Other Resources on Paper Recycling

- Website with about 800 powerpoint slides on paper recycling: go.ncsu.edu/Venditti (downloads)

- youtube.com Then search for Richard Venditti paper recycling: 23 videotaped lectures with approximately 25 hours of lectures. Several guest lecturers discussing industrial issues. (all listed at go.ncsu.edu/Venditti)

- A course is being offered through Alabama Community College for college credit.

- Secondary Fiber Recycling, Tappi Press, Atlanta GA, 1993

Learning objectives

- To be able to describe:
  - trends in the paper recycling industry
  - common contaminants
  - the purpose and operation of common unit operations in a paper recycling mill
  - the major types of paper recycling mills
Recovered fiber greater than virgin fibers (408 million ton, 2016)

Source: RISI
Total Production in 2016 was 408,000 mt, Source: RISI, 2017

North America accounts for >20% of Global Export of Recovered Paper
US Paper Recycling Recovery Rate:

● 1999 (the peak US consumption)
  ■ Total Paper Consumption: 105 million tons
  ■ Total Paper Recovered: 47 million tons
  ■ Recovery Rate: = 45%

● 2004
  ■ Total Paper Consumption: 102 million tons
  ■ Total Paper Recovered: 50 million tons
  ■ Recovery Rate: = 49%

● 2015
  ■ Total Paper Consumption: 78 million tons
  ■ Total Paper Recovered: 52 million tons
  ■ Recovery Rate: = 66.8 %

Source: afandpa.org, 2015
Paper/board Recovery Rate in the US, 66.8%

RR = tons recovered/tons produced

Source: afandpa.org, 2016
Municipal solid waste

- MSW: everyday items that are discarded by the public
- Also referred to as trash, or rubbish
- Includes packaging, food scraps, grass clippings, sofas, computers, tires and refrigerators, for example.
- Does not include industrial, hazardous, or construction waste.
- Residential waste (houses and apartments): 55-65% of total MSW generation
- Commercial and institutional locations (businesses, schools, hospitals..): 35-45%
Figure 5. Total MSW Generation (by material), 2009
243 Million Tons (before recycling)

- Paper: 28.2%
- Food scraps: 14.1%
- Other: 3.5%
- Plastics: 12.3%
- Metals: 8.6%
- Glass: 4.8%
- Wood: 6.5%
- Rubber, leather, and textiles: 8.3%
- Yard trimmings: 13.7%

Source: EPA
Recovered and Landfilled Paper

Source: afandpa.org, 2016
Products with highest % recovery.

- Lead acid batteries, 96%
- Corrugated boxes, 85%
- Newspapers, 72%
- Steel packaging, 69%
- Major appliances, 65%
- Yard trimmings, 58%
- Aluminum cans, 50%
- Mixed paper, 45%
- Tires, 35%
- Glass Containers, 31%
- HDPE, milk containers, 29%
- PET Bottles, 28%

Source: EPA
*Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2009*
Where Recovered Paper Goes:

Source: afandpa.org, 2016
5 Major Recovered Paper Groups

- **Old Corrugated Containers (OCC), also known as corrugated cardboard:** Mills use old corrugated containers to make new recycled-content shipping boxes, as well as recycled paperboard for product packaging (cereal boxes, shoe boxes, etc.). POST-CONSUMER

- **Old Newspapers (ONP):** Mills primarily use old newspapers to make new recycled-content newsprint and in recycled paperboard and tissue, among other paper grades. POST-CONSUMER

- **Mixed paper:** Mixed paper is a broad category that often includes items such as discarded mail, telephone books, paperboard, magazines, and catalogs. Mills use mixed paper to produce paperboard and tissue, as a secondary fiber in the production of new paper, or as a raw material in non-paper product such as gypsum wallboard, chipboard, roofing felt, cellulose insulation, and molded pulp products such as egg cartons. POST-CONSUMER

- **High Grade Deinked Paper:** This grade is made of high grade paper such as letterhead, copier paper, envelopes, and printer and convertor scrap that has gone through the printing process. It must first be deinked before it can be reprocessed into high grade paper products such as printing and writing papers or tissue. PRECONSUMER

- **Pulp substitutes:** A high grade paper, pulp substitutes are often shavings and clippings from converting operations at paper mills and print shops. Mills can use pulp substitutes in place of virgin materials to make back into high grade paper products. PRECONSUMER

[http://www.epa.gov/osw/conserve/materials/paper/basics/grade.htm](http://www.epa.gov/osw/conserve/materials/paper/basics/grade.htm)
Recovery of OCC, 92.9%

