Lecture

Refining of Recovered Fibers

Several Slides Courtesy of Dr. Med Byrd.
What is Refining?

- Refining is a physical treatment performed on pulp fibers to improve their papermaking characteristics.
- It is essential to the production of strong, smooth, useful paper.

Several Slides Courtesy of Dr. Med Byrd.
Why do we need refining?

- Increasing bonding area by:
  - Collapsing hollow cell walls into flat ribbons
  - Fraying the fiber surface – “fibrillation”
- Making the fibers more flexible and conformable, delaminating the wall
- Cutting some of the longer fibers into smaller lengths to help formation

*Courtesy of M. Hubbe*
Refining

- The effects of refining on freeness, density, tear index, and tensile index in virgin bleached kraft pulps.

Fig. 17.1. Effects of refining.
Fiber Structure

- Thin **primary wall** (P), which is delicate and easily removed
- **Secondary wall** has three layers
  - **S1** – thin and not easily wetted
  - **S2** – 70-85% of total mass; easily wetted and swollen
  - **S3** - thin, waxy, warty

*Fig. 17.3. Structure of a Cellulose Fiber.*

Secondary Fibers, Tappi
Fiber Structure

- Refining damages and removes the Primary and S1 wall layers, exposing the S2 layer
- Once the S2 layer is exposed and swollen, mechanical action causes the layer to delaminate and collapse
- Mechanical action also fibrillates the surface, cuts some fibers, and makes them less stiff and more conformable

Photomicrograph showing a refined fiber with fibrillation on the surface
Refining: Subprocesses

First Step
- Wad gathering and preliminary localized dewatering order of 15% to 30%

Second Step
- Mechanical pressure order of 1000 to 5000 psi
- Water expulsion order of 50 to 60%

Third Step
- Sliding wads under pressure

Fourth Step
- Mechanical release
- Water reabsorption

Fifth Step
- Dispersion
- Wad gathering for next cycle
The Refining Action

- The mechanical action required for proper refining is not a simple brushing, cutting, grinding or pounding.
- Rather, it is a more precise shearing of the fibers between two surfaces, both moving, or one moving and one stationary.
- The cyclic shearing, compression, and release of fibers between moving surfaces causes the desired effect – "rolling friction".
- Refining equipment is designed to pass the stock slurry (2-5% consistency) between the moving surfaces, either in multiple passes or a single-pass.
The Refining Action

- **Cutting**
  - Reduces the average length of the fibers, producing short, stiff fibers that form a bulk sheet
  - Reduces the drainage rate (freeness)

- **Bruising**
  - Retains fiber length while developing flexible fibers that conform well to produce high strength and low bulk
The Refining Action

- Splitting
  - Combination of Cutting and Bruising
  - Paper properties fall between the two extremes
  - Most stock preparation involves splitting
The Refining Action

- The effect of different refining actions have on various properties
Freeness

- **Definition**: how freely water drains from a fiber slurry
- It is an indirect indication of amount of refining via generation of fines from the P and S1 layers (as well as cutting)
- High Freeness = High Drainage Rate
Fundamentals of Refining

- **Canadian Standard Freeness (CSF)**
  - Most common test used in North America
Fundamentals of Refining

Measuring Freeness

- Freeness is very sensitive to several factors
  - Surface area – must fix the sample weight
  - Temperature of the stock – must fix or compensate
  - Fines content of the stock – varies with the degree of refining
Fundamentals of Refining

- Typical CSF Values
  - Unrefined chemical pulps – 700+
  - Chemical pulps after refining – 400-500
  - Refined mechanical pulps – 100-300
  - Groundwood pulp for newsprint – 40-100
Fundamentals of Refining

- Other types of Freeness Tests
  - Schopper-Riegler – used in Europe
  - Williams Slowness Tester
  - Drainage Resistance Analyzer
  - TAPPI Drainage
Secondary Fiber Refining

- LC refining used in deinking processing lines for Supercalendered (SC) paper.

*Figure 153. LC refining arrangement for deinked pulp in SC paper production with red. = reductive and oxid. = oxidative bleaching.*

• Recycled Fiber and Deinking, Parkarinen
Refining Equipment

Rotating Disk Refiners

- Stock is pumped between two circular, bar-covered disks (plates)
  - Single-disk – one disk rotating, one stationary
  - Double-disk – one rotating disk with two sides plus two stationary disks = two refining chambers in one refiner

- This configuration maximizes refining efficiency, reducing equipment size
Refining Equipment

- Single Disk refiner
Refining Equipment

- Double-Disk Refiner
Refining Equipment

- Double-Disk refiners
Example of a typical kind of refiner filling

Figure 157. LC refiner fillings for low intensity refining.
Advantages of the disk refiner

- Most energy efficient design
- Higher stock consistencies can be used, maximizing fibrillation and strength
- Can use higher loads and RPM
- More compact, lower capital cost
- Easy to maintain
- Plate patterns can be customized
Fundamentals of Refining

Flow

Problems with low flow
- Little or no fiber mat between plates
- Fiber channeling
- High pressure rise (25-50 psi)
- Plate crashing
- Short plate life
- Inefficient refining (power vs fiber development)
- Poor strength development
- Increased fines generation
Fundamentals of Refining

- Problems with high flow
  - Inability to optimize plate design for maximum strength development (compromise)
  - Short plate life
  - High pressure drop
  - Motors maxed out
Fundamentals of Refining

Why is the Proper Consistency Important to Refining?
- Increases the Probability of Fiber Mat Formation
- Fiber Strength Potential is Maximized
- Plate Life Potential is Maximized
- Variation is Minimized
## Fundamentals of Refining

### Consistency

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Recommended Range of Refining Consistency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unbleached Softwood Kraft</td>
<td>3.5 - 4.5%</td>
</tr>
<tr>
<td>Bleached Softwood Kraft</td>
<td>3.5 - 5%</td>
</tr>
<tr>
<td>Bleached Hardwood/Eucalyptus Kraft</td>
<td>4 - 6%</td>
</tr>
<tr>
<td>OCC</td>
<td>3.5 - 5%</td>
</tr>
<tr>
<td>Mechanical Pulps</td>
<td>4.5 - 6%</td>
</tr>
<tr>
<td>Unbleached Semi-Chem Hardwood</td>
<td>4.5 - 6%</td>
</tr>
<tr>
<td>Mixed Waste</td>
<td>4 - 6%</td>
</tr>
</tbody>
</table>
Fundamentals of Refining

Effects of Operating outside Recommended Consistency

- **High Consistency**
  - Plate Plugging
  - Poor Fiber Development

- **Low Consistency**
  - Little to no fiber mat between plates
  - Inefficient refining
  - Poor fiber development
  - Fiber cutting
  - Plate clashing
  - Short plate life
Fundamentals of Refining

Specific Refining Energy (SRE)

Definition: The amount of energy transferred from the refiner’s motor to the fiber

- $SRE = \text{kWh/t} = \text{Motor Load (kW)} - \text{No Load (kW)}$
  - metric tonnes per Hour

- $SRE = \text{HPD/T} = \text{Motor Load(HP)} - \text{No Load(HP)}$
  - Tons per Day
Fundamentals of Refining

No Load Energy

Definition: The energy required to spin the rotor in a pulp slurry.

- No Load (kW) = \((2.299 \times 10^{-13})(\text{Diam}^{4.249})(\text{RPM}^{3})\)
  - Diam = Plate diameter in inches
  - RPM = Refiner motor speed

The refiner is an inefficient pump!
## Fundamentals of Refining

### Specific Energy Guidelines

<table>
<thead>
<tr>
<th>GRADE</th>
<th>HPD/UST</th>
<th>KWH/UST</th>
<th>KWH/MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linerboard</td>
<td>Base</td>
<td>5 - 7</td>
<td>89 - 125</td>
</tr>
<tr>
<td></td>
<td>Top</td>
<td>10 - 12</td>
<td>179 - 215</td>
</tr>
<tr>
<td>Sack, Bag</td>
<td></td>
<td>12 - 14</td>
<td>215 - 250</td>
</tr>
<tr>
<td>Medium</td>
<td>Virgin</td>
<td>6 - 10</td>
<td>107 - 179</td>
</tr>
<tr>
<td></td>
<td>HWD</td>
<td>2 - 3</td>
<td>36 - 54</td>
</tr>
<tr>
<td></td>
<td>Waste</td>
<td>1.0 - 1.5</td>
<td>18 - 27</td>
</tr>
<tr>
<td></td>
<td>Tickler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Papers</td>
<td>Hardwood</td>
<td>4 - 6</td>
<td>72 - 107</td>
</tr>
<tr>
<td></td>
<td>Softwood</td>
<td>6 - 8</td>
<td>107 - 143</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0 - 1.5</td>
<td>18 - 27</td>
</tr>
<tr>
<td></td>
<td>Tickler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foodboard, Milk Carton</td>
<td>Hardwood</td>
<td>2 - 3</td>
<td>36 - 54</td>
</tr>
<tr>
<td></td>
<td>Softwood</td>
<td>3 - 4</td>
<td>54 - 72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0 - 1.5</td>
<td>18 - 27</td>
</tr>
<tr>
<td></td>
<td>Tickler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>News</td>
<td>SB Kraft</td>
<td>2 - 5</td>
<td>36 - 89</td>
</tr>
<tr>
<td></td>
<td>Groundwood</td>
<td>2 - 3</td>
<td>36 - 54</td>
</tr>
<tr>
<td>Grades w/ OCC</td>
<td>OCC</td>
<td>2.5 - 5.0</td>
<td>81 - 117</td>
</tr>
</tbody>
</table>

