BIOTECHNOLOGICAL APPLICATION OF ENZYMES FOR MAKING PAPER PULP FROM GREEN JUTE / KENAF

PROJECT NO. FC/RAS/00/153
UNIDO CONTRACT No. 2001/107

SUBMITTED TO

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION VIENNA (AUSTRIA)

BY

CENTRAL PULP & PAPER RESEARCH INSTITUTE SAHARANPUR – 247001, INDIA

January 2004
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FOREWORD
FOREWORD

The paper industry in Asia is facing severe crunch for the fibrous raw materials and the environmentalists exert pressure to reduce the dependency of paper industry on forest for fibrous raw materials. In view of this, International Jute Study Group (IJSG) came forward with a proposal to use the green jute and Kenaf as eco-friendly fiber source, which is a seasonal crop for making paper pulp to add one more fiber source for paper industry. Later on UNIDO was approached and its suggestions were taken and the finally the project was recast according to the suggestions of Common Fund for Commodities (CFC). The project is titled as “Biotechnological Application of Enzymes for Making Paper Pulp from Green Jute / Kenaf” This project involves 7 institutes of 5 countries namely BJRI & BCIC from Bangladesh, IBFC & Yuanjiang Mill from China, CPPRI from India, CTP from France and ATO-DLO from The Netherlands.

The work reported here was carried out under the PROJECT NO. FC/RAS/00/153 UNIDO CONTRACT No. 2001/107 "BIOTECHNOLOGICAL APPLICATION OF ENZYMES FOR MAKING PAPER PULP FROM GREEN JUTE / KENAF" as a part of research activities being carried out at Central Pulp and Paper Research Institute, Saharanpur.

The findings of this report are related to the work done at the central Pulp & Paper Research Institute and are those considered appropriate at the time of its preparation.

Dr.A.G.KULKARNI
DIRECTOR

Central Pulp & Paper Research Institute
ACKNOWLEDGEMENTS
ACKNOWLEDGEMENTS

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Acknowledgments are due to the research, pilot plant, and engineering staff of the Institute without whose help many of the research activities would not have been possible. Acknowledgements are also due to Dr. H.C. Sen, Director, and Dr. M.K. Sinha, Sr. Scientist of Central Research Institute for Jute and Allied Fibers who helped in the procurement of Thosa jute for pilot trials from Barrackpore, Kolkata. The time-to-time help from Finance and Administrative staff have helped in smooth execution of the project.
## LIST OF SCIENTISTS ASSOCIATED WITH THE PROJECT

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Name</th>
<th>Designation</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dr. S.V. Subrahmanyam</td>
<td>Scientist – E1</td>
<td>Project Leader</td>
</tr>
<tr>
<td>2.</td>
<td>Dr. Abha Gupta (Late)</td>
<td>Scientist - E1</td>
<td>Member</td>
</tr>
<tr>
<td>3.</td>
<td>Dr. Priti S. Lal</td>
<td>Scientist - B</td>
<td>Member</td>
</tr>
<tr>
<td>4.</td>
<td>Dr. Vasantha Thakur</td>
<td>SSA</td>
<td>Member</td>
</tr>
<tr>
<td>5.</td>
<td>Dr. Ravi D. Godiyal</td>
<td>Scientist - B</td>
<td>Member</td>
</tr>
<tr>
<td>6.</td>
<td>Mr. Vipul Janbade</td>
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<td>Member</td>
</tr>
<tr>
<td>7.</td>
<td>Mr. Sandeep Tripathi</td>
<td>SRF</td>
<td>Member</td>
</tr>
<tr>
<td>8.</td>
<td>Mr. Arvind K. Sharma</td>
<td>SRF</td>
<td>Member</td>
</tr>
<tr>
<td>9.</td>
<td>Mr. D.K. Chowdary</td>
<td>JRF</td>
<td>Member</td>
</tr>
<tr>
<td>10.</td>
<td>Ms. Deepti Misra</td>
<td>JRF</td>
<td>Member</td>
</tr>
<tr>
<td>11.</td>
<td>Mr. Piyush Verma</td>
<td>JRF</td>
<td>Member</td>
</tr>
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</table>

## LIST OF SCIENTISTS SUPPORTED THE PROJECT ACTIVITIES

<table>
<thead>
<tr>
<th>Sl.No.</th>
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<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mr. V.K. Mohindru</td>
<td>Scientist – F</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Dr. Y.V. Sood</td>
<td>Scientist – E2</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Dr. R.M. Mathur</td>
<td>Scientist – E2</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Dr. R.K. Jain</td>
<td>Scientist – E1</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Dr. Suresh Panwar</td>
<td>Scientist – E1</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Mr. P.C. Pande</td>
<td>Scientist – E1</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Mr. G.C. Agaarwal</td>
<td>Tech. Officer – E1</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Mr. J.C. Sharma</td>
<td>Tech. Officer – E1</td>
<td></td>
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</tbody>
</table>
BACKGROUND
BACKGROUND

UNIDO-IJSG and CFC have sponsored a project on “Biotechnological application of enzymes for making paper pulp from jute / Kenaf” PROJECT NO. FC/RAS/00/153 UNIDO CONTRACT No. 2001/107. The aim of the project was to find a biotechnical route to produce paper pulp from jute / Kenaf. The project involved seven institutes from five countries namely BJRI & BCIC from Bangladesh, IBFC and Yuanjiang Mill from China, CPPRI from India, CTP from France and ATO-DLO from The Netherlands. The project has reached its Final stage and in final year of project period. The objectives are broadly successful and the recent review meeting held on 14 and 15 December 2002 at IJSG headquarters in Dhaka, Bangladesh has discussed the priorities and course of action. During the project presentation CPPRI has discussed the viability of green field pulp mills based on environmental regulations and economics of production technologies.

Current Scenario of Jute in India

India is the world’s largest producer of jute and allied fibers (1.941 million Metric tons), which accounts for about two third of the world’s production (3.092 million Metric tons). The area under jute cultivation is 0.817 million hectares and mesta cultivation is 0.184 million hectares in the year 2001-2002 in India (Source: Ministry of Agriculture, Govt. of India).

Jute plants are classified into two broad groups i.e. *Corchorus capsularis* (White jute) and *Corchorus olitorius* (Tossa jute). Mesta / Kenaf yielding fibers of commerce are similar to jute, constitute a third group. All these four varieties can be considered as one, although it is known that there are marginal variations in their pulping characteristics.

The Jute advisory board of India’s preliminary estimates indicates 8.7% increase in the raw jute crop in the year 2002-2003 and the board has resolved to apprise the Union Ministry of Textiles about the concerns of the jute industry regarding the apprehended decline in mill’s consumption and purchase of raw jute in current season which could have far reaching consequences, particularly on jute growers in India. – This statement in the INDIAN JUTE – the quarterly newsletter of the Jute manufacturers Development council indicate the gravity of problem due to lack of alternative and sustained raw jute consumers like paper industry. A consistent consumer of jute and allied fibers on a sustained basis will give a boost for increased production by the farmers.
Commercial aspects of Jute and Allied fibers:
Jute and allied fibers are used after retting the bark for manufacture of sacks, carpet backing cloth, yarn and other handicraft items. The handicraft items include carpets, soft luggage, decorative fabrics, curtains, blankets, shopping bags and jute composites. The other potential sustained bulk consumer could be pulp and paper industry, provided the right kind of cleaner technology, which can produce specialty and ecograde pulp, is identified for the jute and allied fibers.

Paper market:
Traditionally wood is used for producing paper grade pulp. Other fiber sources like nonwood raw materials are converted to paper grade pulp, mostly in China and Indian subcontinent due to shortage of forest based fiber.

New development in printing technology has revolutionized the industry worldwide. The scenario has changed rapidly from letterpress to offset and to laser printing and every day newer innovations are being carried out in this area in order to meet the requirement of modern society. This has resulted in great demand for superior quality i.e. high strength and high brightness papers like fax papers, computer stationary, copier paper, higher GSM bond papers etc. Their demand is rising faster than the cultural grades of paper. There is a sizeable consumption of high quality paper in the industrialized countries. The papermakers abroad find it a more profitable proposition to produce and market this type of paper more, so in the recent years, paper units registering low return on investment. Strict pollution laws forcing the industry to spend a sizeable amount of money on pollution abatement program or using other process which may be expensive but less polluting.

Jute and Kenaf are annual plants, widely cultivated in the Eastern and Central part of India. The main users of these raw materials are the gunny bag Industries using only bast portion discarding the jute sticks as waste. The bast fiber also being used Jute textiles industry, but to a limited level. The papermaking properties of jute are well established for a long time and work on this has been time-to-time published in different journals and periodicals. Use of biotechnological for papermaking can make this process more economical and environment friendly. A project for “Biotechnological application of enzymes for making paper pulp from jute and Kenaf “ was sponsored by UNIDO with association of IJO, Bangladesh. The objective of this program is to promote jute utilization in papermaking by eco-friendly processes.

Central Pulp & Paper Research Institute
Biotechnological applications of whole jute
Continuous pressure from global market and environmental management authorities is forcing the Pulp & Paper Industry to devise pulping and technologies which are eco friendly in nature. Efforts are being made to do away with these chemicals by using sulfur free pulping, extended delignification and chlorine free bleaching technologies. Biotechnology has been identified as one of the cleaner production options in pulp & paper making processes. The technology has been received considerable attention because of its enormous environmental potential in number of areas like pulping, bleaching papermaking and pollution control. Biopulping and Biobleaching are environmentally friendly technologies offers both economic and environmental benefits.

Biopulping:
Biological pre-treatment of fibrous raw materials with identified & selected strains of ligninolytic fungi could reduce the cost of pulping processes in terms of energy, cooking chemicals with improved pulp properties. Although many microorganisms are involved in the decomposition of the fibrous raw materials, fungi are the dominant decomposers. White rot fungi are the only known microorganisms, which degrades lignin completely. The emphasis is on their characteristics of ligninolytic enzymes, which are useful for biopulping.

Biobleaching:
The use of biotechnology implies the use of biological processes in pulp bleaching has attracted considerable attention & achieved interesting results in recent years. Enzymes of the hemicellulolytic type, particularly xylan attacking enzymes, xylanases are now used in commercial mills for pulp treatment and subsequent in corporation in to bleach sequences.

Central Pulp & Paper Research Institute as a part of promotion of green and clean technology in Indian Paper Industry could identify biotechnology as one of the promising technology option with an aim of promotion of biotechnological applications for Pulp & Paper manufacturing. Thrust has been laid upon few of the biotechnological applications like enzymatic prebleaching of pulp, control of slime employing ecologically compatible biocides and biopulping of wood and non wood based raw materials employing screened and identified microbial strains.

The main objectives of the project is the evaluation of the scope of biotechnological applications i.e. biopulping and biobleaching using both commercially available / developed microbes/enzymes.
OBJECTIVES
OBJECTIVES
(SCOPE OF CPPRI WORK)

1. Laboratory chemical pulping using Soda, Soad-Aq and Kraft processes.
2. Biopulping experiments on jute.
3. Bleaching of unbleached jute pulp from Soda-Aq and Kraft processes using sequences such as CEH, CE₂H, C/DEH, C/DE₂H, C/DE₀₂H.
4. Enzymatic Bleaching using commercial and IJSG developed enzymes based on the best laboratory results of unbleached jute pulp from Kraft processes using sequences such as CEH, CE₂H, C/DEH, C/DE₂H, C/DE₀₂H.
5. Confirmatory pilot chemical pulping in duplicate.
6. Enzymatic bleaching of Kraft pulp produced in pilot trials at CPPRI, using commercial and IJSG developed enzymes based on the best laboratory results.
WORK PLAN
THE WORK PLAN FOR PROJECT IS AS GIVEN BELOW

- Optimization of pulping chemical dose for jute, untreated and treated with micro-organism/enzymes, for producing bleachable grade chemical pulp.
- Determination of pulp yield, reject content as per the standard methods.
- Determination of pulp kappa number using TAPPI standard methods Number T 236 om - 99.
- Bleaching of the above pulps produced under optimum conditions with and without use of newly developed enzymes in pre bleaching stages:
- Pre-enzymatic bleaching with the newly developed xylanase enzyme for further CEH bleaching to reduce chlorine demand.
- Bleaching of the enzymatic treated pulps in the laboratory for optimizing bleaching chemical dosages for CEH bleaching sequence.
- Pulp evaluation by beating of the above pulps to 4-5 levels of freeness (CSF) and preparation of hand sheets using TAPPI standard methods Number T 205 sp – 95.
- Evaluations of physical strength properties of hand sheets like tensile, burst, tear etc using ISO standard methods Number 1924, 2758, 1974 respectively.
- Procurement of 5 tons of green Thosa jute on bone dry basis from Kolkata region.
- Optimization of pulping chemical dose for green Thosa jute procured from Kolkata, India, using kraft process prior to pilot trials at CPPRI.
- Determination of pulp yield, reject content, kappa number in pilot trials as per the standard methods.
- Pilot scale trials in duplicate at CPPRI using kraft process pilot pulping facility using the optimized laboratory conditions.
- Determination of pulp yield, reject content in the pilot trials.
- Bleaching of the pulps from pilot trials
- Pulp evaluation by beating of the pulps from pilot trials to 4-5 levels of freeness (CSF) and preparation of hand sheets using TAPPI standard methods Number T 205 sp – 95.
- Evaluations of physical strength properties of hand sheets, made of pulps pilot trials, like tensile, burst, tear etc using ISO standard methods Number 1924, 2758, 1974 respectively.
METHODOLOGY
METHODOLOGY

Raw material preparation:
Jute sample in the form of stalks was received from IJO- Bangladesh. It was kept in polythene bag to attain the uniform moisture content and moisture was analyzed before starting the pulping experiment.

Proximate chemical analysis of jute:
Proximate chemical analysis of jute before and after enzyme treatment was carried out as per standard procedures.

Pulping experiments:
Pulping experiments were carried out using different cooking chemical dosage of kraft, soda and soda AQ process in order to optimize cooking chemical demand for getting bleachable grade pulps of kappa no. around 20-25. Experiments were performed in a series digester consisting of six bombs of 2.5 liter capacity, rotating in an electrically heated polyethylene glycol bath. At the end of the cooking time, the bombs were removed and quenched in the water tank to cool down and the cooked mass from each bomb was taken for washing. Washing was carried out with hot water till the cooked mass was free from spent liquor. After thorough washing, the unscreened pulp yield was determined and the pulp was screened in laboratory ‘Serla’ screen by using 0.25 mm. slot width mesh. Kappa number of the screened pulp was determined as per the Tappi standard procedure T-236-OS-76. The constant cooking conditions are given below:

Cooking conditions:

<table>
<thead>
<tr>
<th>Raw material taken in each bomb</th>
<th>200 gm. (B.D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bath ratio (raw material to liquor ratio)</td>
<td>1:4</td>
</tr>
<tr>
<td>Sulphidity of cooking liquor</td>
<td>19 %</td>
</tr>
<tr>
<td>Cooking temperature</td>
<td>165 °C</td>
</tr>
<tr>
<td>Cooking time</td>
<td>90 min.</td>
</tr>
</tbody>
</table>

Cooking schedule:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient to 100 °C</td>
<td>30 min.</td>
</tr>
<tr>
<td>100 °C to 165 °C</td>
<td>90 min.</td>
</tr>
<tr>
<td>At 165 °C</td>
<td>90 min.</td>
</tr>
</tbody>
</table>
Black Liquor Analysis:
Complete Black Liquor analysis including thermal and rheological properties was carried out using the standard testing procedures.

Biopulping:
Fungal degradation of raw material
The scope of studies covers the biopulping of Jute at CPPRI employing the screened & the selected fungal strain by BCIC & IJSG. Due to the unavailability of the IJSG screened strains, preliminary studies were carried out with the selected strain of CPPRI. Eight fungal strains were screened by IJSG to identify their suitability for biopulping. In these 8 strains, 2 strains namely ST1 & ST2 are of CPPRI. As observed by IJSG, the following 3 strains were found suitable for biopulping. These are:-

1. Phanerochaete chrysosporium (Named PC in text)
2. Fomes lignosus (Named FL in text)
3. Ceriporiopsis subvermispora (Named CS in text).

Therefore on part of CPPRI, it was required to study the effect of these strains on biochemical pulping of whole jute.

Action plan:
- Fungal treatment of whole jute raw material with fungal strains CPPRI-1, PC, FL and CS.
- Chemical characterisation of fungal treated raw material for various parameters of importance - solubility in NaOH and Alcohol-Benzene, Klason lignin, Holocellulose, α-Cellulose & Pentosans.
- Chemical pulping & bleaching of bio treated raw materials keeping original raw materials under controlled conditions as standards for comparison. Conventional bleaching of bio-treated pulps.
- Morphological studies of fungal treated & untreated raw materials
Raw Material:
The experiments were conducted with Indian whole Jute for the studies which was obtained from West Bengal. The moisture content of the raw material was ~ 9.0%.

Bio-pulping Experiments:

a. Preparation of the Inoculum:
The inoculum was prepared by transferring the 4 – 5 day old, 5.0 mm diameter mycelial discs in 100 ml nutrient medium (Malt extract – IJO medium) and incubated at 35°C. After 7 days growth, the mycelial mat was homogenised in sterile water and was used as inoculum.

Observations - The growth rate of Ceriporiopsis subvermispora was observed to be extremely slow in slants as well as in petri plates, so the bio - pulping studies were continued with the remaining two strains i.e. PC & FL.

Media used:

1. Malt-yeast extract medium
2. Glucose + Mineral salts - IJO Medium as detailed in Table- 1.
3. Corn Steep Liquor (CSL) - Procured from an Indian Mill.