Source: afandpa.org, 2016
Recovery of ONP (mechanical), 72.8%

Source: afandpa.org, 2016
Recovery of Printing Writing Papers, 58.6%

Source: afandpa.org, 2016
<table>
<thead>
<tr>
<th></th>
<th>Northeast</th>
<th>Midwest (Chicago)</th>
<th>Southeast³</th>
<th>Southwest³</th>
<th>LA SF¹</th>
<th>SF</th>
<th>Pacific NW³</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mixed (2) - OBM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown Grades</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bobk cut (4) - OBM</td>
<td>80-85</td>
<td>70-75</td>
<td>66-70</td>
<td>66-70</td>
<td>70-75</td>
<td>70-75</td>
<td>75-80</td>
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<tr>
<td>OCC (11) - OBM</td>
<td>80-85</td>
<td>80-85</td>
<td>75-80</td>
<td>70-75</td>
<td>90-95</td>
<td>80-85</td>
<td>75-80</td>
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<tr>
<td>DLK (13) - OBM</td>
<td>85-90</td>
<td>85-90</td>
<td>90-95</td>
<td>90-95</td>
<td>95-100</td>
<td>85-90</td>
<td>80-85</td>
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<tr>
<td><strong>Groundwood</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ONP (6) - OBM</td>
<td>50-55</td>
<td>55-60</td>
<td>55-60</td>
<td>55-60</td>
<td>75-80</td>
<td>65-70</td>
<td>55-60</td>
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<tr>
<td>OMG (10)</td>
<td>95-100</td>
<td>95-100</td>
<td>90-100</td>
<td>90-100</td>
<td>110-120</td>
<td>90-100</td>
<td></td>
</tr>
<tr>
<td>CGS (44)</td>
<td>95-100</td>
<td>95-100</td>
<td>90-100</td>
<td>90-100</td>
<td>110-120</td>
<td>90-100</td>
<td></td>
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<tr>
<td><strong>High Grades</strong></td>
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<tr>
<td>SOP (37)</td>
<td>135-145</td>
<td>110-120</td>
<td>110-120</td>
<td>110-120</td>
<td>150-160</td>
<td>125-135</td>
<td></td>
</tr>
<tr>
<td>CBS (43)</td>
<td>135-145</td>
<td>110-120</td>
<td>110-120</td>
<td>110-120</td>
<td>150-160</td>
<td>125-135</td>
<td></td>
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<tr>
<td>SBS heavy print (45)</td>
<td>160-170</td>
<td>130-140</td>
<td>135-145</td>
<td>135-145</td>
<td>165-175</td>
<td>125-135</td>
<td></td>
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<tr>
<td>SWL (40)</td>
<td>215-225</td>
<td>190-200</td>
<td>190-200</td>
<td>185-205</td>
<td>220-230</td>
<td>200-210</td>
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</tr>
<tr>
<td>MVL (41)¹</td>
<td>215-225</td>
<td>190-200</td>
<td>190-200</td>
<td>195-205</td>
<td>220-230</td>
<td>200-210</td>
<td></td>
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<tr>
<td><strong>Pulp Subs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>HWS (30)</td>
<td>310-320</td>
<td>290-295</td>
<td>305-315</td>
<td>305-315</td>
<td>295-305</td>
<td>270-285</td>
<td></td>
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<tr>
<td>HWE (31)</td>
<td>330-340</td>
<td>310-320</td>
<td>315-325</td>
<td>315-325</td>
<td>320-330</td>
<td>290-300</td>
<td></td>
</tr>
</tbody>
</table>

US$ per short ton for open market purchases by mills, FOB seller’s dock, for delivery this month. (Further specifications below.)

Incorporating Official Board Markets

³ Pacific NW refers to the Pacific Northwest region.

¹ MVL stands for Medium Value Light.

² LA SF stands for Long Beach South and Far West regions.

³ Southeast and Southwest regions vary in specifications and prices.

March 4, 2016
## PRICE WATCH: Recovered Paper - Export

March 4, 2016

Open market transactions for delivery this month, US$. (Further specifications noted at right.)

### FAS port of origin (per ton)

<table>
<thead>
<tr>
<th>Destination</th>
<th>New York</th>
<th>Chicago</th>
<th>LA</th>
<th>SF/Oakland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed Paper (2) - OBM* - China</td>
<td>79-82 (+8)</td>
<td>56-59 (+5)</td>
<td>91-94 (+8)</td>
<td>85-88 (+7)</td>
</tr>
<tr>
<td>OCC (11) - OBM* - China</td>
<td>132-135 (+8)</td>
<td>107-110 (+8)</td>
<td>144-147 (+9)</td>
<td>138-141 (+8)</td>
</tr>
<tr>
<td>DLK (13) - China</td>
<td>149-153 (+8)</td>
<td>162-165 (+10)</td>
<td>155-158 (+8)</td>
<td></td>
</tr>
<tr>
<td>ONP (8) - OBM* - China</td>
<td>100-103 (+8)</td>
<td>70-73 (+7)</td>
<td>101-104 (+10)</td>
<td></td>
</tr>
<tr>
<td>SOP (37) - China</td>
<td>175-178 (+8)</td>
<td>187-190 (+7)</td>
<td>180-183 (+5)</td>
<td></td>
</tr>
<tr>
<td>SWL (40) - Asia</td>
<td>264-267 (+4)</td>
<td>260-263 (+1)</td>
<td>253-256 (+3)</td>
<td></td>
</tr>
</tbody>
</table>

### CFR to destination port (per tonne)

<table>
<thead>
<tr>
<th>Destination</th>
<th>New York</th>
<th>Chicago</th>
<th>LA</th>
<th>SF/Oakland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed Paper (2) - China</td>
<td>112-115 (+10)</td>
<td>115-118 (+9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCC (11) - China</td>
<td>165-168 (+5)</td>
<td>167-170 (+4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select OCC (11) - India</td>
<td>180-183 (+7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double-sorted OCC (12) - India</td>
<td>187-190 (+5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DLK (13) - China</td>
<td>189-192 (+8)</td>
<td>194-197 (+10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ONP (8) - China</td>
<td>133-136 (+10)</td>
<td>135-138 (+9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOP (37) - China</td>
<td>212-215 (+0)</td>
<td>222-225 (+7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWL (40) - Asia³</td>
<td>332-335 (+0)</td>
<td>332-335 (+0)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* OBM PRICES
Continuation of price series from Official Board Markets (see note at bottom of Price Watch: Domestic).