J&L Fiber Services
Fundamentals of Refining

Freeness Drop / HPD/T

- Great measure to determine the refiner(s) efficiency and if it is operating correctly

\[ -\Delta \text{CSF} / \text{HPD/T} = \text{CSF}_{\text{in}} - \text{CSF}_{\text{out}} \]
### Fundamentals of Refining

**Freeness Drop / HPD/T Guidelines**

#### Various Furnishes

<table>
<thead>
<tr>
<th>Various Furnishes</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UNBLEACHED SOFTWOOD KRAFT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern U.S.</td>
<td>15 - 25 CSF / Net HPD/T</td>
<td></td>
</tr>
<tr>
<td>Southern U.S.</td>
<td>15 - 30 CSF / Net HPD/T</td>
<td></td>
</tr>
<tr>
<td><strong>BLEACHED SOFTWOOD KRAFT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern U.S.</td>
<td>25 - 50 CSF / Net HPD/T</td>
<td></td>
</tr>
<tr>
<td>Southern U.S.</td>
<td>25 - 60 CSF / Net HPD/T</td>
<td></td>
</tr>
<tr>
<td><strong>BLEACHED HARDWOOD KRAFT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most Species</td>
<td>60 - 100 CSF / Net HPD/T</td>
<td></td>
</tr>
<tr>
<td>Eucalyptus</td>
<td>45 - 50 CSF / Net HPD/T</td>
<td></td>
</tr>
<tr>
<td><strong>SECONDARY FIBER</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCC</td>
<td>40 - 70 CSF / Net HPD/T</td>
<td></td>
</tr>
<tr>
<td>Mixed</td>
<td>50 - 70 CSF / Net HPD/T</td>
<td></td>
</tr>
<tr>
<td>News</td>
<td>20 - 35 CSF / Net HPD/T</td>
<td></td>
</tr>
</tbody>
</table>

Note that these results are a combination of both fiber properties and conditions in which the refiner is operated.
Fundamentals of Refining

- Refining Intensity, Specific Edge Load (SEL)
  - Definition: The amount of energy expended per unit length of bar crossings
  - Describes the intensity of the refining impacts
    - Higher SEL = more shortened and cut fibers
    - Lower SEL = more pronounced fibrillation
  - Recycling requires lower SEL
Lower SEL provides better properties.

Figure 163. Effects of specific edge load in LC refining on characteristics of writing and printing papers.
### Fundamentals of Refining

#### Effects of refining outside the recommended intensity range

<table>
<thead>
<tr>
<th>Lower than recommended</th>
<th>Higher than recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Potentially poor fiber development (all fibers require a certain intensity to break down their walls)</td>
<td></td>
</tr>
<tr>
<td>▪ Maintain fiber length</td>
<td>▪ Severe fiber cutting</td>
</tr>
<tr>
<td>▪ Inefficient freeness drop</td>
<td>▪ Plate clashing, exceed fiber threshold</td>
</tr>
<tr>
<td></td>
<td>▪ Short plate life</td>
</tr>
<tr>
<td></td>
<td>▪ Poor strength development</td>
</tr>
</tbody>
</table>
Secondary Fiber Refining

OCC for Board Grades

- The properties of mill-refined unbleached kraft pulp for linerboard to those of an OCC furnish developed for the same mill.

Table 17.1. Linerboard Base Sheet Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Virgin Furnish Mill Refined 3.8% Cons. 54&quot; DD, 450 RPM</th>
<th>OCC Furnish Lab Refined 3.6% Cons. 20&quot; DD, 900 RPM</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Change</td>
</tr>
<tr>
<td>Gross. Energy</td>
<td>kWh/t</td>
<td>130</td>
<td>-</td>
</tr>
<tr>
<td>Net Energy</td>
<td>kWh/t</td>
<td>110</td>
<td>-</td>
</tr>
<tr>
<td>Refining Intensity</td>
<td>Ws/m</td>
<td>3.6</td>
<td>-</td>
</tr>
<tr>
<td>Freeness</td>
<td>ml</td>
<td>745</td>
<td>-90 ml</td>
</tr>
<tr>
<td>Density</td>
<td>g/cc</td>
<td>.379</td>
<td>.468</td>
</tr>
<tr>
<td>Burst Index</td>
<td>-</td>
<td>2.48</td>
<td>4.68</td>
</tr>
<tr>
<td>Tear Index</td>
<td>-</td>
<td>20.8</td>
<td>13.5</td>
</tr>
<tr>
<td>Tensile Index</td>
<td>-</td>
<td>38.9</td>
<td>64.6</td>
</tr>
<tr>
<td>Fiber Length (Kajaani)</td>
<td>mm</td>
<td>2.36</td>
<td>2.32</td>
</tr>
</tbody>
</table>
Secondary Fiber Refining

- Deinked Ledger Grades for White Paper
  - Grades such as office waste or other white recovered papers made from wood-free chemical pulps
    - Main problem with regard to strength is the high ash content, which leads to low freeness after repulping
# Secondary Fiber Refining

Table 17.2. Effects of Fines Removal on Handsheet Properties of Deinked Ledger Pulp Washed on 100-Mesh Screen

<table>
<thead>
<tr>
<th>Property</th>
<th>Raw Pulp Before</th>
<th>Raw Pulp After</th>
<th>&quot;Refined Pulp&quot; Before</th>
<th>&quot;Refined Pulp&quot; After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight Loss (%)</td>
<td>- -</td>
<td>6.4</td>
<td>- -</td>
<td>9.3</td>
</tr>
<tr>
<td>Freeness (ml)</td>
<td>410</td>
<td>600</td>
<td>350</td>
<td>550</td>
</tr>
<tr>
<td>Fines (Kajaani FS-100) (%)</td>
<td>29.9</td>
<td>16.7</td>
<td>31.2</td>
<td>17.1</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>.600</td>
<td>.581</td>
<td>.607</td>
<td>.580</td>
</tr>
<tr>
<td>Burst Index</td>
<td>- 3.04</td>
<td>2.55</td>
<td>3.47</td>
<td>3.20</td>
</tr>
<tr>
<td>Tear Index</td>
<td>- 10.2</td>
<td>12.9</td>
<td>9.5</td>
<td>9.9</td>
</tr>
<tr>
<td>Tensile Index</td>
<td>- 48.1</td>
<td>39.9</td>
<td>56.3</td>
<td>49.9</td>
</tr>
</tbody>
</table>

Washing DI pulp increases freeness but have low tensile.
Refining DI pulp increases tensile but low freeness.
Refining and then washing DI pulp gives good tensile and freeness.
Fundamentals of Refining

Recycled Fiber and Deinking, Parkarinens

Combined effects of densification of sheet and fines generation
Note mechanical pulps generate fines mostly.
Lecture

Fiber Fractionation

Several Slides Courtesy of Terry Bliss.
Fractionation

Definition: Separation of a heterogeneous mixture of fibers into two or more streams of different properties

- At least one stream has properties more suitable for some end use than the original mixture
Basis of Separation

- Fiber length
- Fiber diameter
- Fiber flexibility (fiber wall thickness, degree of hydration, degree of refining)
- Fiber specific surface area
- Springwood / Summerwood
- Hardwood / Softwood
- Lignin content (wettability)
- Brightness or color (optical means)
- Kappa number
Fractionation Hardware

- Pressure screens (fiber length, flexibility, fines removal)
- Washers (fines, ash, ink removal)
  - Gravity screens
  - Deckers
  - High speed belt washers
- Centrifugal cleaners (fiber specific surface area, coarseness in milligram/meter)
- Rarely used methods
  - Froth flotation (fiber length, lignin content)
  - Spinning disc (wettability, fiber length)
  - Dry sorting
Pressure Screens

