3900	2.1	32	98
Cotton wood	-	-	1343	83	0.7	2.5	1900	-	52	98
	Na_2SO_3	6.5	698	483	0.7	3.1	1900	3.0	48	91
	NaOH	2.6	644	94	2.4	5.9	4600	1.7	41	94
Yellow poplar	-	-	1110	61	0.5	2.3	1600	-	51	99
	Na_2SO_3	6.1	806	452	0.6	3.5	1900	3.2	44	94
	NaOH	3.7	716	117	2.1	5.9	6000	1.7	43	95

Table-6, CRMP from Hardwood (10).

Species	Aspen	White birch	Yellow birch	Red maple	Sugar maple
NaOH, % used	1.2	2.1	1.9	1.8	4.3
Na_2SO_3, % used	1.3	1.7	2.8	2.5	0.0
Energy, kwh/bdt	1575	1378	1575	1772	1772
Freeness, CSF	95	67	80	83	125
Bulk	2.5	2.8	2.7	2.6	2.8
Burst index	1.2	1.3	1.6	1.2	0.7
Tear index	4.3	3.9	4.9	2.7	2.2
Breaking length	-	3000	3500	2700	2000
Shives, %	0.4	0.8	0.2	0.3	0.2
Brightness	54	58	43	46	36
Opacity	95	94	96	96	98

Table-7, Process comparison (11).

	Cold Soda	Alkaline ground wood
NaOH absorbed, %	6.55	-
Energy, kwh/odt	906.00	1530.00
Freeness, CSF	142.00	68.00
Burst index	2.19	0.77
Tear index	4.53	1.97

Table-8, Effect of tree age (11).

Species	Old growth regnans	Pole regnans	Old growth obliqua	Pole obliqua	E. gigantea	Sassafras
Wood age, year	200-400	35	300-400	40	300	150
NaOH absorbed,%	6.7	6.8	7.6	5.8	7.1	5.8
Energy, hpd/t	53.9	66.5	55.1	62.8	42.4	50.7
Freeness, CSF	143	179	141	142	142	133
Bulk	2.22	1.95	2.33	2.09	2.27	2.14
Burst index	2.26	3.27	1.73	2.63	2.19	1.92
Tear index	4.85	5.89	3.83	5.19	4.64	4.43

Table-9, Quality characteristics of cold soda pulps from Eucalyptus and Gmelina (12).

		Eucalyptus globlus	Eucalyptus globlus	Gmelina arborera
Sodium hydroxide take-up	kg/t	40	50	50
Temperature	°C	40	40	40
Reaction time	min.	30	30	30
Yield	%	93.0	90.0	90.0
Energy consumption	kwh/ADT	2500	2100	3000
Freeness	ml CSF	100	100	100
Shiv content	%	<0.05	<0.05	0.5
Bauer McNet				
Long fiber (R30)	%	9	7	9
Fines (P200)	%	25	23	24
Wet web strength	N/m	50	66	50
Density	kg/m^3	335	425	350
Tensile index	Nm/g	40	49	41
Burst index	$kPa-m^2/g$	1.6	2.6	1.7
Tear index	$mN-m^2/g$	4.5	6.5	4.5
Scattering coefficient	m^2/g	59	55	60
Unbleached brightness, ISO	%	52	47	54
Bleached brightness, ISO	%	62	56	65

Table-10, Propertiess of Eucalyptus pulp after refining

No. Chemical treatment	Yield	Freeness	Bauer McNet classification for pulp									
			Before beating					After beating				
			+28	-28 +48	-48 +100	-100 +200	-200	+28	-28 +48	-48 +100	-100 +200	-200
1. 5% NaOH + Bleaching with H_2O_2	93	200	18	06	46	19	21	02	01	24	23	50
2. 3% NaOH + 2% Na_2SiO_3 + EDTA + 1% H_2O_2	95	225	08	12	42	14	24	04	02	38	48	08
3. 3% NaOH + 2% Na_2CO_3 + EDTA + 1% H_2O_2	97	210	31	15	30	02	22	01	01	34	36	28
4. 3% NaOH + 3% Hypo	96	200	08	06	15	48	23	14	05	30	29	22
5. 5% NaOH + 1% H_2O_2	94	200	48	12	29	02	09	03	02	22	25	48
6. 4% NaOH + 2% Na_2SO_3	94	240	07	05	45	17	26	02	03	40	27	28
7. 6% NaOH	97	360	30	08	25	20	17					
8. 8% NaOH	97	450	31	05	29	23	12					
9. 10% NaOH	96	370	23	05	18	23	31					