### SPECIFICATIONS

Prices represent open market purchases agreed to for delivery within 30 days. Contractually indexed transactions (i.e., transactions whose price is determined in whole or in part by a formula in a long-term contract) are excluded. Specifications: baled, full-trackload quantities, exclusive of premium or distress lots. Grades and preparation requirements are as defined in the current ISRI Scrap Specifications Circular (now PS-13).

### NOTES

2. “LA” includes Long Beach and LA ports.
3. SWL prices are for ports in South Korea, Indonesia, and Thailand.
In general, …….. most paper food containers are common in the recycling stream now. Paper plates and cups are common and we don’t see rejections for minor contamination like that. Foil is a big no-no as always. Mills will reject quickly if they see foil in bales.

Wax boxes are slowly becoming less and less common, but still an easy rejection target for mills.

It is really amazing to see how much single stream recycling has reduced the quality of the OCC, news, and mix paper. Yes it has increased recycling rates, but at the detriment of material processors.
Overview of the Paper Recycling Industry: Review Quiz

- The percentage of paper in the US that is recycled overall is about ___ %
- The amount of paper produced in the US has ______________ in the last decade.
- The US is a net importer / net exporter of recovered paper
- Which major group of recovered paper is recycled the most based on annual tonnage? ____________
Learning Objectives

- To be able to describe:
  - the trends of paper recycling
  - **Common Contaminants**
  - the purpose and operation of common unit operations in a paper recycling mill
  - the major types of paper recycling mills
Common Contaminants in Recovered Paper

- **Large Junk**
  - metals: nuts, screws, foil, cans
  - plastics: films, bags, envelopes
  - dirt, cloth, yard waste, leather, etc.,

- **Inks & toners**

- **Stickies** -- most difficult problem currently

- **Coatings** – can appear as white/colored chips,

- **Wax Coatings** – present in some boxes

- **Fillers** – damaging to the tissue creping process

- **Papermaking additives** – dyes, wet strength agent
<table>
<thead>
<tr>
<th>Type</th>
<th>Component</th>
<th>Drying System</th>
<th>Ink Resin Film</th>
<th>Particle Size (microns)</th>
<th>End Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Letter Press</td>
<td>Pigment + Mineral Oil</td>
<td>Absorption into Web</td>
<td>Weak</td>
<td>1-15</td>
<td>Letterpress, Early Newsprint</td>
</tr>
<tr>
<td>Newsprint and Offset</td>
<td>Pigment + Soft Resin &amp; Mineral Oil</td>
<td>Penetration of Vehicle into Web + Resin Oxidation</td>
<td>Soft Film</td>
<td>2-30</td>
<td>Newsprint, Books</td>
</tr>
<tr>
<td>Rotogravure</td>
<td>Pigment + Hard Resin &amp; Solvent</td>
<td>Solvent Evaporation</td>
<td>Hard Film</td>
<td>2-250</td>
<td>We Offset, Letter Press, Magazines, Catalogues</td>
</tr>
<tr>
<td>Flexographic</td>
<td>Pigment + Resin &amp; Water Emulsification</td>
<td>Amine Absorption, Evaporation</td>
<td>Water Resistant Film</td>
<td>small</td>
<td>Newsprint inserts, Corrugated</td>
</tr>
<tr>
<td>UV Cured</td>
<td>Pigment + Monomer</td>
<td>UV Photopolymerization</td>
<td>Non swelling, Non saponif. Hard Film</td>
<td>50-100</td>
<td>High Speed Coated Papers</td>
</tr>
<tr>
<td>Specialty</td>
<td>Various Pigments and Rosins</td>
<td>Heat set or Other</td>
<td>Hard, Coherent Films</td>
<td>40+</td>
<td>Xerography, Laser Printers, Electronic Forms</td>
</tr>
</tbody>
</table>
Stickies

- Currently the most challenging problem in paper recycling
- Stickies: contaminants in pulp that have the potential to deposit on solid surfaces
- Typically organic materials:
  - Man made stickies: adhesives, coatings...
  - Natural stickies: pitch, resins...
- May deposit on papermachine wires, press felts, dryer fabrics, calendar rolls and cause significant down-time on machine
- Are hard to remove in recycling due to often having a neutral density, and an ability to flow and change shape
Why is contaminant removal so difficult?

- Contaminates vary by:
  - size
  - density
  - shape
  - surface properties
  - solubility
  - strength

- No single separation device can remove all of the different types of contaminants

- Thus, recycling processes consist of many sub-operations that complement each other
Contaminant Size vs. Removal Efficiency

- **Washing**
- **Flotation**
- **Cleaning**
- **Screening**

**Table:**

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Removal Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 100 μm</td>
<td>Screening &amp; centrifugal cleaning</td>
</tr>
<tr>
<td>10 - 100 μm</td>
<td>Flotation</td>
</tr>
<tr>
<td>&lt; 10 μm</td>
<td>Washing</td>
</tr>
</tbody>
</table>


Major Recycling Unit Operations

- Pulping
- Cleaning
- Screening
- Deinking  --- used to produce printing or tissue, not OCC or similar
  - Washing
  - Flotation
- Dispersion and Kneading
- Bleaching  --- used to produce printing or tissue, not OCC or similar
- Water Treatment
- Solid Waste Handling
Learning Objectives

- To be able to describe:
  - the trends of paper recycling
  - Common Contaminants
  - the purpose and operation of common unit operations in a paper recycling mill
  - the major types of paper recycling mills
Main Function: Disperse recovered paper into separated fibers.