Feed (generally tangential)

Accepted stock
Fiber fines, short fibers, flexible fibers

Reject
Long, whole fibers
Typical Pressure Screen Fractionation Data

- Furnish: Groundwood, second stage screen rejects

<table>
<thead>
<tr>
<th>Property</th>
<th>Feed</th>
<th>Long</th>
<th>Short</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistency</td>
<td>1.61</td>
<td>2.71</td>
<td>0.75</td>
</tr>
<tr>
<td>Shives, %</td>
<td>10.9</td>
<td>16.19</td>
<td>2.45</td>
</tr>
<tr>
<td>Burst Index</td>
<td>8.18</td>
<td>7.10</td>
<td>11.5</td>
</tr>
<tr>
<td>Tear Index</td>
<td>65.1</td>
<td>68.4</td>
<td>52.3</td>
</tr>
<tr>
<td>Breaking length</td>
<td>2.6</td>
<td>2.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Bulk</td>
<td>3.47</td>
<td>3.5</td>
<td>3.01</td>
</tr>
<tr>
<td>+14 mesh</td>
<td>16.1</td>
<td>24.8</td>
<td>3.6</td>
</tr>
<tr>
<td>-200 mesh</td>
<td>13.7</td>
<td>3.5</td>
<td>17.9</td>
</tr>
</tbody>
</table>

Fiber Fractionation, Bliss
Washing: Gravity Screens

Feed
1% consistency

Fines, ash, ink
0.35% consistency

Long fiber
4% consistency
75% yield
A "+" before the sieve mesh indicates the particles are retained by the sieve, while a "-" before the sieve mesh indicates the particles pass through the sieve.
Washers: High Speed Belts

Feed
1% consistency

Fines, ink, ash
0.35% consistency
25% of feed solids
90% of feed flow

Washed Stock
10-14% consistency
Centrifugal Cleaner Fractionation

Overflow - lower consistency and freeness, light debris, flexible, well refined fibers, fines

Spring wood

Feed

Cylindrical Section

Conical Section

Vortex Finder

Roof

Downward flow

Upward flow

Air Core

Underflow tip

Underflow - higher consistency and freeness, heavy debris, coarse, stiff, whole, unrefined fibers, summerwood
Centrifugal Cleaner Fractionation: accepts=overflow, rejects=underflow

Fig. 3. Average fiber length (a) and coarseness (b) versus pressure variables for the mixture of unbeaten and beaten pulps. The feed pulp had an average fiber length of 1.82 mm (dashed line) and coarseness of 0.264 mg/m (dashed line).

Centrifugal Cleaner Fractionation

Graph: Burst Index vs. Freeness, kPa(m^2)/g vs. mL CSF.

- Points: Overflow, Feed, Underflow
- Furnish: Mixed waste
Centrifugal Cleaner Fractionation

Furnish: Mixed waste

- Refined underflow samples
- Refined feed samples
- Underflow refining model
- Feed refining model

Freeness, mL CSF vs. Burst Index, kPa (m^2)/g
Fractionation by Automated “Dry” Sorting

- Detect fundamental differences by optical or other non-contact means
  - Color or brightness
  - Lignin content
- Separate with air jets or other means at very high speeds
- Technology is in its infancy, but is operating commercially
- Manual sorting very common
Fractionation Goals and Applications

- Reduce furnish cost by using lower cost fiber
  - Highly mixed fibers usually sell for a lower price
- Improved strength
- Produce sheets with unique properties
- Reduced processing cost
  - Reduced refining energy
  - Reduced screening or cleaning
Hot Stock Fractionation

- Unwashed brown stock can be fractionated with a pressure screen into a high hardwood, low Kappa stock suitable for top liner, and a softwood-rich stock suitable for base stock for linerboard.
- Now common practice in virgin linerboard mills.
Fractionation Screening with Recovered Fibers

- Fractionation is often combined with screening systems.
- Typically, pressure screen fractionated short fiber is very clean - it usually does not need additional fine screening – top liner.
- The long fiber fraction is more difficult to fine screen, but sometimes the end use (base sheet) does not need to be as clean.
“Engineered” Sheets

- Separate long fibers from short fibers:
  - Long fibers have higher bulk
  - Short fibers have higher stiffness
- Make a three layer sheet with short fibers on the outside, long fibers on the inside
- Result: A stiffer composite sheet than an equal weight sheet of uniform composition
Top Liner and Back Liner for Cylinder board from single Stock

- Multi-layer cylinder paperboard is generally produced from
  - 2 layers of top liner (smooth, bright surface for printing or coating),
  - 4-6 layers of filler (low cost, high bulk),
  - and sometimes 2 layers of back liner (intermediate properties).

- Fractionation can be used to direct fibers to different layers

- Filler can be upgraded by fractionation, but great care must be taken to produce stocks of suitable properties (cleanliness, smoothness, and freeness)

- Some commercial success
Separate Grades Produced on Separate Paper Machines

- Pressure screens or cleaners can be used to separate a heterogeneous stock into streams suitable for production of different grades of paper;
- The paper is made on different paper machines;
- Example: Linerboard and corrugating medium from OCC;
- Generally not feasible due to lack of compatible grades and production rates at the same mill site.
Selective Refining / Recombination

- Fractionated long fibers can be refined, and then recombined with the short fibers to improve strength, save energy, and reduce the generation of fines.
Selective vs Joint Refining

Fig. 19.5. Fractionation and joint processing: Development of burst strength in laboratory test.
Selective Refining / Recombination Data

![Graph showing Selective Refining / Recombination Data]

- **CSF (mL)**
  - Underflow
  - Feed
  - Overflow
  - Recombined

- **Furnish: deinked ledger**

- **Refining Energy (relative units)**
The Curse of Fractionation

What to do with the “other” fraction

- The short fiber fraction is much lower consistency and freeness than the long fiber fraction
  - Pressure screens: shorts = 1-2%, 150-300 CSF;
  - Centrifugal cleaners: shorts <0.5%, 20-300 CSF;
  - Flotation: shorts <1%, high ash content;
  - Washing devices: shorts <0.3%, high ash content

- Yield loss, disposal of fiber fines and ash is very costly
  - Deink systems typically must have a yield of 70-85%
  - OCC or mixed waste yields must be much higher
  - No yield loss, no fractionation, no property improvement
Where is the Greatest Potential for Fiber Fractionation

- Multilayer papermaking from a common furnish
- Upgrading of sludge from pulp mills and fine paper mills for use in packaging and building papers
- Making multiple grades of market pulp from highly mixed recycled paper
- Automated dry sorting
- Finding new uses for low freeness, high fines, high ash pulps
  - High density construction board?
  - Fuel source?
Demands on a Fractionation System

- A primary requirement of any fractionation system is high selectivity.

- Other requirements include:
  - Adaptability to changing raw materials and to various characteristics.
  - High feed stock consistency to save pump energy and chest capacity and to avoid intermediate thickening.
  - Low specific energy consumption.
  - Low specific floor space needs.
  - Low overall capital and maintenance costs.
  - Lack of environmental problems.
  - High operational reliability and low manpower requirements.
Conclusions

- In selected cases fractionation has been used in stock preparation systems as an economically viable method of improving quality, cutting costs, and stabilizing the properties of the end product, especially with multi-layered boards.
Lecture

Stickies: Tacky Contaminants
Stickies

Contributors
Richard A. Venditti(1), Mahendra Doshi(2)

(1) North Carolina State University
Dept. of Wood and Paper Science

(2) Progress in Paper Recycling
Sticky Contaminants (Stickies)

A sticky particle:
- is typically hydrophobic
- is tacky and depositable
- often DEPOSITS ON EQUIPMENT
- Often adsorbs particulates/dissolved species on its surface

Examples of adsorbed species might include talc, Calcium Carbonate, Inks, Toners, polymers …
What are stickies?