Table-11, Table for residual alkali

Chemical treatment	Alkali(gm) Charged	HCl(ml) consumed	Residual alkali (gm)	Residual H_2O_2
1. 5% NaOH + Bleaching with H_2O_2	22.1	0.15	1.7	trace
2. 3% NaOH + 2% Na_2SiO_3 + EDTA + 1% H_2O_2	13.3	0.10	1.4	trace
3. 3% NaOH + 2% Na_2CO_3 + EDTA + 1% H_2O_2	13.3	0.10	1.5	trace
4. 3% NaOH + 3% Hypo	13.3	0.10	1.4	trace
5. 5% NaOH + 1% H_2O_2	22.1	0.20	1.6	
6. 4% NaOH + 2% Na_2SO_3	17.7	0.10	1.5	
7. 6% NaOH	27.0	0.30	4.0	
8. 8% NaOH	36.0	0.25	3.4	
9. 10% NaOH	45.0	0.28	3.8	

Total chips = 650 gm

Moisture of chips = 30%

Total od chips = 650 - 208 = 442 gm

Water aded = 1500 ml

Total moisture = 1708 gm

Table-12, Properties of Hand made sheets from beaten Eucalyptus pulp

Chemical treatment	Basis weight	Tensile index	Tear index	Brightness	Opacity R_0/R_∞	Scattering coefficient	Absorption coefficient
						($m^2/kg \cdot 10^{+3}$)	
1. 5% NaOH + Bleaching with H_2O_2	83	12.7	2.1	44	98.2	38.42	5.83
2. 3% NaOH + 2% Na_2SiO_3 + EDTA + 1% H_2O_2	92	5.5	0.6	45	98.2	33.70	5.40
3. 3% NaOH + 2% Na_2CO_3 + EDTA + 1% H_2O_2	94	4.4	0.8	46	98.3	35.20	4.90
4. 3% NaOH + 3% Hypo	89	9.7	1.3	36	97.8	24.40	7.60
5. 5% NaOH + 1% H_2O_2	91	6.5	1.5	43	98.2	33.70	5.40
6. 4% NaOH + 2% Na_2SO_3	93	15.0	1.9	38	98.0	25.90	5.70
7. 6% NaOH	115	16.0	1.9	30	99.5	21.29	9.18
8. 8% NaOH	114	11.0	1.8	32	99.6	25.74	9.56
9. 10% NaOH	106	15.0	1.8	31	99.55	30.75	26.30

Table-13, Commercial Insstallation- Comparisson of Bagasse Newsprints (14, 15)

PROCESS	UNITS	Beloit-SPB	CUSI	PEADCO
MILL LOCATION		TNPL-INDIA	TUCUMAN-ARGENTINA	LETJES-INDONESIA
FURNISH		MBP-50%	SCBP-75%	SCBP/SCSP-40%
		CBP-35%	GWD -15%	TMP-B -45%
		HW -15%	SBK -10%	SBK -15%
PROPERTIES :				
BASIS WEIGHT	gsm	50.6	49.6	50.8
CALIPER	microns	85.0	67.0	78.0
TEAR-FACTOR (CD)		44.0	61.0	53.0
PRINTING OPACITY	%	93.5	88.0	93.3
SCATTERING COEFFICIENT	cm^2/g	450.0	437.0	407.0
BRIGHTNESS	°GE	50.5	59.0	56.0
MACHINE SPEED	mpm	630.0	600.0	NA

MBP - MECHANICAL BAGASSE PULP

TMP-B - THERMO MECHANICAL PULP (BAGASSE)

SCBP - SEMI CHEMICAL BAGASSE PULP

SCSP - SEMI CHEMICAL STRAW PULP

SBK - SEMIBLEACHED KRAFT

GWD - GROUNDWOOD PULP

Table-14, Properties of Bagasse pulp after refining

Sl. No.	Chemical treatment	Yield	Freeness	Bauer McNet classification				
				+28	-28 +48	-48 +100	-100 +200	-200
1.	6% NaOH	75.5	90	23	26	10	02	39
2.	4% NaOH	84.0	300	15	36	17	16	14
3.	4% NaOH + 2% Na_2SO_3	86.5	210	14	23	12	16	35