Several sub-objectives that are also important:

1. Detach contaminants from fibers.
2. Mix paper with water and chemicals at the correct ratios.
3. Maintain contaminants as large as possible to aid subsequent removal processes.
4. Avoid damage to the fibers (fiber cutting).
5. Removal of large debris from system.
Low Consistency Pulping: Harsh, used for OCC

- Consistency from 3 -6 %.
- Low profile rotor that rotates at high speeds.
- Motion of rotor causes a vortex of pulp stock. The baffles are used to improve mixing.
- High mechanical force due to impacts of rotor can damage fiber and break contaminants.
- 100 kWh/t (6.8 cents/kWh)
Low consistency continuous pulper typically have an extraction plate that accepts pulped fibers and rejects debris and unpulped flakes.

The extraction plate/rotor can cause attrition, resulting in fiber cutting.

A junker is used to collect unpulpables such as bolts or rocks. This debris is thrown out of the pulper into a junk tower where it is removed.

A ragger is also used in many cases to remove bale wire, strings, plastics, etc. The ragger is a continuous “rope” formed by entangled debris. The “rope” is continuously pulled out of the pulper and cut into sections and disposed. Common in OCC mills.
Ragger removing debris from the pulper surface

Low Consistency Continuous Pulping

Junker Claw
Pulper Types: High Consistency:
Mild: Used for Printing Grades

- Typically 8-18%.
- High profile rotor used. The helical screw type rotor is needed to “pull down” the non-fluid like high % K stock, from the top to the bottom of the pulper.
- At the high % K, fiber-fiber (solid-solid) rubbing dominates the forces experienced in the pulper.
- 30 kWh/t
High Consistency Batch Pulper with External Detrasher

- The pulper is “full” at high consistency during pulping.
- At the end of the pulping dilution water is added at the bottom of the pulper diluting the pulp in the bottom to less than 6%.
- A large opening on the bottom/side of the pulper is used as the exit for the pulper contents.
- The pulp and debris are separated by an external detrasher.
- Note: There is no extraction plate in the pulper.

Note: drawing not to scale.
Pulping Summary

- High consistency pulping used on _______
- Low consistency pulping used on _______
- Pulping Objectives:
  - __________________________
  - __________________________
  - __________________________
  - __________________________
  - __________________________
- Bottom Line: If pulping is not done properly, subsequent processing steps will be ineffective and product quality will be unacceptable
Screening

- Screening separates contaminants based mainly on size, but also on shape and deformability.
- Performed by presenting a barrier for large contaminants (slots or holes) that allow fibers to pass through.
One meter has $1,000,000$ microns. 0.001 inch equals approx 25 microns. A HW fiber has a width of about 20, a SW about 40 microns.
Screening

- Types of screen basket openings
  - coarse holes .110 in or 2.7 mm
  - fine holes .060 in or 1.52 mm
  - coarse slots .010 in or .254 mm
  - fine slots .006 in or .152 mm

- Also, the fibers offer a resistance to passage, related to the consistency
Pressure screen
Pressure Screen Principle to Prevent Blinding of Screen

The leading edge of the rotating foil accelerates the stock.

The negative pulse under the sweeping foil momentarily reverses the flow, effectively purging the screen openings.
Effect of Reject Rate & Plate Opening on Screen Cleanliness
Always have cascaded screens to save fiber.
Summary Pressure Screen:

Objective: separate large contaminants from fibers

Utilize holes or slots to reject ______ contaminants

Typically ______ configurations to save fiber.

Foils used to ____________.
Centrifugal Cleaning

- Remove impurities from the pulp stream based mainly on density
- Density = mass / volume
- Rotational fluid flow within the cone causes denser particles to move to the outside faster than lighter particles due to centrifugal forces
- Centrifugal cleaners remove
  - metals
  - inks
  - sand
  - bark
  - dirt
Centrifugal Cleaner: Features and Flow
“Bank Arrangement” of Cleaners: stages

Several cleaners are piped in parallel fashion: a stage. A single cleaner is not capable of providing enough through put for typical industrial flows.
Cleaners Pump
Typical Separation “Curve”

Separation Ratio:
\[ \frac{m(\text{in}) - m(\text{acc})}{m(\text{in})} \]
\( m = \) mass flow contaminant

Cleanliness Efficiency:
\[ \frac{\text{PPM}(\text{in}) - \text{PPM}(\text{acc})}{\text{PPM}(\text{in})} \]
\( \text{PPM} = \) contaminant concentration

Reject Ratio: OD mass flow reject / OD mass flow inlet
Cascade Arrangement of Cleaners

- **FEED**
- **Secondary Stage Cleaners**
- **Tertiary Stage Cleaners**
- **ACCEPSTS**
- **Primary Stage Cleaners**

- Dilution Water flow through each stage
- REJECTS
Three Basic Cleaner Types:

- **High Density Cleaner**: separates very large, heavy contaminants such as rocks, staples, glass. Used after pulping (early in the process) to protect downstream equipment. Diameter = 300-700 mm.