Stickies in paper recycling are believed to be a mixture of:

----Hot melts adhesives
----Pressure-sensitive adhesives (PSA’s)
----Glues
----Wax
----Inks, Paper additives, Coatings
----Wood derived extractives…
*The actual surface behavior of stickies depends on the adsorbed species.*
Composition of Hot Melts

- Vinyl Acetate Polymers and Copolymers
- Tackifiers
- Wax
Properties of Hot Melts

- 100% Solid Formulations
- Soften at 150°F to 250°F
- Insoluble in Aqueous Media
- Soluble in Many Organic Solvents
- Density 0.9 to 1.0 g/cc
Composition of PSA

- Rubber Elastomer
  (e.g. Styrene-butadiene or poly-acrylate)
- Tackifiers
- Fillers (MgO, ZnO, etc.)
Properties of PSA

- Tacky at room temperature
- Insoluble in Aqueous Media
- Soluble in Many Organic Solvents
- Density 0.9 to 1.1 g/cc
- Often (but not always) precipitate with drops in pH
CLASSIFICATION OF STICKIES

PRIMARY
(Formed in pulper)

SECONDARY
(Change in environment, pH, temp., etc.)
Micro versus Macro Stickies

Macrostickies
Retained on 6-cut
6 cut = 0.006 inches
(0.15 mm)
(150 micrometers)
slotted screen

Microstickies
Pass thru a 6-cut slotted screen
Stickies Size Classifications:

- **Dissolved**
- **Colloidal**
- **Dispersed**
- **Suspended**
- **Macro**

**Microstickies**

- 6 - cut
- 0.006 inches
- (0.15 mm)
- (150 microns)
- (150 micrometers)
Micro vs Macro Sticky:

- **Macro stickies**
  - Are large, can be screened
  - Are visible and offensive in products

- **Micro stickies**
  - Are small, are carried along with water, can not be screened
  - Are very chemistry sensitive, can agglomerate and precipitate
  - Water clarification can be effective
  - Often must dump water or be retained in product to deal with
  - Can not generally be seen in a product
Stickies-Related Problems

- **Product quality**
  - Dirty spots in paper
  - Holes in the paper
  - Picks in the paper
  - Converting issues
    - Coating
    - Printing
    - Folding, scoring, cutting

- **Operational problems**
  - Deposition on machine
  - Breaking web
  - Down time for cleaning
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (recyclable adhesive)
- Avoidance: Control of recovered paper quality
- Mechanical removal: screening and cleaning
- Water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganic particles
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Continuous cleaning of papermaking clothing
- Water dumping
- Mill shut down for clean-up
Lecture

Stickies: Control and Removal
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (EBA, recyclable adhesive)
- Avoidance: Control of recovered paper quality
- Mechanical removal: screening, cleaning and water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganics
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Mill shut down for clean-up

Richard A. Venditti, Mahendra Doshi
Governmental efforts to promote benign adhesives

- US Postal Service, USPS P1238-F, qualifies products,
  - all stamps are EBA

  - Mandates use of EBA’s for government purchases
  - Not all tapes and labels are EBA

- Cost circa $100,000,000 in United States
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (recyclable adhesive)
- **Avoidance**: Control of recovered paper quality
- Mechanical removal: screening and water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganics
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Mill shut down for clean-up
Recovered Paper Quality Control

- Stickies
  - Dirt
  - Groundwood
  - Strength
  - Coated
- Plastic films
- Brightness
- Glass, Metal
- Municipal trash
- Uniformity
What to measure in bales if stickies are the concern?

1. Visually inspect outside of bales for stickers....

2. Visually inspect bale after opening.

3. Can supplier/location/grade be identified with high stickies content: keep track?

4. Reject bales with justification or simply discuss needs with supplier.
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (recyclable adhesive)
- Avoidance: Control of recovered paper quality
- Mechanical removal: screening, cleaning and water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganics
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Mill shut down for clean-up
Pulper Performance

- Often can not change parameters
- Gentle pulping
- Drum pulping
- Pre soaking
- Short pulping time
- Low temperature
- Low pH
Analysis of Macro Stickies - SOW

M. A. Pikulin, AF&PA and USPS Joint Conference to Address PSA Issues, June 1996
Intense Forces in a Pressure Screen Break/Deform Adhesives: Decreases Screening Efficiency

Shredding makes particles more 1-dimensional

"Thousands of small particles generated"
Improved screening efficiency:

- Lower consistency
- Lower pressure drop
- Lower temperature
- Lower passing velocity
- Feed forward versus cascade arrangement
SCREENING SYSTEM

Simple Common Sense Principles

1. Do not mix a clean stream with a dirty stream.

2. Avoid recirculation of contaminants.
SCREENING SYSTEMS

Conventional Cascade Arrangement

FEED

ACCEPTS

REJECTS
SCREENING SYSTEMS

Forward Flow Arrangement

0.008” slots

0.006” slots

Or higher reject ratio
SCREENING SYSTEMS
Forward Flow Arrangement

FEED

ACCEPTS

REJECTS
SCREENING SYSTEMS

Forward Flow Arrangement

FEED

ACCEPTS

REJECTS
Through Flow Cleaner: removes low density contaminants

Also note, that reverse cleaners are another type of cleaner used to remove low density contaminants.

Reverse cleaners look like a forward cleaner except the top middle port is the rejects (and is smaller) and the bottom cone tip is the accepts (but is wider), picture not shown here.
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (recyclable adhesive)
- Avoidance: Control of recovered paper quality
- Mechanical removal: screening and water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganics
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Mill shut down for clean-up
Water Treatment

- Re-use filtrates (often from thickening or washing process) to conserve water
- Clarifier objective: take filtrate and make a sludge and a filtrate
- Filtrate to Clarifier: 2000 ppm suspended solids
- Clarified water: 100 ppm suspended solids
- Sludge: 3-7% solids
- No change in colloidal or dissolved species
DAF Clarifier

- Raw Water
- Chemicals
- Settled Sludge
- DAF Clarifier
- Floated Sludge
- Scoop
- Air
- Clarified Water
Improved **micro** stickies removal efficiency:

- Improvement to the water clarification process.
- Maximum air addition and retention time.
- Proper type/dosage/mixing of chemicals.
- Routine testing of suspended solids removal.
- Additional clarifier capacity
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (recyclable adhesive)
- Avoidance: Control of recovered paper quality
- Mechanical removal: screening and water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganics
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Mill shut down for clean-up
Additives to Combat Stickies

- **Solids/Slurry**
  - Inorganic (Talc)

- **Liquids/Emulsions**
  - Inorganic (Zirconium Compounds)
  - Organic
    - Cationic fixatives to fibers
    - Anionic (Negative Charge)
    - Nonionic (Surfactant)—stabilize adhesive particles
    - Starch

- **Enzymes**: hydrolyze ester groups making stickies more stable in water
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (recyclable adhesive)
- Avoidance: Control of recovered paper quality
- Mechanical removal: screening and water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganics
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Mill shut down for clean-up
Physical adsorption to paper fibers: retention

- Cationic polymers with high charge density and low MW used to fix anionic stickies to anionic fibers
- Starch, proteins, alum and others…
- Needs good mixing in stock prep area
- Requires passivation of papermaking equipment
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (recyclable adhesive)
- Avoidance: Control of recovered paper quality
- Mechanical removal: screening and water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganics
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Mill shut down for clean-up
Dispersion

- Dispersing System:
  - Process stock is dewatered to 30%K
  - Clods of stock are broken in the breaker screw
  - Steam introduced into a heating screw to increase temperature to 185-245 C
  - Stock fed to dispersing unit
  - Stock is diluted and agitated for further processing
Dispersion

- Must have excellent washing and water clarification directly after dispersion
- Should use an additive to pacify the particles
- Otherwise, the problem will worsen for papermachine
- Not recommended, energy intensive and harm to the fibers
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (recyclable adhesive)
- Avoidance: Control of recovered paper quality
- Mechanical removal: screening and water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganics
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Mill shut down for clean-up
Control and Removal Methods for Stickies

- Use of environmentally benign adhesive (recyclable adhesive)
- Avoidance: Control of recovered paper quality
- Mechanical removal: screening and water clarification
- Chemical control: polymers surfactants, others
- Passivation with inorganics
- Enzyme hydrolysis
- Physical adsorption to paper fibers: retention
- Dispersion
- Protection: treatment of equipment to limit deposits
- Mill shut down for clean-up
If a clean-up is needed:

- The amount of residual cleaner in the paper machine water loop should be minimized if not reduced to zero concentration before start up.
- Basically, cleaners are dispersants for stickies, any residual cleaning material can actually interact with stickies and possibly cause increased stickies deposits.
- Follow the instructions of the cleaner manufacturer carefully.
Lecture

Stickies: Measurement
How to detect a sticky?

- **Sticky detection is incredibly difficult**
  - Must detect the particles and also make sure they are tacky
  - Low concentrations of stickies
  - Intermittent concentration of stickies
  - Sometimes the stickies exist, but are in a pacified state and might not be detectable
  - Statistical significance often impossible
  - Testing methods tedious
How to detect a sticky?

- Stickies: typically a synthetic polymer (hydrophobic)
- Papermaking Fiber Furnish: Lignocellulosic materials (hydrophilic)

  - Hydrophobicity
  - May be dyed differently a different color
  - Screening plus.....
  - Deposition on a surface
  - Melt versus decompose
  - Tack
  - Solubility in organic solvents
  - Others
How to detect a sticky?

