Paper Recycling Technology

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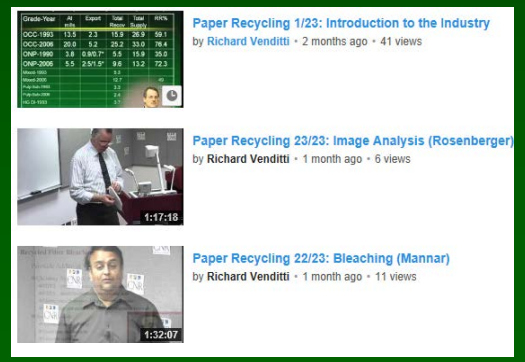
For more detailed slides go to: http://go.ncsu.edu/venditti

Paper Science and Engineering
North Carolina State University

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.)

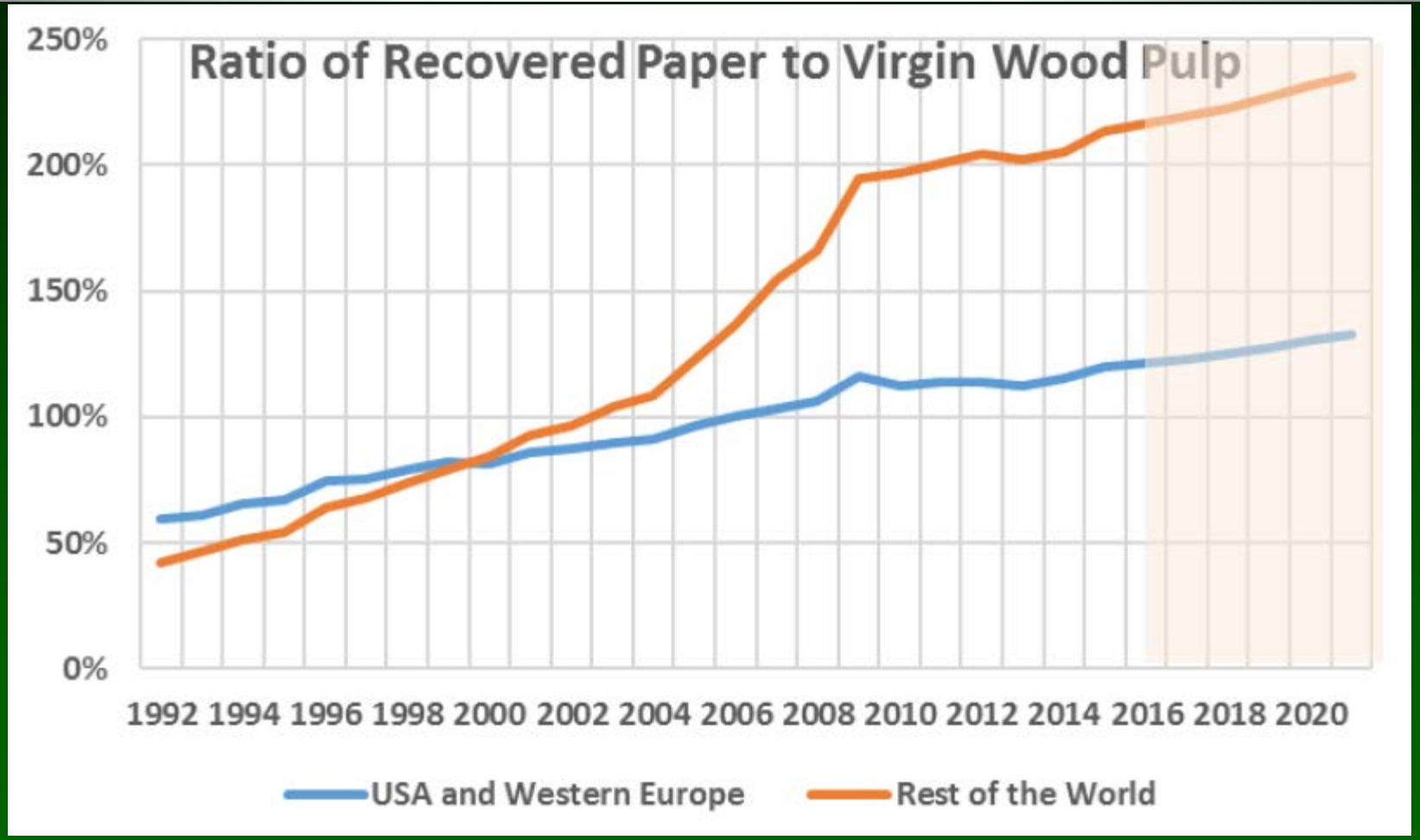


- Secondary Fiber Recycling, Tappi Press, Atlanta GA, 1993
- Recycled Fiber and Deinking in the Papermaking Science and Technology Series, Volume 7, Fapet Oy, Helsinki Finland, 2000.

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

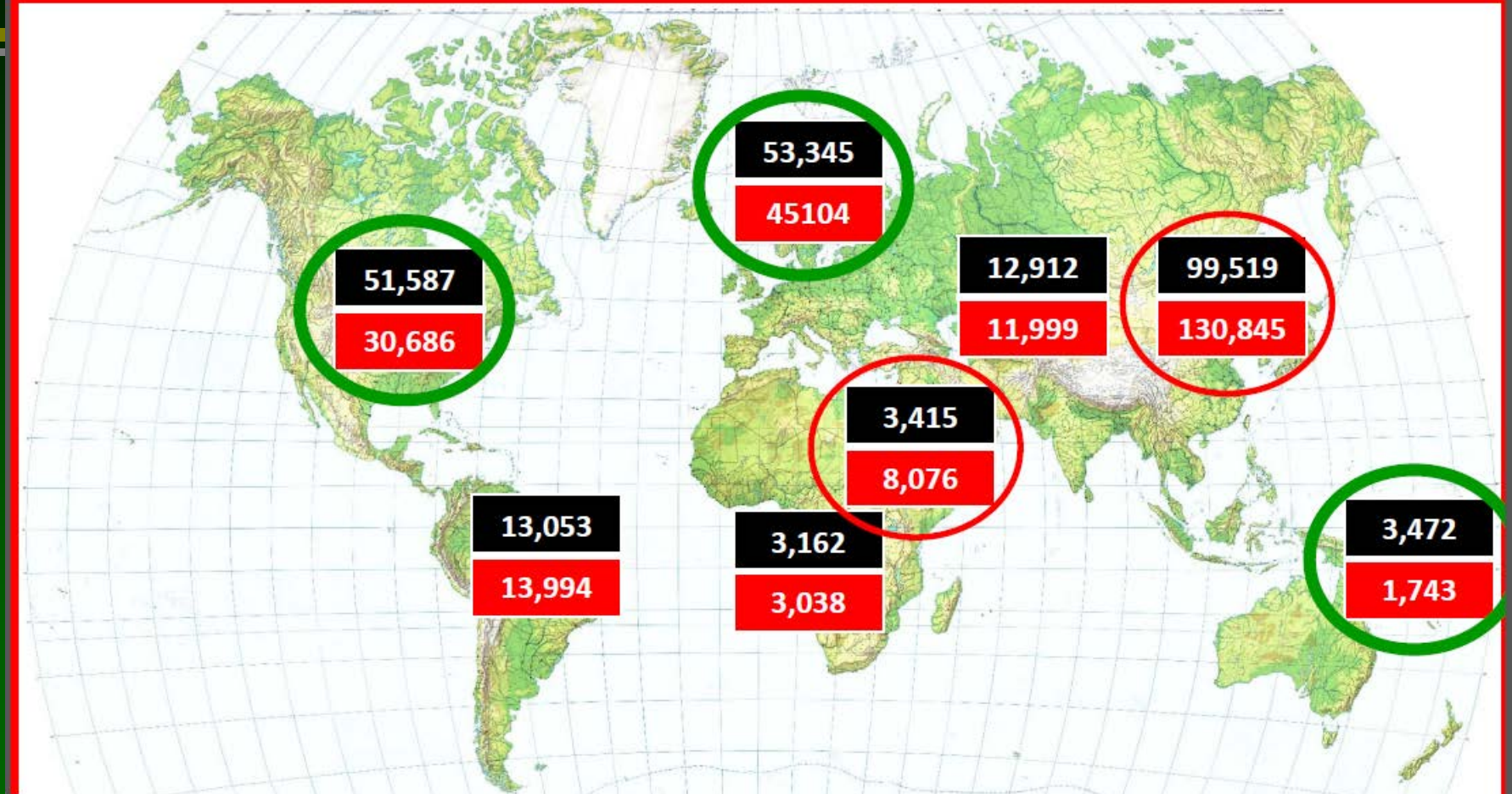
Recovered fiber greater than virgin fibers (408 million ton, 2016)



Source: RISI

2015 Global Production / Consumption of Recovered Paper

24% of Production is Exported



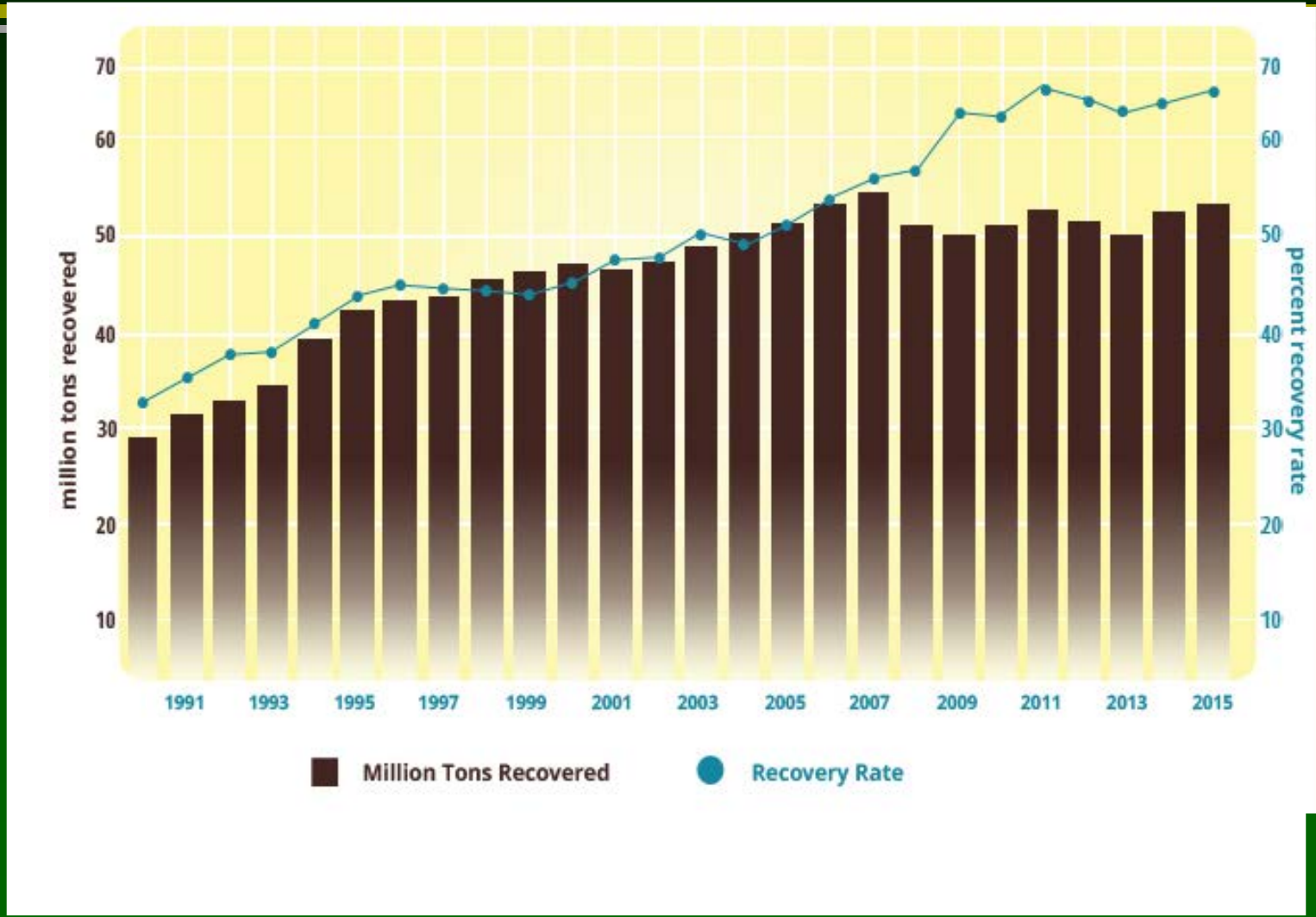
Total Production in 2016 was 408,000 mt, Source: RISI, 2017