- **Forward Cleaners**: separates fine, heavy contaminants such as sand and inks. Also called cyclones, hydrocyclones, or cleaners. (Described previously) Diameter = 70-400 mm

- **Through Flow Cleaner**: separates fine, light contaminants such as glues, adhesives, plastics, foam. Also called light-weight cleaners or reverse cleaners. Diameter = 100-400 mm
High Density Cleaner
(immediately after pulper)
Through Flow Cleaner
(Removes Low Density Contaminants)

Feed

Rejects

Accepts
Cleaner Summary

- Cleaners: remove contaminants based on ____________ differences relative to fibers

- Cleaners: Must reject about _____ % of the solid material to operate effectively (individual stage)

- Sets of cleaners piped in parallel are called a __________ of cleaners.
Washers

- **Definition:** a separation device that rinses small particulate contaminants away from fiber while minimizing fiber loss

- **Wire mesh utilized:** (60-100 mesh or 250-150 micron openings)
  - fine often defined as less than 200 microns,
  - fillers around 1-20 microns
  - Inks around 1-100 microns

- **Deinking Washer**
  - Dilute pulp with wash water
  - Disperse small contaminant in water phase
  - Remove contaminant laden water
  - Always a compromise between fiber/fine loss and ink removal
Gravity Decker

- Pulp enters at 0.8% and leaves at 5%
- Water (and ink) passes through wire mesh cylinder
- Vacuum created by liquid falling increases water removal
Double Nip Thickener (DNT)
Double Nip Thickener (DNT)
Pulp mats prevent the removal of small particles in washing!!!!!

<table>
<thead>
<tr>
<th>Type</th>
<th>Inlet % K</th>
<th>Outlet % K</th>
<th>Ash Removal %, Theoretical</th>
<th>Ash Removal %, Actual</th>
<th>Pulp Mat Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sidehill Scrn</td>
<td>0.8</td>
<td>3</td>
<td>74</td>
<td>60</td>
<td>Minimal</td>
</tr>
<tr>
<td>Grav Decker</td>
<td>0.8</td>
<td>5</td>
<td>85</td>
<td>55</td>
<td>Yes</td>
</tr>
<tr>
<td>Incl. Screw</td>
<td>3.0</td>
<td>10</td>
<td>72</td>
<td>45</td>
<td>Extensive</td>
</tr>
<tr>
<td>Horiz. Screw Press</td>
<td>4.0</td>
<td>28</td>
<td>89</td>
<td>35</td>
<td>Extensive</td>
</tr>
<tr>
<td>Belt Washer</td>
<td>1.0</td>
<td>10</td>
<td>80</td>
<td></td>
<td>Minimal</td>
</tr>
<tr>
<td>Vario Split</td>
<td>0.8</td>
<td>10</td>
<td>85</td>
<td>80</td>
<td>Minimal</td>
</tr>
</tbody>
</table>
Flotation

- Definition: a process in which hydrophobic contaminants are preferentially removed from a pulp stock by attachment to air bubbles.
Contaminant Characteristics: Hydrophobicity

- **Hydrophobic** - lacking affinity for water (inks, oils…)
- **Hydrophilic** - having a strong affinity for water (cellulose fibers, starch, sugars…).

A hydrophobic material (ink) suspended in water has a greater tendency to contact and adhere to air bubbles than a hydrophilic material (fiber).
Flotation

- For successful flotation of a contaminant (e.g., ink) several sub-processes must occur:
  1. The ink must be free from the fibers.
  2. Ink must collide with an air bubble.
  3. A strong attachment must form between the ink & the bubble.
  4. The ink-bubble must rise to the surface.
  5. The ink-bubble must be incorporated into the foam.
  6. The foam must be removed from the system.
Flotation Cell

- Voith-Sulzer Flotation Machine, each pump in series, stock follows: feed->1->2->3>Accepts
# Washing vs. Flotation

<table>
<thead>
<tr>
<th></th>
<th>Flotation</th>
<th>Washing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry-Sensitive</td>
<td>more</td>
<td>less</td>
</tr>
<tr>
<td>Water Use</td>
<td>lower</td>
<td>higher</td>
</tr>
<tr>
<td>Yield</td>
<td>higher</td>
<td>lower</td>
</tr>
<tr>
<td>Ash Removal</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Tensile Str.</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Opacity</td>
<td>Higher</td>
<td>Lower</td>
</tr>
</tbody>
</table>

Challenge question: why is the tensile strength lower for pulps that have been floated relative to those that have been washed?  ______________________________________
Flotation and Washing Summary

- Washing: removes ____________ contaminants
- Flotation: removes contaminants based on ____________ differences relative to fibers
- Pulp mat formation ____________ the efficiency of de-inking washers
- Flotation / Washing retains more of the smaller particles (fillers) and has higher yield.
Dispersion and Kneading

- Definition: The use of mechanical action to decrease the particle size of contaminants and release the contaminants from the fiber surfaces (below, an example of pulp before and after dispersion).
Dispersion

How does it work?
- Pulp at high consistency is passed between disks that have bars or teeth protruding from the surface.
- Rotation of one of the disks causes intense shearing action on the fibers breaking down the contaminants.