Table-15, Properties of Hand made sheets from Bagasse pulp

Sl. No.	Chemical treatment	Basis weight	Tensile index	Tear index	Brightness	Opacity R_0/R_∞	Scattering coeff. ($m^2/kg. 10^{+3}$)	Absorption Coeff.
1.	6% NaOH	87	39	2.2	30	96.96	38.3	3.4
2.	4% NaOH	83	7.2	1.2	35	95.65	9.0	11.6
3.	4% NaOH + 2% Na_2SO_3	81	17.0	1.2	33	91.93	7.1	9.2

Table-16, Comparable properties of Eucalyptus and Bagasse pulp

Sl. No.	Chemical treatment	Basis weight	Tensile index	Tear index	Brightness	Opacity R_0/R_∞	Scattering coeff.	Absorption Coeff.
							(m^2/kg. 10^{+3})	
For Eucalyptus pulp								
1.	6% NaOH	115	16.0	1.9	30	99.5	21.29	9.18
2.	4% NaOH+2% Na_2SO_3	93	15.0	1.9	38	98.0	25.9	5.70
For Bagasse pulp								
4.	6% NaOH	87	39.0	2.2	30	96.9	38.3	3.40
5.	4% NaOH+2% Na_2SO_3	81	17.0	1.2	33	91.9	7.1	9.20

Table-17, Properties of Mechanical pulps (16)

Sl. No.	Properties	Units	SGW pulp	TMP	CTMP	Mechanical Bagasse pulp
1.	Freeness	CSF(ml)	100-150	100-150	100-150	200-250
2.	Bulk	cc/gram	2.5-3.2	2.5-3.0	2.5-3.0	2.9-3.4
3.	Burst index	$kPam^2$/gram	0.6-1.0	1.0-1.5	1.5-2.0	0.8-1.2
4.	Tear index	mNm^2/gram	2.5-3.0	6.0-7.0	7.0-8.0	3.0-4.8
5.	Tensile index	Nm/gram	15 -20	30 -35	33 -37	22 -30
6.	Brightness	% ISO	58 -60	55 -60	55 -58	42 -48
7.	Scattering coefficient	m^2/kg	65 -70	55 -60	48 -55	45 -52

Table-18, Properties of Bagasse pulp (16)

Sl. No.	Properties	Units	Unbleached Bagasse TMP	Unbleached Bagasse CMP	Bleached MBP	Bagasse Chemical pulp	Refined chemical	Hardwood pulp
1.	Pulp freeness	CSF (ml)	100-150	300-400	200-250	450-500	350-400	
2.	Bulk	cc/gram	3.6-4.2	2.9-3.6	2.9-3.4	1.5-1.6	1.8-2.2	
3.	Burst index	$kPam^2/gram$	0.1-0.2	1.0-2.0	0.8-1.2	3.0-4.0	3.8-4.5	
4.	Tear index	$mNm^2/gram$	1.7-2.5	3.5-6.0	3.0-4.8	5.3-5.8	6.5-7.5	
5.	Tensile index	Nm/gram	10 -15	20 -35	22 -30	60 -65	65 -70	
6.	Printing Opacity	%	99.5-99.8	96 -99	96 -98	76 -80	86 -92	
7.	Scattering coefficient	m^2/kg	50 -59	38 -44	45 -52	30 -32	45 -50	
8.	Brightness	% ISO	32 -38	32 -37	42 -48	75 -80	70 -75	

MBP - Mechanical Bagasse Pulp (50% TMP + 50% CMP)