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

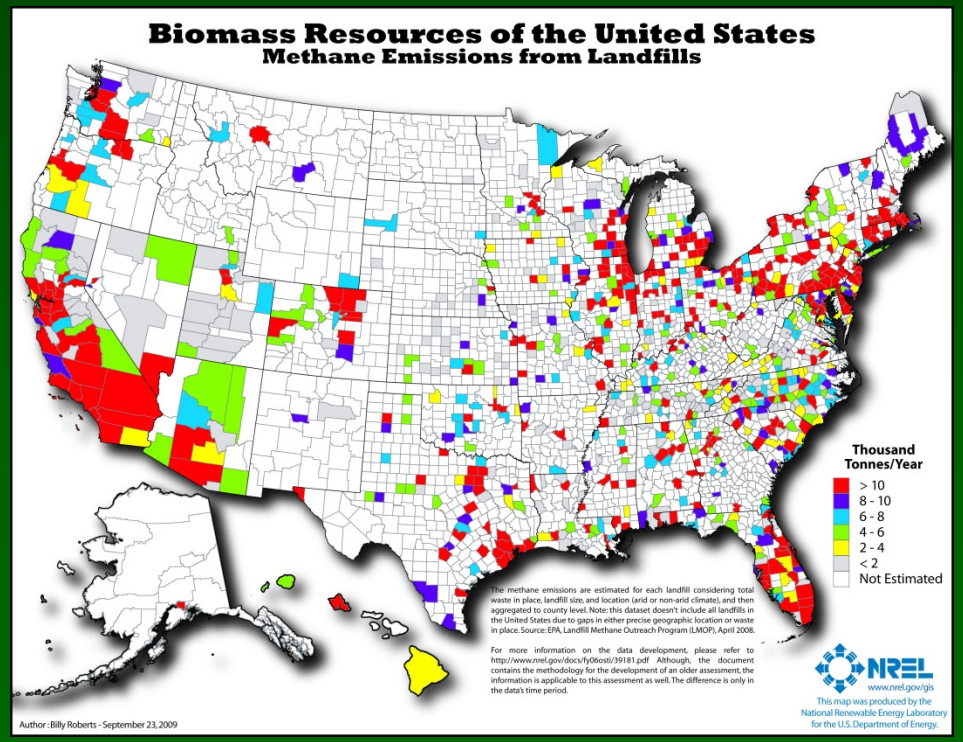
Paper/board Recovery Rate in the US, 66.8%
RR = tons recovered/tons produced



Source: afandpa.org, 2016

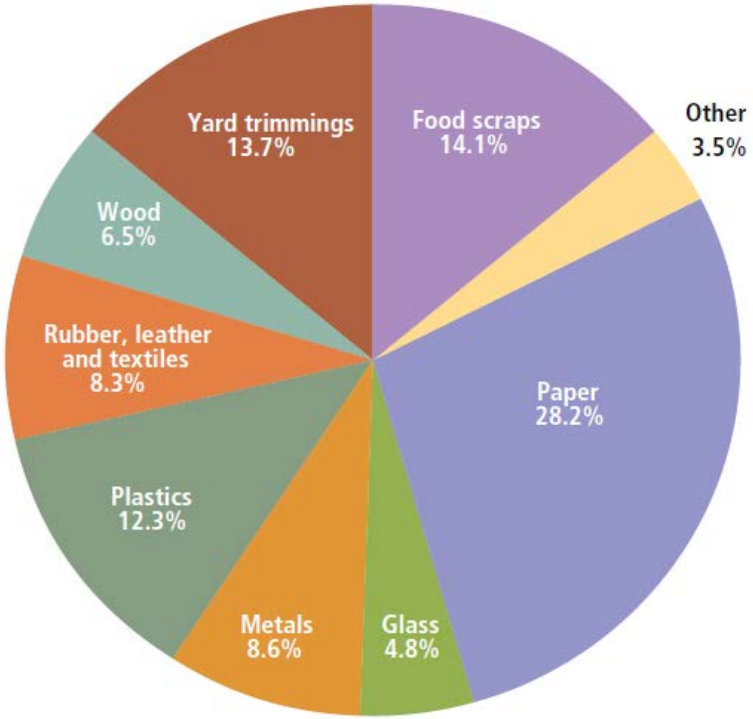
Municipal solid waste

- 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%



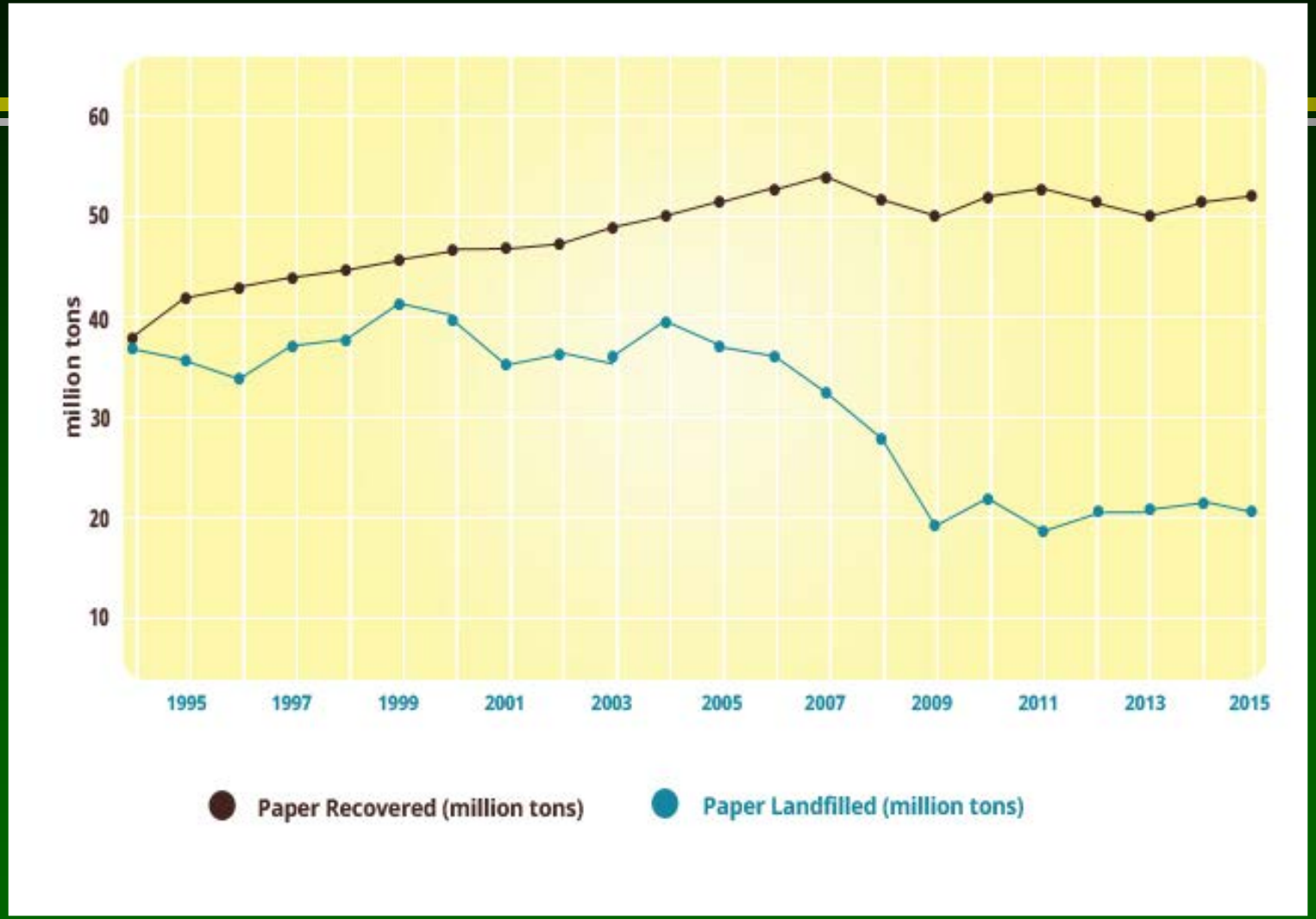
MSW by Material Before Recycling

Figure 5. Total MSW Generation (by material), 2009
243 Million Tons (before recycling)



Source: EPA
Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2009

Recovered and Landfilled Paper



Source: afandpa.org, 2016

Products with highest % recovery.

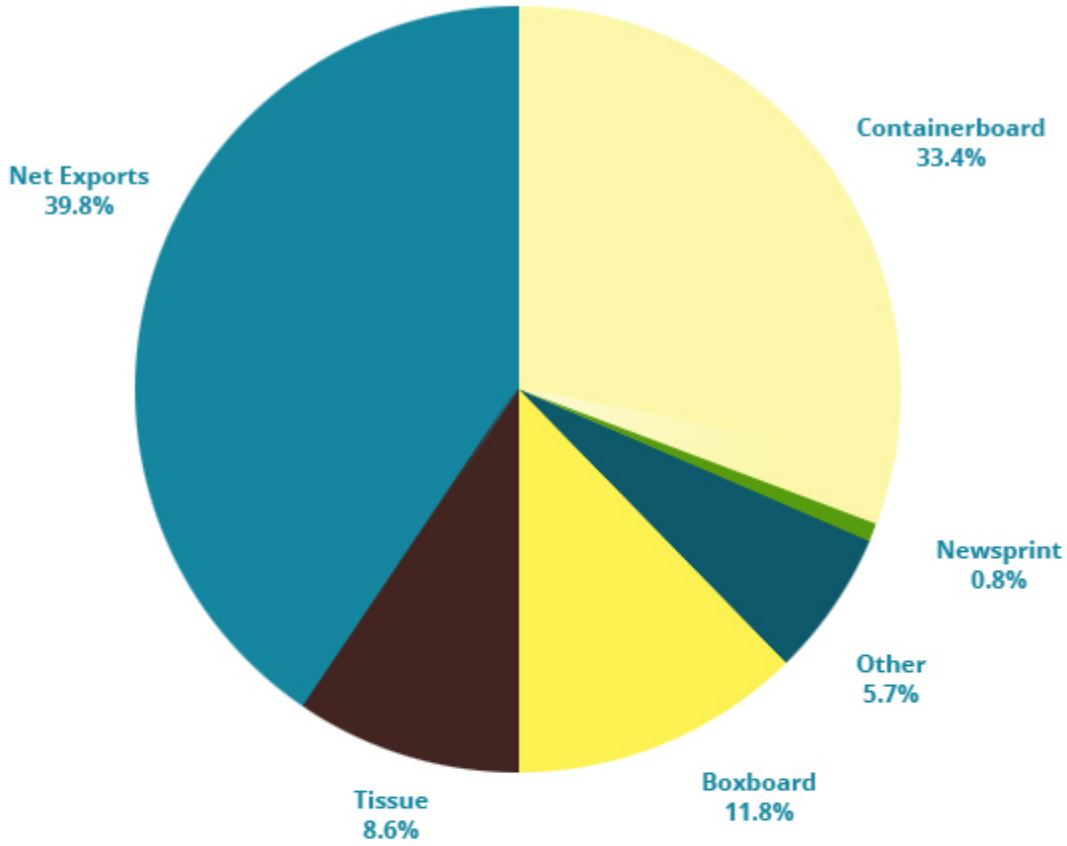
- Lead acid batteries, 96%
- Corrugated boxes, 85%
- Newspapers, 72%
- Steel packaging, 69%
- Major appliances, 65%
- Yard trimmings, 58%
- Aluminum cans, 50%
- Mixed paper, 45%
- *Tires, 35%*
- *Glass Containers, 31%*
- *HDPE, milk containers, 29%*
- *PET Bottles, 28%*

Source: Wikipedia

Source: EPA

Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2009

Where Recovered Paper Goes:



Paper/Packaging Type	Thousand Tons Recovered	Share of Total
Newsprint	395	0.8%
Tissue	4,477	8.6%
Containerboard	17,373	33.4%
Boxboard	6,130	11.8%
Other	-	5.7%
Net Exports	20,701	39.8%
Total	52,040	100%

2015 data
Annual AF&PA Fiber Survey/U.S.