Typical Conditions
- Consistency = 30% K
- Temperature = 95 C
- Retention Time = 2 seconds
- RPM = 1200-1800
- Gap between disks = 0.5-1.5 mm
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
Kneading

- How does it work?
  - Pulp at high consistency is mixed between moving bars on a slow-rotating shaft and stationary bars attached to the housing.
  - Strong shear forces (mainly fiber-fiber rubbing) break the contaminants.

- Typical Conditions
  - Consistency = 30% K
  - Temperature = 50°C
  - Retention Time = 10-60 seconds
  - RPM = 100-900
  - Gap between bars = 10-40 mm
Double Shaft Kneader

- Operation principles the same as the single shaft kneader
- Contains two shafts rotating in different directions at slightly different speeds (20% difference in RPM)
- The different speeds and directions of the shafts generate intense shearing action.
Kneading vs. Dispersion

Methods to decrease contaminant size.

<table>
<thead>
<tr>
<th></th>
<th>Dispersion</th>
<th>Kneading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanism</td>
<td>Shear</td>
<td>Rub</td>
</tr>
<tr>
<td>Consistency</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Temp.</td>
<td>95</td>
<td>50</td>
</tr>
<tr>
<td>RPM</td>
<td>1200-1800</td>
<td>100-900</td>
</tr>
<tr>
<td>Retent. Time</td>
<td>2 s</td>
<td>10-60 s</td>
</tr>
<tr>
<td>Gap, mm</td>
<td>.5-1.5</td>
<td>10-40</td>
</tr>
</tbody>
</table>
# Kneading vs. Dispersion

**Methods to decrease contaminant size.**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Dispersion</th>
<th>Kneading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tappi Dirt Reduct.</td>
<td>75%</td>
<td>85%</td>
</tr>
<tr>
<td>Toner Reduct.</td>
<td>yes</td>
<td>better</td>
</tr>
<tr>
<td>Stickies Reduct.</td>
<td>better</td>
<td>no effect</td>
</tr>
<tr>
<td>Fiber Cutting</td>
<td>substantial</td>
<td>none</td>
</tr>
<tr>
<td>Fines Generation</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>
Bleaching

- The chemical process applied to pulp to destroy chromophores, increasing the brightness and reducing color:
  - Dye and Fluorescency Whitening Agents Destruction
  - Destruction of lignin from wood-containing fibers
  - Does not affect pigments
  - Oxidative and Reductive Bleaching Processes
  - Typically have 1 or 2 stages

- "Chromophore Absorbs Light"
Bleaching

- Oxidative bleaching: peroxide, hypochlorite, chlorine dioxide, oxygen, ozone
- Reductive bleaching: hydrosulfite, fomamidine sulphinic acid (FAS)

Issues:
- chlorine free effluent
- operations concerns
  - consistency
  - pH (avoid acidic state)
- furnish/product characteristics

Can you bleach ink? ________________

Can you bleach blue cotton fabrics? ________________
Bleaching: Where is it done?

- Depends on the Bleaching Chemicals, desired product, and existing equipment. Common points are:
  - Pulper
  - Bleaching tower
  - Disperser or kneader system
Amount of Rejects and Sludges for Production of Paper Grades, Virgin PM = ______

<table>
<thead>
<tr>
<th>Produced paper</th>
<th>Recovered paper grade</th>
<th>Amount of total waste</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></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>8–13</td>
<td>2–5</td>
</tr>
<tr>
<td></td>
<td>Superior grades</td>
<td>10–25</td>
<td>&lt;1</td>
<td>7–16</td>
<td>1–5</td>
</tr>
<tr>
<td>Hygienic paper</td>
<td>Files, office paper</td>
<td>28–40</td>
<td>1–2</td>
<td>8–13</td>
<td>15–25</td>
</tr>
<tr>
<td></td>
<td>ordinary, medium</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>12–15</td>
<td>15–25</td>
</tr>
<tr>
<td>Liner, fluting</td>
<td>Sorted mixed recov.</td>
<td>4–9</td>
<td>1–2</td>
<td>–</td>
<td>0–(1)</td>
</tr>
<tr>
<td></td>
<td>paper, supermarket</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>waste</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Board</td>
<td>Sorted mixed recov.</td>
<td>4–9</td>
<td>1–2</td>
<td>–</td>
<td>0–(1)</td>
</tr>
<tr>
<td></td>
<td>paper, supermarket</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>waste</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Implications of yield:

- If a mill takes in 400 tons per day of paper and has a fiber yield of 70%, how much dry paper does it make?

- How much sludge at 50% moisture does it make?
Water Treatment

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

Most common clarifier for recycling
Raw water treated with chemicals to form flocs of suspended solids
Tiny air bubbles mixed with the water and attach to flocs
Flocs rise to surface and are scooped out
Some flocs settle to the bottom and are removed
Sludge Processing

- composition: fiber, fines, ash, contaminants, water
- dewatering equipment: typically dewatering table followed by a screw or belt press
- disposition
  - landfill
  - incineration
  - composting
  - other
Learning objectives

- To be able to describe:
  - the trends of paper recycling
  - Common contaminants
  - the purpose and operation of common unit operations in a paper recycling mill
  - the major types of paper recycling mills
Major Recycling Systems

- Can be categorized by the products they produce
  - Packaging Materials
    - Typically, OCC materials are recycled back into linerboard, medium, tube stock, and solid board products
  - Newsprint
    - Old newspapers and magazines are converted into newsprint
  - Tissue
    - Bleached printing and writing wastes are converted into tissue
  - Printing and Writing Materials
    - Bleached printing and writing wastes are converted into pulp for application in new printing and writing grades
Paper Recycling Operations:
A Balancing Act