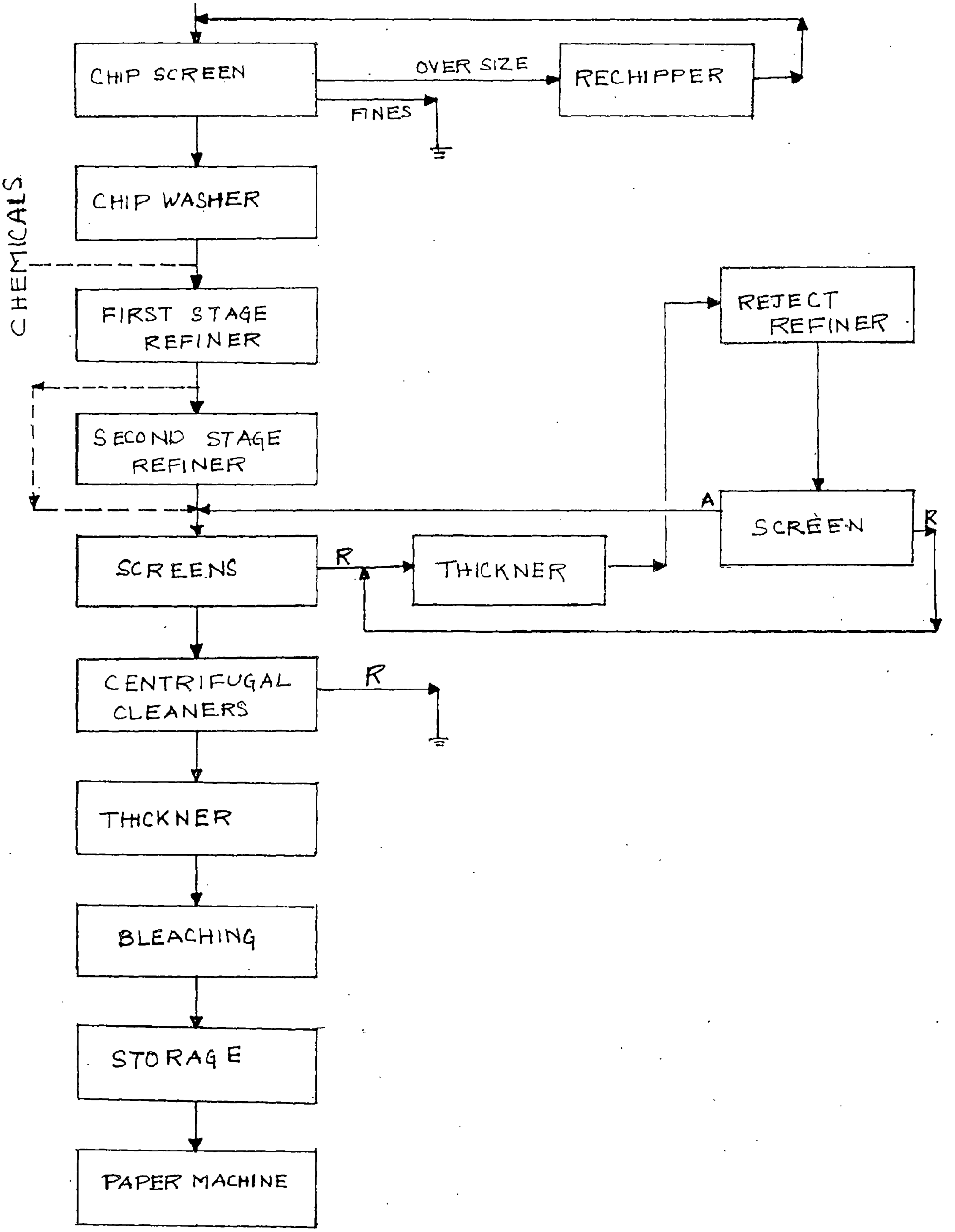

FIG-1, TYPICAL REFINING PULPING PLANT.