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

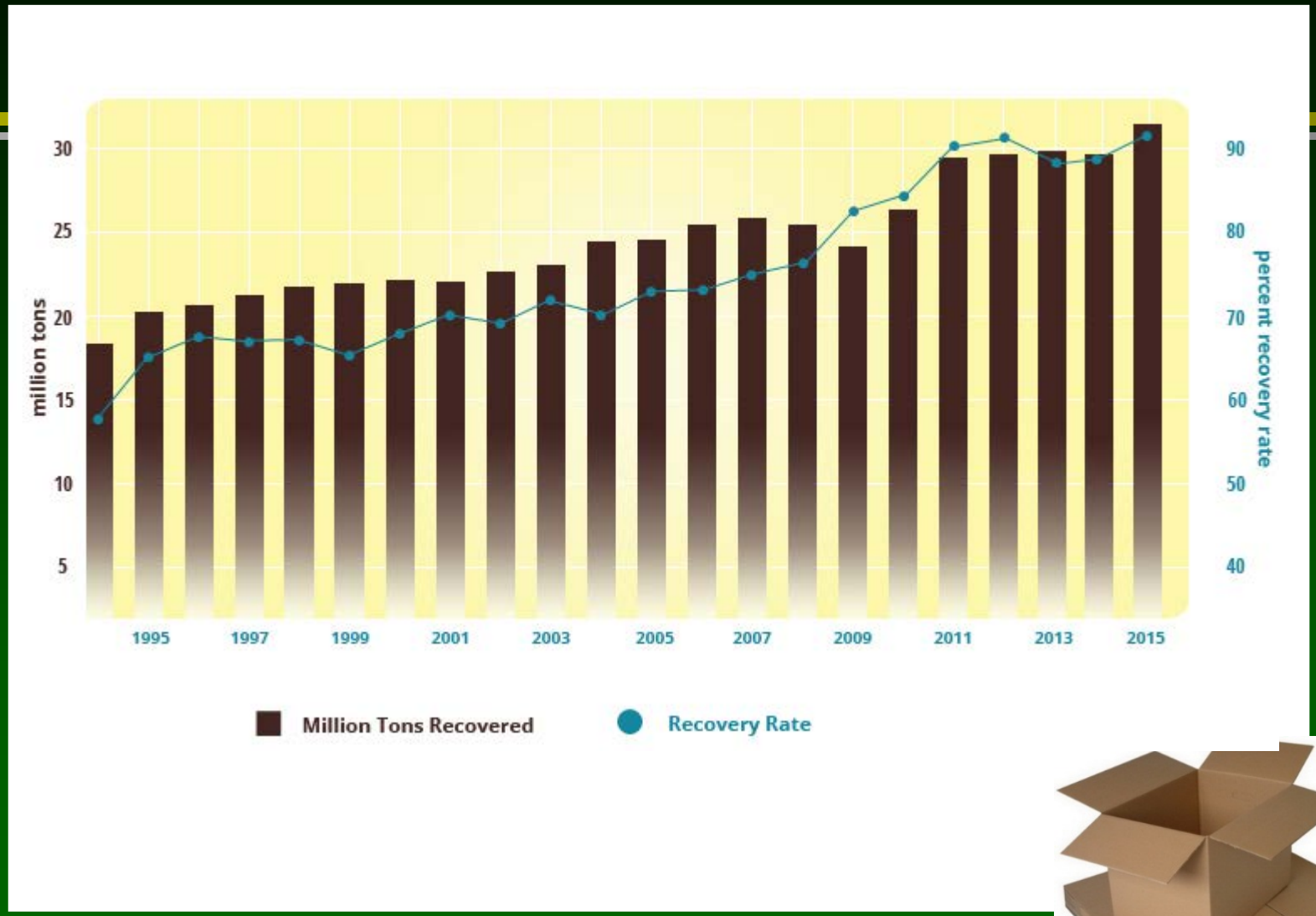
- **Mixed paper:** Mixed paper is a broad category that often includes items such as discarded mail, telephone books, paperboard, magazines, and catalogs. Mills use mixed paper to produce paperboard and tissue, as a secondary fiber in the production of new paper, or as a raw material in non-paper product 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

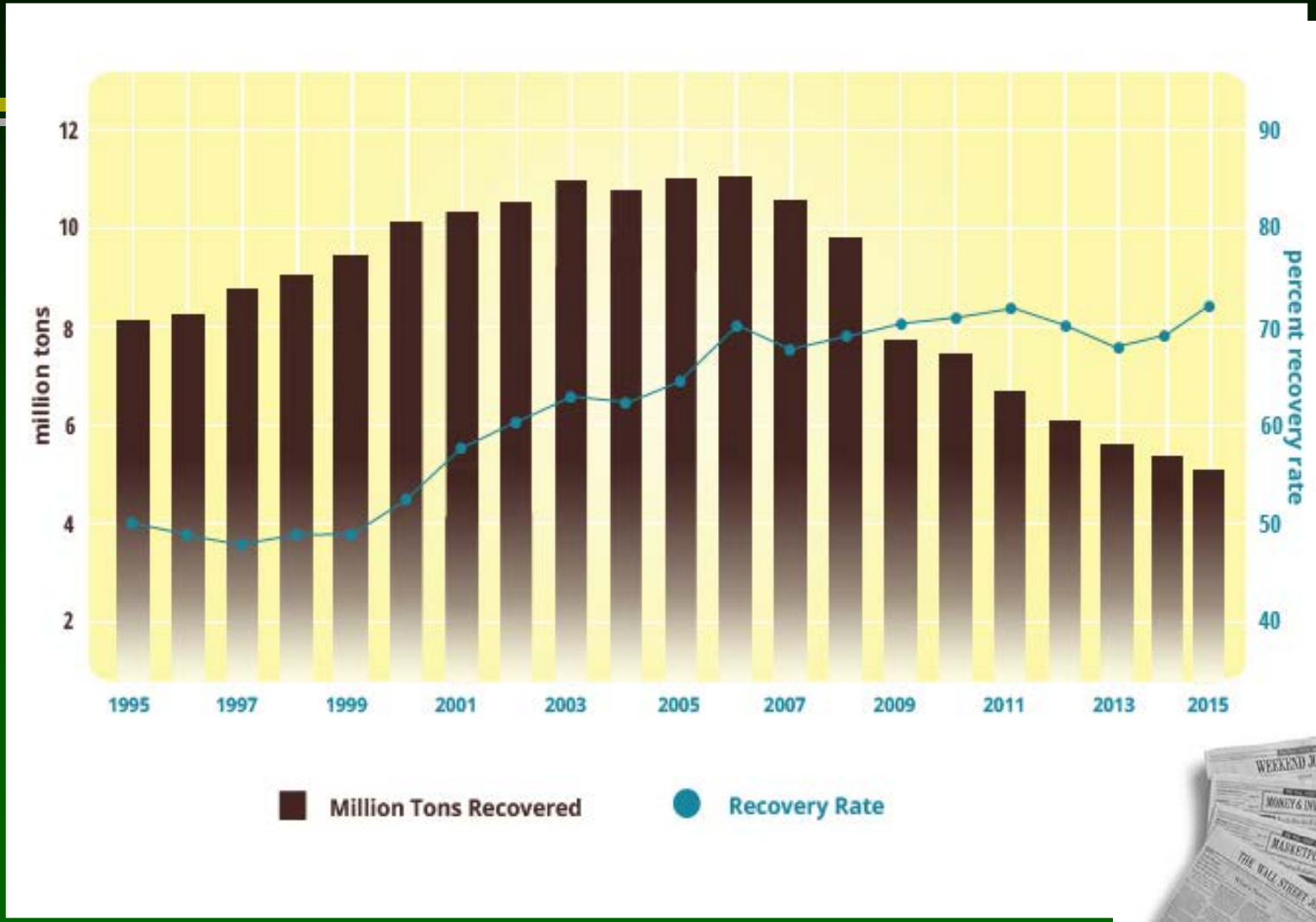
http://www.epa.gov/osw/conserve/materials/paper/basics/grade.htm

Recovery of OCC, 92.9%



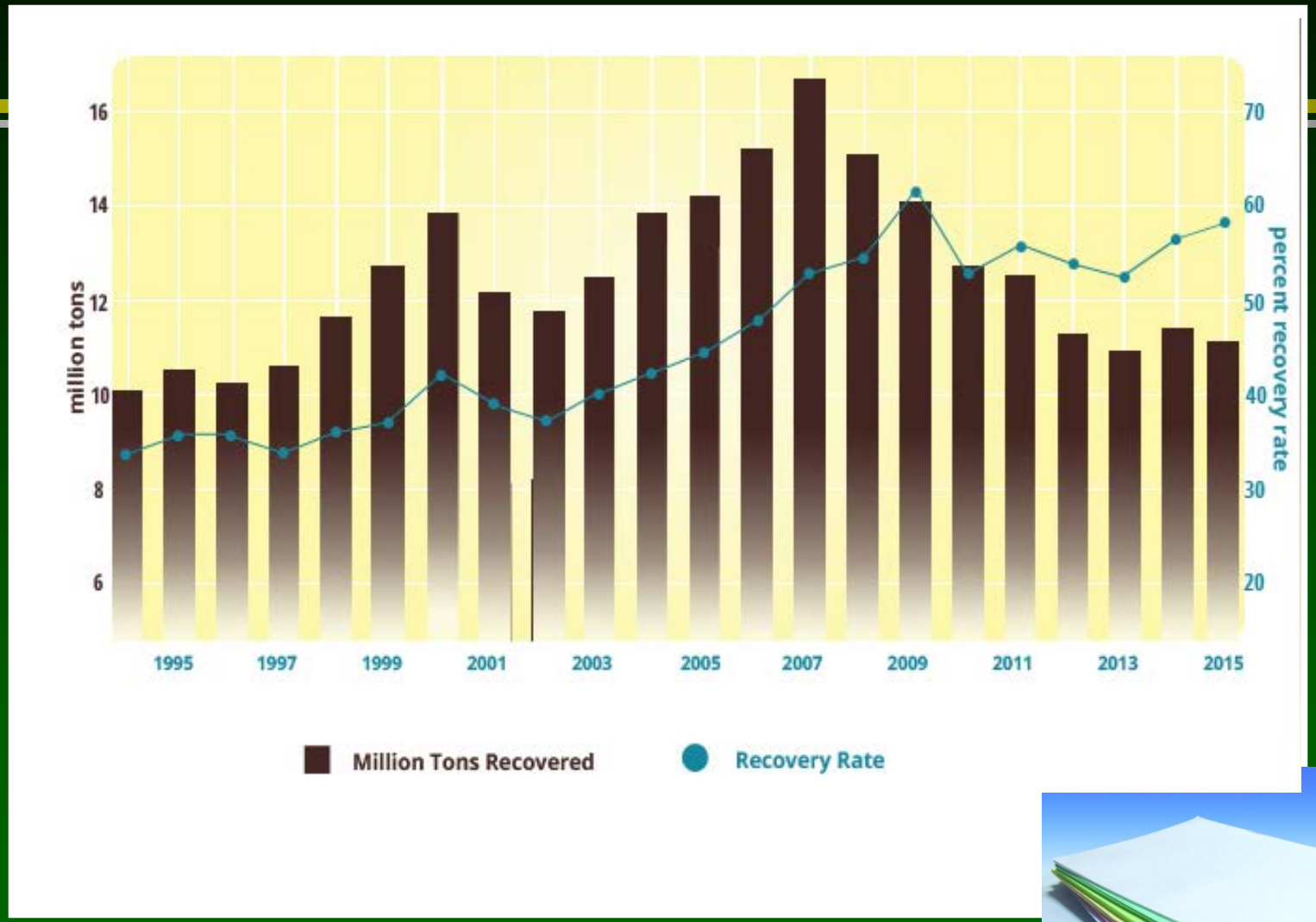
Source: afandpa.org, 2016

Recovery of ONP (mechanical), 72.8%



Source: afandpa.org, 2016

Recovery of Printing Writing Papers, 58.6%



Source: afandpa.org, 2016

PULP&PAPER WEEK

Monthly Recovered Paper Prices

Yellow Sheet

PRICE WATCH: Recovered Paper - Domestic

March 4, 2016

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

	Northeast			Midwest (Chicago)[3]	Southeast[3]	Southwest[3]	LA-SF		Pacific NW[3]
	New England	New York	Buffalo				LA	SF	
MIXED PAPER									
Mixed (2) - OBM*	40-45 (+0)	45-50 (+0)	30-35 (+0)	40-45 (-5)	40-45 (+0)	45-50 (+0)	60-65 (+0)	50-55 (+0)	45-50 (+5)
BROWN GRADES									
Boxb cutt (4) - OBM*	80-85 (+10)	70-75 (+0)	70-75 (+0)	65-70 (+0)	60-65 (+5)	60-65 (+0)	70-75 (+0)	65-70 (+0)	55-60 (+0)
OCC (11) - OBM*	80-85 (+0)	80-85 (+0)	80-85 (+0)	60-65 (+0)	75-80 (+0)	70-75 (-5)	90-95 (+0)	80-85 (+0)	75-80 (+5)
DLK (13) - OBM*		85-90 (+0)	(Northeast)	75-80 (+0)	85-90 (+0)	90-95 (+0)	95-100 (+5)	85-90 (+5)	80-85 (+5)
GROUNDWOOD									
ONP (8) - OBM*	50-55 (+0)	55-60 (+0)	35-40 (+0)	50-55 (+0)	55-60 (+5)	50-55 (+0)	75-80 (+5)	65-70 (+5)	55-60 (+0)
		Northeast					LA-SF[2]		
OMG (10)		95-100 (+0)		90-95 (+0)	95-100 (+0)	80-85 (+0)	110-120 (+0)		90-100 (+0)
CGS (44)		95-100 (+0)		90-95 (+0)	95-100 (+0)	80-85 (+0)	110-120 (+0)		90-100 (+0)
WBN (24)		230-240 (-10)		220-230 (+0)	225-235 (+0)	225-235 (+0)	245-255 (+0)		220-230 (-5)
HIGH GRADES									
SOP (37)		135-145 (+0)		110-120 (+5)	110-120 (+0)	110-120 (+0)	150-160 (+5)		125-135 (+5)
CBS (43)		135-145 (+5)		110-120 (+5)	110-120 (+0)	110-120 (+0)	150-160 (+5)		125-135 (+5)
SBS heavy print (45)		160-170 (+0)		130-140 (+0)	135-145 (+0)		165-175 (+5)		
SWL (40)		215-225 (+0)		190-200 (+0)	190-200 (+0)	195-205 (+0)	220-230 (+0)		200-210 (+5)
MWL (41) [1]		215-225 (+0)		190-200 (+0)	190-200 (+0)	195-205 (+0)	220-230 (+0)		200-210 (+5)
SBS light print (45)		215-225 (+5)		185-195 (+0)	185-195 (+0)	185-195 (+0)	215-225 (+5)		
PULP SUBS									
SBS unprinted (47)		295-305 (+0)		270-280 (+0)	280-290 (+0)	280-290 (+0)	275-285 (+0)		
HWS (30)		310-320 (+0)		285-295 (+0)	300-310 (+0)	305-315 (+0)	295-305 (+0)		
HWEC (31)		330-340 (+0)		315-325 (-5)	310-320 (-5)	325-335 (+0)	320-330 (+0)		280-290 (-5)