Inoculum dose

Inoculum dose used, % - 0.08

Biopulping conditions *

Moisture maintained, % - 66.6
Treatment Time, days - 15
Temperature maintained, °C - 35

*As per conditions provided by IJO, Bangladesh.

Media for inoculation on Raw material - Two media was used for inoculation.
Composition of Inoculation Media:

1. Malt-yeast extract medium
   - 0.3% Malt extract
   - 0.3% Yeast extract
   - 1% Glucose

2. Table 1. Medium

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Chemical</th>
<th>Amount in 1000 ml</th>
<th>Chemical</th>
<th>Amount in 1000 ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>KH₂PO₄</td>
<td>100mg</td>
<td>NaH₂PO₄</td>
<td>200mg</td>
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<tr>
<td>2.</td>
<td>MgSO₄</td>
<td>450mg</td>
<td>FeSO₄</td>
<td>100µg</td>
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<tr>
<td>3.</td>
<td>CuSO₄</td>
<td>20µg</td>
<td>ZnSO₄</td>
<td>10µg</td>
</tr>
<tr>
<td>4.</td>
<td>MnSO₄</td>
<td>10µg</td>
<td>CaCl₂</td>
<td>100µg</td>
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<tr>
<td>5.</td>
<td>Thiamine-HCl</td>
<td>10µg</td>
<td>Glucose</td>
<td>20g</td>
</tr>
</tbody>
</table>

3. Corn-Steep liquor – 0.5%

1 b. Fungal treatment of the raw material:
   - 300g (OD) of whole jute was put in the bioreactor., Sterile water / 0.5% (on basis dryweight raw material ) of corn steep liquor was added, mixed thoroughly and decontaminated by autoclaving and were then cooled to room temperature.
   - The raw material was decontaminated and the humidity of 75% was maintained. Raw material was inoculated with the fungus at the inoculum dose of 10-15mg/g (dry mycelium weight ) of raw material and kept for incubation.
   - Control bioreactor using the same amount of raw material by maintaining all the conditions except the medium and fungal inoculum was run in parallel.
   - The bioreactors were incubated at 35°C and after two weeks incubation, both untreated & fungus treated raw materials were harvested and air dried
   - After air drying, the weight loss of the treated & untreated raw materials was determined and both the raw materials were subjected to proximate chemical characterization and conventional chemical pulping.
2. Chemical characterisation of the treated materials:

The harvested raw materials are being analysed for physicochemical changes with respect to weight loss. Klason lignin, 1% NaOH solubility, Hot water solubility, Alcohol -benzene solubility were determined according to TAPPI Test methods. Holocellulose was analysed by Chlorite-Acetic acid method. Furfural method was used for estimation of pentosan content. Brightness of the raw material was analysed by ISO Standard methods. Detailed methodology is mentioned in Annexure.

3. Pulping studies of fungal treated & untreated raw materials:

Both fungal treated and untreated raw materials were subjected to conventional chemical pulping soda – AQ process. The pulps and black liquor obtained were analysed for the following parameters (Table 2)

Table – 2 Conditions for chemical pulping of whole jute

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Pulping Conditions Used</th>
<th>Material: Liquor</th>
<th>Max Temp. °C</th>
<th>Cooking schedule, minutes (Rising+Top)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NaOH</td>
<td>AQ</td>
<td>Raw material</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Original raw material</td>
<td>22.0</td>
<td>0.05</td>
<td>1:5</td>
<td>170</td>
</tr>
<tr>
<td>2.</td>
<td>Control</td>
<td>22.0</td>
<td>0.05</td>
<td>1:5</td>
<td>170</td>
</tr>
<tr>
<td>3.</td>
<td>PC with IJO medium</td>
<td>22.0</td>
<td>0.05</td>
<td>1:5</td>
<td>170</td>
</tr>
<tr>
<td>4.</td>
<td>PC with CSL</td>
<td>22.0</td>
<td>0.05</td>
<td>1:5</td>
<td>170</td>
</tr>
<tr>
<td>5.</td>
<td>FL with IJO Medium</td>
<td>22.0</td>
<td>0.05</td>
<td>1:5</td>
<td>170</td>
</tr>
</tbody>
</table>

*As per conditions given by IJO, Bangladesh.

**Pulps:**
1. Unscreened & Screened yields
2. Kappa number
3. Brightness
4. Strength & optical Properties
Black Liquor:
1. pH
2. Residual alkali
3. Total solids

Bleaching of biopulps:
Fungal treated and untreated pulps after were subjected to conventional CEH bleaching.

4. Morphological studies of fungal treated & untreated raw materials:
After harvesting, the fungal treated and untreated raw materials are preserved in 40% formaldehyde solution for photomicrographic studies.
PILOT PLANT KRAFT PULPING TRIALS ON WHOLE JUTE
(TRIALS CONDUCTED ON 1ST & 10TH OF DECEMBER, 2003):

The pilot plant kraft pulping trials were conducted using 17.5% alkali dose, which is 0.5% higher than the requirement worked out in the laboratory. The cooking conditions applied for the two cooks in the pilot plant are as follows (Table 3):

Table 3 Pulping conditions

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cooking conditions:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Raw material taken in the digester</td>
<td>678.2 Kg OD</td>
</tr>
<tr>
<td>2.</td>
<td>Bath ratio (raw material to liquor ratio)</td>
<td>1:4</td>
</tr>
<tr>
<td>3.</td>
<td>Sulphidity of cooking liquor</td>
<td>20.0 %</td>
</tr>
<tr>
<td>4.</td>
<td>Cooking temperature</td>
<td>165 °C</td>
</tr>
<tr>
<td>5.</td>
<td>Cooking time</td>
<td>90 min.</td>
</tr>
</tbody>
</table>

Cooking schedule:

| 6.    | Ambient to 100 °C                                                                  | 30 min.|
| 7.    | Degas pressure                                                                     | At 2.0 Kg/cm² pressure |
| 8.    | 100 °C to 165 °C                                                                   | 90 min.|
| 9.    | At 165 °C                                                                          | 90 min.|
| 10.   | Blow pressure                                                                      | At 5.0 Kg/cm² pressure |
Enzymatic prebleaching:
Studies were carried out to evaluate the response of xylanases towards the whole jute kraft pulp cooked in laboratory conditions.

Action plan:
- Procurement of commercial xylanases.
- Studies on enzymatic prebleaching of pulps under specific conditions of temperature, pH, treatment time and consistency.
- Subsequent bleaching of enzymatic treated pulps by conventional bleaching sequences as in the work plan of CPPRI.

Pulp samples:
Laboratory cooked unbleached kraft pulp samples of whole jute were used for the present studies. The pH and kappa number of the pulps were evaluated.

Xylanase enzymes:
According to the work plan, enzymatic prebleaching has to be conducted with IJSG enzyme and commercial enzyme. But due to the unavailability of the IJSG enzyme the studies were conducted with two commercial xylanases.

1. Pulpzyme HC - Novozymes
2. Biopulp - Biocon, India.

Xylanase enzyme activity:
Xylanase activity was estimated by Bailey’s method determining the release of reducing sugars (measured as xylose equivalents) from oat-spelt xylan.

Enzyme treatment of the pulp:
Xylanase treatment of the pulp samples was carried out without pH adjustment of the pulp. The original pH of the pulp is in the range of 8.0-8.5. Enzyme was properly mixed by kneading mechanism. Enzyme treatment conditions are shown in tables respectively. Enzyme doses were optimized so that minimum quantity of enzyme is required under normal pulp residence time of nearly 90-120 minutes. Doses were optimized at optimized
temperature and pH optimum by measuring the release of lignin & chromophores in pulp filtrates besides determining the reduction in kappa no. of enzyme treated pulp, if any against control pulp sample.

**Unbleached pulp characteristics:**
Enzyme treated and untreated pulps were analysed for kappa number andBrightness.

**Analysis of Pulp filtrates:**
The extractability of the dissolved lignin and the chromophores in pulp filtrates after Xylanase treatment and the control pulp sample were studies and the solubilised lignin and chromophores were measured by UV at 280nm and in visible range at 465nm respectively.

**Bleaching of enzyme treated pulps:**
Enzyme treated and untreated pulps were subjected to conventional bleaching sequences. Following bleach sequences (as per the work plan of CPPRI) are used for the present studies. The process conditions used for the bleaching stages are shown in the table – 4.

1. CEH
2. C50/D50EH
3. C50/D50E(P)H
4. C50/D50 E(op)H

**Table 4 Process conditions used during bleaching of pulps**

<table>
<thead>
<tr>
<th>Particulars</th>
<th>C/ (C50/50D) Stage</th>
<th>Alkali Extraction Stage (Ep)</th>
<th>Hypo Stage</th>
<th>E (OP) Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, °C</td>
<td>Ambient</td>
<td>65</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td>Pulp Consistency, %</td>
<td>3.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Retention Time, min</td>
<td>45</td>
<td>60</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>Final pH</td>
<td>1.8-2.0</td>
<td>&gt;10.5</td>
<td>&gt;9.0</td>
<td>&gt;10.5</td>
</tr>
</tbody>
</table>

*Central Pulp & Paper Research Institute*
FINDINGS
PHYSICAL AND CHEMICAL PROPERTIES OF JUTE
PHYSICAL PROPERTIES OF RAW MATERIAL

The jute plant is an annual plant and grows to a height of 5–16 feet in height and normally do not have significant branches. Diameter of the stem may reach up to 10 to 20 mm on maturity. The stem portion has two distinct zones viz. bark and core. The bark portion becomes loosely attached to core when the plant is dry. The dry bark is dark brown in color and the core (wood) is pale yellow or cream colored (fig 1,2,3).

![Fig 1. Chips of Whole Jute](image1)
![Fig 2. Chips of Jute corewood](image2)
![Fig 3. Chips of Jute bast](image3)

The physical properties of Jute raw material are furnished in table 5. Bast fiber constitutes 36% of the weight in the whole jute, and the balance 64% is core wood.Bulk density of the whole jute is very low compared to the hardwood and softwood. Bulk density of jute bast fiber is very low compared to core wood. Bulkiness of the raw jute fiber has disadvantages in terms of volumetric loading, throughput etc. Impregnation of chips with liquor also is affected due to high bulkiness, as the chips tend to float.

Table 5  Physical Properties

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Particulars</th>
<th>Whole Jute</th>
<th>Bast Fibre</th>
<th>Core Fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ratio of Bast and Core, %</td>
<td>-</td>
<td>36</td>
<td>64</td>
</tr>
<tr>
<td>2</td>
<td>Bulk Density, kg/m³</td>
<td>93.4</td>
<td>69.2</td>
<td>110.5</td>
</tr>
</tbody>
</table>

Central Pulp & Paper Research Institute
CHEMICAL PROPERTIES OF RAW MATERIAL

Complete proximate analysis of whole jute, bast fiber and core wood was carried out the results are furnished in Table 6. The ash content of the bast is higher since the bast portion carries extraneous silica. The holo-cellulose component in the bark is comparatively higher. Higher $\alpha$ - Cellulose content in the bark indicates that the pulp yield levels will be significantly higher and the pulp strength will also be superior.

Table 6  Chemical Properties of Raw Material

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Particulars</th>
<th>Whole Jute</th>
<th>Bast Fibre</th>
<th>Core Fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ash content, %</td>
<td>3.58</td>
<td>4.43</td>
<td>1.89</td>
</tr>
<tr>
<td>2</td>
<td>Cold Water Solubility, %</td>
<td>4.12</td>
<td>4.51</td>
<td>2.44</td>
</tr>
<tr>
<td>3</td>
<td>Hot Water Solubility, %</td>
<td>4.88</td>
<td>8.57</td>
<td>2.98</td>
</tr>
<tr>
<td>4</td>
<td>1/10 N NaOH Solubility, %</td>
<td>26.21</td>
<td>30.05</td>
<td>23.30</td>
</tr>
<tr>
<td>5</td>
<td>Alcohol Benzene, %</td>
<td>2.65</td>
<td>3.73</td>
<td>2.75</td>
</tr>
<tr>
<td>6</td>
<td>Klasson Lignin, %</td>
<td>21.13</td>
<td>15.30</td>
<td>24.23</td>
</tr>
<tr>
<td>7</td>
<td>Acid soluble Lignin, %</td>
<td>1.04</td>
<td>1.10</td>
<td>1.20</td>
</tr>
<tr>
<td>8</td>
<td>Holo-cellulose, %</td>
<td>79.50</td>
<td>81.40</td>
<td>75.50</td>
</tr>
<tr>
<td>9</td>
<td>$\alpha$ - Cellulose, %</td>
<td>43.52</td>
<td>54.72</td>
<td>36.50</td>
</tr>
<tr>
<td>10</td>
<td>$\beta$ - Cellulose, %</td>
<td>19.88</td>
<td>14.60</td>
<td>25.90</td>
</tr>
<tr>
<td>11</td>
<td>$\chi$ - Cellulose, %</td>
<td>16.15</td>
<td>12.08</td>
<td>13.10</td>
</tr>
<tr>
<td>12</td>
<td>Pentosan, %</td>
<td>15.3</td>
<td>14.57</td>
<td>16.04</td>
</tr>
</tbody>
</table>
MORPHOLOGY OF JUTE
The cross section of jute is illustrated in figs 4, 5. The outer layers (sheath) are of bast and the fiber from which is used as cordage etc. after retting. The central most core portion is filled with parenchyma tissue, which is termed as pith. The woody tissue located between pith and bast. The fibers from this woody tissue are short and are normally discarded as waste or used as domestic fuel.

The jute fibers have different dimensions based on the tissue source. The fibers from the bast are long with thick fiber walls. Whereas the fibers from core (wood) are short and relatively thin walled. The average length of the whole jute fiber is 1.01 mm and average width is 18.4 µm.

<table>
<thead>
<tr>
<th>Fig 4. Cross section of Jute stem</th>
<th>Fig 5. Magnified view of cross section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig 6. Magnified view of bast fibers</td>
<td>Fig 7. Bast fibers in sectional view</td>
</tr>
</tbody>
</table>

The diagnostic feature of the jute bast fiber is the irregular width of the broad and well defined lumen. Sometimes the lumen closes up and is entirely missing for a short distance. The individual fiber is cylindrical with little variation in diameter. The fiber walls are thick and generally smooth (fig 6, 7), having more or less numerous nodes and cross markings depending upon the mechanical they have received. The fiber ends are slender and pointed. The cross section of the fiber is of polygonal shape with sharply defined angles and a round or oval lumen (fig. 7). The comparative fiber dimensions and properties are recorded in table 7 and fig. 8 – 13 for Whole jute, Central core wood (stick) and bast fibers (skin).
Table 7 Comparative fiber dimensions and properties of Jute fibers*

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Dimensions</th>
<th>Unit</th>
<th>Whole Jute</th>
<th>Core Wood</th>
<th>Bast Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mean Fiber Length</td>
<td>mm</td>
<td>1.389</td>
<td>0.687</td>
<td>1.953</td>
</tr>
<tr>
<td></td>
<td>(Weight weighted)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(L = 0.20 – 5.0mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Mean Fiber width</td>
<td>µm</td>
<td>20.1</td>
<td>21.9</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>(w= 7 – 35)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Fiber curl index</td>
<td>-</td>
<td>0.077</td>
<td>0.033</td>
<td>0.114</td>
</tr>
<tr>
<td></td>
<td>(Weight weighted)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(L = 0.50 – 5.0mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Fiber kink index</td>
<td>(1/mm)</td>
<td>0.70</td>
<td>0.44</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>(L = 0.50 – 5.0mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.a</td>
<td>Kink index</td>
<td>(1/mm)</td>
<td>0.70</td>
<td>0.44</td>
<td>1.05</td>
</tr>
<tr>
<td>4.b</td>
<td>Total kink angle</td>
<td>degrees</td>
<td>14.23</td>
<td>5.35</td>
<td>30.90</td>
</tr>
<tr>
<td>4.c</td>
<td>Kinks per mm</td>
<td>(1/mm)</td>
<td>0.44</td>
<td>0.25</td>
<td>0.54</td>
</tr>
<tr>
<td>5.</td>
<td>Fines (L = 0.01 – 0.20 mmm)</td>
<td>%</td>
<td>32.07</td>
<td>33.58</td>
<td>20.87</td>
</tr>
<tr>
<td>5.a</td>
<td>Arithmetic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.b</td>
<td>Length weighted</td>
<td>5</td>
<td>5.10</td>
<td>6.86</td>
<td>1.56</td>
</tr>
</tbody>
</table>

* For the detailed Fiber Quality Analyser data, please is pages from 30 to 41.
<table>
<thead>
<tr>
<th>Fig. 8 Whole Jute Pulp</th>
<th>Fig. 9 Mag. View of Whole Jute Pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 10 Jute Core wood Pulp</td>
<td>Fig. 11 Mag. View of Jute Core wood Pulp</td>
</tr>
<tr>
<td>Fig. 12 Jute bast Pulp</td>
<td>Fig. 13 Mag. View of Jute bast Pulp</td>
</tr>
</tbody>
</table>
LABORATORY PULPING STUDIES
OPTIMISATION OF SODA AND SODA AQ PULPING OF JUTE

Optimization experiments were initially carried out using Soda as the cooking chemical. The chemical requirement found to be on higher side, therefore the experiments extended to additive pulping using Soda-Aq (table 8). The bleachable grade pulp with around 18 kappa could be produced by adding 0.05% of anthraquinone to 24% of Soda dose.