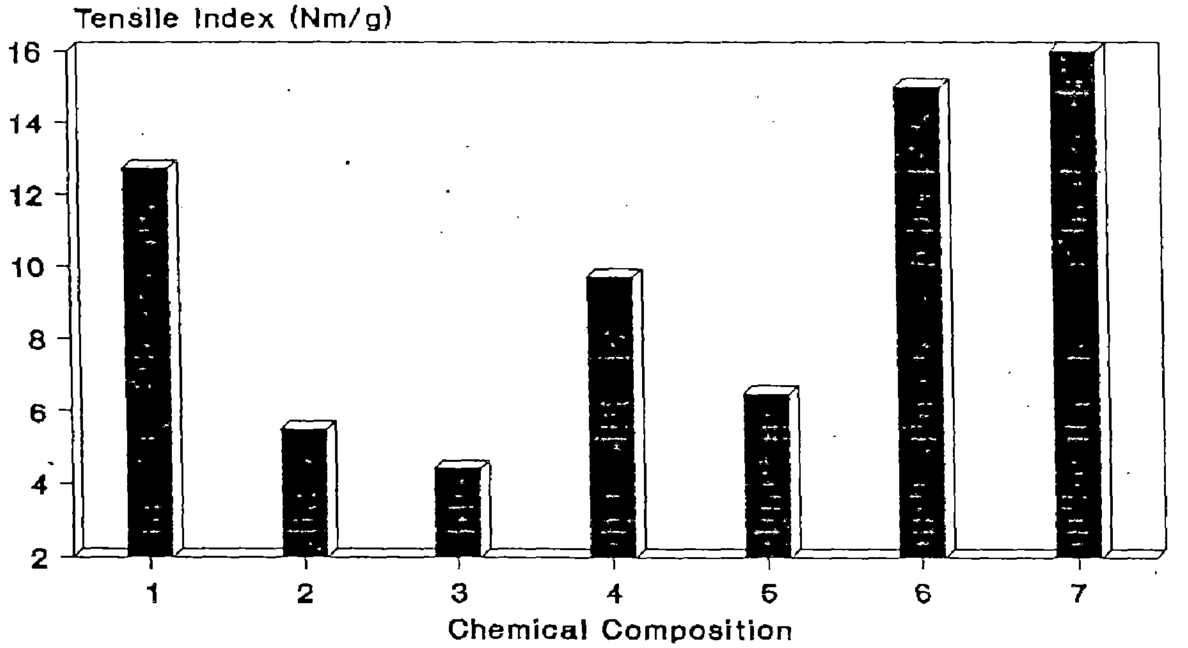

Figure 2 : Chemical Composition vs Tensile Index

1. 5% NaOH + Bleaching with H_2O_2
2. 3% NaOH + 2% Sodium silicate + EDTA + 1% H_2O_2
3. 3% NaOH + 2% Sodium carbonate + EDTA + 1% H_2O_2
4. 3% NaOH + 3% Hypo solution
5. 5% NaOH + 1% H_2O_2
6. 4% NaOH + 2% Sodium sulfite
7. 6% NaOH