PULP&PAPER WEEK

Yellow Sheet

PRICE WATCH: Recovered Paper - Export

March 4, 2016

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

Incorporating Official Board Markets

	Desti-nation	New York[1]		Chicago		LA[2]		SF/Oakland	
FAS port of origin (per ton)									
Mixed Paper (2) - OBM*	China	79-82	(+6)	56-59	(+5)	91-94	(+8)	85-88	(+7)
OCC (11) - OBM*	China	132-135	(+8)	107-110	(+8)	144-147	(+9)	138-141	(+8)
DLK (13)	China	149-153	(+8)			162-165	(+10)	155-158	(+8)
ONP (8) - OBM*	China	100-103	(+8)	70-73	(+7)	107-110	(+8)	101-104	(+10)
SOP (37)	China	175-178	(+1)			187-190	(+7)	180-183	(+5)
SWL (40)	Asia	264-267	(+4)			260-263	(+1)	253-256	(+3)
CFR to destination port (per tonne)									
Mixed Paper (2)	China	112-115	(+10)			115-118	(+9)		
OCC (11)	China	165-168	(+5)			167-170	(+4)		
Select OCC (11)	India	180-183	(+7)						
Double-sorted OCC (12)	India	187-190	(+5)						
DLK (13)	China	189-192	(+9)			194-197	(+10)		
ONP (8)	China	133-136	(+10)			135-138	(+9)		
SOP (37)	China	212-215	(+0)			222-225	(+7)		
SWL (40)	Asia[3]	332-335	(+0)			332-335	(+0)		

*** 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-truckload 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

1. "New York" includes ports in Northern New Jersey
2. "LA" includes Long Beach and LA ports
3. SWL prices are for ports in South Korea, Indonesia, and Thailand

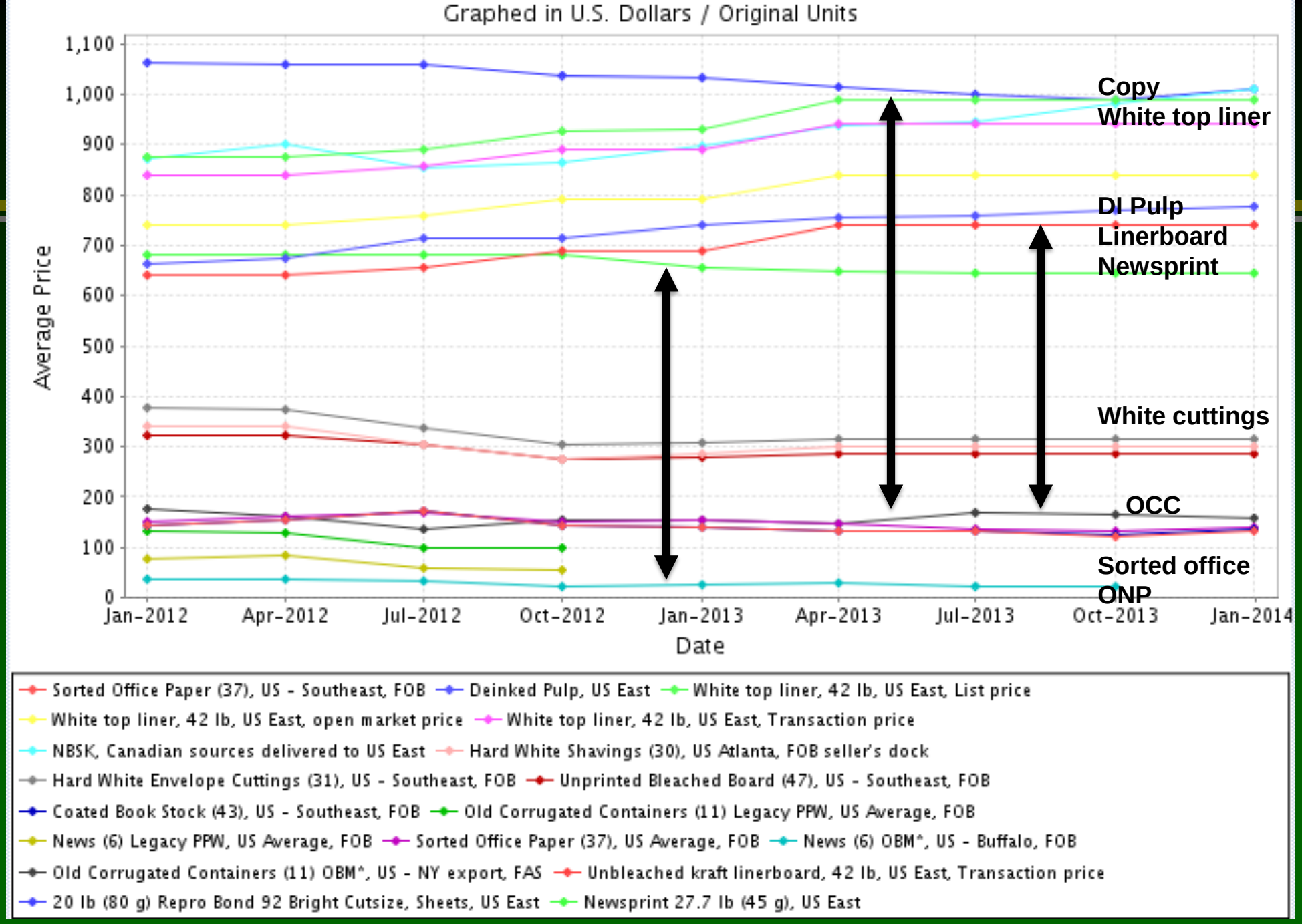
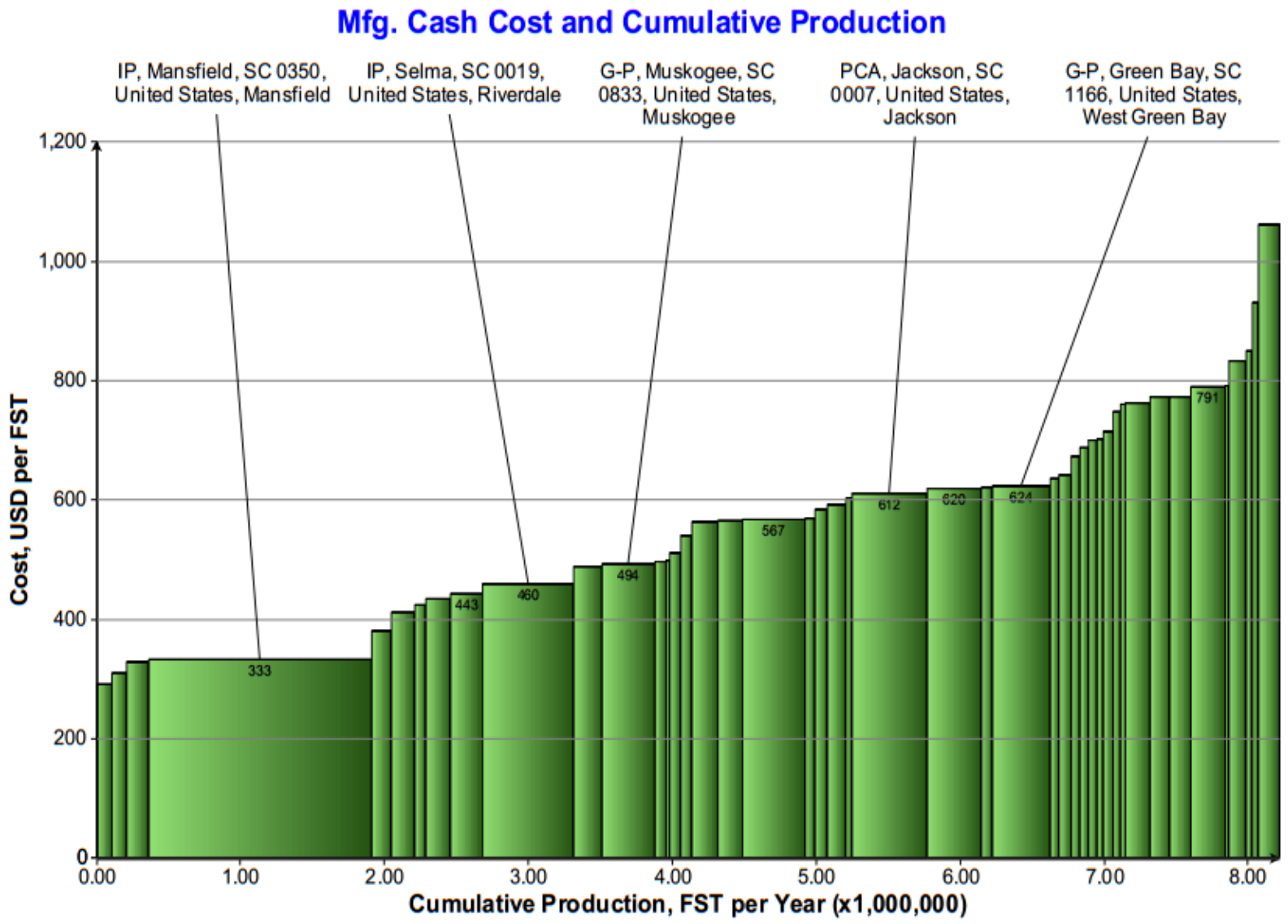

Graphed in U.S. Dollars / Original Units
Average Price
1,100
1,000
900
800
700
600
500
400
300
200
100
0
Jan-2012
Apr-2012
Jul-2012
Oct-2012
Jan-2013
Apr-2013
Jul-2013
Oct-2013
Jan-2014
Date
Copy
White top liner
DI Pulp
Linerboard
Newsprint
White cuttings
OCC
Sorted office
ONP
Sorted Office Paper (37), US - Southeast, FOB
Deinked Pulp, US East
White top liner, 42 lb, US East, List price
White top liner, 42 lb, US East, open market price
White top liner, 42 lb, US East, Transaction price
NBSK, Canadian sources delivered to US East
Hard White Shavings (30), US Atlanta, FOB seller's dock
Hard White Envelope Cuttings (31), US - Southeast, FOB
Unprinted Bleached Board (47), US - Southeast, FOB
Coated Book Stock (43), US - Southeast, FOB
Old Corrugated Containers (11) Legacy PPW, US Average, FOB
News (6) Legacy PPW, US Average, FOB
Sorted Office Paper (37), US Average, FOB
News (6) OBM^, US - Buffalo, FOB
Old Corrugated Containers (11) OBM^, US - NY export, FAS
Unbleached kraft linerboard, 42 lb, US East, Transaction price
20 lb (80 g) Repro Bond 92 Bright Cutsize, Sheets, US East
Newsprint 27.7 lb (45 g), US East

Figure A2-1: Mills deinking SOP, MP, OMG, pulp substitutes, or shavings (30)



Source: FisherSolve™

Quote from Recovered Paper Collector

- 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

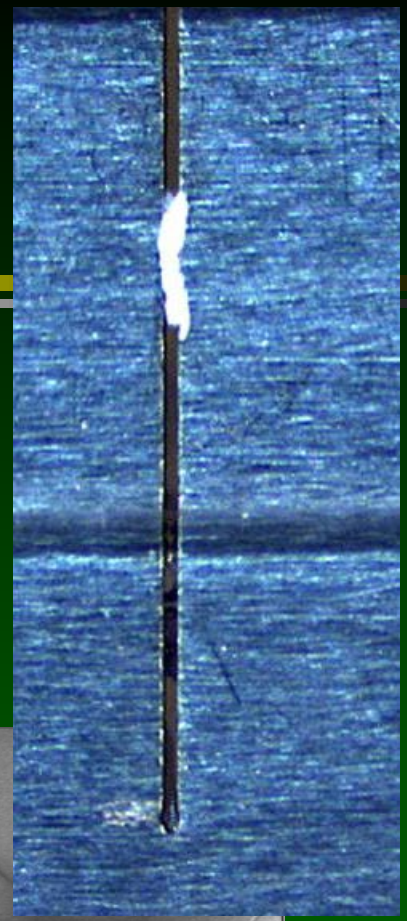
- Large Junk
  - metals: nuts, screws, foil, cans
  - plastics: films, bags, envelopes
  - dirt, cloth, yard waste, leather, etc.,
- Inks & toners
- Stickies -- most difficult problem currently
- Coatings – can appear as white/colored chips,
- Wax Coatings – present in some boxes
- Fillers – damaging to the tissue creping process
- Papermaking additives – dyes, wet strength agent