Table 8 Soda and Soda-Aq pulping of Jute

<table>
<thead>
<tr>
<th>S,N</th>
<th>Particulars</th>
<th>Soda</th>
<th>Soda-Aq</th>
<th>Soda</th>
<th>Soda-Aq</th>
<th>Soda</th>
<th>Soda-Aq</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooking chemical as NaOH, %</td>
<td>20</td>
<td>20</td>
<td>24</td>
<td>24</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>Anthraquinone, %</td>
<td>0.00</td>
<td>0.05</td>
<td>0.00</td>
<td>0.05</td>
<td>0.00</td>
<td>0.05</td>
</tr>
<tr>
<td>3</td>
<td>Unscreened yield, %</td>
<td>55.5</td>
<td>50.4</td>
<td>51.9</td>
<td>50.7</td>
<td>47.9</td>
<td>48.9</td>
</tr>
<tr>
<td>4</td>
<td>Screened rejects, %</td>
<td>10.9</td>
<td>0.4</td>
<td>3.5</td>
<td>0.2</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>5</td>
<td>Kappa number</td>
<td>56.7</td>
<td>25.9</td>
<td>36.7</td>
<td><strong>18.4</strong></td>
<td>21.5</td>
<td>14.9</td>
</tr>
<tr>
<td>6</td>
<td>Black liquor analysis:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>11.0</td>
<td>11.2</td>
<td>11.8</td>
<td>11.9</td>
<td>11.9</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>RAA, gpl</td>
<td>1.6</td>
<td>2.4</td>
<td>4.2</td>
<td>5.76</td>
<td>7.3</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>Total solids, % (w/w)</td>
<td>10.5</td>
<td>12.0</td>
<td>12.6</td>
<td>12.8</td>
<td>12.8</td>
<td>13.2</td>
</tr>
</tbody>
</table>
OPTIMISATION OF KRAFT PULPING OF JUTE

Optimisation experiments for kraft pulping were carried out for jute and the results are furnished in table 9. The Sulphidity of the white liquor was maintained at 19 to 20 keeping the Asian countries like India, Bangladesh and China in view. Bleachable grade pulp with a kappa around 20 could be produced by a chemical charge of 16% as Na₂O.

Table 9 Kraft Pulping of jute

<table>
<thead>
<tr>
<th>S.L</th>
<th>Particulars</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cooking chemical dose as Na₂O</td>
<td>16 %</td>
<td>18%</td>
<td>20%</td>
</tr>
<tr>
<td>2.</td>
<td>Sulphidity,%</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>Unscreened yield, %</td>
<td>49.3</td>
<td>48.1</td>
<td>47.2</td>
</tr>
<tr>
<td>4</td>
<td>Screened rejects, %</td>
<td>1.8</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>5</td>
<td>Kappa number</td>
<td>20.7</td>
<td>17.2</td>
<td>15.7</td>
</tr>
<tr>
<td>6</td>
<td>Black liquor analysis:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) pH</td>
<td>10.8</td>
<td>11.1</td>
<td>11.6</td>
</tr>
<tr>
<td></td>
<td>b) RAA, gps</td>
<td>1.4</td>
<td>2.6</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>c) Total solids, % (w/w)</td>
<td>12.9</td>
<td>13.4</td>
<td>18.5</td>
</tr>
</tbody>
</table>
BIO PULPING OF JUTE USING WHITE ROT FUNGAL STRAINS

Bio-pulping experiments were conducted on whole jute using CPPRI – 1 and IJSG screened strains, *Phanerochaete chrysosporium* and *Fomes lignosus*.

**Effect of fungal treatment on chemical composition of raw material:**

One of the main objective of the study was to determine the delignification efficiency of the fungus i.e loss of lignin with out / little cellulose loss corresponding to weight loss. The weight loss of the fungal treated raw material is 8.5% which includes mainly the lignin content and a little of cellulose content. From the results shown in Table-10, it is indicated that by fungal treatment there was reduction in Klason lignin content 4.2 % i.e from 18.1 to 13.9 % in fungal treated material correspondingly the $\alpha$-cellulose content is 42.3 % in treated material where as 46.4 % in untreated material i.e 4.1 % loss. The treatment period can be optimised for the less cellulose degradation. The increase in acid soluble lignin and the decrease in klason lignin content showed that the degradation and depolymerisation of lignin has taken place during the fungal treatment period. The 1% NaOH solubility of the fungal treated material is increased from 24.3 % of control to 29.0 % indicating that fungal treatment solubilised the raw material so that the amount and nature of the extracted material which includes tannins, kinos, colouring matter, some carbohydrate material and lignin increased significantly. The results showed the delignification efficieciency of the fungus CPPRI –1.

Chemical composition of the fungal treated raw materials with PC , FL showed no significant change in lignin and holocellulose contents when compared to control.
Table 10 Proximate Chemical analysis of raw material treated with CPPRI – 1 Strain:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Untreated raw material</th>
<th>CPPRI-1 Fungal treated raw material.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Weight loss of the raw material after fungal treatment, %</td>
<td>0.3</td>
<td>8.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Untreated raw material</th>
<th>Fungal (S2) treated raw material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before weight loss correction</td>
<td>After weight loss correction</td>
</tr>
<tr>
<td>2. Hot Water Solubility, %</td>
<td>5.57</td>
<td>7.39</td>
</tr>
<tr>
<td>3. 1% NaOH Solubility, %</td>
<td>24.26</td>
<td>28.95</td>
</tr>
<tr>
<td>4. Alcohol -Benzene Solubility, %</td>
<td>3.04</td>
<td>3.50</td>
</tr>
<tr>
<td>5. Klasson lignin (Acid insoluble lignin), %</td>
<td>18.09</td>
<td>15.12</td>
</tr>
<tr>
<td>6. Acid soluble lignin, %</td>
<td>1.08</td>
<td>1.28</td>
</tr>
<tr>
<td>7. Holo cellulose, %</td>
<td>78.37</td>
<td>77.56</td>
</tr>
<tr>
<td>8. α -- cellulose content, %</td>
<td>46.35</td>
<td>46.04</td>
</tr>
<tr>
<td>9. Pentosan content, %</td>
<td>11.26</td>
<td>12.36</td>
</tr>
<tr>
<td>10. Brightness of the raw material</td>
<td>23.33</td>
<td>27.20</td>
</tr>
<tr>
<td>11. Ash, %</td>
<td>3.48</td>
<td>3.52</td>
</tr>
</tbody>
</table>

Table – 11 Chemical characterization of fungal treated and untreated Jute

<table>
<thead>
<tr>
<th>S. no</th>
<th>Particulars</th>
<th>Original</th>
<th>Control</th>
<th>PC with IJO medium</th>
<th>PC with CSL</th>
<th>FL with IJO medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1% NaOH Solubility, %</td>
<td>27.64</td>
<td>26.14</td>
<td>32.18</td>
<td>33.15</td>
<td>30.44</td>
</tr>
<tr>
<td>2</td>
<td>Alcohol -Benzene Solubility, %</td>
<td>2.54</td>
<td>2.27</td>
<td>2.25</td>
<td>2.31</td>
<td>2.12</td>
</tr>
<tr>
<td>3</td>
<td>Klasson lignin (Acid insoluble lignin), %</td>
<td>19.00</td>
<td>20.00</td>
<td>19.52</td>
<td>20.33</td>
<td>20.00</td>
</tr>
<tr>
<td>4</td>
<td>Acid soluble lignin, %</td>
<td>1.03</td>
<td>0.94</td>
<td>1.4</td>
<td>1.61</td>
<td>1.34</td>
</tr>
<tr>
<td>5</td>
<td>Holo cellulose (ash corrected), %</td>
<td>75.52</td>
<td>76.61</td>
<td>72.65</td>
<td>71.00</td>
<td>74.60</td>
</tr>
<tr>
<td>6</td>
<td>α -- cellulose content, %</td>
<td>46.8</td>
<td>48.1</td>
<td>42.1</td>
<td>39.3</td>
<td>42.2</td>
</tr>
<tr>
<td>7</td>
<td>Pentosan content, %</td>
<td>17.52</td>
<td>19.25</td>
<td>17.00</td>
<td>18.68</td>
<td>20.18</td>
</tr>
<tr>
<td>8</td>
<td>Ash, %</td>
<td>2.26</td>
<td>2.25</td>
<td>2.65</td>
<td>3.00</td>
<td>2.63</td>
</tr>
</tbody>
</table>
Effect of fungal treatment on Pulping & bleaching of whole jute:

Results of the pulping and bleaching studies of the biotreated materials are tabulated in tables from 12 to 15. From the results shown in table – 12, it is clearly evident that there is three-unit improvement in unbleached brightness of the PC treated pulps compared to control i.e. Kappa number of fungal treated pulps showed slight reduction when compared to control. No significant change in black liquor characteristics of the fungal treated materials. The strength properties of the fungal treated unbleached pulps showed very little improvement or at par with the properties of the control pulps.

CEH bleaching of the fungal treated pulps showed encouraging results in terms of brightness improvement and also yellowness reduction. i.e. 1-2 unit brightness improvement and 1.5-2.5 unit yellowness reduction. Slight reduction in observed in AOX levels of the fungal treated pulp effluents compared to the control pulp effluents.

Biopulping of jute treated with Phanerochaete chrysosporium supplemented with CSL in the medium showed encouraging results in terms of delignification efficiency and also improvement of strength & optical properties showing the importance of the fungus and the treatment conditions for the success of biopulping.

Table – 12 Unbleached pulp characteristics of untreated and fungal treated raw materials

<table>
<thead>
<tr>
<th>S. No</th>
<th>Particulars</th>
<th>Unscreened yield, %</th>
<th>Screened yield, %</th>
<th>Kappa Number</th>
<th>Brightness, % ISO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Original raw material under A.D. conditions</td>
<td>50.97</td>
<td>50.87</td>
<td>17.17</td>
<td>30.1</td>
</tr>
<tr>
<td>2.</td>
<td>Control</td>
<td>44.57</td>
<td>44.31</td>
<td>15.3</td>
<td>31.0</td>
</tr>
<tr>
<td>3.</td>
<td>PC with IJO medium</td>
<td>44.62</td>
<td>43.64</td>
<td>15.7</td>
<td>31.9</td>
</tr>
<tr>
<td>4.</td>
<td>PC with CSL</td>
<td>36.62</td>
<td>36.56</td>
<td>14.4</td>
<td>33.3</td>
</tr>
<tr>
<td>5.</td>
<td>FL with IJO Medium</td>
<td>41.29</td>
<td>41.15</td>
<td>14.4</td>
<td>30.8</td>
</tr>
</tbody>
</table>
Table 13: Physico-chemical analysis of black liquors obtained on biopulping of jute

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Particular</th>
<th>pH at room temp.</th>
<th>Total Solids, % w/w</th>
<th>Residual Active Alkali as NaOH, g/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Original raw material</td>
<td>12.08</td>
<td>8.82</td>
<td>3.28</td>
</tr>
<tr>
<td>2.</td>
<td>Control</td>
<td>12.40</td>
<td>8.17</td>
<td>4.76</td>
</tr>
<tr>
<td>3.</td>
<td>PC with IJO medium</td>
<td>12.30</td>
<td>8.22</td>
<td>4.08</td>
</tr>
<tr>
<td>4.</td>
<td>PC with CSL</td>
<td>12.40</td>
<td>7.91</td>
<td>5.36</td>
</tr>
<tr>
<td>5.</td>
<td>FL with IJO Medium</td>
<td>12.40</td>
<td>7.75</td>
<td>3.28</td>
</tr>
</tbody>
</table>

Table -14: Strength properties of control & fungal treated whole jute unbleached pulp

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Particulars</th>
<th>Freeness, CSF (ml)</th>
<th>Burst index, k. Pa m²/g</th>
<th>Tensile index, Nm/g</th>
<th>Tear index, MNm²/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Original raw material</td>
<td>230</td>
<td>5.0</td>
<td>90.0</td>
<td>10.9</td>
</tr>
<tr>
<td>2.</td>
<td>Control</td>
<td>255</td>
<td>6.65</td>
<td>100.0</td>
<td>10.8</td>
</tr>
<tr>
<td>3.</td>
<td>PC with IJO medium</td>
<td>290</td>
<td>6.60</td>
<td>98.0</td>
<td>10.0</td>
</tr>
<tr>
<td>4.</td>
<td>PC with CSL</td>
<td>305</td>
<td>5.60</td>
<td>91.0</td>
<td>9.80</td>
</tr>
<tr>
<td>5.</td>
<td>FL with IJO Medium</td>
<td>315</td>
<td>4.8</td>
<td>82.0</td>
<td>10.7</td>
</tr>
</tbody>
</table>

Table 15: Results of CEH bleaching of fungal treated and untreated jute

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Particulars</th>
<th>Origin</th>
<th>Control</th>
<th>PC with IJO medium</th>
<th>PC with CSL</th>
<th>FL with IJO medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Bleaching conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Applied Cl₂</td>
<td>3.47</td>
<td>3.44</td>
<td>3.64</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>3.</td>
<td>Applied NaOH, %</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>4.</td>
<td>Applied hypo, %</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>5.</td>
<td>Characteristics of hypo bleached pulp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Final bleached pulp brightness %</td>
<td>81.5</td>
<td>81.2</td>
<td>82.6</td>
<td>83.5</td>
<td>81.3</td>
</tr>
<tr>
<td>7.</td>
<td>Brightness improvement, % ISO</td>
<td>-</td>
<td>-</td>
<td>1.4</td>
<td>2.3</td>
<td>-</td>
</tr>
<tr>
<td>8.</td>
<td>Bleached pulp yellowness, %</td>
<td>10.5</td>
<td>8.47</td>
<td>6.30</td>
<td>5.95</td>
<td>7.01</td>
</tr>
<tr>
<td>9.</td>
<td>Reduction in yellowness</td>
<td>-</td>
<td>-</td>
<td>2.17</td>
<td>2.52</td>
<td>1.46</td>
</tr>
<tr>
<td>10.</td>
<td>Bleach shrinkage, %</td>
<td>4.06</td>
<td>2.15</td>
<td>3.4</td>
<td>3.32</td>
<td>3.31</td>
</tr>
<tr>
<td>11.</td>
<td>Characteristics of bleach effluents</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>AOX, kg/tp</td>
<td>2.36</td>
<td>2.18</td>
<td>2.16</td>
<td>1.99</td>
<td>2.03</td>
</tr>
</tbody>
</table>
**Effect of fungal treatment on morphology of Jute chips**

The inoculated white rot fungal strains CPPRI-1, PC, FL, and CS grew very well on whole Jute in the bioreactors. Good growth was achieved even without addition of nutrients. The fungal treated chips appeared brighter than the control chips, which were clearly showed by the estimation of brightness of the raw material. The CPPRI-1 fungal treated & the Fig 14 & 15 shows untreated raw materials respectively. From the results shown in Table-2, it is clearly evident that there is improvement in brightness of untreated material after fungal treatment, which has been increased by 3.9 points i.e. from 23.3 to 27.2.

| Fig 14. Whole Jute after fungal treatment | Fig 15. Whole Jute Untreated (Control) |
Penetration and spread of P. chrysosporium

The growth of fungal mycelium is studied in the whole jute. The fungal mycelium is not seen in the control specimens (fig 16) but prominent mycelia strands are observed in the vessels of treated samples. Some of the vessels are completely plugged with the mycelia, which also contain thick walled spores (fig 17,18). The presence of mycelia is less in parenchyma tissue (fig 19). The concentration of mycelia is very high between the wood and bast layers.

<table>
<thead>
<tr>
<th>16. Cross section of control wood. Note the vessels are free of mycelium</th>
<th>17. Cross section of wood treated with P. chrysosporium. Note the spores in vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>18. Radial section of wood treated with P. chrysosporium. Note the mycelium in vessels</td>
<td>19. Radial section of wood treated with P. chrysosporium. Note the mycelium in parenchyma cells</td>
</tr>
</tbody>
</table>

Central Pulp & Paper Research Institute
Penetration and spread of *F. lignosus*

The growth of fungal mycelium is studied in the whole jute treated with *Fomes lignosus*. The fungal mycelium is not seen in the control specimens (fig.20) but prominent mycelia strands are observed in the vessels, (fig.21, 22). The appearance of mycelia is significant in parenchyma tissue (fig.23). The concentration of mycelia is very high between the wood and bast layers.

<table>
<thead>
<tr>
<th>20. Cross section of control wood. Note the vessels are free of mycelium</th>
<th>21. Cross section of wood treated with <em>F. lignosus</em>. Note the mycelium in vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>22. Radial section of wood treated with <em>F. lignosus</em>. Note the mycelium in vessels</td>
<td>23. Radial section of wood treated with <em>F. lignosus</em>. Note the mycelium in parenchyma</td>
</tr>
</tbody>
</table>
LABORATORY BLEACHING STUDIES
BLEACHING OF JUTE KRAFT AND SODA AQ PULPS

The pulp prepared by kraft and soda AQ process with kappa around 20 was taken for CEH bleaching. CEH bleaching was carried out in conventional conditions.

Table 16 Conditions for different stages of bleaching:

<table>
<thead>
<tr>
<th>Se.No.</th>
<th>Chlorination</th>
<th>Extraction</th>
<th>Hypo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Consistency, %</td>
<td>3.0</td>
<td>8.0</td>
</tr>
<tr>
<td>2.</td>
<td>Retention time, min</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>3.</td>
<td>Reaction temp, °C</td>
<td>Ambient</td>
<td>60</td>
</tr>
</tbody>
</table>

The chlorine dose to be applied on pulp was decided after the chlorine dose optimisation on 20 g OD pulp at different kappa factors. A chlorine dose 4% for kraft pulp and 3.9% for soda AQ was sufficient during chlorination (Table 17). Extraction stage followed by hypo (1.5%) was sufficient to raise brightness 79.5 % and 78.2% ISO respectively for kraft and soda AQ pulp.