- **Stickies**: typically a synthetic polymer (hydrophobic)
- **Papermaking Fiber Furnish**: Lignocellulosic materials (hydrophillic)

![Poly(styrene)](image1)

![Cellulose](image2)
How to detect a sticky?

- **Stickies**: typically a synthetic polymer (hydrophobic)
- **Papermaking Fiber Furnish**: Lignocellulosic materials (hydrophillic)

![Poly(styrene)](image)

![Lignin](image)
Categories of Methods for Stickies Detection

- Macro (large) stickies methods
- Micro (small) stickies methods
- Dissolved and colloidal methods
Stickies Size Classifications:

- **Dissolved**
- **Colloidal**
- **Dispersed**
- **Suspended**
- **Macro**

**Microstickies**

- 6 – cut
- 0.006 inches
- (0.15 mm)
- (150 microns)
- (150 micrometers)
Macro-stickies Detection Methods Studied

- **Bleaching and dyeing**
  - Bleach with Chlorite and make Handsheets
  - Perform Image Analysis
  - Dye with Morplas Blue
  - Perform Image Analysis
Macro-stickies Detection Methods Studied

- **Deposition:**
  - Low Consistency pulp slurry exposed to counter rotating paper machine wires
  - Determine Gravimetrically the Deposits
  - Dye deposits and perform Image analysis
Stickies Deposition Tester

Motor

Gears

Paddle

Water Bath
Macro-stickies Detection Methods

- **Tappi Test Method T-277**:
  - Screen pulp with Pulmac Masterscreen (0.006 inch slots)
  - Collect rejects on black filter paper
  - Press against white coated paper: adhesives pick-up white coating
  - Use black marker to darken brown fiber
  - Image Analysis
Macro-stickies Detection Methods

- Port Townsend Method 1: Handsheets (Steve Nordwell)
  - Make Handsheets
  - Dye with black ink, stickies do not pick-up ink
  - Perform Image Analysis
Macro-stickies Detection Methods

- Port Townsend Method 2: Screening
  - Screen pulp with Pulmac Masterscreen (0.006 inch slots)
  - Dye rejects with black ink, stickies do not pick-up ink
  - Perform Image Analysis
Effort Required for Test Methods

- **Macro-stickies Test Methods:**
  - Bleaching and Dyeing Method: 4 hrs
  - Deposition Testing:
    - gravimetric: 2 hrs
    - image analysis: 3 hrs
  - Tappi T277 pm-99: 1.5 hrs
  - Port Townsend 1: Handsheets: 1.5 hrs
  - Port Townsend 2: Screening: 2 hrs
## Summary of Macro-Stickies Tests

<table>
<thead>
<tr>
<th>Weyerhaeuser Mill Samples</th>
<th>Avg. 95% CI</th>
<th>SPAN</th>
<th>100%* Avg CI / SPAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleaching and Dyeing</td>
<td>3900</td>
<td>1330</td>
<td>300</td>
</tr>
<tr>
<td>PT Method 1</td>
<td>6060</td>
<td>5800</td>
<td>104</td>
</tr>
<tr>
<td>PT Method 2</td>
<td>8920</td>
<td>17360</td>
<td>52</td>
</tr>
<tr>
<td>T277</td>
<td>12540</td>
<td>7690</td>
<td>164</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inland Mill Samples</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleaching and Dyeing</td>
<td>1720</td>
<td>100</td>
<td>1710</td>
</tr>
<tr>
<td>PT Method 1</td>
<td>1940</td>
<td>3830</td>
<td>50</td>
</tr>
<tr>
<td>PT Method 2</td>
<td>5100</td>
<td>21000</td>
<td>24</td>
</tr>
<tr>
<td>T277</td>
<td>21930</td>
<td>128330</td>
<td>17</td>
</tr>
</tbody>
</table>
OTHER MACROSTICKIES QUANTIFICATION

- Fluorescent Speck Counting Method
- Sulzer Escher Wyss Method
- Southeast Paper Method
- Dye Method
- Manual Method
Manual Method

- Screen 100 g stock through 6-cut (0.150 mm) slotted screen. Collect rejects on filter paper.
- Dry and press against clean sheet, stickies transfer.
- Manually probe under microscope with pin all spots.
- Count sticky spots/100g pulp.
- This is tedious but can be very dependable compared to other methods!!!
Micro-stickies Research Methods (Tests):

- Deposition: polyethylene bottle
- Deposition: polyethylene film
- Solvent Extraction (requires screening)
- Pulmac Macro and Micro method, United States Patent 7674355
PE Bottle Deposition Method
PE Film Deposition Method
Solvent Extraction
Method of measuring macro and micro stickies in a recycled sample containing pulp fibers

United States Patent 7674355

- Screen the macrostickies with the Pulmac and weigh the macrostickies
- Retain the material that passed through the screen, agglomerating the micro stickies to form agglomerated micro stickies.
- Screen the agglomerated micro stickies.
- The agglomerated micro stickies are removed separation device and weighed.
Manufacture of packaging grades from recovered paper
Introduction

- Recovered paper began being used in packaging grades during WWI
- It was used more in fiber deficient countries like the UK
- differences between fiber deficient countries and fiber rich countries, like the USA and Canada

<p>| Table 8.1 Wastepaper use in the production of packaging grades in the UK, in 1992 |
|------------------------------------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Grade</th>
<th>Total production (Mt)</th>
<th>Total wastepaper use (Mt)</th>
<th>Utilisation rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrugated case materials</td>
<td>1.381</td>
<td>1.510</td>
<td>109</td>
</tr>
<tr>
<td>Packaging board</td>
<td>0.670</td>
<td>0.461</td>
<td>41</td>
</tr>
<tr>
<td>Packaging papers</td>
<td>0.092</td>
<td>0.038</td>
<td>69</td>
</tr>
<tr>
<td>Total</td>
<td>2.143</td>
<td>2.009</td>
<td>94</td>
</tr>
</tbody>
</table>

<p>| Table 8.2 Wastepaper use in containerboard production, in the USA, in 1992 |
|------------------------------------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Grade</th>
<th>Total production (Mt)</th>
<th>Total wastepaper use (Mt)</th>
<th>Utilisation rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Containerboard</td>
<td>27.7</td>
<td>15.1</td>
<td>35</td>
</tr>
</tbody>
</table>

Technology of Paper Recycling, McKinney
Introduction

- The USA and Canada had considerable government pressure to increase recovered paper use due to the significant contribution of paper and board packaging to domestic and solid waste steams.

Table 8.3 Contribution of fibrous packaging grades to solid wastes (% of total)

<table>
<thead>
<tr>
<th></th>
<th>Commercial waste</th>
<th>Domestic waste</th>
<th>Municipal solid waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>13.9</td>
<td>6.5</td>
<td>-</td>
</tr>
<tr>
<td>USA [1]</td>
<td>19.2</td>
<td>7.7</td>
<td>13.5</td>
</tr>
</tbody>
</table>

\(^a\)Average of surveys in City of London [2], City of Westminster [2] and West Midlands [3]

Introduction: Packaging Grades from Recovered paper

- Components of corrugated containers – liner grades, jute or test liner, and waste-based corrugating medium.
  - In white-top liner grades the white layer can be deinked fiber from wood free wastepapers or bleached virgin fibers
- Solid board- called folding box-board, containerboard, and paper board.
  - Solid board grades may also have a white layer and may be coated as in white lined chipboard
- Packaging Papers – paper bags, wrapping papers, etc.
Introduction: Corrugated Containers

- Stiffness is the most important criterion for corrugating, which is why hardwood fibers are used.
- The structure of combined board, medium, and liner is illustrated in Figure 8.1.
Properties of Recycled Fiber Grades

- Corrugating medium or fluting
  - Medium is hidden: appearance not important
  - Mechanical properties and runnability issues on the corrugator are major performance criteria
  - Compressive strength is the single most important requirement for corrugated boxes, related to the edgewise compressive strength (ECT)
    - ECT is largely dependent on the compressive properties of the components of combined board (liners and corrugated fluting)
  - Various tests are used to measure properties related to strength and stiffness:
    - Concora medium test (CMT)
    - Ring crush test (RCT)
    - STFI (short span compression test, or index)
    - Edgewise compression test (ECT)
Introduction: Corrugated Containers
**Bursting Strength:**
The combined tensile strength and stretch of a material as measured by the ability of the material to resist rupture when pressure is applied under specified conditions to one of its sides by an instrument used for testing the property. Testing for the bursting strength of paper is a very common procedure, although its value in determining the potential permanence or durability of paper is suspect.