Production

Quality

Yield

Profit

Safety

Environment
**Crude Cleaning System for Packaging Product**

- Used to produce liner, medium, folding board, tube stock
- Often used with a continuous pulper
- Yield?
- Contaminant removal?
- Ink removal?
OCC Recycling for Higher Grades

- Used to produce linerboard or medium
- Often have a continuous pulper with cleaning system
- Note the strategy:
  - 1st remove coarse contaminants
  - 2nd remove smaller contaminants
  - 3rd disperse unremoved contaminants
- Use alkali to swell fibers and regenerate strength
- Problems with stickies necessitate extra cleaning steps
- Fractionation to provide cleaner top liner
- Extensive water recycling
Test Liner Production
ONP-OMG Recycling

- Used to produce recycled newsprint
- May have batch, continuous tub or drum pulping
- Note the strategy:
  - 1st remove coarse contaminants
  - 2nd remove smaller contaminants, deinking
  - 3rd disperse unremoved contaminants
- Often bleaching is used to increase brightness
- Problems with stickies may be caused by OMG
- Extensive water recycling
  - Two water loops: pseudo countercurrent water-pulp flows
Newsprint Recycle Process:

Pulping. Low or high consistency? Why?

Coarse Screen. What contaminants are removed?

Flotation? What consistency?

Cleaners and LC Screen. What consistency?

Why filter and press here?

Why dispersion so late in process?

Why bleaching so late in process?

Why flotation again, here?

Why 3 DAF’s, not just one?
Deinking of Printing-Writing Grades for Tissue

- Use sorted or non-sorted office waste to make tissue
- For tissue making, filler level must be low for creping (see 1-2 stages of washing)
- Depending on quality of tissue, brightness and dirt count also important
- Lower grade tissue pulp production omits 1 stage of cleaners, bleaching and washing. May also omit flotation.
- Extensive water recycling
  - Two water loops: pseudo countercurrent water-pulp flows

Recycled Away From Home Tissue (about 30% of all tissue)
High Grade Tissue: Wood Free

Dispersion could also be kneading.
Deinking of Printing Grades for Printing/Writing

- Used to produce new printing and writing grades
- May use mixed or sorted waste ($ vs production trade-off)
- Note the strategy:
  - 1st remove coarse contaminants
  - 2nd remove smaller contaminants, deinking
  - 3rd disperse unremoved contaminants
  - 4th bleach to high brightness
- Most complex system to produce highest standard pulp
- Extensive water recycling
  - Multiple water loops: pseudo countercurrent water-pulp flows
Dispersion could also be kneading.
Process Flow to Produce 100 TPD Deinked Pulp
## Capital Equipment Required

<table>
<thead>
<tr>
<th>Description</th>
<th>Delivered Cost, $</th>
<th>Estimate Source</th>
<th>Installed Cost, $</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Kadant Deinking Facility (150 ODT/day)</td>
<td>$ 4,290,000</td>
<td>Kadant Black-Clawson</td>
<td>$ 17,252,000</td>
<td>4.01</td>
</tr>
<tr>
<td>1- HD Storage Tank (75 ODT @ 4%)</td>
<td>N/A</td>
<td>Jacobs Engineering</td>
<td>$ 1,960,000</td>
<td>3.69</td>
</tr>
<tr>
<td>1- Peroxide Bleach Tower (7.5 ODT @ 10%)</td>
<td>$ 64,000</td>
<td>Matche</td>
<td>$ 235,000</td>
<td>3.69</td>
</tr>
<tr>
<td>1- Dithionite Bleach Tower (6.4 ODT @ 4%)</td>
<td>$ 83,000</td>
<td>Matche</td>
<td>$ 306,000</td>
<td>3.69</td>
</tr>
<tr>
<td>1- H₂O₂ Tank (5,000 Gal)</td>
<td>$ 15,000</td>
<td>Matche</td>
<td>$ 54,000</td>
<td>3.69</td>
</tr>
<tr>
<td>1- NaHSO₃ Tank (7,000 Gal)</td>
<td>$ 18,000</td>
<td>Matche</td>
<td>$ 67,000</td>
<td>3.69</td>
</tr>
<tr>
<td>1- NaOH Tank (7,000 Gal)</td>
<td>$ 18,000</td>
<td>Matche</td>
<td>$ 67,000</td>
<td>3.69</td>
</tr>
<tr>
<td>1- Raw Material Warehouse (15,000 sq. ft.)</td>
<td>$ 180,000</td>
<td>General Steel</td>
<td>$ 503,000</td>
<td>2.80</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td></td>
<td></td>
<td><strong>$ 20,444,000</strong></td>
<td></td>
</tr>
</tbody>
</table>
Cost Breakdown - SWL

Cost break down for SWL

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>$/ton DIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWL</td>
<td>294.1</td>
</tr>
<tr>
<td>Chemicals</td>
<td>34.1</td>
</tr>
<tr>
<td>Energy</td>
<td>49.5</td>
</tr>
<tr>
<td>Trash</td>
<td>2.1</td>
</tr>
<tr>
<td>Wet Sludge</td>
<td>16.9</td>
</tr>
<tr>
<td>Fresh Water</td>
<td>1.3</td>
</tr>
<tr>
<td>Waste Treatment</td>
<td>29.8</td>
</tr>
<tr>
<td>Labor</td>
<td>27.3</td>
</tr>
<tr>
<td>Freight</td>
<td>144.6</td>
</tr>
<tr>
<td>Maintenance</td>
<td>2.4</td>
</tr>
<tr>
<td>Property Tax</td>
<td>0.4</td>
</tr>
<tr>
<td>Operating Materials</td>
<td>11.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>614.0</strong></td>
</tr>
</tbody>
</table>
# Cost Breakdown- Comparison