Table 17 Bleaching of jute kraft and soda AQ pulp:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Stage</th>
<th>Parameters</th>
<th>Kraft</th>
<th>Soda AQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Unbleached pulp kappa</td>
<td>20.5</td>
<td>18.4</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>C-STAGE</td>
<td>Chlorine % (Factor 0.25)</td>
<td>4.0</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>Chlorine consumed, % as Cl₂</td>
<td>3.5</td>
<td>3.35</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>E-STAGE</td>
<td>Alkali applied, % as NaOH</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>End pH</td>
<td>12.8</td>
<td>12.8</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>H-STAGE</td>
<td>Hypo (Na ClO) applied, % as Cl₂</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Hypo consumed, %</td>
<td>1.25</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alkali applied, % as buffer</td>
<td>0.25</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>End pH</td>
<td>11.1</td>
<td>11.4</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Brightness, % ISO</td>
<td>79.5</td>
<td>78.2</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Bleached pulp yield</td>
<td>95.3</td>
<td>96.0</td>
<td></td>
</tr>
</tbody>
</table>
BIO-BLEACHING OF JUTE KRAFT PULPS

Effect of enzyme treatment on kraft jute pulps:
Various sets of experiments are conducted and finally the results of enzymatic pretreatment of kraft jute pulps are detailed in tables from 8 – 21.

Effect of enzyme treatment on pulp:

Kappa number of pulp:
The unbleached pulp characteristics showed that there is reduction in kappa number of unbleached kraft jute pulps after enzyme treatment which has been decreased by 1.0-1.5.

Pulp filtrates:
The filtrate after enzyme treatment was found to be more coloured as compared to control pulp samples. Lignin content of enzyme treated pulp filtrates showed extraction of higher amount of lignin nearly 0.2 kg/tp than control pulps. The chromophores release was also high i.e 1.0-2.0 kg/tp in enzyme treated pulp filtrates as against control pulp indicating the effectivity of the Xylanase enzyme for kraft jute pulps.

Impact on brightness of the pulp:
The main objective of enzymatic prebleaching is to improve the final brightness of the bleached pulp. Brightness of enzyme treated pulps showed higher brightness levels i.e 1.0-3.0 units with all evaluated bleach sequences compared to brightness levels of untreated pulps. Similar levels of brightness improvement of enzyme treated pulps with evaluated sequences CEH, C50/D50 EH C50/D50 E(p)H C50/D50 E(p)H indicated that the enzyme treated pulps can be subjected to a wide range of conventional bleach sequences.

Savings in bleach chemicals:
The other main objective of enzymatic prebleaching technology is to evaluate the response of xylanases as prebleaching agent to reduce the requirement of chlorine as bleaching chemical by maintaining targeted brightness levels. The results shown in the following tables indicated that there is a scope for reduction of chlorine demand of the enzyme treated pulps. The overall response of xylanases as prebleaching agents towards kraft jute pulps with a wide range of conventional bleach sequences looks very encouraging.
CEH Bleaching of whole Jute Kraft Pulp:

Table – 18 Enzyme Pretreatment Conditions

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC</td>
<td>Biopulp (Biocon)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Novo Nordisk)</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Enzyme Dose , % on OD pulp</td>
<td>-</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>2.</td>
<td>Pulp Consistency , %</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Temperature , °c</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>4.</td>
<td>Treatment time , hrs</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>5.</td>
<td>pH</td>
<td>8.2</td>
<td>8.3</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Table – 19 Effect of xylanase treatment on kraft Jute pulps

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC</td>
<td>Biopulp (Biocon)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Novo Nordisk)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Characteristics of unbleached pulp</td>
<td>20.12</td>
<td>19.08</td>
<td>19.2</td>
</tr>
<tr>
<td>1.</td>
<td>Kappa number</td>
<td>20.12</td>
<td>19.08</td>
<td>19.2</td>
</tr>
<tr>
<td>2.</td>
<td>Brightness , %</td>
<td>27.43</td>
<td>27.7</td>
<td>27.6</td>
</tr>
<tr>
<td></td>
<td>Characteristics of Water Extracts</td>
<td>8.4</td>
<td>8.7</td>
<td>8.7</td>
</tr>
<tr>
<td>3.</td>
<td>Colour , kg/tp</td>
<td>0.33</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Lignin , Kg/tp</td>
<td>0.3</td>
<td>0.54</td>
<td>2.86</td>
</tr>
</tbody>
</table>

Central Pulp & Paper Research Institute
### Table – 20 CEH bleaching of enzyme treated & untreated jute pulp

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pulpzyme HC</td>
<td>Biopulp (Novo Nordisk)</td>
</tr>
<tr>
<td>1.</td>
<td>Initial Pulp Kappa</td>
<td>21.2</td>
<td>21.2</td>
</tr>
<tr>
<td>2.</td>
<td>Kappa after enzyme treatment</td>
<td>20.12</td>
<td>19.08</td>
</tr>
<tr>
<td>3.</td>
<td>Brightness after enzyme treatment</td>
<td>27.43</td>
<td>27.7</td>
</tr>
<tr>
<td></td>
<td>Chlorination stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Chlorine added, %</td>
<td>4.78</td>
<td>4.78</td>
</tr>
<tr>
<td>5.</td>
<td>Residual chlorine, %</td>
<td>0.298</td>
<td>0.229</td>
</tr>
<tr>
<td>6.</td>
<td>Chlorine consumption, %</td>
<td>93.8</td>
<td>95.2</td>
</tr>
<tr>
<td></td>
<td>Extraction stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Alkali added, %</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>8.</td>
<td>CE stage Kappa</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td>9.</td>
<td>Brightness, %ISO</td>
<td>48.48</td>
<td>50.11</td>
</tr>
<tr>
<td>10.</td>
<td>Viscosity, cm³/g</td>
<td>620</td>
<td>657</td>
</tr>
<tr>
<td></td>
<td>Hypo stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Hypo added, %</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>12.</td>
<td>Brightness</td>
<td>81.08</td>
<td>81.58</td>
</tr>
<tr>
<td>13.</td>
<td>Brightness improvement, %</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>14.</td>
<td>Viscosity cm³/g</td>
<td>422</td>
<td>397</td>
</tr>
</tbody>
</table>

### CEH Bleaching of Whole Jute Kraft Pulp After Chlorine Optimization

### Table – 21 Enzyme Pretreatment Conditions

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pulpzyme HC (Novo Nordisk)</td>
<td>Biopulp (Biocon)</td>
</tr>
<tr>
<td>1.</td>
<td>Enzyme Dose, % on OD pulp</td>
<td>-</td>
<td>0.06</td>
</tr>
<tr>
<td>2.</td>
<td>Pulp Consistency, %</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Temperature, °C</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>4.</td>
<td>Treatment time, hrs</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>5.</td>
<td>pH</td>
<td>8.2</td>
<td>8.3</td>
</tr>
</tbody>
</table>
Table – 22 Effect of xylanase treatment on kraft Jute pulps

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Novo Nordisk)</td>
</tr>
<tr>
<td>1.</td>
<td>Kappa number</td>
<td>20.12</td>
<td>19.08</td>
</tr>
<tr>
<td>2.</td>
<td>Brightness , % ISO</td>
<td>27.43</td>
<td>27.7</td>
</tr>
</tbody>
</table>

**Characteristics of unbleached pulp**

**Characteristics of Water Extracts**

| 3.    | Colour , kg/tp               | 4.88             | 7.6                  | 6.2               |
| 4.    | Lignin , Kg/tp               | 0.28             | 0.45                 | 0.51              |
| 5.    | Xylose Sugars , Kg/tp        | 1.5              | 1.7                  | 6.8               |

Table – 23 CEH Bleaching of whole Jute Kraft Pulp After Chlorine Optimization

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Novo Nordisk)</td>
</tr>
<tr>
<td>1.</td>
<td>Initial Pulp Kappa</td>
<td>21.2</td>
<td>21.2</td>
</tr>
<tr>
<td>2.</td>
<td>Kappa after enzyme treatment</td>
<td>20.12</td>
<td>19.08</td>
</tr>
<tr>
<td>3.</td>
<td>Brightness after enzyme</td>
<td>27.43</td>
<td>27.7</td>
</tr>
<tr>
<td></td>
<td>treatment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Chlorination stage**

| 4.    | Chlorine added,%            | 3.7              | 3.7                  | 3.4               |
| 5.    | Residual chlorine            | 0.034            | 0.011                | 0.011             |
| 6.    | Consumption, %              | 99.08            | 99.7                 | 99.7              |

**Extraction stage**

| 7.    | Alkali added, %             | 2.0              | 2.0                  | 2.0               |
| 8.    | Hypo added,%                | 1.5              | 1.5                  | 1.5               |
| 9.    | Brightness, % ISO           | 83.11            | 83.36                | 82.40             |
| 10.   | Brightness improvement, %   | -                | 0.2                  | 0.4               |
C E H Bleaching of Jute Kraft Pulp
(Increased retention time during enzyme treatment)

Table – 24 Enzyme Pretreatment Conditions

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC (Novo Nordisk)</td>
<td>Biopulp (Biocon)</td>
</tr>
<tr>
<td>1.</td>
<td>Enzyme Dose, % on OD pulp</td>
<td>-</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>2.</td>
<td>Pulp Consistency, %</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Temperature, °C</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>4.</td>
<td>Treatment time, hrs</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>5.</td>
<td>pH</td>
<td>8.2</td>
<td>8.3</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Table – 25 Effect of xylanase treatment on kraft Jute pulps

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC (Novo Nordisk)</td>
<td>Biopulp (Biocon)</td>
</tr>
<tr>
<td>1.</td>
<td>Characteristics of unbleached pulp</td>
<td></td>
<td>19.33</td>
<td>18.66</td>
</tr>
<tr>
<td>2.</td>
<td>Characteristics of Water Extracts</td>
<td></td>
<td>27.02</td>
<td>27.33</td>
</tr>
<tr>
<td>3.</td>
<td>Colour, Kg/tp</td>
<td>9.1</td>
<td>9.8</td>
<td>10.8</td>
</tr>
<tr>
<td>4.</td>
<td>Lignin, Kg/tp</td>
<td>0.58</td>
<td>0.61</td>
<td>0.71</td>
</tr>
<tr>
<td>5.</td>
<td>Xylose Sugars, Kg/tp</td>
<td>--</td>
<td>2.8</td>
<td>1.71</td>
</tr>
</tbody>
</table>
Table – 26  CEH Bleaching of whole Jute Kraft Pulp

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC (Novo Nordisk)</td>
</tr>
<tr>
<td>1.</td>
<td>Initial Pulp Kappa</td>
<td>21.2</td>
<td>21.2</td>
</tr>
<tr>
<td>2.</td>
<td>Kappa after enzyme treatment</td>
<td>19.33</td>
<td>18.66</td>
</tr>
<tr>
<td>3.</td>
<td>Brightness after enzyme treatment</td>
<td>27.02</td>
<td>27.33</td>
</tr>
<tr>
<td></td>
<td>Chlorination stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Chlorine added, %</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Extraction stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Alkali added, %</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>6.</td>
<td>CE stage Kappa</td>
<td>2.86</td>
<td>2.51</td>
</tr>
<tr>
<td>7.</td>
<td>Brightness, %ISO</td>
<td>47.34</td>
<td>50.78</td>
</tr>
<tr>
<td>8.</td>
<td>Viscosity, cm³/g</td>
<td>767</td>
<td>703</td>
</tr>
<tr>
<td></td>
<td>Hypo stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Hypo added,%</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>10.</td>
<td>Brightness</td>
<td>81.41</td>
<td>83.69</td>
</tr>
<tr>
<td>11.</td>
<td>Brightness improvement, %</td>
<td>-</td>
<td>2.3</td>
</tr>
<tr>
<td>12.</td>
<td>Viscosity cm³/g</td>
<td>451</td>
<td>452</td>
</tr>
</tbody>
</table>
C50/D50EH Bleaching of Whole Jute enzyme treated Kraft Pulps

Table – 27 Enzyme Pretreatment Conditions

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Novo Nordisk)</td>
</tr>
<tr>
<td>1.</td>
<td>Enzyme Dose, % on OD pulp</td>
<td>-</td>
<td>0.06</td>
</tr>
<tr>
<td>2.</td>
<td>Pulp Consistency, %</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Temperature, °c</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>4.</td>
<td>Treatment time, hrs</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>5.</td>
<td>pH</td>
<td>8.2</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Table – 28 C50/D50EH Bleaching of enzyme treated & untreated Jute Kraft Pulp

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Novo Nordisk)</td>
</tr>
<tr>
<td>1.</td>
<td>Bleaching sequence</td>
<td>C/DEH</td>
<td>C/DEH</td>
</tr>
<tr>
<td>2.</td>
<td>Initial Pulp Kappa</td>
<td>21.2</td>
<td>21.2</td>
</tr>
<tr>
<td>3.</td>
<td>Kappa after enzyme treatment</td>
<td>19.6</td>
<td>18.5</td>
</tr>
<tr>
<td>4.</td>
<td>Brightness after enzyme treatment</td>
<td>27.8</td>
<td>27.2</td>
</tr>
<tr>
<td>5.</td>
<td>Chlorination stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Chlorine added,%</td>
<td>2.8</td>
<td>2.75</td>
</tr>
<tr>
<td>7.</td>
<td>Dioxide added as avl. Cl2</td>
<td>2.8</td>
<td>2.75</td>
</tr>
<tr>
<td>8.</td>
<td>Extraction stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Alkali added, %</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>10.</td>
<td>Peroxide added,%</td>
<td>-</td>
<td>--</td>
</tr>
<tr>
<td>11.</td>
<td>CE stage Kappa</td>
<td>2.65</td>
<td>2.22</td>
</tr>
<tr>
<td>12.</td>
<td>Brightness, %ISO</td>
<td>53.8</td>
<td>56.6</td>
</tr>
<tr>
<td>13.</td>
<td>Hypo stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Hypo added,%</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>12.</td>
<td>Brightness</td>
<td>82.0</td>
<td>83.5</td>
</tr>
<tr>
<td>13.</td>
<td>Brightness improvement, %</td>
<td>-</td>
<td>1.5</td>
</tr>
</tbody>
</table>
C50/D50E(p)H Bleaching of enzyme treated whole Jute Kraft Pulp

Table – 29 Enzyme Pretreatment Conditions

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC (Novo Nordisk)</td>
</tr>
<tr>
<td>1.</td>
<td>Enzyme Dose, % on OD pulp</td>
<td>-</td>
<td>0.07</td>
</tr>
<tr>
<td>2.</td>
<td>Pulp Consistency, %</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Temperature, °C</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>4.</td>
<td>Treatment time, hrs</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>5.</td>
<td>pH</td>
<td>8.2</td>
<td>8.3</td>
</tr>
</tbody>
</table>

Table – 30 Effect of xylanase treatment on kraft Jute pulps

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulpzyme HC (Novo Nordisk)</td>
</tr>
<tr>
<td>1.</td>
<td>Kappa number</td>
<td>19.6</td>
<td>18.5</td>
</tr>
<tr>
<td>2.</td>
<td>Brightness, %</td>
<td>27.8</td>
<td>27.2</td>
</tr>
<tr>
<td>3.</td>
<td>Colour, kg/tp</td>
<td>6.15</td>
<td>7.02</td>
</tr>
<tr>
<td>4.</td>
<td>Lignin, Kg/tp</td>
<td>0.39</td>
<td>0.48</td>
</tr>
<tr>
<td>5.</td>
<td>Xylose Sugars, Kg/tp</td>
<td>1.58</td>
<td>2.25</td>
</tr>
</tbody>
</table>
### Table – 31 C50/D50E(p)H Bleaching of enzyme treated & untreated whole Jute Kraft Pulp

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>Control</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pulpzyme HC (Novo Nordisk)</td>
<td>Biopulp (Biocon)</td>
</tr>
<tr>
<td></td>
<td>Bleaching sequence</td>
<td>C/DEpH</td>
<td>C/DEpH</td>
</tr>
<tr>
<td>1.</td>
<td>Initial Pulp Kappa</td>
<td>21.2</td>
<td>21.2</td>
</tr>
<tr>
<td>2.</td>
<td>Kappa after enzyme treatment</td>
<td>19.6</td>
<td>18.5</td>
</tr>
<tr>
<td>3.</td>
<td>Brightness after enzyme treatment</td>
<td>27.8</td>
<td>27.2</td>
</tr>
<tr>
<td></td>
<td>Chlorination stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Chlorine added, %</td>
<td>2.8</td>
<td>2.75</td>
</tr>
<tr>
<td>5.</td>
<td>Dioxide added as avl. Cl2</td>
<td>2.8</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>Extraction stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Alkali added, %</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7.</td>
<td>Peroxide added,%</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>8.</td>
<td>CE stage Kappa</td>
<td>2.29</td>
<td>1.64</td>
</tr>
<tr>
<td>9.</td>
<td>Brightness, %ISO</td>
<td>69.7</td>
<td>71.7</td>
</tr>
<tr>
<td>10.</td>
<td>Viscosity, cm3/g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Hypo added, %</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>12.</td>
<td>Brightness</td>
<td>83.0</td>
<td>85.0</td>
</tr>
<tr>
<td>13.</td>
<td>Brightness improvement , %</td>
<td>-</td>
<td>2.0</td>
</tr>
</tbody>
</table>

### C50/D50E(op)H Bleaching of whole Jute Kraft Pulp

### Table –32 Enzyme Pretreatment Conditions

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Enzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pulpzyme HC (Novo Nordisk)</td>
</tr>
<tr>
<td>1.</td>
<td>Enzyme Dose, % on OD pulp</td>
<td>0.07</td>
</tr>
<tr>
<td>2.</td>
<td>Pulp Consistency, %</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Temperature, ºc</td>
<td>50</td>
</tr>
<tr>
<td>4.</td>
<td>Treatment time, hrs</td>
<td>2.0</td>
</tr>
<tr>
<td>5.</td>
<td>pH</td>
<td>8.3</td>
</tr>
</tbody>
</table>
### Table – 33 C50/D50 E(op) H Bleaching of enzyme treated & untreated Jute Kraft Pulp

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>Control</th>
<th>Pulpzyme HC (Novo Nordisk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Bleaching sequence</td>
<td>C/DE (op)H</td>
<td>C/DE(op)H</td>
</tr>
<tr>
<td>2.</td>
<td>Initial Pulp Kappa</td>
<td>21.2</td>
<td>21.2</td>
</tr>
<tr>
<td>3.</td>
<td>Kappa after enzyme treatment</td>
<td>19.6</td>
<td>18.5</td>
</tr>
<tr>
<td>4.</td>
<td>Brightness after enzyme treatment</td>
<td>27.8</td>
<td>27.2</td>
</tr>
<tr>
<td></td>
<td><strong>Chlorination stage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Chlorine added, %</td>
<td>2.8</td>
<td>2.75</td>
</tr>
<tr>
<td>6.</td>
<td>Dioxide added as avl. Cl2</td>
<td>2.8</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td><strong>Extraction stage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Alkali added, %</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>8.</td>
<td>Peroxide added, %</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>9.</td>
<td>Oxygen added, kg</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>10.</td>
<td>CE stage Kappa</td>
<td>1.39</td>
<td>1.32</td>
</tr>
<tr>
<td>11.</td>
<td>Brightness, %ISO</td>
<td>73.1</td>
<td>72.1</td>
</tr>
<tr>
<td></td>
<td><strong>Hypo stage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Hypo added, %</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>13.</td>
<td>Brightness</td>
<td>86</td>
<td>87</td>
</tr>
<tr>
<td>14.</td>
<td>Brightness improvement, %</td>
<td>-</td>
<td><strong>1.0</strong></td>
</tr>
</tbody>
</table>
EVALUATION OF LABORATORY PULPS
UNIDO-IJSG Project Report

STRENGTH PROPERTIES OF JUTE PULPS

Evaluation of unbleached jute pulps:

The physical strength properties of jute unbleached kraft pulp and soda Aq were carried out in laboratory PFI mill at 500, 1000, 2000 and 3000 revolutions are given in Table 34. The results indicate that there is substantial improvement in burst index and tensile index in unbleached kraft pulp compared to unbleached soda Aq pulp. However, the unbleached kraft pulp has lower strength properties as compared to unbleached soda Aq pulp.