**Ring Crush Test:**
Ring Crush is a traditional test of linerboard and corrugating medium strength. Ring crush measures compression resistance, and this compression strength is considered to relate to the eventual compression strength of combined board made from the component. Linerboard called high strength or high performance linerboard is board that is able to achieve a specified minimum ring crush at basis weights that are lower than traditional basis weights.

**Concora Crush Test:**
The Concora Crush Tester performs a series of tests to determine the rigidity and crush resistance of corrugated material. It is used in conjunction with the Concora Liner Tester. The first test measures the flat crushing resistance of a laboratory-fluted corrugated material. The second test determines the edgewise strength, parallel to the flutes, of a short column of single-, double-, or triple-wall corrugated board. The third test evaluates the ability of corrugated material to contribute to the compression strength of a corrugated box by measuring the edgewise compression strength of a laboratory-fluted strip of corrugated material in a direction parallel to the fluted tips.

http://www.uccbox.com/page/standard_testing-eng.html
Recovered paper use in Liner Grades

- In virgin kraft liner production, filler fibers can be used, up to about 15-20%, without adversely affecting strength properties.
- Frequently, old news print (ONP) or similar grades are used, without deinking, though centrifugal cleaning and screening may be necessary to remove contaminants such as grit and stickies.
- Up to 20% wastepaper use still permits the linerboard to be classified as virgin liner board in the USA.
- Test, jute, or bogus liner is usually made from 100% waste, but from grades which contain some softwood kraft fibers.
Recovered paper use in Liner Grades

- White top liner can be produced from 100% wastepaper.
  - The white ply is made from deinked woodfree grades made to have a clean, bright layer with good printing properties.
  - Because the top ply needs to be so clean, there must be two separate fiber prep systems, including water, although backwater from the white prep may feed to the brown prep, but not vice versa.
Introduction: Folding Box-Board Grade

- Heavyweight grades of solid board are normally produced on multi-ply machines.

Figure 8.2 Coated packaging board (box-board).
Recovered paper use in Folding Box-Board Grade

- This grade has to be stiff, able to fold and scores, and usually has to have good printing properties.
- Short fibers enhance stiffness but long fibers give strength and runnability properties.
- Short fibers in the top ply provide good printing properties, which are improved by coating.
Recovered paper use in Folding Box-Board Grade

- Inner or filler plies tend to be produced from low-quality grades while outer plies (top liner and back liner) are made from higher quality grades.

- If white-top or coated board is produced, a news ply can be added between the white top and the brown grade, called the under liner ply, to reduce the weight of the white ply needed to cover the brown.
Machine Runnability with Recycled Grades

- Major problem is stickies
  - contamination of board machine clothing,
  - holes and tears in the product and
  - contamination of printing blankets
- Another runnability problem is the slower drainage of recycled fibers
  - the concentration of fines higher for recycled than virgin
  - Must take a reduction in yield to remove fines
  - Since board grades have very high basis weights, drainage limitations can considerably reduce machine productivity
Machine Runnability with Recycled Grades

- Box-board
  - Machine configurations are similar for virgin or recycled grades but vary appreciably according to the type of product
  - White lined chip and box-board machines usually use vat formers
    - A major disadvantage of the vat former with respect to recycled-fiber grades is a problem with poor ply bonding
    - Fines help form strong ply bonds
    - Fines from recycled pulp are inert and do not form inter-fiber bonds, thus acting as a hindrance to good ply bonding
    - Inert fines removal reduces yield, but helps improve ply bonding
Liner board and medium

- Liner board machines are fourdriniers
- Newer machines tend to produce two (or more) ply liner, which is achieved by the use of, for example, a secondary headbox, two wires, or a multilayer headbox
- Twin wire gap formers are being used due to their potential for higher speed operation and good formation, among other things
Effect of the Use of Recycled Fibers on Product Properties

When recycled fibers are used, it is inevitable that strengths are lower, since inter-fiber bonding is reduced by a combination of mechanisms, including:

- fines build-up that don’t bond well and interfere with fiber-fiber bonding
- Hornification of the cell wall, stiff fibers, preventing bonding
- Hornification at the surface of the fiber, which increases stiffness, less inter-fiber bonds will be formed
- Non-fibrous contaminants accumulate – clay, ink particles, stickies, etc.
  - Prevent inter-fiber bond formation
  - result in localized weak points in the sheet, leading to erratic sheet properties
- Some multivalent cations and salts may bond to carboxyl groups of fibers, preventing inter-fiber bond formation
- Due to freeness considerations, recycled fibers may not be refined to their full strength potential
Effect of the Use of Recycled Fibers on Product Properties

- There is a constant compromise between cleanliness, yield of wastepaper, and strength development.

- Other means to improve strength properties are:
  - Increased basis weight to give equivalent performance to virgin grades
  - Use of strength aids, such as starch, which is very widely used in Europe, but less so in the USA
  - Use of higher grades of fiber,
Effect of the Use of Recycled Fibers on Product Properties

- Starch use in recycled papers
  - Starch is the most important dry strength additive used in brown grades, and can be >5% of the final sheet weight, excluding starch used as a corrugating adhesive.
  - Starch improves inter-fiber bonding through adsorption and the creation of new bonding sites on fiber surfaces, with stronger than original fiber-to-fiber bonds.
  - Despite the disadvantages, starch is widely used since it provides a low-cost method by which recycled grades can reach necessary strength properties.
  - Starch addition also improves surface strength, pick resistance, and inter-ply bonding.
Effect of the Use of Recycled Fibers on Product Properties

● Starch use in recycled grades

■ Several disadvantages:
  – Addition increasing drying requirements,
    ● especially via a size press, which can reduce machine speed, given a fixed drying capacity
  – Organic strength of effluents is much higher
  – Machines tend to run ‘dirtier’
  – Must make up and store properly or else use is inefficient and performance variable
  – Dependent on the type of starch used, control of wet end chemistry can become more difficult
  – Internal sizing can be impaired, together with formation
Improving the Properties of Recycled Fiber Grades

- **Solid fiberboard, box-board**
  - Finished boxes must have stacking strength, to avoid collapse or excessive bulge, and are frequently printed, so that the appearance and printability may be as important as protection.
  - Stiffness is the most important mechanical property.
  - Stiffness can be increased
    - with refining, which improves fiber bonding
    - with the use of starch or other chemical additives
Improving the Properties of Recycled Fiber Grades

- Solid fiberboard, box-board
  - Strong surfaces are needed with the ability to accept high printing and converting speeds
    - Smoothness can be achieved by calendering, but it also reduces caliper, which decreases stiffness and compressive strength
  - A specky top ply is unattractive and difficult to print on
    - Tools to improve appearance
      - Recovered paper type for top ply
      - Contaminant removal system
      - Separation of stock and water for top ply
      - Good machine cleanliness
Improving the Properties of Recycled Fiber Grades

- Corrugating medium or fluting

- To improve strength or stiffness the options are
  - to use starch, normally applied at the size press,
  - or to increase wet pressing, making a more dense sheet

- Where starch is used to improve strength, porosity is an indicator of starch uptake
  - If the porosity is low, it may not be able to absorb sufficient starch

- Starch viscosity can also be changed to improve starch absorption, but reducing viscosity may mean reducing machine speeds
Improving the Properties of Recycled Fiber Grades

- Liner board, test liner
  - Due to its lower strength properties, but lower cost, test liners were first used as the inner liner, to give cost savings in box production.
  - Since then, developments have allowed test liner to substitute for kraft over a much wider range of applications
    - Techniques which have been adopted to improve mechanical properties of test liner include:
      - Starch or other chemical additives or treatment
      - Increased basis weight
      - Increased mechanical pressing
      - Wastepaper processing techniques, such as fractionation
      - Wastepaper grade selection
Lecture

Manufacture of newsprint from recovered paper
Historically, the majority of newsprint producers who used recycled fibers were in the fiber limited regions.