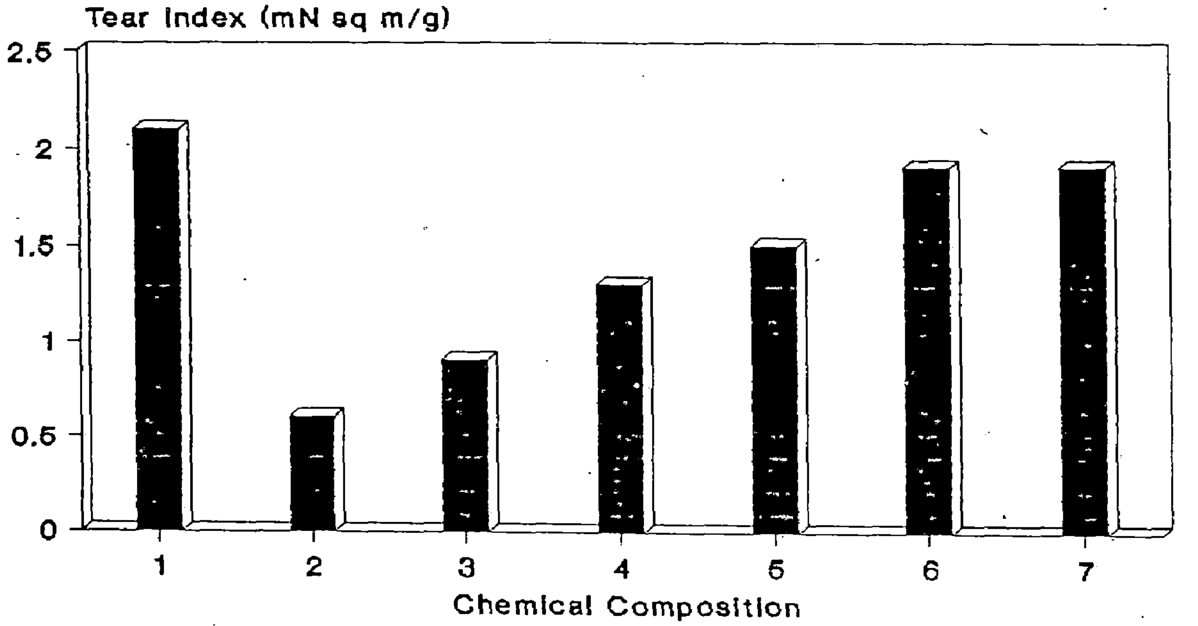

Figure 3 : Chemical composition vs Tear Index

1. 5% NaOH + Bleaching with H_2O_2
2. 3% NaOH + 2% Sodium silicate + EDTA + 1% H_2O_2
3. 3% NaOH + 2% Sodium carbonate + EDTA + 1% H_2O_2
4. 3% NaOH + 3% Hypo solution
5. 5% NaOH + 1% H_2O_2
6. 4% NaOH + 2% Sodium sulfite
7. 6% NaOH

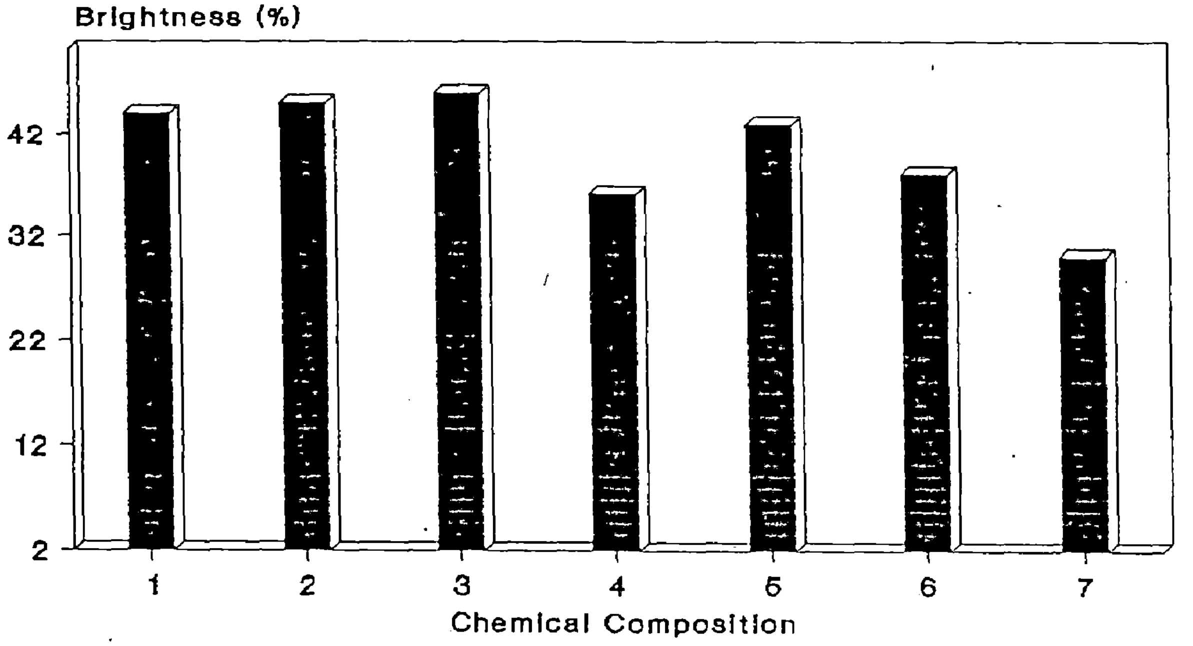

Figure 4 : Chemical Composition vs Brightness

1. 5% NaOH + Bleaching with H_2O_2
2. 3% NaOH + 2% Sodium silicate + EDTA + 1% H_2O_2
3. 3% NaOH + 2% Sodium carbonate + EDTA + 1% H_2O_2
4. 3% NaOH + 3% Hypo solution
5. 5% NaOH + 1% H_2O_2
6. 4% NaOH + 2% Sodium sulfite
7. 6% NaOH