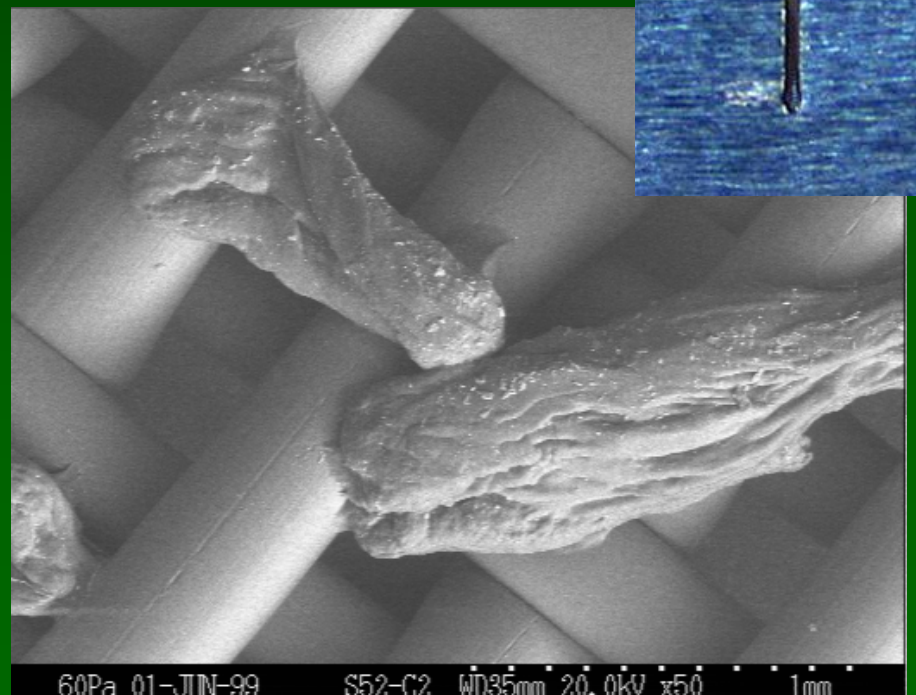
Inks & Toners

Type	Component	Drying System	Ink Resin Film	Particle Size (microns)	End Products
Simple Letter Press	Pigment + Mineral Oil	Absorption into Web	Weak	1-15	Letterpress Early Newsprint
Newsprint and Offset	Pirgment + Soft Resin & Mineral Oil	Penetration of Vehicle into Web + Resin Oxidation	Soft Film Hard Film	2-30	Newsprint, Books We Offset, Letter Press
Rotogravure	Pigment +Hard Resin & Solvent	Solvent Evaporation	Hard Film	2-250	Magazines, Catalogues
Flexographic	Pigment + Resin & Water Emulsification	Amine Absorption, Evaporation	Water Resistant Film	small	Newsprint inserts, Corrugated
UV Cured	Pigment +Monomer	UV Photopolymerization	Non swelling, Non saponif. Hard Film	50-100	High Speed Coated Papers
Specialty	Various Pgiments and Rosins	Heat set or Other	Hard, Coherent Films	40+	Xerography Laser Printers Electronic Forms

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

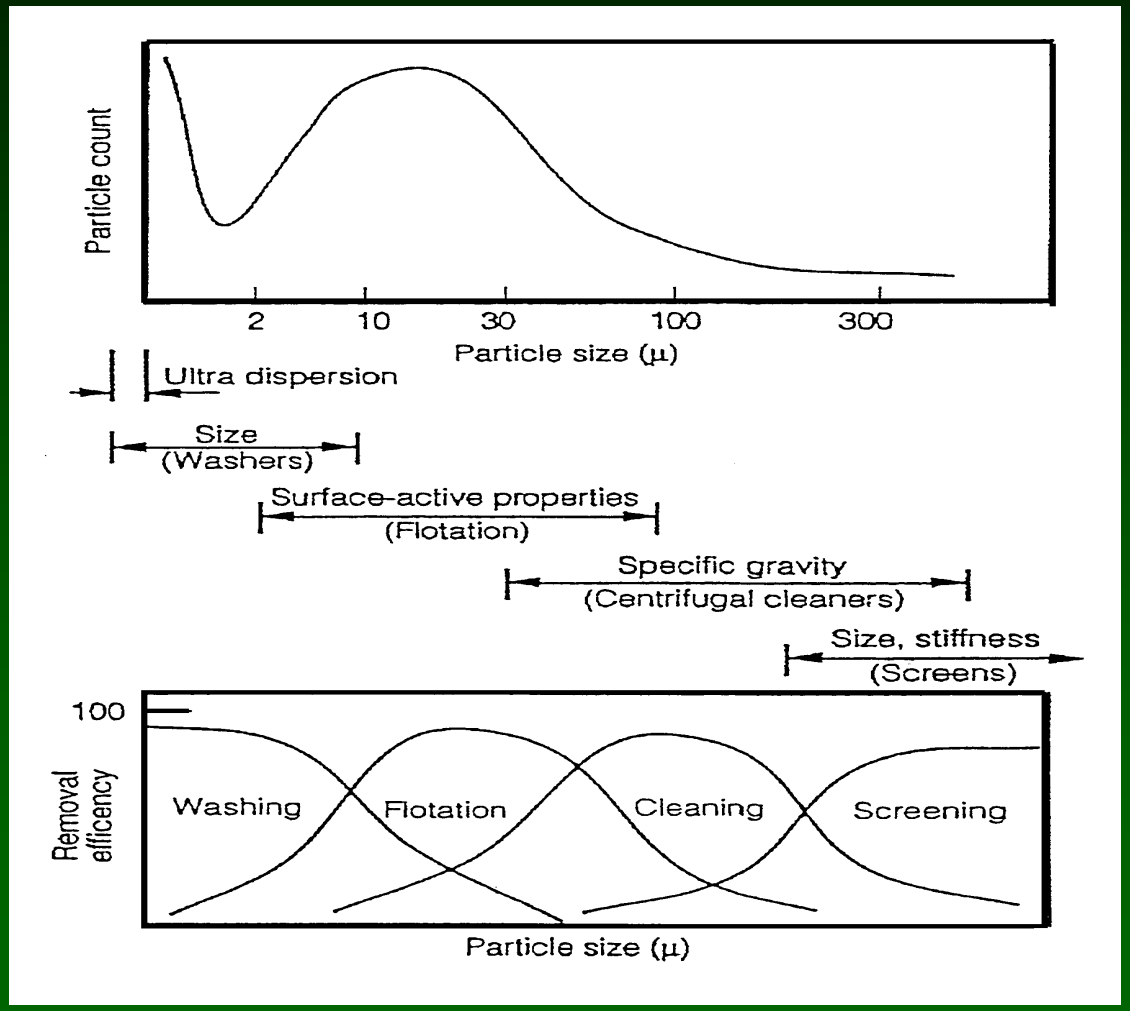


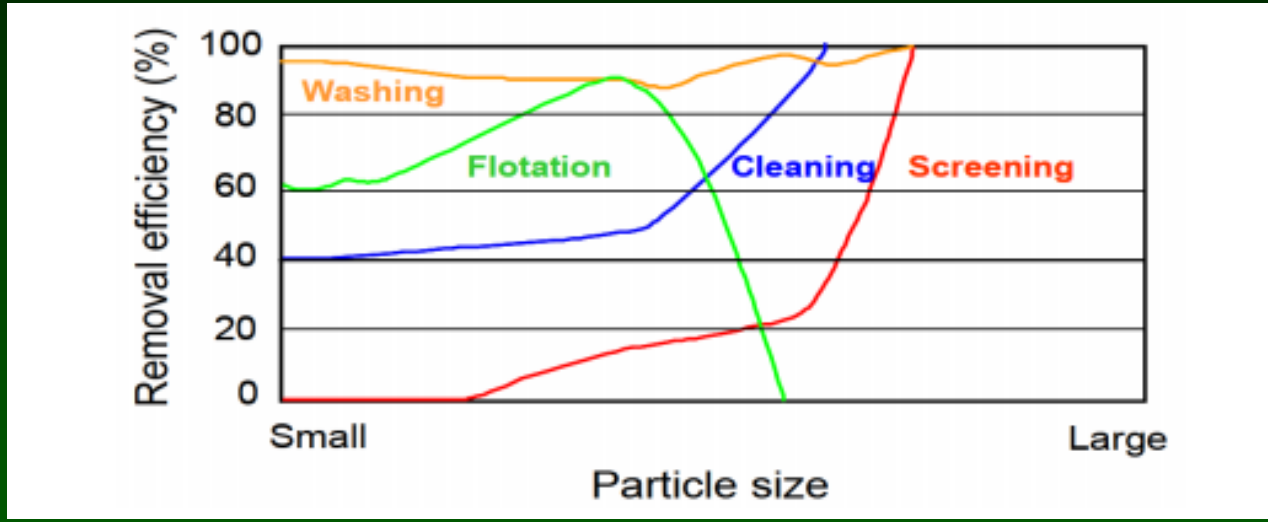


Why is contaminant removal so difficult?

- 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





TAPPI. (2011)."Deinking Review," Progress in Paper Recycling 20(1): 1-43.

Particle Size	Removal Method
> 100 μm	Screening & centrifugal cleaning
10 - 100 μm	Flotation
< 10 μm	Washing

Bajpai, P. (2013). "Recycling and Deinking of Recovered Paper," Elsevier, Waltham, MA.

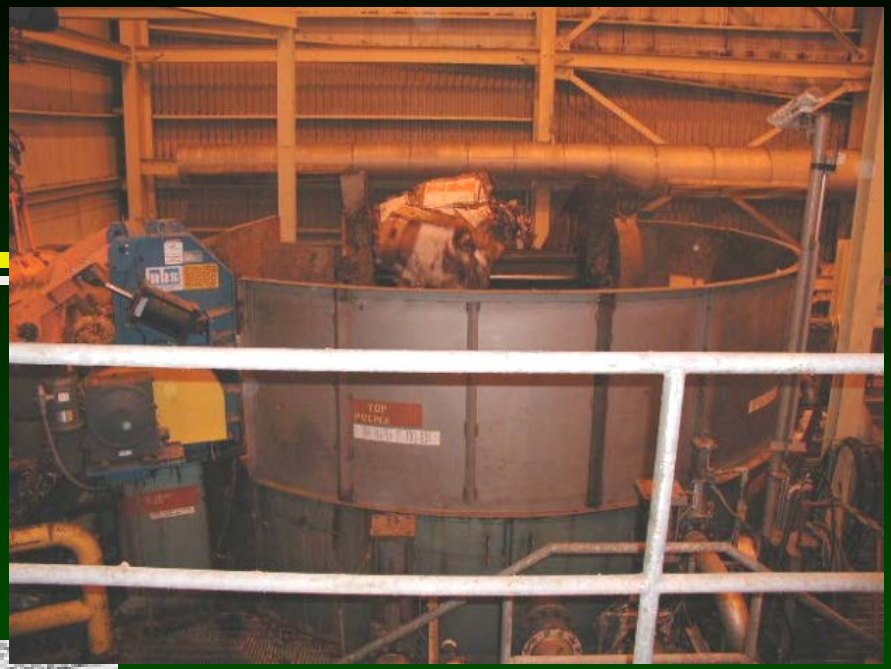
Major Recycling Unit Operations

- 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

Pulping



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.

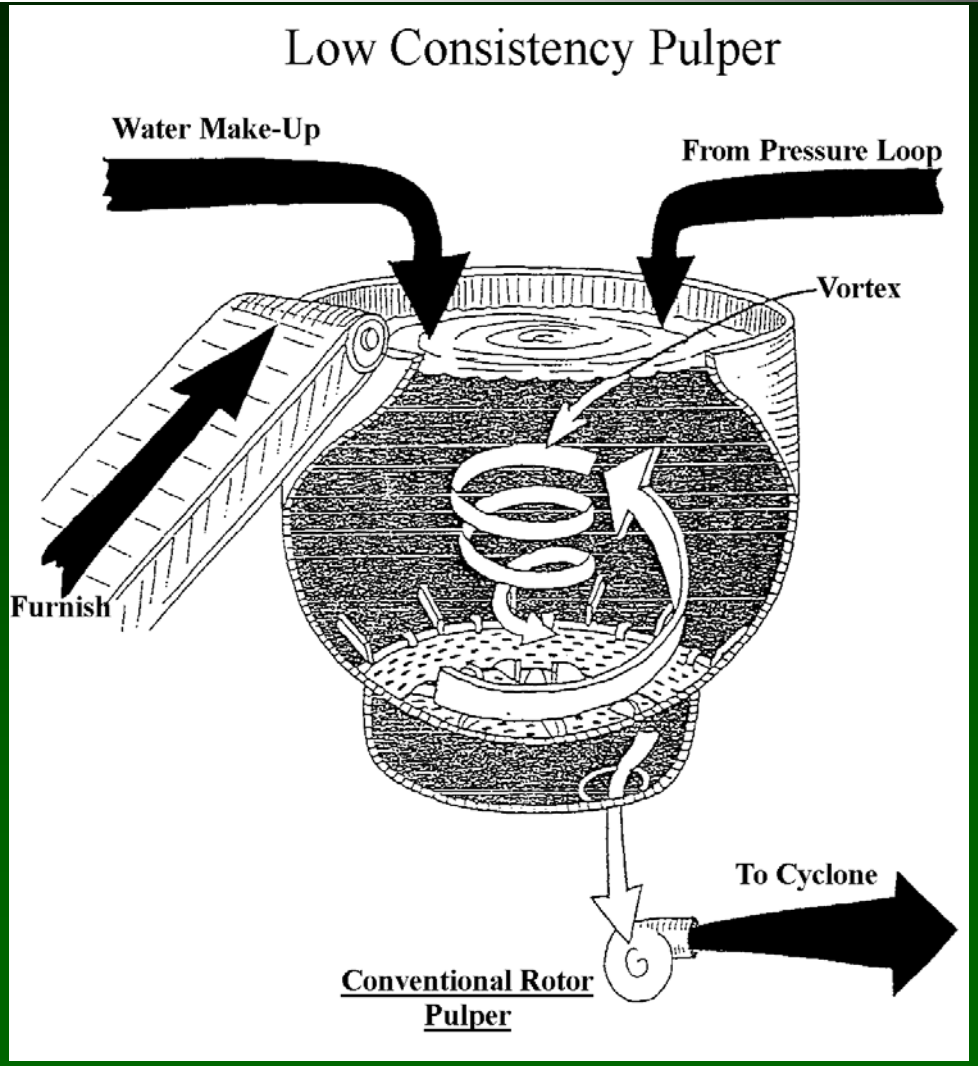
3. Maintain contaminants as large as possible to aid subsequent removal processes.