Table 34 Strength Properties of Jute Unbleached Kraft and Soda Aq Pulp

<table>
<thead>
<tr>
<th>S.No.</th>
<th>PFI (rev)</th>
<th>Freeness ml,CSF</th>
<th>Apparent Density g/cm³</th>
<th>Burst Index KPa m²/g</th>
<th>Tensile Index Nm/g</th>
<th>Tear Index mN m²/g</th>
<th>Fold Kohler Molin (log)</th>
<th>Porosity Bendtsen (ml/min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNBLEACHED SODA AQ</td>
<td>1</td>
<td>0</td>
<td>610</td>
<td>0.51</td>
<td>1.10</td>
<td>21.0</td>
<td>8.10</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1000</td>
<td>400</td>
<td>0.64</td>
<td>4.00</td>
<td>54.5</td>
<td>12.50</td>
<td>2.55</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2000</td>
<td>300</td>
<td>0.66</td>
<td>4.10</td>
<td>57.5</td>
<td>16.00</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3000</td>
<td>250</td>
<td>0.71</td>
<td>4.80</td>
<td>69.5</td>
<td>14.10</td>
<td>3.38</td>
</tr>
<tr>
<td>UNBLEACHED KRAFT</td>
<td>5</td>
<td>0</td>
<td>480</td>
<td>0.66</td>
<td>3.0</td>
<td>53.5</td>
<td>11.0</td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>500</td>
<td>335</td>
<td>0.72</td>
<td>5.25</td>
<td>83.0</td>
<td>10.1</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1000</td>
<td>290</td>
<td>0.75</td>
<td>5.70</td>
<td>105.0</td>
<td>9.0</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2000</td>
<td>215</td>
<td>0.80</td>
<td>6.50</td>
<td>116.0</td>
<td>8.50</td>
<td>2.68</td>
</tr>
</tbody>
</table>
Evaluation of bleached jute pulps:

The physical strength properties of jute bleached kraft pulp and soda Aq were carried out in laboratory PFI mill at 500, 1000 and 2000 revolutions are given in Table 35. The results indicate that there is substantial improvement in burst index, tear index and tensile index in bleached kraft pulp compared to unbleached soda Aq pulp.

<table>
<thead>
<tr>
<th>Pulp</th>
<th>PFI (rev)</th>
<th>Freeness ml,CSF</th>
<th>Apparent Density g/cm³</th>
<th>Burst Index KPa/m²/g</th>
<th>Tensile Index Nm/g</th>
<th>Tear Index mN/m²/g</th>
<th>Fold Kohler Molin (log)</th>
<th>Porosity Bendtsen (ml/min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLEACHED SODA AQ</td>
<td>1</td>
<td>0</td>
<td>440</td>
<td>0.69</td>
<td>3.8</td>
<td>54.0</td>
<td>9.7</td>
<td>1.79</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>500</td>
<td>330</td>
<td>0.76</td>
<td>5.1</td>
<td>80.0</td>
<td>8.7</td>
<td>2.48</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1000</td>
<td>260</td>
<td>0.80</td>
<td>4.0</td>
<td>77.5</td>
<td>8.3</td>
<td>2.42</td>
</tr>
<tr>
<td>BLEACHED KRAFT</td>
<td>1</td>
<td>0</td>
<td>500</td>
<td>0.69</td>
<td>2.6</td>
<td>48.5</td>
<td>9.7</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>500</td>
<td>370</td>
<td>0.76</td>
<td>5.1</td>
<td>76.0</td>
<td>9.1</td>
<td>2.72</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1000</td>
<td>330</td>
<td>0.78</td>
<td>5.3</td>
<td>80.0</td>
<td>8.7</td>
<td>2.74</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2000</td>
<td>245</td>
<td>0.80</td>
<td>6.0</td>
<td>81.0</td>
<td>8.4</td>
<td>2.90</td>
</tr>
</tbody>
</table>
PILOT KRAFT PULPING TRIALS
PILOT PLANT KRAFT PULPING TRIALS ON JUTE
(TRIALS CONDUCTED ON 1ST & 10TH OF DECEMBER, 2003):

During the laboratory experimental pulping evaluations, we have studied Soda, Soad-Aq and Kraft pulping processes. The results were discussed in the review meeting conducted at IJSG in Dhaka, Bangladesh in December 2002, and it was decided that the pilot plant trials shall be carried on whole jute using Kraft pulping process.

The Thosa variety green jute was procured from Barrackpore area of Kolkata region in West Bengal and transported to CPPRI, Saharanpur for further processing (Fig. 24 – 29). Complete proximate analysis of whole jute was carried out and the results are furnished in Table 36. The ash content of the jute is significant and carries extraneous silica. The holo-cellulose component in the jute stalk is in acceptable range.

Table 36 Chemical Properties of Raw Material

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Particulars</th>
<th>Whole Jute</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ash content, %</td>
<td>2.5</td>
</tr>
<tr>
<td>2.</td>
<td>Cold Water Solubility, %</td>
<td>5.7</td>
</tr>
<tr>
<td>3.</td>
<td>Hot Water Solubility, %</td>
<td>6.2</td>
</tr>
<tr>
<td>4.</td>
<td>1/10 N NaOH Solubility, %</td>
<td>25.8</td>
</tr>
<tr>
<td>5</td>
<td>Alcohol Benzene, %</td>
<td>2.8</td>
</tr>
<tr>
<td>6</td>
<td>Klason Lignin, %</td>
<td>22.1</td>
</tr>
<tr>
<td>7</td>
<td>Acid soluble Lignin, %</td>
<td>0.87</td>
</tr>
<tr>
<td>8</td>
<td>Holo-cellulose, %</td>
<td>77.2</td>
</tr>
<tr>
<td>9</td>
<td>$\alpha$ - Cellulose, %</td>
<td>42.5</td>
</tr>
<tr>
<td>10</td>
<td>$\beta$ - Cellulose, %</td>
<td>20.0</td>
</tr>
<tr>
<td>11</td>
<td>$\chi$ - Cellulose, %</td>
<td>12.7</td>
</tr>
<tr>
<td>12</td>
<td>Pentosan, %</td>
<td>16.3</td>
</tr>
<tr>
<td>Fig. 24</td>
<td>Harvesting of green jute from the fields in Barrackpore, Kolkata, India</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Fig. 25</td>
<td>Harvesting of green jute from the fields in Barrackpore, Kolkata, India</td>
<td></td>
</tr>
<tr>
<td>Fig. 26</td>
<td>Bundling of green jute in the fields in Barrackpore, Kolkata, India</td>
<td></td>
</tr>
<tr>
<td>Fig. 27</td>
<td>Transportation of green jute for weighment in Barrackpore, Kolkata, India</td>
<td></td>
</tr>
<tr>
<td>Fig. 28</td>
<td>Transported and stacked jute at CPPRI, Saharanpur</td>
<td></td>
</tr>
<tr>
<td>Fig. 29</td>
<td>Chipping of green jute at CPPRI, Saharanpur</td>
<td></td>
</tr>
</tbody>
</table>
OPTIMISATION OF KRAFT PULPING OF JUTE IN LABORATORY

Optimisation experiments (Table 37) for kraft pulping were carried out for jute and the results are furnished in table 38. The Sulphidity of the white liquor was maintained at 20.6 keeping the Asian countries like India, Bangladesh and China in view. Bleachable grade pulp with a kappa around 20 could be produced by a chemical charge of 17% as Na₂O.

Table 37 Pulping conditions optimized in laboratory

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cooking conditions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Raw material taken in each bomb 200 gm. (B.D)</td>
</tr>
<tr>
<td>2.</td>
<td>Bath ratio (raw material to liquor ratio) 1:4</td>
</tr>
<tr>
<td>3.</td>
<td>Sulphidity of cooking liquor 20.6 %</td>
</tr>
<tr>
<td>4.</td>
<td>Cooking temperature 165 °C</td>
</tr>
<tr>
<td>5.</td>
<td>Cooking time 90 min.</td>
</tr>
<tr>
<td>6.</td>
<td>Cooking schedule:</td>
</tr>
<tr>
<td>7.</td>
<td>Ambient to 100 °C 30 min.</td>
</tr>
<tr>
<td>8.</td>
<td>100 °C to 165 °C 90 min.</td>
</tr>
<tr>
<td>9.</td>
<td>At 165 °C 90 min.</td>
</tr>
</tbody>
</table>

The laboratory optimisation trials indicate that the chemical requirement is 17% as Na₂O with which we could produce a pulp with about 20 kappa (table 2). The reject content is also low. Based on these laboratory results, we have carried out the pilot plant trials using the kraft pulping process.

Table 38 Laboratory optimisation of kraft pulping of jute:

<table>
<thead>
<tr>
<th>S.L</th>
<th>Particulars</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cooking chemical dose as Na₂O</td>
<td>15</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>2.</td>
<td>Sulphidity,%</td>
<td>20.6</td>
<td>20.6</td>
<td>20.6</td>
</tr>
<tr>
<td>3.</td>
<td>Unscreened yield, %</td>
<td>49.3</td>
<td>47.7</td>
<td>47.2</td>
</tr>
<tr>
<td>4.</td>
<td>Screened rejects, %</td>
<td>1.3</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>5.</td>
<td>Kappa number</td>
<td>26.0</td>
<td>23.0</td>
<td>20.0</td>
</tr>
<tr>
<td>6.</td>
<td>Black liquor analysis:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d)</td>
<td>pH</td>
<td>11.0</td>
<td>11.3</td>
<td>11.8</td>
</tr>
<tr>
<td>e)</td>
<td>RAA, gpl</td>
<td>2.9</td>
<td>3.5</td>
<td>5.3</td>
</tr>
<tr>
<td>f)</td>
<td>Total solids, % (w/w)</td>
<td>10.1</td>
<td>11.1</td>
<td>11.3</td>
</tr>
</tbody>
</table>
PILOT PLANT KRAFT PULPING OF JUTE

The pilot plant kraft pulping trials were conducted using 17.5% alkali dose, which is 0.5% higher than the requirement worked out in the laboratory. The cooking conditions applied for the two cooks in the pilot plant are as follows (Table 39). The visuals of pilot trials were also documented (Fig. 30 – 35) and the flowchart is placed in page 71.

Table 39 Pulping conditions adopted in Kraft pulping trials in Pilot Plant.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Cooking conditions:</th>
<th>Unit</th>
<th>1 DEC 2003</th>
<th>10 DEC 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>OD Raw material taken in the digester</td>
<td>kg</td>
<td>678.2</td>
<td>626.9</td>
</tr>
<tr>
<td>2.</td>
<td>Bath ratio</td>
<td>-</td>
<td>1:4</td>
<td>1:4</td>
</tr>
<tr>
<td>3.</td>
<td>Sulphidity of cooking liquor</td>
<td>%</td>
<td>20.0</td>
<td>20.0</td>
</tr>
<tr>
<td>4.</td>
<td>Cooking temperature</td>
<td>°C</td>
<td>165</td>
<td>165</td>
</tr>
<tr>
<td>5.</td>
<td>Cooking time</td>
<td>min</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Cooking schedule:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Ambient to 100 °C</td>
<td>min</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>7.</td>
<td>Degas pressure</td>
<td>Kg/cm²</td>
<td>At 2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>8.</td>
<td>100 °C to 165 °C</td>
<td>min</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>9.</td>
<td>At 165 °C</td>
<td>min</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>10.</td>
<td>Blow pressure</td>
<td>Kg/cm²</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Table 40 Kraft Pulping of jute in pilot plant on 1st and 12th December, 2003

<table>
<thead>
<tr>
<th>S.L</th>
<th>Particulars</th>
<th>Unit</th>
<th>1 DEC 2003</th>
<th>10 DEC 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cooking chemical dose as Na₂O</td>
<td>%</td>
<td>17.5</td>
<td>17.5</td>
</tr>
<tr>
<td>2.</td>
<td>Sulphidity</td>
<td>%</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>3.</td>
<td>Unscreened yield</td>
<td>%</td>
<td>47.3</td>
<td>47.0</td>
</tr>
<tr>
<td>4.</td>
<td>Screened rejects</td>
<td>%</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>5.</td>
<td>Kappa number</td>
<td>-</td>
<td>19.8</td>
<td>19.9</td>
</tr>
<tr>
<td>6.</td>
<td>Unbleached pulp brightness</td>
<td>% ISO</td>
<td>30.5</td>
<td>31.5</td>
</tr>
<tr>
<td>7.</td>
<td>Unbleached pulp viscosity</td>
<td>Cm³/g</td>
<td>849</td>
<td>810</td>
</tr>
</tbody>
</table>
### Table 41. Physical strength properties of unbleached pulp of pilot plant trial pulp

<table>
<thead>
<tr>
<th>Parameters</th>
<th>PFI (rev)</th>
<th>Freeness ml, CSF</th>
<th>Apparent Density g/cm³</th>
<th>Burst Index KPA/m²/g</th>
<th>Tensile Index Nm/g</th>
<th>Tear Index mN/m²/g</th>
<th>Fold Kohler Molin (log)</th>
<th>Porosity Bendtsen (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unbleached pulp</td>
<td>0</td>
<td>320</td>
<td>0.68</td>
<td>3.50</td>
<td>61.0</td>
<td>5.60</td>
<td>1.90</td>
<td>166</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>250</td>
<td>0.71</td>
<td>4.50</td>
<td>74.0</td>
<td>5.10</td>
<td>2.24</td>
<td>58.3</td>
</tr>
</tbody>
</table>

### Table 42. CEH, C/DEH, C/DEPH and C/DEopPH bleaching of pilot plant pulp.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Initial Pulp Kappa</td>
<td>19.8</td>
<td>19.8</td>
<td>19.8</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td>Chlorination stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Chlorine added as aval. Cl₂, %</td>
<td>4.35</td>
<td>2.17</td>
<td>2.17</td>
<td>2.17</td>
</tr>
<tr>
<td>3.</td>
<td>Dioxide added as avl. Cl₂</td>
<td>nil</td>
<td>2.17</td>
<td>2.17</td>
<td>2.17</td>
</tr>
<tr>
<td>4.</td>
<td>Residual chlorine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extraction stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Alkali added, %</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>6.</td>
<td>Peroxide added, %</td>
<td>nil</td>
<td>nil</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>7.</td>
<td>Oxygen applied, kg</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Hypo stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Hypo added, %</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>9.</td>
<td>Brightness, % ISO</td>
<td>82</td>
<td>82.7</td>
<td>83.4</td>
<td>84.0</td>
</tr>
<tr>
<td>PFI (rev)</td>
<td>Freeness ml,CSF</td>
<td>Apparent Density g/cm³</td>
<td>Burst Index KPa·m²/g</td>
<td>Tensile Index Nm/g</td>
<td>Tear Index mN·m²/g</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>------------------------</td>
<td>---------------------</td>
<td>-------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>CEH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>340</td>
<td>0.71</td>
<td>3.50</td>
<td>66.5</td>
<td>4.55</td>
</tr>
<tr>
<td>500</td>
<td>260</td>
<td>0.74</td>
<td>3.80</td>
<td>73.0</td>
<td>4.50</td>
</tr>
<tr>
<td>C/DEH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>360</td>
<td>0.70</td>
<td>3.10</td>
<td>58.5</td>
<td>5.75</td>
</tr>
<tr>
<td>500</td>
<td>290</td>
<td>0.73</td>
<td>4.30</td>
<td>78.0</td>
<td>5.00</td>
</tr>
<tr>
<td>C/DEpH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>360</td>
<td>0.63</td>
<td>3.00</td>
<td>58.5</td>
<td>5.50</td>
</tr>
<tr>
<td>500</td>
<td>280</td>
<td>0.67</td>
<td>3.80</td>
<td>73.0</td>
<td>4.60</td>
</tr>
<tr>
<td>C/DEopH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>350</td>
<td>0.67</td>
<td>2.90</td>
<td>49.0</td>
<td>5.40</td>
</tr>
<tr>
<td>500</td>
<td>250</td>
<td>0.73</td>
<td>3.70</td>
<td>63.0</td>
<td>4.65</td>
</tr>
</tbody>
</table>

Table 43 Physical strength properties of CEH, C/DEH, C/DEPH and C/DEOPH bleached pilot plant pulp
<table>
<thead>
<tr>
<th>Fig. 30 Pulley lifting of weighed jute chips to Pulping Digester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig 31. Pulping Digester filled with jute chips</td>
</tr>
<tr>
<td>Fig. 32 Addition of make-up water for maintaining bath ratio</td>
</tr>
<tr>
<td>Fig. 33 Addition of kraft liquor to the digester through pump from Liquor Tank</td>
</tr>
<tr>
<td>Fig. 34 Blowing of Kraft pulp at 5 kg pressure</td>
</tr>
<tr>
<td>Fig. 35 Pumping of Blown Kraft unbleached Pulp to Chest</td>
</tr>
<tr>
<td>Fig. 36 Washing of unbleached pulp(at arrow) Double Wire Belt Washer</td>
</tr>
</tbody>
</table>
BLEACHING OF JUTE KRAFT PULPS

ENZYMATIC PREBLEACHING OF JUTE PULP USING XYLANASE ENZYMES

To evaluate the response of xylanase enzymes as prebleaching agents towards the whole jute pulp, the enzymatic prebleaching experiments were carried out with the whole jute kraft pulp obtained from pilot plant scale trial of CPPRI.