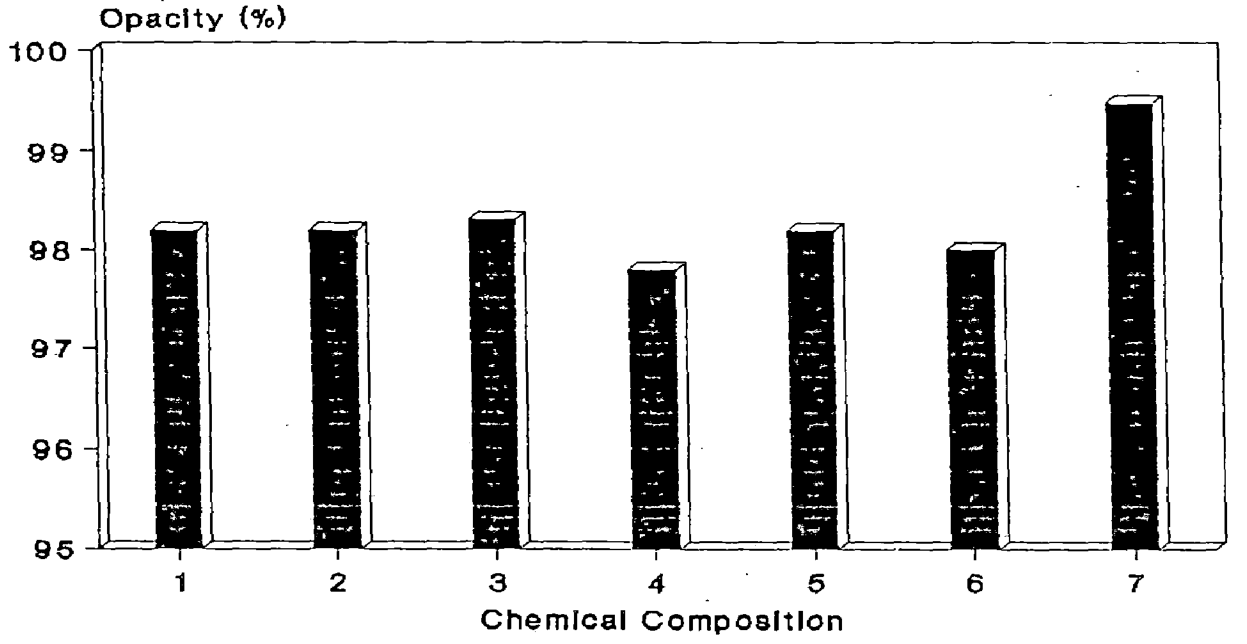

Figure 5 : Chemical Composition vs Opacity

1. 5% NaOH + Bleaching with H_2O_2
2. 3% NaOH + 2% Sodium silicate + EDTA + 1% H_2O_2
3. 3% NaOH + 2% Sodium carbonate + EDTA + 1% H_2O_2
4. 3% NaOH + 3% Hypo solution
5. 5% NaOH + 1% H_2O_2
6. 4% NaOH + 2% Sodium sulfite
7. 6% NaOH