4. Avoid damage to the fibers (fiber cutting).

5. Removal of large debris from system.

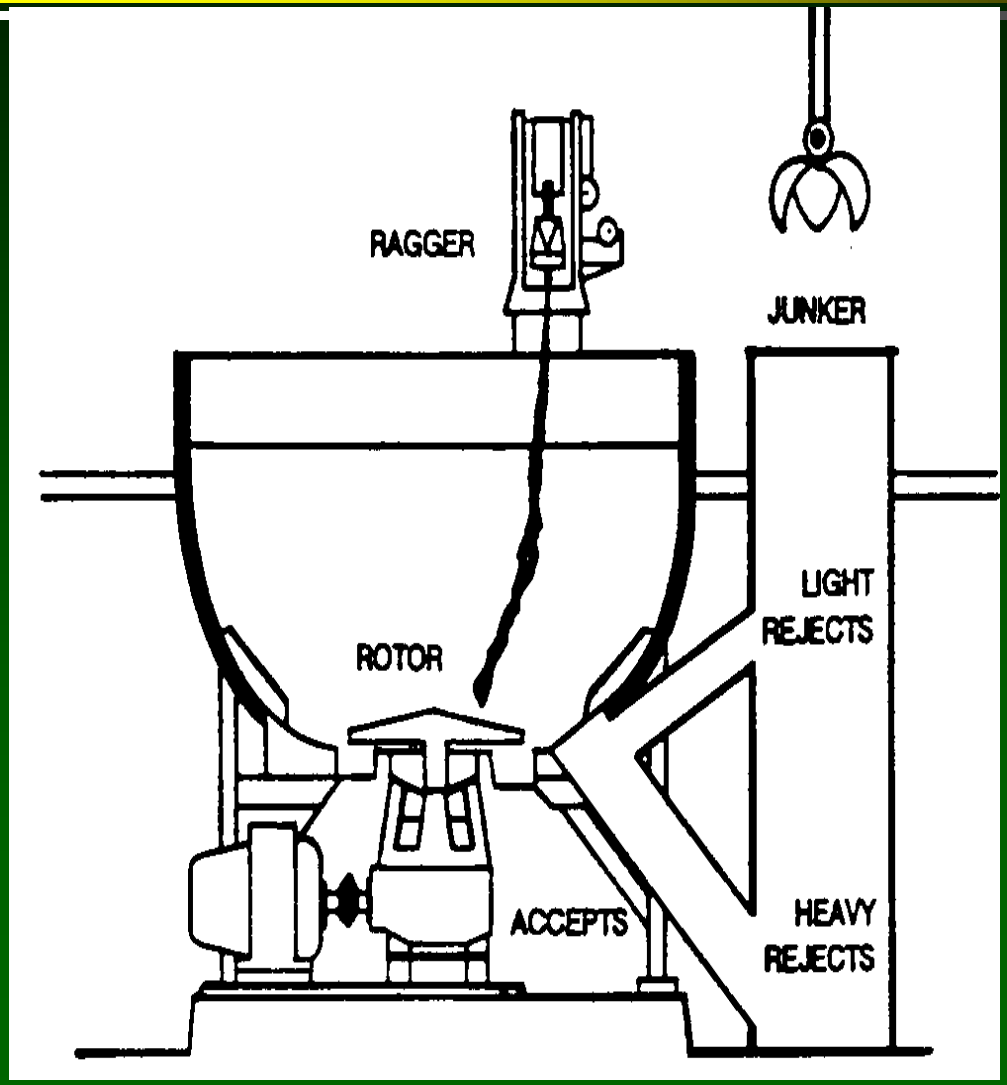
Low Consistency Pulping: Harsh, used for OCC

- 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)



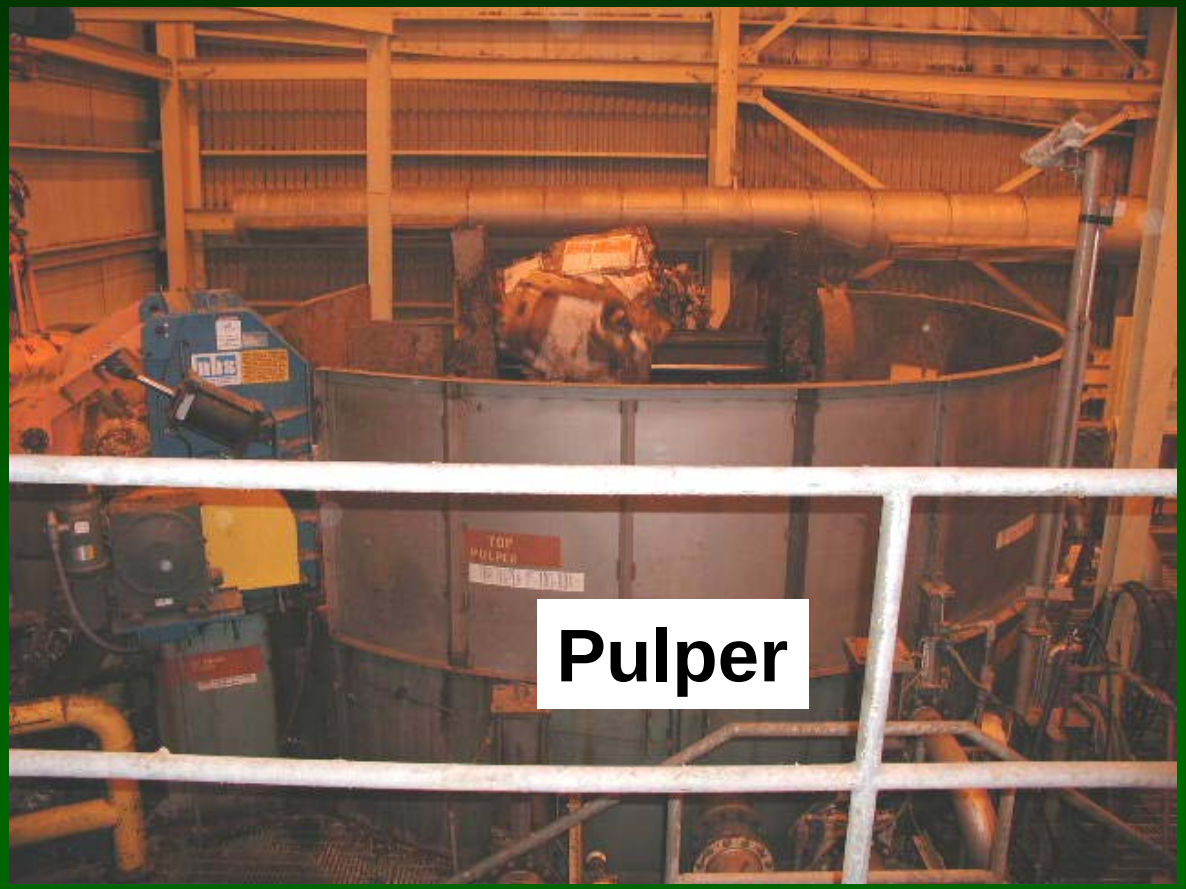
Continuos Low Consistency Pulper with Ragger and Junk Tower

- Low consistency continuos 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 continuos “rope” formed by entangled debris. The “rope” is continously pulled out of the pulper and cut into sections and disposed. Common in OCC mills.



Wire bale cutter

Low Consistency Continuous Pulping



Pulper

Warehouse

Ragger removing debris from the pulper surface

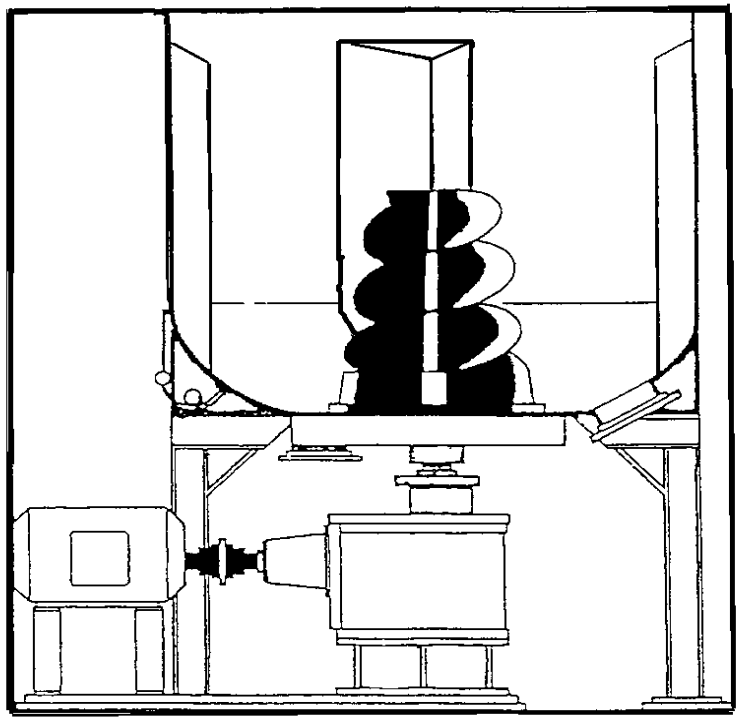
Low
Consistency
Continuous
Pulping

Junker Claw

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

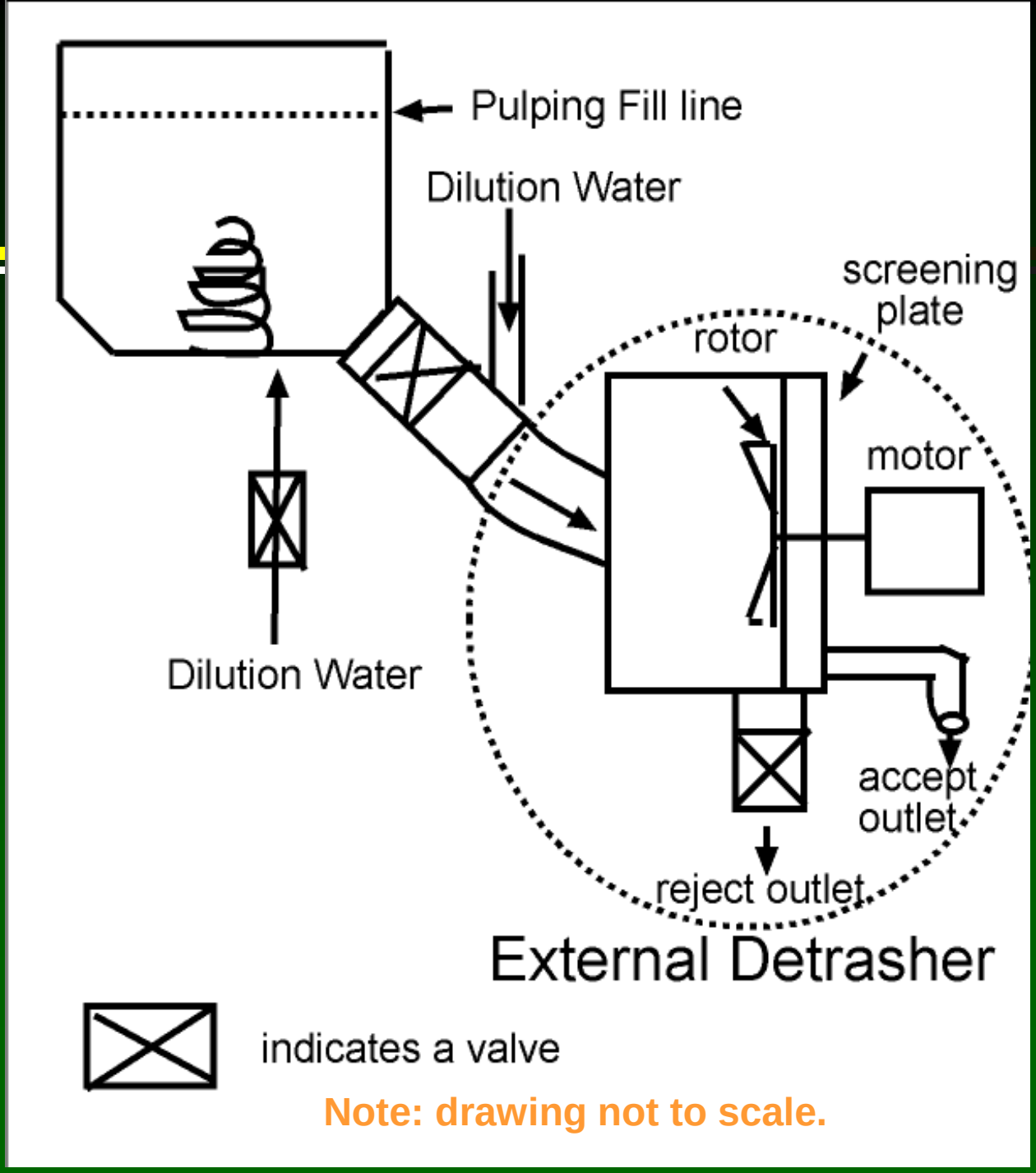
- Typically 8-18 %.
- High profile rotor used. The helical screw type rotor is needed to “pull down” the non-fluid like high % K stock, from the top to the bottom of the pulper.
- At the high % K, fiber-fiber (solid-solid) rubbing dominates the forces experienced in the pulper.
- 30 kWh/t

High Consistency
Rotor Type Pulper
(Black Clawson High-Con Pulper)



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.