- Fiber limitations, in regions such as the Far East and western Europe, will continue to contribute to the growth of recycled fibers in newsprint production.
- However, other factors, such as legislative requirements, strict energy usage requirements, and technological advances in both processing of wastepaper as well as paper making has resulted in sustained use of recycled fibers in newsprint.
Recovered Grades Used

Old newspapers (ONP)

- Generally speaking, ONP has a high percentage of mechanical fiber, groundwood, or thermochemical pulp
  - Chemical pulp (kraft or sulphite pulp) can be as much as 30% by weight of the furnish
- ONP includes additives such as starch, inorganic fillers and dyes for color control
  - ONP is relatively low in these additives, with ash ranging from 3-12 wt%
- Ink makes up 1-2 wt% of the ONP furnish
**Recovered Grades Used**

- **Magazine:** A generic term which generally refers to coated paper that is bound with staples or glue
  - Highly variable raw material
    - Fiber content can range from 100% kraft pulp to 100% groundwood
    - An individual magazine may have several different grades of paper included in its production
    - In addition to fiber variability, the additives are also highly variable
      - In magazine stock, the inorganic portion of the furnish can range from 10 wt% in the uncoated sheets to as high as 50 wt% in a sheet coated on both sides
    - Contaminants associated with magazine grades are introduced in the converting process
      - Adhesives associated with bindings, thermal plastics, and hot melts can all contribute to stickies
      - Ink printed on coated paper can present a removal challenge in the deinking stages
        - Ink can range from 1-7 wt%
Recycled Fiber Processing

- Process flow sheets
  - Deinking technology varies for different reasons including quality requirements, resource availability, wastepaper characteristics, per cent of recycled fiber in furnish, and environmental regulations.
Quality and Performance of Recycled Newsprint

- In general terms newsprint produced from recycled fibers relative to virgin newsprint has:
  - a higher density,
  - lower caliper,
  - is more absorbent
  - has a lower coefficient of friction
  - Has a potentially better smoothness and porosity,
  - Strength properties are generally equivalent
  - Optical properties, such as scattering coefficient and opacity are generally improved
  - Brightness tends to be lower and shade variability increases
Quality and Performance of Recycled Newsprint

- Pulp from deinking operations uses slightly more raw material and significantly less electricity.
- Variable manufacturing costs excluding raw materials and energy are larger for the deinked pulp.

ADMT = air dry metric tonnes

Table 9.4 Comparison of units of consumption for virgin and recycled fibres

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>TMP</th>
<th>Deink</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>ADMT</td>
<td>1.042</td>
<td>1.176</td>
</tr>
<tr>
<td>Energy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh</td>
<td>2200</td>
<td>600</td>
</tr>
<tr>
<td>Steam</td>
<td>MJ</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*ADMT, air dry metric tonnes

Table 9.5 Comparison variable manufacturing costs for virgin and recycled fibres

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>TMP</th>
<th>Deink</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour (fully loaded)</td>
<td>$25/effort hour</td>
<td>9.00</td>
<td>10.25</td>
</tr>
<tr>
<td>Pulp process</td>
<td></td>
<td>2.25</td>
<td>1.75</td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemicals</td>
<td>$/ADMT</td>
<td>10.00</td>
<td>25.00</td>
</tr>
<tr>
<td>Supplies</td>
<td>$/ADMT</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>Pulp process</td>
<td></td>
<td>5.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscellaneous operating expense</td>
<td>$/ADMT</td>
<td>15.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Overhead</td>
<td>$/ADMT</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Solid-waste disposal</td>
<td>$/ADMT</td>
<td>0</td>
<td>8.75</td>
</tr>
<tr>
<td>Total (excluding raw material and energy)</td>
<td></td>
<td>49.75</td>
<td>66.25</td>
</tr>
</tbody>
</table>

*ADMT, air dry metric tonnes
Overall variable cost of deinked pulp versus virgin pulp is lower in general

- a constant wood chip price of $75/ADMT.
- Case 1: low wastepaper cost - $50/ADMT
  low energy cost - $0.02/kWh
- Case 2: high wastepaper cost - $100/ADMT high energy cost - $0.05/kWh
- Case 3: low wastepaper cost - $50/ADMT
  high energy cost - $0.05/kWh
- Case 4: high wastepaper cost - $100/ADMT
  low energy cost - $0.02/kWh
Lecture

Manufacture of tissue from recovered paper
Introduction: Tissue

- Tissue is a light weight paper
- Can be made from virgin or recycled pulps
- Grammage can be as low as 5 g/m²
  - Reference: (copy paper is about 75 g/m²)

Requirements
- Strong
  - Product
  - Runnability
- Absorbant
- Soft
- Clean
Tissue Machine

Fourdrinier

Yankee Dryer

Calender

Detail of Creping Action

Wet Press

After Dryer
Introduction: Tissue

- Produced on a single large steam heated drying cylinder (yankee dryer) fitted with a hot air hood.
- Creping is done by the Yankee's doctor blade that is scraping the dry paper off the cylinder surface.
Introduction: Tissue

Fig. 3. Creped sheet of paper for a creping angle of (A) and (B), in which the creping direction is horizontal [2]
**Creping**

- Doctor blades are "consumables".
- Wear rates can be high!
- The wear changes the contact geometry which can change performance during the run.
- Courtesy Joel Pawlak, NCSU
Introduction: Tissue

- Tissue is unique in the pulp and paper industry in that the product which leaves an integrated converting facility is ready for use by the final consumer.
- Because of this, competition amongst producers for retailers’ business is intense, and retailers respond very rapidly to changes in customer preferences.
  - Example. Inclusion of recycled fibers.
Introduction

- Recovered paper had been used prior to the late 1980s due to significant cost advantages over virgin fiber use
  - May be up to 50% less expensive
- When using recycled fiber, however, it is not always possible to maintain some attributes of high quality premium products
Grade Structure

- In the US about 30% is away from home grades (low quality) and 70% is at home.

- This is a large growth sector of the paper industry.

- The final product has a very high profit margin:
  - Recovered paper $100/ton
  - Virgin pulp $600/ton
  - Finished tissue product $30,000/ton

![Table 10.1 Typical wastepaper utilisation rates and grades used in toilet paper production](image)

*a Mixed printed – mixed woodfree and wood-containing.  
*b Mixed woodfree – printed and coloured woodfree*
Grade Structure

- In the US about 30% is away from home grades (low quality)
- In the US about 70% is at home grades (high quality)
Grade Structure

- In the US about 30% is away from home grades (low quality)
- In the US about 70% is at home grades (high quality)
Specifications of recycled fiber for tissue production

- Some specs are related to product quality, others to tissue machine runnability, and some to both.
- Low ash is required to protect the creping blade.
- Some vary based on the type of product being produced:
  - Premium quality tissue requires a minimum brightness of 75-80 ISO.
  - Industrial toilet tissue requires a minimum brightness of 60-70 ISO.

### Table 10.4 Quality criteria for recycled bathroom tissue production

<table>
<thead>
<tr>
<th>Quality parameter</th>
<th>Woodfree, high quality</th>
<th>Typical range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash (%)</td>
<td>1–3</td>
<td>3–6</td>
</tr>
<tr>
<td>Brightness (ISO)</td>
<td>75–80</td>
<td>60–65</td>
</tr>
<tr>
<td>Ink/Dirt (Tappi ppm)</td>
<td>30–60</td>
<td>30–100</td>
</tr>
<tr>
<td>Stickies Content (#/100 g bdf)</td>
<td>10–50</td>
<td>10–50</td>
</tr>
<tr>
<td>Freeness (CSF, ml)</td>
<td>min. 350</td>
<td>min. 200</td>
</tr>
<tr>
<td>Burst strength (kPa m² g⁻¹)</td>
<td>min. 2.5</td>
<td>min. 1.5</td>
</tr>
<tr>
<td>Tear index (mN m² g⁻¹)</td>
<td>min. 7.0</td>
<td>min. 5.0</td>
</tr>
<tr>
<td>Breaking length (km)</td>
<td>min. 3.5</td>
<td>min. 3.0</td>
</tr>
</tbody>
</table>

Technology of Paper Recycling, McKinney
Amount of Rejects and Sludges for Production of Paper Grades

<table>
<thead>
<tr>
<th>Produced paper</th>
<th>Recovered paper grade</th>
<th>Amount of total waste [% by dry weight]</th>
<th>Amount of waste [% by dry weight]</th>
<th>Rejects</th>
<th>Sludges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flotation deinking</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heavy-weight &amp; coarse</td>
<td>Light-weight &amp; fine</td>
<td></td>
</tr>
<tr>
<td>Graphic paper</td>
<td>News, magazines</td>
<td>15–20</td>
<td>1–2</td>
<td>3–5</td>
<td>8–13</td>
</tr>
<tr>
<td></td>
<td>Superior grades</td>
<td>10–25</td>
<td>&lt; 1</td>
<td>≤ 3</td>
<td>7–16</td>
</tr>
<tr>
<td>Hygienic paper</td>
<td>Files, office paper, ordinary, medium grades</td>
<td>28–40</td>
<td>1–2</td>
<td>3–5</td>
<td>8–13</td>
</tr>
<tr>
<td>Market DIP</td>
<td>Office paper</td>
<td>32–40</td>
<td>&lt; 1</td>
<td>4–5</td>
<td>12–15</td>
</tr>
<tr>
<td>Liner, fluting</td>
<td>Sorted mixed recov. paper, supermarket waste</td>
<td>4–9</td>
<td>1–2</td>
<td>3–6</td>
<td>–</td>
</tr>
<tr>
<td>Board</td>
<td>Sorted mixed recov. paper, supermarket waste</td>
<td>4–9</td>
<td>1–2</td>
<td>3–6</td>
<td>–</td>
</tr>
</tbody>
</table>
Example tissue production process:

- A schematic outline of a wastepaper processing system, to produce good quality fiber from medium and low-quality wastepaper grades.
- A compromise between recycled fiber quality and fiber yield.
- Must have low ash, causes low yield, see two significant washing processes.