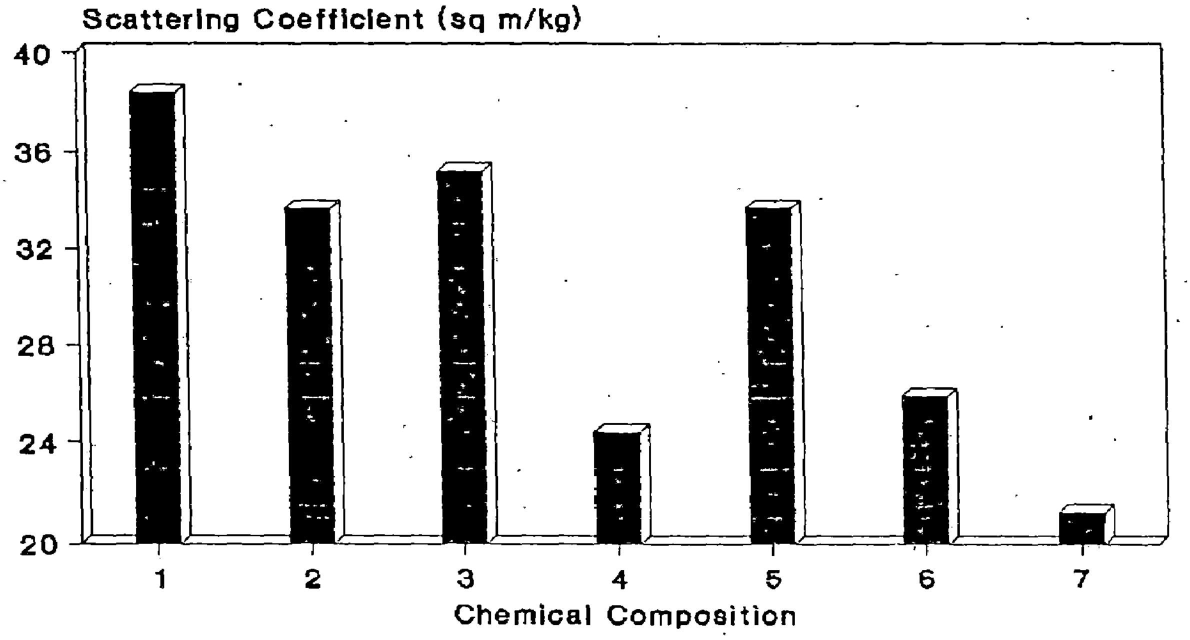

Figure 6 : Chemical Composition vs Scattering coefficient

1. 5% NaOH + Bleaching with H_2O_2
2. 3% NaOH + 2% Sodium silicate + EDTA + 1% H_2O_2
3. 3% NaOH + 2% Sodium carbonate + EDTA + 1% H_2O_2
4. 3% NaOH + 3% Hypo solution
5. 5% NaOH + 1% H_2O_2
6. 4% NaOH + 2% Sodium sulfite
7. 6% NaOH

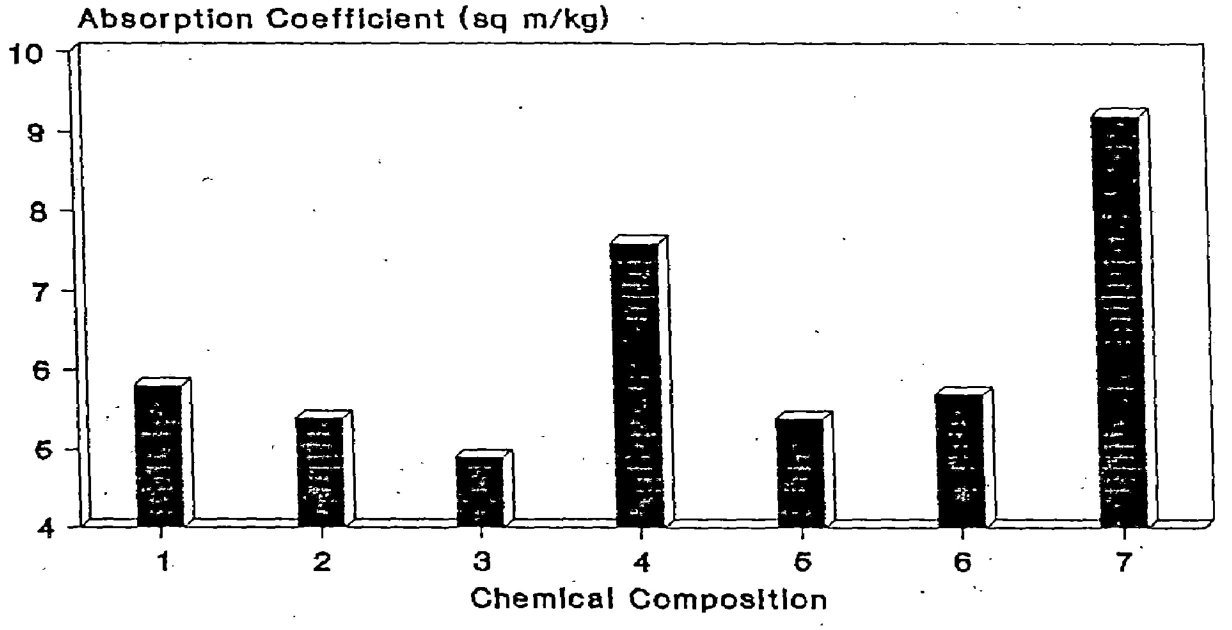

Figure 7 : Chemical Composition vs Absorption Coefficient

1. 5% NaOH + Bleaching with H_2O_2
2. 3% NaOH + 2% Sodium silicate + EDTA + 1% H_2O_2
3. 3% NaOH + 2% Sodium carbonate + EDTA + 1% H_2O_2
4. 3% NaOH + 3% Hypo solution
5. 5% NaOH + 1% H_2O_2
6. 4% NaOH + 2% Sodium sulfite
7. 6% NaOH