Evaluation of the enzyme response on the pulp as prebleaching agent in order to
• Assess the gain in brightness of the pulp after final bleach stage without loosing the strength properties.

Experimental

Pulp Samples:
Unbleached screened pulp samples of whole jute kraft pulp.
  o Kappa number – 20.0
  o pH - 8.4

Enzymes:
1. Xylanase enzyme – 1 received from IJSG
2. Enzyme activity: 210 IU/ml
3. Commercial Xylanase Pulpzyme HC – from Novozymes

Enzyme treatment of the pulp:
Xylanase pretreatment of the jute pulp (500 gm OD) was carried out. Enzymes were added to the pulp after sufficient dilution & mixed properly by kneading mechanism. Conditions for enzyme treatment of pulp are shown in Table 44. Control was run parallel with maintaining all conditions except enzyme.
Bleaching of enzyme treated pulps:
Both the enzyme treated and untreated pulps were followed by conventional bleaching.
Process conditions employed for bleaching of pulps for various bleach sequences are given below.

Bleach sequences used:
1. CEH
2. CE(pH)
3. C/DEH
4. C/DE(pH)

Results & Discussion

Impact of xylanase treatment on pilot kraft pulps:
Studies on evaluation of two xylanases i.e Xylanase supplied by IJSG and Commercial enzyme, Pulpzyme HC showed that the biobleaching response of xylanases towards pilot kraft jute pulp is significant. Results showed in tables from 44 to 50 are found to be encouraging.
No significant yield loss after enzyme treatement. Brightness gain of the bleached pulps after treatment with IJSG enzyme is 2 - 3 % ISO and with Pulpzyme HC is 3 - 4 % ISO. IJSG supplied enzyme is active at 6.5 pH for which the pH of the original pulp 8.4 has to be adjusted to pH 6.5 with acid whereas the response of pulpzyme HC is good even at pH 8.4.

Table - 44 Enzyme Pretreatment Conditions

<table>
<thead>
<tr>
<th>S.No</th>
<th>Particulars</th>
<th>Control</th>
<th>Pulp treated with IJSG enzyme</th>
<th>Control</th>
<th>Pulp treated with pulpzyme</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH</td>
<td>6.5</td>
<td>6.5</td>
<td>8.4</td>
<td>8.4</td>
</tr>
<tr>
<td>2.</td>
<td>Enzyme dose, % / IU/g OD</td>
<td>-</td>
<td>2.0 IU</td>
<td>-</td>
<td>0.07 %</td>
</tr>
<tr>
<td>3.</td>
<td>Treatment time, (hrs)</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>4.</td>
<td>Temperature, °C</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>5.</td>
<td>Consistency of the pulp, %</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>6.</td>
<td>Yield, %</td>
<td>98.9</td>
<td>98.2</td>
<td>98.2</td>
<td>98.1</td>
</tr>
<tr>
<td>7.</td>
<td>Kappa Number</td>
<td>19.4</td>
<td>19.3</td>
<td>19.8</td>
<td>19.1</td>
</tr>
</tbody>
</table>
### Table 45: Effect of xylanase Treatment on jute pulp Bleached with CEH Sequence

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>pH 6.5</th>
<th>pH 8.4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>IJSG enzyme treated pulp</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorination stage (Kappa factor – 0.22)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Cl₂, % applied</td>
<td>4.27</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>Alkali Extraction (Ep) stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>NaOH, % applied</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3.</td>
<td>Kappa number</td>
<td>3.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Hypo stage – H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Hypo, % applied</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>5.</td>
<td>Final brightness of the pulp, % ISO</td>
<td>80.2</td>
<td>83.83</td>
</tr>
<tr>
<td>6.</td>
<td>Brightness improvement</td>
<td>-</td>
<td>3.6</td>
</tr>
</tbody>
</table>

### Table 46: Effect of xylanase Treatment on jute pulp Bleached With CE(p)H Sequence

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>pH 6.5</th>
<th>pH 8.4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>IJSG enzyme treated pulp</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorination stage (Kappa factor – 0.22)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Cl₂, % applied</td>
<td>4.27</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>Alkali Extraction (Ep) stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>NaOH, % applied</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3.</td>
<td>Peroxide, %</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>4.</td>
<td>Kappa number</td>
<td>2.7</td>
<td>2.5</td>
</tr>
<tr>
<td>Hypo stage – H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Hypo, % applied</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>6.</td>
<td>Final brightness of the pulp, % ISO</td>
<td>82.1</td>
<td>82.1</td>
</tr>
<tr>
<td>7.</td>
<td>Brightness improvement</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table: 47 Effect of xylanase Treatment on jute pulp Bleached with C50/D50EH

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>pH 6.5</th>
<th>pH 8.4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>IJSG enzyme treated pulp</td>
</tr>
<tr>
<td>1.</td>
<td>Total chlorine, % as available Cl₂</td>
<td>4.27</td>
<td>4.25</td>
</tr>
<tr>
<td>2.</td>
<td>Cl₂, % applied</td>
<td>2.14</td>
<td>2.13</td>
</tr>
<tr>
<td>3.</td>
<td>Dioxide % as chlorine</td>
<td>2.14</td>
<td>2.13</td>
</tr>
<tr>
<td>4.</td>
<td>NaOH, % applied</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>5.</td>
<td>Kappa number</td>
<td>5.6</td>
<td>5.1</td>
</tr>
<tr>
<td>6.</td>
<td>Hypo, % applied</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>7.</td>
<td>Final brightness of the pulp, % ISO</td>
<td>81.2</td>
<td>83.4</td>
</tr>
<tr>
<td>8.</td>
<td>Brightness improvement</td>
<td>-</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Table: 48 Effect of xylanase Treatment on jute pulp Bleached With C50/D50E(p)H

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>pH 6.5</th>
<th></th>
<th>pH 8.4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control</td>
<td>IJSG enzyme treated pulp</td>
<td>Control</td>
<td>Pulpzyme treated pulp</td>
</tr>
<tr>
<td>1.</td>
<td>Chlorination stage (Kappa factor – 0.22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Total chlorine, % as available Cl₂</td>
<td>4.27</td>
<td>4.25</td>
<td>4.36</td>
<td>4.21</td>
</tr>
<tr>
<td>3.</td>
<td>Cl₂, % as available chlorine</td>
<td>2.14</td>
<td>2.13</td>
<td>2.18</td>
<td>2.10</td>
</tr>
<tr>
<td>4.</td>
<td>Dioxide % as chlorine</td>
<td>2.14</td>
<td>2.13</td>
<td>2.18</td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td><strong>Alkali Extraction (p) stage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>NaOH, % applied</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>6.</td>
<td>Peroxide, %</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>7.</td>
<td>Kappa number</td>
<td>4.4</td>
<td>3.4</td>
<td>4.2</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td><strong>Hypo stage – H</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Hypo, % applied</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>9.</td>
<td>Final brightness of the pulp, % ISO</td>
<td>82.4</td>
<td>85.5</td>
<td>82.4</td>
<td>86.7</td>
</tr>
<tr>
<td>10.</td>
<td><strong>Brightness improvement</strong></td>
<td>--</td>
<td>3.1</td>
<td>-</td>
<td>4.3</td>
</tr>
</tbody>
</table>
Table 49 Effect of xylanase Treatment on jute pulp Bleached with C50/D50EH

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>pH 6.5 Control</th>
<th>pH 6.5 IJSG enzyme treated pulp</th>
<th>pH 8.4 Control</th>
<th>pH 8.4 Pulpzyme treated pulp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chlorination stage (Kappa factor – 0.22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Total chlorine, % as available Cl₂</td>
<td>4.27</td>
<td>4.25</td>
<td>4.18</td>
<td>4.20</td>
</tr>
<tr>
<td>2.</td>
<td>Cl₂, % applied</td>
<td>2.14</td>
<td>2.13</td>
<td>2.09</td>
<td>2.10</td>
</tr>
<tr>
<td>3.</td>
<td>Dioxide % as chlorine</td>
<td>2.14</td>
<td>2.13</td>
<td>2.09</td>
<td>2.10</td>
</tr>
<tr>
<td>4.</td>
<td>Chlorine consumed %</td>
<td>98.9</td>
<td>98.3</td>
<td>98.9</td>
<td>95.6</td>
</tr>
<tr>
<td></td>
<td>Alkali Extraction (Ep) stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>NaOH, % applied</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>6.</td>
<td>Kappa number</td>
<td>3.1</td>
<td>3.6</td>
<td>4.6</td>
<td>4.6</td>
</tr>
<tr>
<td>7.</td>
<td>Brightness, %ISO</td>
<td>49.0</td>
<td>52.6</td>
<td>54.0</td>
<td>54.4</td>
</tr>
<tr>
<td></td>
<td>Hypo stage – H</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Hypo, % applied</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>9.</td>
<td>Final brightness of the pulp, % ISO</td>
<td>81.2</td>
<td>83.1</td>
<td>81.6</td>
<td>85.1</td>
</tr>
<tr>
<td>10.</td>
<td>Brightness improvement</td>
<td>-</td>
<td>2.0</td>
<td>-</td>
<td>4.5</td>
</tr>
<tr>
<td>11.</td>
<td>Viscosity, cm³/g</td>
<td>500</td>
<td>618</td>
<td>503</td>
<td>661</td>
</tr>
</tbody>
</table>

Table 50 Physical strength properties of C/DEH, bleached pulp of pilot plant trial (after enzyme treatment)

<table>
<thead>
<tr>
<th></th>
<th>PFI (rev)</th>
<th>Freeness ml,CSF</th>
<th>Apparent Density g/cm³</th>
<th>Burst Index KPam²/g</th>
<th>Tensile Index Nm/g</th>
<th>Tear Index mNm²/g</th>
<th>Fold Kohler Molin(log)</th>
<th>Porosity Bendtsen (ml/min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0</td>
<td>345</td>
<td>0.70</td>
<td>3.10</td>
<td>51.5</td>
<td>5.00</td>
<td>1.70</td>
<td>149</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>235</td>
<td>0.76</td>
<td>4.20</td>
<td>71.0</td>
<td>4.30</td>
<td>1.90</td>
<td>45.8</td>
</tr>
<tr>
<td>C2</td>
<td>0</td>
<td>370</td>
<td>0.70</td>
<td>3.30</td>
<td>55.5</td>
<td>6.80</td>
<td>2.11</td>
<td>158</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>280</td>
<td>0.75</td>
<td>4.60</td>
<td>72.0</td>
<td>5.70</td>
<td>2.32</td>
<td>51.1</td>
</tr>
<tr>
<td>E1</td>
<td>0</td>
<td>360</td>
<td>0.72</td>
<td>3.80</td>
<td>58.1</td>
<td>6.10</td>
<td>2.09</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>230</td>
<td>0.77</td>
<td>4.90</td>
<td>77.0</td>
<td>5.30</td>
<td>2.39</td>
<td>38.4</td>
</tr>
<tr>
<td>E3</td>
<td>0</td>
<td>395</td>
<td>0.67</td>
<td>3.10</td>
<td>46.0</td>
<td>6.90</td>
<td>1.71</td>
<td>278</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>270</td>
<td>0.68</td>
<td>4.20</td>
<td>61.0</td>
<td>5.60</td>
<td>1.98</td>
<td>102</td>
</tr>
</tbody>
</table>

C1-Control at pH 8.0; C2-Control at pH 6.5; E1-IJSG enzyme treated pulp; E3-Pulpzyme treated pulp.

The biobleaching experiments conducted have shown highly promising results in terms of reduction in kappa number, bleach chemical demand and improvement in brightness of the pulp. The data generated on enzyme prebleaching of jute will provide new opportunities to adopt the technology as eco-friendly biotechnological application for papermaking from jute.
BLACK LIQUOR QUALITY
AND
TREATMENT OPTIONS
BLACK LIQUOR PROPERTIES

Kraft black liquor:

In order to obtain a representative black liquor quality as envisaged under the mill conditions, jute kraft black liquor was generated under the specified pulping conditions after taking into considerations the washing of the pulp. The black liquor obtained using the kraft process was studied for its suitability in the chemical recovery section. The black liquor characteristics analysed for studying its suitability in the recovery section are as follows:

**Total Solids**: From the viewpoint of processing of non-wood black liquors, solids level of \( \approx 12.6\% \) is quite satisfactory in the rotary tumbling digesters. However, further improvement in solids concentration would help in improving the steam economy in the train of evaporators (Table 51).

**Suspended Solids**: The S.S. level can be further improved by installing a melone filter while actually processing the black liquor at mill site (Table 51).

<table>
<thead>
<tr>
<th>S.No</th>
<th>Particulars</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Raw material</td>
<td>Whole jute</td>
</tr>
<tr>
<td>2.</td>
<td>Chemical charges on raw material basis, % as Na₂O</td>
<td>16.0</td>
</tr>
<tr>
<td>3.</td>
<td>Sulphidity on raw material basis, %</td>
<td>20</td>
</tr>
<tr>
<td>4.</td>
<td>Bath Ratio</td>
<td>1:4</td>
</tr>
<tr>
<td>5.</td>
<td>Time at top temperature, minutes</td>
<td>90</td>
</tr>
<tr>
<td>6.</td>
<td>Top temperature, ºC</td>
<td>165</td>
</tr>
<tr>
<td>7.</td>
<td>pH at 25ºC</td>
<td>11.13</td>
</tr>
<tr>
<td>8.</td>
<td>Total Solids, %</td>
<td>12.56</td>
</tr>
<tr>
<td>9.</td>
<td>Suspended Solids, g/l</td>
<td>0.471</td>
</tr>
<tr>
<td>10.</td>
<td>Residual active alkali, g/l as NaOH</td>
<td>1.55</td>
</tr>
<tr>
<td>11.</td>
<td>Total Alkali, g/l as NaOH</td>
<td>37.6</td>
</tr>
<tr>
<td>12.</td>
<td>Inorganic, % w/w as NaOH (Sulphated ash)</td>
<td>31.18</td>
</tr>
<tr>
<td>13.</td>
<td>Organics, % w/w (by difference)</td>
<td>68.82</td>
</tr>
<tr>
<td>14.</td>
<td>Lignin, % w/w</td>
<td>37.0</td>
</tr>
</tbody>
</table>

Table 51 Physico Chemical Properties of kraft black liquor
Residual Active Alkali:
RAA level is on the lower side, while studying the rheological behaviour of the jute kraft black liquor, the liquor was found to be quite stable. However, it is still recommended to maintain an active alkali level of at least 3.0 g/l as Na₂O (Table 51)

Organic / Inorganic Ratio: The inorganic content of nearly 31% is quite optimum, however, looking in to the wide variations in the total alkali level and Sulphated ash values, it seems quite prominent that inert material is noticeable in the fresh black liquor itself, which has not been recycled so far (Table 8).

Process and Non-Process Elements:
Compared to the Soda-AQ black liquor, which was studied in the previous quarter of this year, the carbon values are on the lower side and other inerts such as silica and potassium are on the higher side, which indicates processing of jute kraft black liquor is rather difficult in comparison to soda- AQ liquor (Table 52).