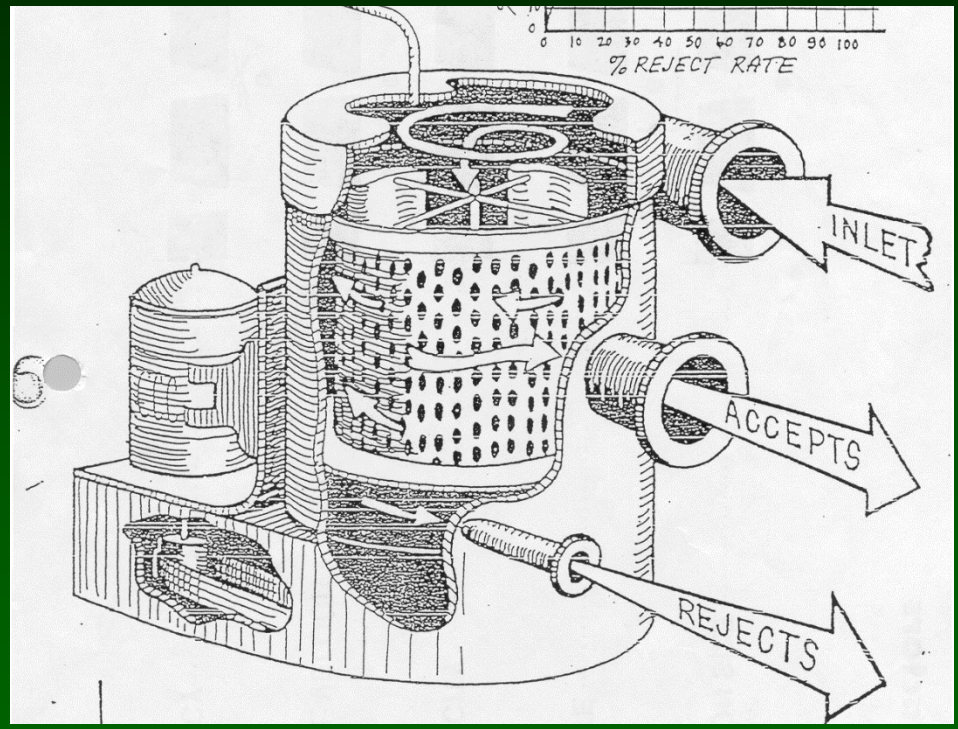
Pulping Summary

- High consistency pulping used on _____
- Low consistency pulping used on _____
- Pulping Objectives:
  - _____
  - _____
  - _____
  - _____

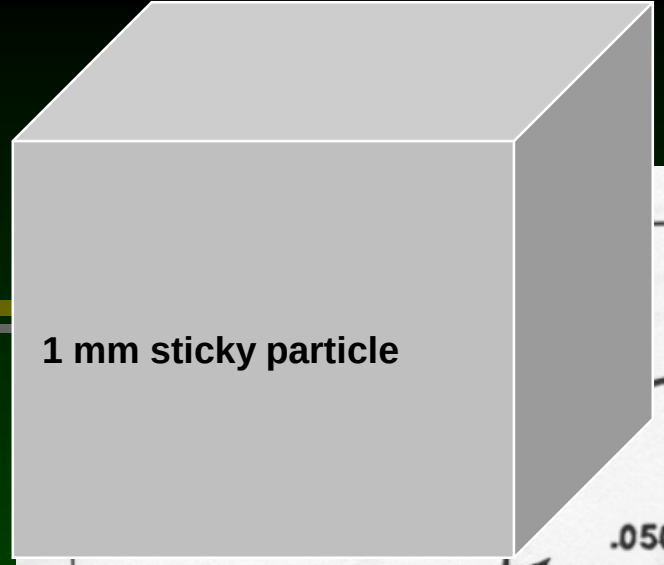
- Bottom Line: If pulping is not done properly, subsequent processing steps will be ineffective and product quality will be unacceptable

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



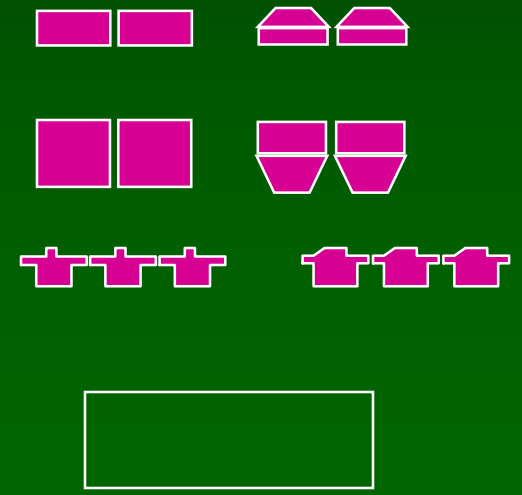
Screening



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.

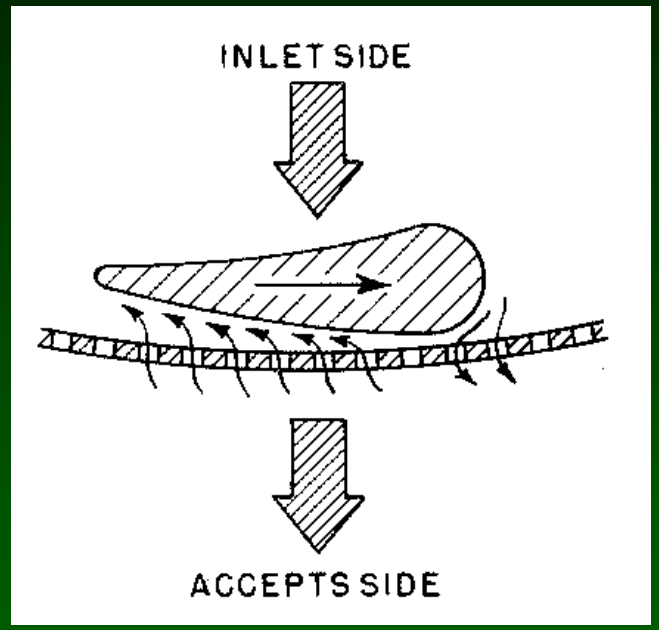
Screening

- 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



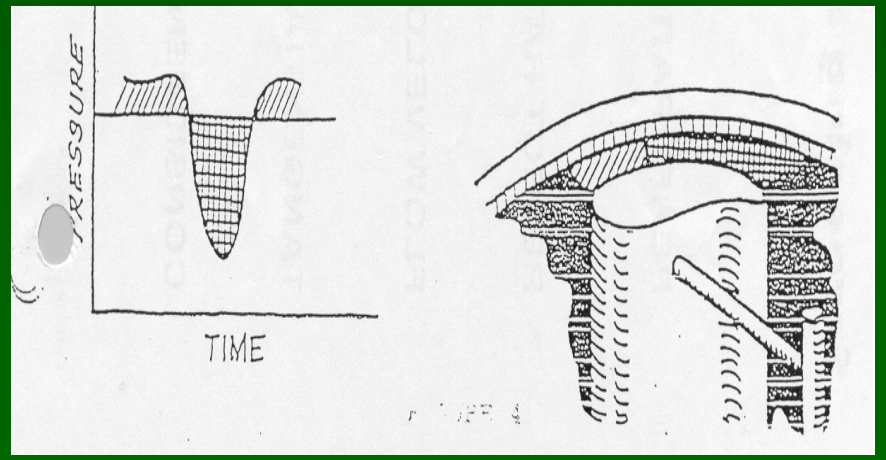

Pressure screen

Pressure Screen Principle to Prevent Blinding of Screen

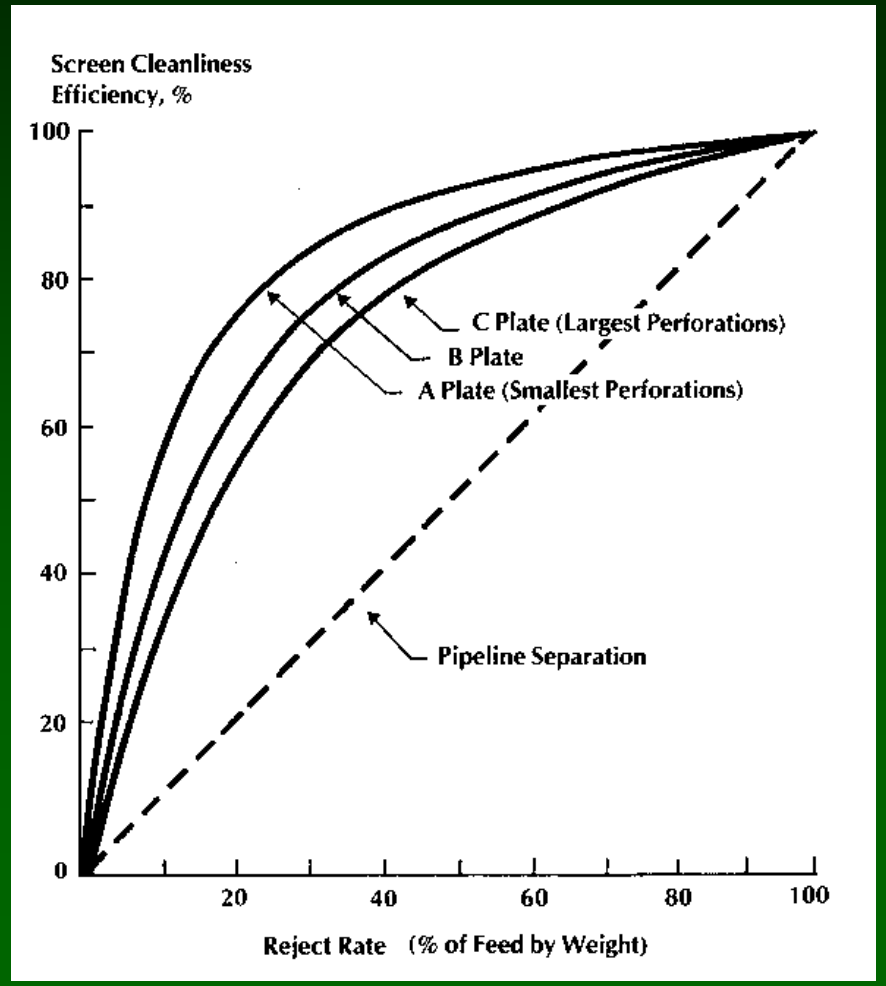


The leading edge of the rotating foil accelerates the stock.

The negative pulse under the sweeping foil momentarily reverses the flow, effectively purging the screen openings.