Figure 10.1 Schematic wastepaper processing system suitable for tissue.
Production Problems Associated with Recycled Fibers

Issues arising from the use of recycled fibers:

- Separate treatments of virgin and recycled fibers in stock prep
- High Ash
- Stickies
- Cleanliness
- Brightness
Production Problems Associated with Recycled Fibers

- **Stock Prep**
  - The use of a small amount of virgin pulp to mainly recycled pulp can improve strength (long fibers) or softness (short fibers)
  - To best exploit the virgin fibers separate stock prep lines must be used
  - Also a multi-layered headbox should be used
  - Adds extra equipment but better properties
Production Problems Associated with Recycled Fibers

- Stock Prep
  - a schematic of a single layered stock prep option
Production Problems Associated with Recycled Fibers

- Stock Prep
  - a twin layered stock prep option

Figure 10.3 Layered option (two layers) stock preparation system.
Production Problems Associated with Recycled Fibers

- Problems due to high ash
  - High ash has a major impact on tissue machine productivity, including:
    - Reduced drainage
    - Increased creping / doctor blade wear
    - Increased ash in white water system which leads to higher ash retention
    - Reduced felt and wire life
    - Increased dust

Production Problems Associated with Recycled Fibers

- Problems due to stickies
  - Stickies can affect productivity
    - Adhere to forming fabrics and press felts and can build up at doctor blades and on rolls, which tend to cause holes and breaks
    - Can reduce machine clothing life
    - Production losses due to machine downtimes to clean wires and felts
  - Stickies affect product quality
    - Unsightly dirt specks
    - Printing issues

- Sticky removal is one of the most critical parts of recovered paper processing.
Effects of Recycled Fiber Use on Tissue Quality

- Effects on Softness
  - Fiber selection is important factor in developing softness
    - Need thin walled flexible fibers
    - Recycled fibers are stiff, not flexible
  - To try to subdue effects of recycled pulp fibers, multilayered headboxes can be used to “hide” recycled fibers between layers of virgin fibers
Effects of Recycled Fiber Use on Tissue Quality

- Effect on Appearance
  - Appearance is adversely affected by recycled fiber
  - Because ink removal is <100% efficient, specks are normally present
  - However, a large proportion of consumers have accepted the recycled signature of a specky product
  - Lower brightness
Lecture

Manufacture of printing and writing papers from recovered paper
Printing and Writing Grades

- Printing grades include a broad classification of paper products that have traditionally been referred to as ‘fine paper’
- The general classification of printing and writing papers is:
  - Uncoated groundwood grades
  - Coated groundwood grades
  - Uncoated free sheet grades  **largest segment**
  - Coated free sheet grades
  - Specialty grades
The following grades can be commercially produced using printing and writing grades:

- Reprographic bond and writing
- Ledger
- Forms bond
- Carbonless
- Tablet
- Envelope
  - Offset
  - Premium text and cover
  - Commercial printing
  - Book paper
  - Technical specialties
Recovered Paper Grades

To make a commercial P&W product
- Recovered paper must be chosen carefully
  - Wood vs wood-free recovered paper
  - Colored versus white paper
- The processing system must be suitable to remove contaminants and produce paper with well defined optical and physical properties
- The market must accept the properties of the paper
Properties of Recycled Fibers

- It is well known by now that chemically pulped and bleached recycled fibers demonstrate a noticeable loss in strength properties.
  - So they are also assumed to be inferior, unpredictable, and unsuitable for the production of quality grades of printing and writing papers.
  - This is not true considering the successful commercial production of printing and writing grades.
Properties of Recycled Fibers

- Much information about running recycled paper has come from experience, one study concluded:
- Recycled paper can have a similar strength but at lower freeness than virgin fiber
- Intrinsic fiber strength is the same
- Similar tear strength
- Anionic trash and other contaminants can lower recycled strength
- Lower bonding capability also lowers recycled strength
Requirement for White Ledger, US Purchasing Guidelines

- Less than 1 % groundwood
- Lignin less than 3%
- pH greater than 6.5 for white paper
- Grammage: 90 g/m²
- Bursting strength: 21.75 psi
- Tear: 340 mN
- Thickness 0.105 mm
- Good erasing
- No feathering
- Brightness > 81 ISO
- No more than 1 speck, less than .025 mm² per 650 cm²
- No more than 650 specks for 1 m²

Government Paper Specification Standards
February 1999 No. 11
# Amount of Rejects and Sludges for Production of Paper Grades

<table>
<thead>
<tr>
<th>Produced paper</th>
<th>Recovered paper grade</th>
<th>Amount of total waste [% by dry weight]</th>
<th>Amount of waste [% by dry weight]</th>
<th>Rejects</th>
<th>Sludges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heavy-weight &amp; coarse</td>
<td>Light-weight &amp; fine</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphic paper</td>
<td>News, magazines</td>
<td>15–20</td>
<td>1–2</td>
<td>3–5</td>
<td>8–13</td>
</tr>
<tr>
<td></td>
<td>Superiors</td>
<td>10–25</td>
<td>&lt; 1</td>
<td>≤ 3</td>
<td>7–16</td>
</tr>
<tr>
<td>Hygienic paper</td>
<td>Files, office paper</td>
<td>28–40</td>
<td>1–2</td>
<td>3–5</td>
<td>8–13</td>
</tr>
<tr>
<td></td>
<td>ordinary, medium</td>
<td></td>
<td></td>
<td></td>
<td>15–25</td>
</tr>
<tr>
<td></td>
<td>grades</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market DIP</td>
<td>Office paper</td>
<td>32–40</td>
<td>&lt; 1</td>
<td>4–5</td>
<td>12–15</td>
</tr>
<tr>
<td>Liner, fluting</td>
<td>Sorted mixed</td>
<td>4–9</td>
<td>1–2</td>
<td>3–6</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>recov. paper,</td>
<td></td>
<td></td>
<td></td>
<td>0–1</td>
</tr>
<tr>
<td></td>
<td>supermarket waste</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Board</td>
<td>Sorted mixed</td>
<td>4–9</td>
<td>1–2</td>
<td>3–6</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>recov. paper,</td>
<td></td>
<td></td>
<td></td>
<td>0–1</td>
</tr>
<tr>
<td></td>
<td>supermarket waste</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
High Grade Printing and Writing Grades

1st remove coarse contaminants
2nd remove smaller contaminants, deinking
3rd disperse unremoved contaminants
4th bleach to high brightness
Production Problems Associated with Recycled Fibers in P& W

- Problems due to stickies
  - Stickies can affect productivity
    - Adhere to forming fabrics and press felts and can build up at doctor blades and on rolls, which tend to cause holes and breaks
    - Can reduce machine clothing life
    - Production losses due to machine downtimes to clean wires and felts
  - Stickies affect product quality
    - Unsightly dirt specks
    - Printing issues
  - Sticky removal is one of the most critical parts of recovered paper processing.
Production Problems Associated with Recycled Fibers in P& W

- Carryover of deinking chemicals
  - Foaming issues
- Problems due to anionic trash
- Lower chemical additive efficiency
- Increased deposits
- Changes in fiber chemistry
- Reduced bonding
- Strength reduction and paper machine breaks
- Slower drainage possible
- Fines Buildup
- Higher COD loads in the water effluent
Effect on Product Properties

- Appearance can be adversely affected by recycled fiber
  - Because ink removal is <100% efficient, specks are normally present
  - Possible: Lower brightness
  - Possible: More color
  - Possible: Color reversion
  - Changes in fiber chemistry and impact on printing
Solutions to the issue of using Recycled Fibers in P& W

- Blending recycled with virgin
- Improved processing of the recycled fibers
- Increased amounts of cationic starch
  - Increased strength
  - Anionic trash collector
- Use of talc or other inorganics to address stickies
- Chemical additives
- Proper refining