<table>
<thead>
<tr>
<th>S.No</th>
<th>Process &amp; Non-Process Elements:</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Carbon, % w/w as C</td>
<td>34.98</td>
</tr>
<tr>
<td>2.</td>
<td>Hydrogen, % w/w as H</td>
<td>4.25</td>
</tr>
<tr>
<td>3.</td>
<td>Nitrogen, % w/w as N</td>
<td>0.013</td>
</tr>
<tr>
<td>4.</td>
<td>Sodium, % w/w as Na</td>
<td>14.3</td>
</tr>
<tr>
<td>5.</td>
<td>Sulphur, % w/w as S</td>
<td>2.40</td>
</tr>
<tr>
<td>6.</td>
<td>Inerts, % w/w as R₂O₃</td>
<td>0.32</td>
</tr>
<tr>
<td>7.</td>
<td>Silica, % w/w as SiO₂</td>
<td>1.27</td>
</tr>
<tr>
<td>8.</td>
<td>Chlorides, % w/w as Cl</td>
<td>0.83</td>
</tr>
<tr>
<td>9.</td>
<td>Potassium, % w/w as K</td>
<td>0.68</td>
</tr>
<tr>
<td>10.</td>
<td>Calcium, % w/w as Ca</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Thermal & Swelling Characteristics:
Although, once again in comparison to soda-AQ black liquor, the thermal and swelling characteristics are on the inferior side, but still the kraft black liquor obtained can be easily processed in the chemical recovery (Table 53).
Rheological Properties:
Black liquor can be concentrated to a solids level of 70% without any liquor instability; and viscosity values are higher than in case of soda-AQ process.
It is therefore inferred that with steps of raw material cleaning, the jute black liquor obtained either by soda-AQ/kraft process is suitable for its processing in the chemical recovery section (Table 53)

### Table 53 Thermal & Rheological properties:

<table>
<thead>
<tr>
<th></th>
<th>Swelling volume ratio, ml/g</th>
<th>Gross Calrofic Value, Kcals/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity, mPa.S at</td>
<td>15</td>
<td>3299</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>S.No</td>
<td>80</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>99</td>
<td>4.46</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>178</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1778</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>631</td>
</tr>
</tbody>
</table>

On comparative basis, the performance of chemical recovery is expected to be better in case of black liquor obtained by Soda-Aq process in comparison to kraft process.

**Soda black liquor:**
Bleachable grade pulp of kappa 18.5 of whole jute was produced from 24% soda along with 0.05% of AQ. The spent liquor obtained by this cook was taken for detailed spent liquor analysis

**Observations on Processing of Jute Black Liquor in the Chemical Recovery Section:**
The jute black liquor obtained during jute pulping (Table 54) appears to be quite suitable for its processing in the chemical recovery section. The major criteria for suitability of any black liquor in the chemical recovery are from the point of view.
Table 54 Properties of Jute black liquor (Including washings)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Pulping Conditions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Raw material</td>
<td>Whole jute</td>
</tr>
<tr>
<td>2.</td>
<td>Chemical charge on raw material basis, %</td>
<td>20.0</td>
</tr>
<tr>
<td>3.</td>
<td>AQ on raw material basis, %</td>
<td>0.05</td>
</tr>
<tr>
<td>4.</td>
<td>Bath Ratio</td>
<td>1:4</td>
</tr>
<tr>
<td>5.</td>
<td>Time at top temperature, minutes</td>
<td>90</td>
</tr>
<tr>
<td>6.</td>
<td>Max. temperature, °C,</td>
<td>165</td>
</tr>
</tbody>
</table>

Total Solids Concentrations:
A solid level of 10.89% is just the optimum level, however a higher solids concentration will improve the steam economy.

Residual Active Alkali:
This seems to be sufficient looking into the stability of the black liquor at higher solids concentrations.

Organic/ Inorganic Ratio:
This value is optimum and with its proximity with the total alkali, it seems the dead load material is not significant, which is quite encouraging in processing the jute black liquor in the chemical recovery section (Table 55).

Table 55 Physico Chemical Properties:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH at 25°C</td>
<td>12.35</td>
</tr>
<tr>
<td>2.</td>
<td>Total Solids, % w/w</td>
<td>10.89</td>
</tr>
<tr>
<td>3.</td>
<td>Suspended solids, g/l</td>
<td>0.38</td>
</tr>
<tr>
<td>4.</td>
<td>Residual active alkali, g/l as Na₂O</td>
<td>2.79</td>
</tr>
<tr>
<td>5.</td>
<td>Total Alkali, g/l as NaOH</td>
<td>34.4</td>
</tr>
<tr>
<td>6.</td>
<td>Inorganics, % w/w as NaOH (Sulphated ash)</td>
<td>33.69</td>
</tr>
<tr>
<td>7.</td>
<td>Lignin, % w/w</td>
<td>45.45</td>
</tr>
</tbody>
</table>
Process & Non-Process Elements:
The higher carbon, negligible nitrogen, lower silica indicate its suitability in various evaporation, recovery boiler and causticization cycles. However, looking in to the values of potassium and chlorides, it is suggested that caution should be made to reduce its entry in the chemical recovery system (Table 56).

Table 56 Process & Non-Process Elements:

<table>
<thead>
<tr>
<th>No.</th>
<th>Element</th>
<th>% w/w as base</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carbon</td>
<td>C</td>
<td>38.14</td>
</tr>
<tr>
<td>2</td>
<td>Hydrogen</td>
<td>H</td>
<td>3.97</td>
</tr>
<tr>
<td>3</td>
<td>Nitrogen</td>
<td>N</td>
<td>nil</td>
</tr>
<tr>
<td>4</td>
<td>Sodium</td>
<td>Na</td>
<td>18.0</td>
</tr>
<tr>
<td>5</td>
<td>Sulphur</td>
<td>S</td>
<td>0.50</td>
</tr>
<tr>
<td>6</td>
<td>Inerts</td>
<td>R_2O_3</td>
<td>0.14</td>
</tr>
<tr>
<td>7</td>
<td>Silica</td>
<td>SiO_2</td>
<td>0.01</td>
</tr>
<tr>
<td>8</td>
<td>Chlorides</td>
<td>Cl</td>
<td>0.87</td>
</tr>
<tr>
<td>9</td>
<td>Potassium</td>
<td>K</td>
<td>0.5</td>
</tr>
<tr>
<td>10</td>
<td>Calcium</td>
<td>Ca</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Thermal and Rheological Properties:
The swelling volume ratio and the GCV values indicate good combustion behaviour of this black liquor and steam generation potential is also high. The viscosity values are reasonably lower in comparison to most other non-wood raw materials, except bamboo (Table 57).

Table 57 Thermal & Rheological Properties:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Total Solids Conc, % w/w</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90 °C</td>
<td>4.7</td>
<td>12.6</td>
<td>22</td>
<td>50</td>
<td>174</td>
<td>1072</td>
</tr>
<tr>
<td>2</td>
<td>98 °C</td>
<td>2.8</td>
<td>8.2</td>
<td>17.4</td>
<td>39</td>
<td>110</td>
<td>437</td>
</tr>
<tr>
<td>3</td>
<td>110 °C</td>
<td>2.0</td>
<td>3.5</td>
<td>6.5</td>
<td>31.6</td>
<td>83.2</td>
<td>331</td>
</tr>
</tbody>
</table>

It is therefore inferred that with few further modifications, jute black liquor can be easily subjected to the chemical recovery.
PRELIMINARY OPTIONS FOR BLACK LIQUOR MANAGEMENT – HANDLING OF JUTE BLACK LIQUOR

In absence of a chemical recovery system, mills are discharging valuable chemicals and at the same time the pollutitional problems are also getting aggravated. Today, with stringent legislations to pollution control, it is necessary for all mills to go either for installation of chemical recovery or treatment of effluents with heavily loaded organic and inorganic pollutants. The pollution load from a jute-based mill is expected to be around as follows (Table 58).

Table 58 Pollution load from a jute based mill without treatment

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameter</th>
<th>Pollution load, kg/tp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Chemical Oxygen Demand, kg/tp</td>
<td>1700</td>
</tr>
<tr>
<td>2.</td>
<td>Biochemical Oxygen Demand, kg/tp</td>
<td>485</td>
</tr>
<tr>
<td>3.</td>
<td>Color</td>
<td>1900</td>
</tr>
</tbody>
</table>

Looking into such high limits and comparing them with the laid down standards, it is quite clear that a suitable treatment option is given for effective handling and management of black liquors.

Table 59 Standard discharge norms from pulp & paper mill in an agro based mill*

<table>
<thead>
<tr>
<th>SL. No.</th>
<th>Parameter</th>
<th>mg/l</th>
<th>Kg/tp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Chemical Oxygen Demand</td>
<td>350</td>
<td>52.5</td>
</tr>
<tr>
<td>2.</td>
<td>Biochemical oxygen Demand</td>
<td>30</td>
<td>4.5</td>
</tr>
</tbody>
</table>

*Standard discharge norms based on Indian Standards.

However, size of the pulp mill is one of the important criteria in deciding the subsequent handling system for the black liquor in a pulp mill. The two options available before the mill for black liquor management include:
1. Setting up of a conventional chemical recovery based on Tomlinson process and incorporating recent advancements in recovery system:

The conventional chemical recovery is the best-suited option for handling of black liquor. For a mill of size above 50 tpd based on jute, the conventional / alternate chemical recovery is required to be an integral part of the system as jute requires comparatively higher chemical charge during pulping than most other non-wood raw materials. However, due to constraint of size / economy, the other available options from energy and environment view point for mill of size below 100 tpd include:

a. Installation of High Rate Biomethanation System.

b. Installation of alternate chemical recovery system such as the Fluidized Bed Chemical Recovery System, wherein caustic soda is recovered in the form of soda ash.

2. Alternate options to conventional chemical recovery system

A-1. Biomethanation technology:

Biomethanation technology was recognized & primarily applied in sugar industry. The anaerobic lagoons pre-dominantly employed in most of the paper mills require huge land area and retention time ranging from 15-30 days and are devoid of system for recovery of any biogas. With changing environmental regulations & awareness in early eighties, anaerobic system became common in the treatment of industrial wastewaters containing easily degradable non-toxic compounds. With the development of high rate biomethanation reactors & increased understanding of biochemistry, limitations & toxicity tolerance of anaerobic microbes, the application of biomethanation technology was extended for treatment of complex industrial wastewaters including pulp & paper mill effluent.
A-2 Adoption of biomethanation technology for treatment of black liquor:

The full scale biomethanation plants based on different configuration are working successfully for treatment of industrial waste waters but most of the installations are operating for treatment of TMP effluent, secondary fibre and semi-chemical pulping spent liquor which contains high proportion or easily biodegradable organic matters. Black liquor is heterogeneous in nature and contains recalcitrant & other inhibitors, which cause inhibition to anaerobic microbes.

The extensive R&D work carried out at CPPRI on characterization or black liquor from agro residues, biochemical reactions leading to potential amounts of methane production, toxicity of black liquor to anaerobic microbes, process configurations and anaerobic treatability of black liquors gave confidence to improve state of the art technology for biomethanation of pulping spent liquors. The full-scale biomethanation plant based on UASB technology was commissioned under supervision of CPPRI at M/s Satia Paper Mills. The schematic is shown in Fig 21.

The additional feature of this biomethanation plant is clarifier, which was incorporated based on experience of CPPRI. The clarifier facilitates in arresting not only suspended solids & lignin but also considerable amounts of silica, which gets precipitated during neutralization of black liquor at pH of 6.5-7.0. Most of the high rate bioreactors have limitations for suspended solids & inorganic matter, since the accumulation of suspended solids in bioreactor can adversely affect the activity & settleability of active anaerobic biomass present in bioreactor. The performance of biomethanation plant achieved is given below:

Performance of biomethanation plant:

The application of biomethanation technology can be extended for treatment of black liquor in small mills along with existing treatment facilities where installation of chemical recovery system is not economically viable immediately due to size constraint. Besides substantial reduction in COD & BOD prior to conventional aerobic treatment nearly 30% of the total energy requirement is met through bio-energy generated in biomethanation process.
# Table 60 Biomethanation parameters

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameters</th>
<th>Designed</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>No. of Bioreactors</td>
<td>Two</td>
<td>-</td>
</tr>
<tr>
<td>2.</td>
<td>Volume of each reactor, m³</td>
<td>2623</td>
<td>-</td>
</tr>
<tr>
<td>3.</td>
<td>Volumetric loading rate Kg COD/m³/d</td>
<td>10.0</td>
<td>12.0</td>
</tr>
<tr>
<td>4.</td>
<td>COD reduction, %</td>
<td>55-60</td>
<td>45-50</td>
</tr>
<tr>
<td>5.</td>
<td>BOD reduction, %</td>
<td>70-75</td>
<td>80-82</td>
</tr>
<tr>
<td>6.</td>
<td>Biogas production, m³/d</td>
<td>8500</td>
<td>11000-11500</td>
</tr>
<tr>
<td>7.</td>
<td>Equivalent rice husk, t/d</td>
<td>17-18</td>
<td>22-24</td>
</tr>
</tbody>
</table>
B. Suitability of alternate chemical recovery systems:

The installation of a technically & economically efficient Chemical Recovery System has become a matter of survival for the small and medium mills based on non-wood fibres. The kraft Chemical Recovery System / Conventional chemical recovery system is well established in large scale sector. The scaling down of these recovery systems is both a technical & commercial problem- a problem of economy of scale.

The increasingly stringent pollution control laws and the realization that the environmental concerns are social obligations, mills of capacity ranging from 40-100 tpd have considered alternate chemical recovery systems such as fluidized bed chemical recovery system.

B-1 Fluidized bed systems:

The high thermal efficiency of fluid bed incinerator provides total combustion of organic matter in waste flows with low heating values or those that are dilute to burn in conventional furnaces. The fluid bed reactor consists of the main sections as shown in Fig.- 2.

The flue gas is scrubbed before letting out to the atmosphere. The typical scrubbing equipment includes wet walled Venturi scrubbers spray type scrubbers, turbulent contact scrubbers. The flue gases after scrubbing will conform to the standards of emission under the air pollution code. There are at least thirty such installations, which are operating in different parts of the world.

Technical assessment for setting up a conventional chemical recovery system in a jute based mill at Bangladesh

Objective of Setting up a Chemical Recovery System: Global environmental imbalances coupled with depleting reserves of fossil fuels has forced the paper industry to maximize the use of internal fuel sources. Black liquor when processed in the chemical recovery section serves as the major renewable energy resource. In view of the more and more stringent environmental regulations across the world and increased cost of caustic soda prices
prevailing at Bangladesh, the installation of a technically and economically efficient chemical recovery system is becoming extremely important.

The technical considerations for setting up a chemical recovery system from the view point of black liquor handling are:

- Weak black liquor solids concentrations achieved, which directly affects the steam demands during black liquor evaporation.
- Black liquor flow behaviour in terms of its viscosity, which determines the heat transfer rates in evaporators and decides the maximum attainable firing concentrations.
- Combustibility of black liquor in terms of Swelling Volume Ratio (SVR) and Temperature of Ignition.
- Amounts of Non-Process Elements in terms of silica, potassium and chlorides, which play a significant impact on evaporation, combustion and causticization depending on the nature of the element and affects various heat transfer operations.
Table 61 shows the physico-chemical properties of the jute black liquor in comparison to black liquors from other conventional fibrous raw materials such as wood. Looking into the black liquor characteristics, it seems quite feasible that jute black liquor either from a soda or a kraft pulping process is quite a suitable raw material for pulping.

**Table 61 Physico-chemical properties of jute black liquor in comparison to other raw materials**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Particulars</th>
<th>Wood kraft black liquor</th>
<th>Jute Soda-AQ black liquor</th>
<th>Jute kraft liquor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH at Room Temperature, °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Total Solids</td>
<td>15.89</td>
<td>10.89</td>
<td>12.56</td>
</tr>
<tr>
<td>3.</td>
<td>Suspended Solids, g/l</td>
<td>0.05</td>
<td>0.38</td>
<td>0.471</td>
</tr>
<tr>
<td>4.</td>
<td>Residual active alkali, g/l as Na₂O</td>
<td>8.0</td>
<td>2.79</td>
<td>1.55</td>
</tr>
<tr>
<td>5.</td>
<td>Total Alkali, g/l as NaOH</td>
<td>51.0</td>
<td>34.4</td>
<td>37.6</td>
</tr>
<tr>
<td>6.</td>
<td>Inorganics, % w/w as NaOH (Sulphated ash)</td>
<td>36.0</td>
<td>33.69</td>
<td>31.18</td>
</tr>
<tr>
<td>7.</td>
<td>Organics, % w/w (by difference)</td>
<td>64.0</td>
<td>66.31</td>
<td>68.82</td>
</tr>
<tr>
<td>8.</td>
<td>Lignin, % w/w</td>
<td>42.0</td>
<td>45.45</td>
<td>37.0</td>
</tr>
<tr>
<td>9.</td>
<td>Carbon, % w/w as C</td>
<td>36.8</td>
<td>38.14</td>
<td>34.98</td>
</tr>
<tr>
<td>10.</td>
<td>Hydrogen, % w/w as H</td>
<td>3.8</td>
<td>3.97</td>
<td>4.25</td>
</tr>
<tr>
<td>11.</td>
<td>Nitrogen, % w/w as N</td>
<td>0.084</td>
<td>nil</td>
<td>0.013</td>
</tr>
<tr>
<td>12.</td>
<td>Sodium, % w/w as Na</td>
<td>18.74</td>
<td>18.0</td>
<td>14.3</td>
</tr>
<tr>
<td>13.</td>
<td>Sulphur, % W/w as S</td>
<td>1.85</td>
<td>0.50</td>
<td>2.40</td>
</tr>
<tr>
<td>14.</td>
<td>Inerts as R₂O₃, % w/w</td>
<td>0.042</td>
<td>0.14</td>
<td>0.32</td>
</tr>
<tr>
<td>15.</td>
<td>Silica, % w/w as SiO₂</td>
<td>0.085</td>
<td>0.01</td>
<td>1.27</td>
</tr>
<tr>
<td>16.</td>
<td>Chlorides, % w/w as Cl</td>
<td>0.11</td>
<td>0.87</td>
<td>0.83</td>
</tr>
<tr>
<td>17.</td>
<td>Potassium, % w/w as K</td>
<td>0.38</td>
<td>0.5</td>
<td>0.68</td>
</tr>
<tr>
<td>18.</td>
<td>Calcium, % w/w as Ca</td>
<td>Not detected</td>
<td>0.39</td>
<td>0.35</td>
</tr>
<tr>
<td>19.</td>
<td>Swelling Volume Ratio, ml/g</td>
<td>25.0</td>
<td>29.5</td>
<td>15.0</td>
</tr>
<tr>
<td>20.</td>
<td>Gross Calorific Value, Cals/g</td>
<td>3160</td>
<td>3438</td>
<td>3299</td>
</tr>
</tbody>
</table>
Table 62  Black liquor viscosity

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Total Solids, % w/w</th>
<th>Viscosity, mPa.S at 90°C</th>
<th>Viscosity, mPa.S at 90°C</th>
<th>Viscosity, mPa.S at 90°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>50</td>
<td>19.5</td>
<td>8.2</td>
<td>20</td>
</tr>
<tr>
<td>2.</td>
<td>55</td>
<td>48</td>
<td>17.4</td>
<td>40</td>
</tr>
<tr>
<td>3.</td>
<td>60</td>
<td>120</td>
<td>39</td>
<td>100</td>
</tr>
<tr>
<td>4.</td>
<td>65</td>
<td>380</td>
<td>110</td>
<td>282</td>
</tr>
</tbody>
</table>

Shaded portion indicate laboratory cooked jute black liquor using fresh white liquor.