<table>
<thead>
<tr>
<th>Cost component</th>
<th>SWL</th>
<th>%</th>
<th>SOP</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Paper</td>
<td>294.1</td>
<td>47.9</td>
<td>259.3</td>
<td>41.2</td>
</tr>
<tr>
<td>Chemicals</td>
<td>34.1</td>
<td>5.5</td>
<td>44.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Energy</td>
<td>49.5</td>
<td>8.1</td>
<td>55.9</td>
<td>8.9</td>
</tr>
<tr>
<td>Trash</td>
<td>2.1</td>
<td>0.3</td>
<td>3.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Wet Sludge</td>
<td>16.9</td>
<td>2.8</td>
<td>30.6</td>
<td>4.9</td>
</tr>
<tr>
<td>Fresh Water</td>
<td>1.3</td>
<td>0.2</td>
<td>1.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Waste Treatment</td>
<td>29.8</td>
<td>4.8</td>
<td>30.4</td>
<td>4.8</td>
</tr>
<tr>
<td>Labor</td>
<td>27.3</td>
<td>4.4</td>
<td>27.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Freight</td>
<td>144.6</td>
<td>23.6</td>
<td>163.3</td>
<td>25.9</td>
</tr>
<tr>
<td>Maintenance</td>
<td>2.4</td>
<td>0.4</td>
<td>2.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Property Tax</td>
<td>0.4</td>
<td>0.1</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Operating Materials</td>
<td>11.7</td>
<td>1.9</td>
<td>11.7</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>614.0</td>
<td></td>
<td>630</td>
<td></td>
</tr>
</tbody>
</table>
Paper Recycling Review

For more detailed slides go to: http://go.ncsu.edu/venditti

- Approximately _____ % of the paper in the US is recycled.
- The production rate of paper has been __________ and the recovery rate has been __________ over the last 5 years in the US.
- High consistency pulping has the following advantages over low consistency pulping:
  ________________  _________________  _______________
- OCC is recycled typically into ______________
- Mixed office waste is typically recycled into ______________ or ______________
- ______________ is a recycling operation used to remove large contaminants
- ______________ is a recycling operation used to remove dense contaminants
- Name the two major de-inking operations: ___________ and ___________
- What type of recycled product does not typically use deinking processes to produce?
  ________________
<table>
<thead>
<tr>
<th></th>
<th>Uncoated free sheet</th>
<th>100% Post consumer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Use</td>
<td>3,467 tons</td>
<td>0 tons</td>
</tr>
<tr>
<td>Total Energy</td>
<td>38,366 million BTU's</td>
<td>3,467 tons less</td>
</tr>
<tr>
<td>Purchased Energy</td>
<td>18,206 million BTU's</td>
<td>21,658 million BTU's less</td>
</tr>
<tr>
<td>Sulfur dioxide (SO2)</td>
<td>26,088 pounds</td>
<td>21,658 million BTU's less</td>
</tr>
<tr>
<td>Greenhouse Gases</td>
<td>5,690,196 lbs CO₂ equiv.</td>
<td>3,452 million BTU's more</td>
</tr>
<tr>
<td>Nitrogen oxides (NOx)</td>
<td>18,417 pounds</td>
<td>25,557 pounds</td>
</tr>
<tr>
<td>Particulates</td>
<td>12,433 pounds</td>
<td>530 pounds less</td>
</tr>
<tr>
<td>Hazardous Air Pollutants (HAP)</td>
<td>2,150 pounds</td>
<td>3,582,112 lbs CO₂ equiv. less</td>
</tr>
<tr>
<td>Volatile Organic Compounds (VOCs)</td>
<td>5,559 pounds</td>
<td>2,108,084 lbs CO₂ equiv. less</td>
</tr>
<tr>
<td>Total Reduced Sulfur (TRS)</td>
<td>340 pounds</td>
<td>0 pounds</td>
</tr>
<tr>
<td>Wastewater</td>
<td>19,075,196 gallons</td>
<td>340 pounds less</td>
</tr>
<tr>
<td>Biochemical Oxygen Demand (BOD)</td>
<td>6,288 pounds</td>
<td>10,325,000 gallons</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS)</td>
<td>10,143 pounds</td>
<td>8,750,196 gallons less</td>
</tr>
<tr>
<td>Chemical Oxygen Demand (COD)</td>
<td>91,744 pounds</td>
<td>6,060 pounds</td>
</tr>
<tr>
<td>Adsorbable organic halogens (AOX)</td>
<td>932 pounds</td>
<td>228 pounds less</td>
</tr>
<tr>
<td>Solid Waste</td>
<td>2,278,349 pounds</td>
<td>6,900 pounds</td>
</tr>
</tbody>
</table>

Papercalculator, Basis of 1000 tons of paper
Effects of Recycling on Pulps

- **The Effect of Recycling on Stone Groundwood**

- **The Effect of Recycling on Beaten, Bleached Kraft**