Observations on Processing Jute Black Liquor Vis-à-vis Wood Black Liquors (Conventional fibrous raw material):

In order to obtain black liquor quality as realistic as under the mill conditions, jute black liquors using Soda-AQ and kraft process was generated under the specified pulping conditions after taking in to considerations the washings of the pulp. The black liquors obtained were studied for its suitability in the chemical recovery section. The black liquor characteristics analyzed for studying its suitability in the recovery section are as follows:

**Total Solids:** From the viewpoint of processing of non-wood black liquors, solids level of ~11-12% are quite satisfactory in the rotary tumbling digesters. However, further improvement in solids concentration would help in improving the steam economy in the train of evaporators.

**Suspended Solids:** The S.S. level can be further improved by installing a melone filter while actually processing the black liquor at mill site.

**Residual Active Alkali:** RAA level is on the lower side, while studying the rheological behaviour of the jute black liquor, the liquor was found to be quite stable. However, it is recommended to maintain an active alkali level of at least 2.0 g/l as Na2O.

**Organic /Inorganic Ratio:** The inorganics content of nearly 31% is quite optimum, however, looking in to the wide variations in the total alkali level and Sulphated ash values, it seems quite prominent that inert material is noticeable in the fresh black liquor itself, which has not been recycled so far.
Process and Non-Process Elements: Compared to the Soda-AQ black liquor, the carbon values are on the lower side and other inerts such as silica and potassium are on the higher side, which indicates that greater caution is required in processing of jute kraft black liquor in comparison to soda-AQ liquor.

Thermal & Swelling Characteristics: Although, once again in comparison to soda – AQ black liquor, the thermal and swelling characteristics are on the inferior side, but still the kraft black liquor obtained can be easily processed in the chemical recovery section as efficiently as any other black liquor from the conventional raw materials.

Rheological Properties: Black liquor can be concentrated to a solids level of 70% without observing any liquor instability, but viscosity values are higher than in case of soda-AQ process.

It is therefore inferred that with steps of raw material cleaning, the jute black liquor obtained either by soda- AQ/ kraft process is suitable for its processing in the chemical recovery section.

On comparative basis, the performance of chemical recovery is expected to be better in case of black liquor obtained by Soda- Aq process in comparison to kraft process.

Expected Steam Generation:

Based the pulp yield, physico-chemical analysis of the various black liquors, thermal behaviour and results of Gross Calorific Value, the expected steam generation value could be around 5.0-5.25 on per tonne basis with chemical recovery efficiency of over 90%.
VARIOUS BLACK LIQUOR MANAGEMENT PROSPECTS IN MILLS OF DIFFERENT SIZES

FOR MILL SIZE - 30 – 50 TPD

ANNUAL PRODUCTION  10500- 17500 TPA

A mill of 30-50 TPD size can look for soda, soda AQ pulping process with CEH bleaching sequence. However in this segment of the paper mill, the chemical recovery system is not economically viable. Such size of mill can therefore go for the high rate biomethanation system.

The environmental situation in these mills are better than in mills of ≤ 30 tpd capacity, but the pollution parameters such as those measured in terms of COD, SAR (Sodium absorption ratio) are higher than the proposed norms. The capital cost work out to be nearly 33% of the mill of size 150tpd, even in absence of chemical recovery.

The final product is saleable in the local market. The schematic of the mill of size 50 TPD is shown in fig 18. The capital investments required for putting up this size of the mill is as shown in Table 63.

Fig 18. Overview of pulping and papermaking process in a mill of 30 – 50 TPD
### Table 63 Investment costs estimation for 30-50 tpd with high rate biomethanation facility

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Department</th>
<th>Assumption for Estimate, Million US $</th>
<th>Estimated Investments, Million US $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Main Equipment, ex Works Works</td>
<td></td>
<td>11.74</td>
</tr>
<tr>
<td></td>
<td>• Cost for Fibre Line</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cost for High Rate Biomethanation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cost for Chemical handling</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cost for steam &amp; Power, Water, Ancillaries</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cost for Stock preparation &amp; Paper making</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>Steel Structure</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>Piping Interconnection</td>
<td>Approx. 8%</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>Electric</td>
<td>Approx. 10%</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>Instrumentation &amp; DCS</td>
<td>App. 15% of Equip. cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub total (2-5)</td>
<td></td>
<td>4.34</td>
</tr>
<tr>
<td>6.0</td>
<td>Total Equipment Cost (1-5)</td>
<td></td>
<td>16.08</td>
</tr>
<tr>
<td>7.0</td>
<td>Engineering: Project Management</td>
<td>Approx. 10%</td>
<td></td>
</tr>
<tr>
<td>8.0</td>
<td>Spare parts for two years, start up &amp; commissioning</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td>Packing &amp; ex Works to site</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td>Training</td>
<td>Approx. 2%</td>
<td></td>
</tr>
<tr>
<td>11.0</td>
<td>Erection</td>
<td>Approx. 8%</td>
<td></td>
</tr>
<tr>
<td>12.0</td>
<td>Supervision of erection/ start up, commissioning</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>13.0</td>
<td>Civil Works</td>
<td>Approx. 12%</td>
<td></td>
</tr>
<tr>
<td>14.0</td>
<td>Sub Total 7-13</td>
<td></td>
<td>7.076</td>
</tr>
<tr>
<td>15.0</td>
<td>Grand Total</td>
<td></td>
<td>23.16</td>
</tr>
</tbody>
</table>

Calculation made for 50 TPD mill size
FOR MILL SIZE - 50 – 100 TPD

ANNUAL PRODUCTION : 17500 – 35000 TPA

This size of the mill is economically & environmentally compatible, however in this size of the mill, only soda, soda AQ pulping process & CEH bleaching stages can be followed. For this typical size of the mill, the conventional chemical recovery is not economically viable and therefore a fluidized bed type of chemical recovery is recommended. The schematic of a FBR system is shown under applied technology and their economy.

In this type of chemical recovery system, the chemical in the form of soda ash is recovered. However, there is no cogeneration of electricity. The heat produced through flue gas by burning of the organic is used to concentrate the black liquor of 25% solid to around 42 %, which is then sprayed on the fluidised bed to regenerate the chemicals & produces heat. The investment in this type of the mill is lower than that of a higher sized mill equipped with conventional chemical recovery system, however, this type of recovery system can work on soda pulping process only.

However, since only conventional bleaching sequence can be followed in this of the mill, even the global market demand, which requires ECF or TCF bleaching sequence during brightening of the pulp can not be met in this segment of the mill. The schematic of the mill of size 50-100 TPD is shown in fig 19. The capital investments cost is shown in Table 64.
Fig 19. Overview of pulping and papermaking process in a mill of 50 - 100 TPD

Table 64 Investments costs estimation for 100 tpd with fluidized bed type of recovery facility

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Department</th>
<th>Assumption for Estimate Million US $</th>
<th>Estimated Investments Million US $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Main Equipment, ex Works</td>
<td></td>
<td>23.00</td>
</tr>
<tr>
<td></td>
<td>• Cost for Fibre Line</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cost for Recovery</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cost for chemical handling</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cost for Steam &amp; Power, Water Ancillaries</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cost for Stock preparation &amp; Papermaking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>Steel Structure</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>Piping Interconnection</td>
<td>Approx. 8%</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>Electric</td>
<td>Approx. 10%</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>Instrumentation &amp; DCS</td>
<td>Approx. 15% of equip. cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub total (2-5)</td>
<td></td>
<td>8.51</td>
</tr>
<tr>
<td>6.0</td>
<td>Total Equipment Cost (1-5)</td>
<td></td>
<td>31.51</td>
</tr>
<tr>
<td>7.0</td>
<td>Engineering: Project Management.</td>
<td>Approx. 10%</td>
<td></td>
</tr>
<tr>
<td>8.0</td>
<td>Spare parts for two years, start up &amp; commissioning</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td>Packing &amp; ex Works to site</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td>Training</td>
<td>Approx. 2%</td>
<td></td>
</tr>
<tr>
<td>11.0</td>
<td>Erection</td>
<td>Approx. 8%</td>
<td></td>
</tr>
<tr>
<td>12.0</td>
<td>Supervision of erection/ start up, commissioning</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>13.0</td>
<td>Civil Works</td>
<td>Approx. 12%</td>
<td></td>
</tr>
<tr>
<td>14.0</td>
<td>Sub Total 7-13</td>
<td></td>
<td>13.86</td>
</tr>
<tr>
<td>15.0</td>
<td>Grand Total</td>
<td></td>
<td>45.40</td>
</tr>
</tbody>
</table>

*Calculation made for 100 TPD mill size
FOR MILL SIZE - 100 – 150 TPD

ANNUAL PRODUCTION: 35000 - 52500 TPA

This size of mill has the advantage of adopting different pulping processes. The bleaching sequence incorporating enzymatic prebleaching and oxygen delignification can be followed. However for going towards TCF bleaching sequence, a mill size above 300 TPD is required.

The conventional type of chemical recovery system is recommended for this size of the paper mill with cogeneration facility unlike FBR type of recovery system, where there is no facility for cogeneration. The Schematic of the system is shown in fig 20. The capital investments cost is shown in Table 65.

Fig 20. Overview of pulping and papermaking process in a mill of 100- 150 TPD
### Table 65 Investments costs estimation: for 100 -150 tpd

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Department</th>
<th>Assumption for Estimate, Million US $</th>
<th>Estimated Investments, Million US $</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Main Equipment, ex Works Works</td>
<td>Cost for Fiber line • Cost for recovery • Cost for chemical handling • Cost for steam &amp; Power, water Ancillaries • Cost for Stock preparation &amp; Papermaking</td>
<td>36.00</td>
</tr>
<tr>
<td>2.0</td>
<td>Steel Structure</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>Piping Interconnection</td>
<td>Approx. 8%</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>Electric</td>
<td>Approx. 10%</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>Instrumentation &amp; DCS</td>
<td>App.15% of Equip. cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sub total (2-5)</td>
<td>13.32</td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>Total Equipment Cost ( 1-5)</td>
<td>49.32</td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>Engineering: Project Management.</td>
<td>Approx.10%</td>
<td></td>
</tr>
<tr>
<td>8.0</td>
<td>Spare parts for two years, start up &amp; commissioning</td>
<td>Approx.4.%</td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td>Packing &amp; ex Works to site</td>
<td>Approx.4%</td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td>Training</td>
<td>Approx. 2%</td>
<td></td>
</tr>
<tr>
<td>11.0</td>
<td>Erection</td>
<td>Approx. 8%</td>
<td></td>
</tr>
<tr>
<td>12.0</td>
<td>Supervision of erection/ start up, commissioning</td>
<td>Approx. 4%</td>
<td></td>
</tr>
<tr>
<td>13.0</td>
<td>Civil Works</td>
<td>Approx.12%</td>
<td></td>
</tr>
<tr>
<td>14.0</td>
<td>Sub Total 7-13</td>
<td>21.70</td>
<td></td>
</tr>
<tr>
<td>15.0</td>
<td>Grand Total</td>
<td>71.00</td>
<td></td>
</tr>
</tbody>
</table>

*Calculation made for 150 TPD mill size*
EFFLUENT QUALITY
AND
MANAGEMENT
EFFLUENT CHARACTERISTICS OF KRAFT AND SODA AQ CEH BLEACHING

The kappa number of kraft pulp was 3 units higher than soda-Aq pulp. These pulps were bleached using CEH bleaching sequence and it has been observed that the pollution load generation during bleaching was significantly high in kraft pulp in comparison to soda-Aq pulp as shown in Table 66.

Table 66 Effluent Characteristics:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameters</th>
<th>Soda-Aq</th>
<th>Kraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH</td>
<td>6.5</td>
<td>6.0</td>
</tr>
<tr>
<td>2.</td>
<td>Total Dissolved Solids mg/l</td>
<td>1.86</td>
<td>2.13</td>
</tr>
<tr>
<td>3.</td>
<td>Chloride mg/l</td>
<td>720</td>
<td>760</td>
</tr>
<tr>
<td>4.</td>
<td>Sulfate mg/l</td>
<td>32</td>
<td>43.8</td>
</tr>
<tr>
<td>5.</td>
<td>COD, kg/t</td>
<td>50.4</td>
<td>118.2</td>
</tr>
<tr>
<td>6.</td>
<td>BOD, kg/t</td>
<td>8.6</td>
<td>25.8</td>
</tr>
<tr>
<td>7.</td>
<td>AOX kg/t</td>
<td>2.8</td>
<td>4.09</td>
</tr>
</tbody>
</table>

Observations:

- The black liquor appears to be comparable with wood black liquor. The properties of black liquor like viscosity and calorific value are similar to those of wood black liquor.
- The studies on liquid effluents indicate that it has higher proportion of AOX and chloride values.
TREATMENT OF BLEACH PLANT EFFLUENT
COLOUR & AOX REDUCTION

Bleach plant effluent presents the highest pollution load responsible for the generation of large amount of wastewater containing high toxicity and color. Lignin & degradation products are the major contributors. In view of the great variety of reactions involved in the various stages of bleaching, large number of varying molecular weight ranging color bodies and chlorinated organic matters are produced. A number of factors are of importance for the pollution load from the bleach plant eg. washing loss of the incoming pulp, the lignin content of incoming pulp and the bleaching conditions (Table 67). The extent of color and AOX present in the bleach plant varies depending on the types of raw materials, bleaching chemicals, bleaching conditions and extent of bleaching. A conventional treatment system for pulp and paper mill effluents is given in fig. 37.

Table 67 Typical characteristics of effluents from different bleaching stages

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameter</th>
<th>C-Stage</th>
<th>E-stage</th>
<th>H-Stage</th>
<th>Combined bleach effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH</td>
<td>2.5</td>
<td>7.0</td>
<td>6.6</td>
<td>5.0</td>
</tr>
<tr>
<td>2.</td>
<td>Total Solids, mg/l</td>
<td>3200</td>
<td>3460</td>
<td>6940</td>
<td>2970</td>
</tr>
<tr>
<td>3.</td>
<td>COD, mg/l</td>
<td>490</td>
<td>1598</td>
<td>1020</td>
<td>1411</td>
</tr>
<tr>
<td>4.</td>
<td>BOD, mg/l</td>
<td>160</td>
<td>391</td>
<td>350</td>
<td>414</td>
</tr>
<tr>
<td>5.</td>
<td>Chloride, mg/l</td>
<td>759</td>
<td>766</td>
<td>2537</td>
<td>1089</td>
</tr>
<tr>
<td>6.</td>
<td>Color, PCU</td>
<td>305</td>
<td>3460</td>
<td>424</td>
<td>2750</td>
</tr>
<tr>
<td>7.</td>
<td>Lignin, mg/l</td>
<td>96</td>
<td>595</td>
<td>158</td>
<td>390</td>
</tr>
<tr>
<td>8.</td>
<td>AOX, mg/l</td>
<td>41.4</td>
<td>87.9</td>
<td>70.5</td>
<td>50.7</td>
</tr>
</tbody>
</table>

Fig. 37 Flow Sheet of Conventional System For Treatment of Pulp & Paper Mills Effluent
External Control Measures for Color and Detoxification (AOX Removal):

Although extent of colour and AOX generation can be reduced to appreciable quantity by various internal control measures and process modifications, however, external methods for treatment of bleach plant effluents will always be essential in order to meet the regulatory standards for color and AOX. Techniques like chemical precipitation & UF are suitable for color reduction from bleach plant effluents. However, for AOX reduction, the conventional methods include primary clarification followed by secondary biological treatment involving aeration lagoon, activated sludge or anaerobic treatment. Due to non biodegradable nature of large number of chlorinated organic matter in bleach plant effluent and in order to meet the existing environmental standards which are becoming more and more stringent, further polishing stage treatment is essential for removal of the residual toxicity and colour.

Some of the external control measure for reducing the toxicity of effluent is given in fig 38. The most widely used method for detoxification of bleach plant effluent is oxidative biological stabilization using aerated stabilization both activated sludge and combination of aerobic and anaerobic.

| Fig. 38 | External control measure for reducing the toxicity of effluent. |