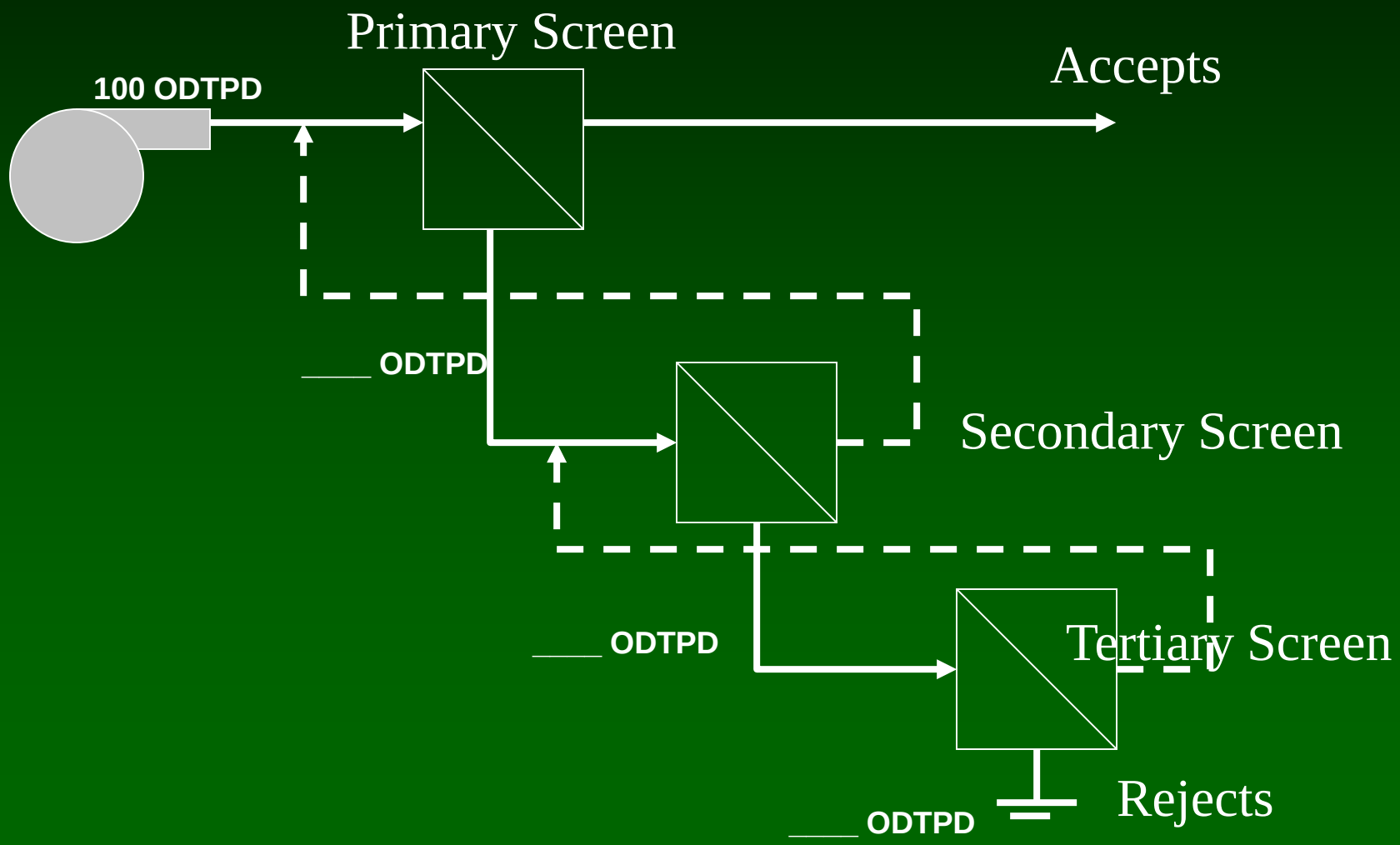


Effect of Reject Rate & Plate Opening on Screen Cleanliness

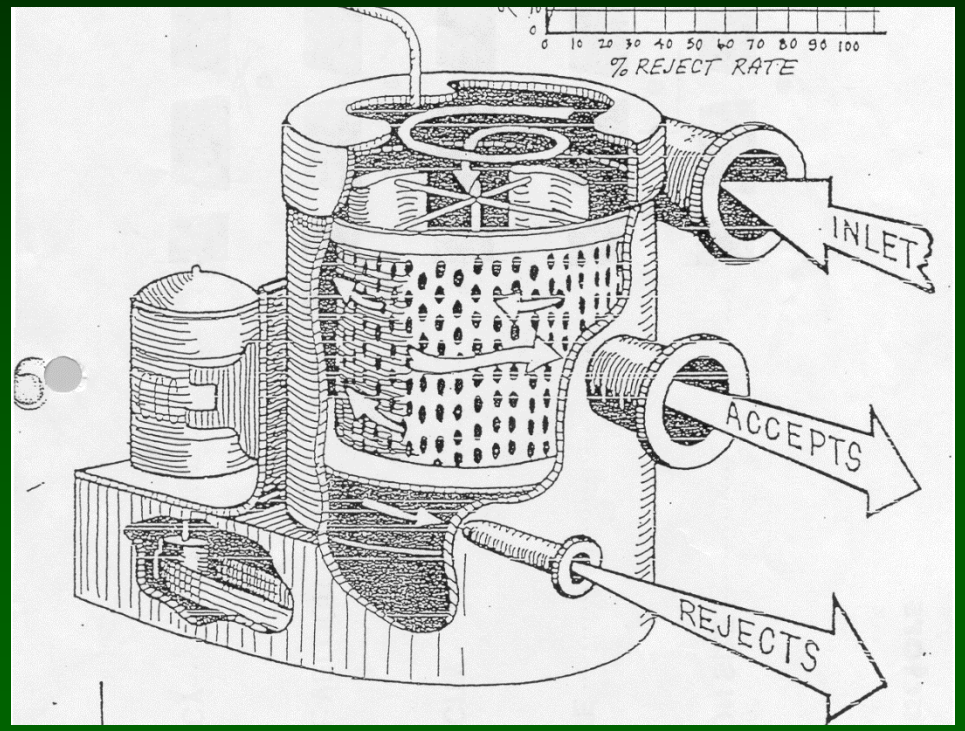


Screen Layout:

Always have cascaded screens to save fiber.



Summary Pressure Screen:



Objective: separate large contaminants from fibers

Utilize holes or slots to reject _____ contaminants

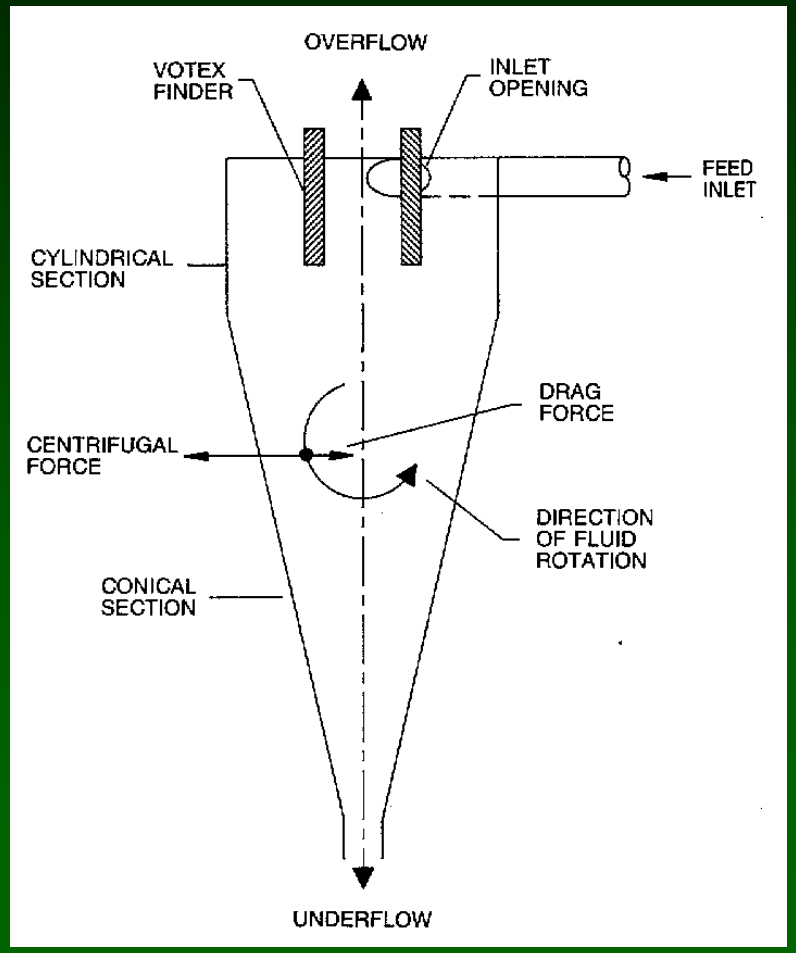
Typically _____ configurations to save fiber .

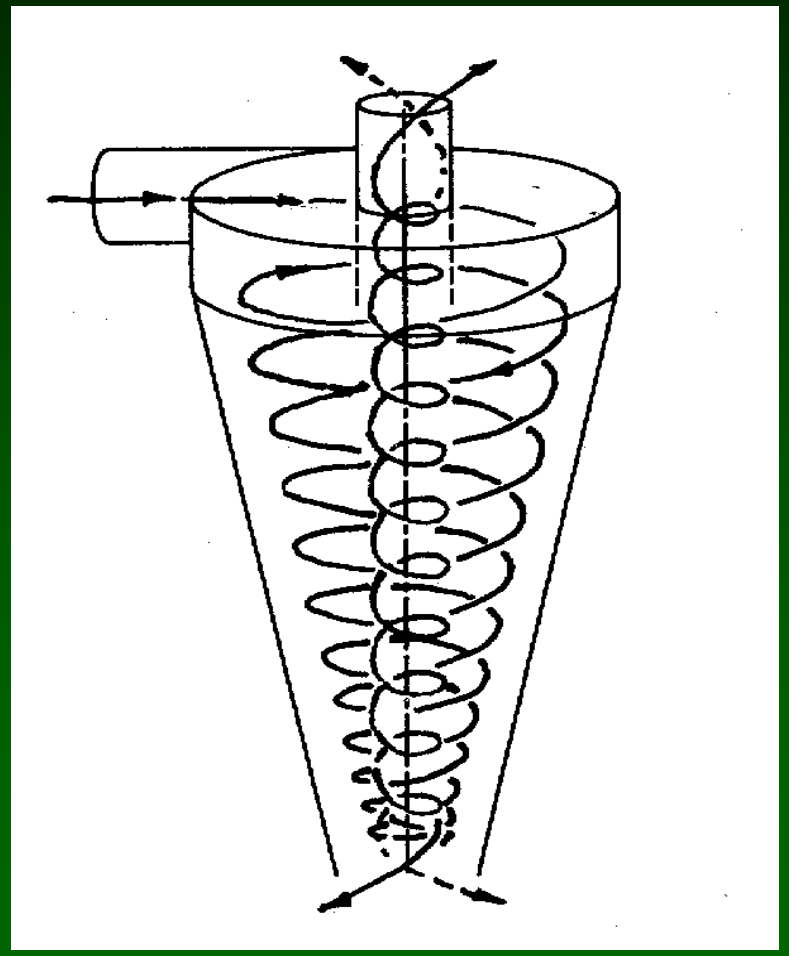
Foils used to _____.

Centrifugal Cleaning

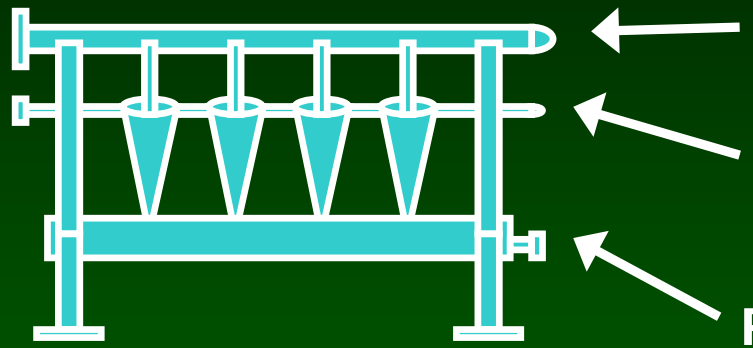
- Remove impurities from the pulp stream based mainly on density
- Density = mass / volume
- Rotational fluid flow within the cone causes denser particles to move to the outside faster than lighter particles due to centrifugal forces
- Centrifugal cleaners remove
  - metals
  - inks
  - sand
  - bark
  - dirt

Centrifugal Cleaner: Features and Flow

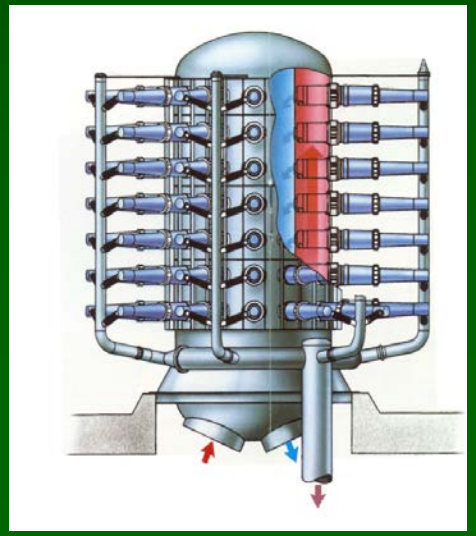


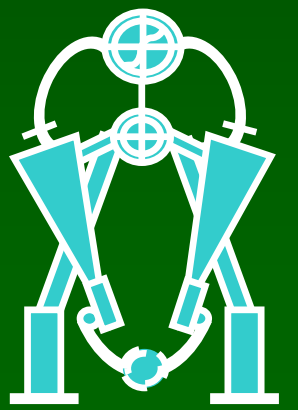


“Bank Arrangement” of Cleaners: stages



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:

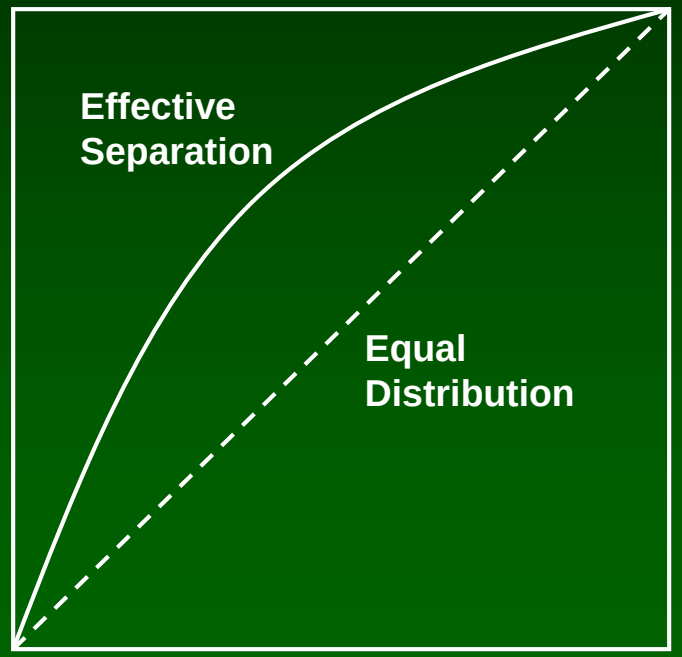
m(in) – m(acc) / m(in)

m= mass flow contaminant

Cleanliness Efficiency:

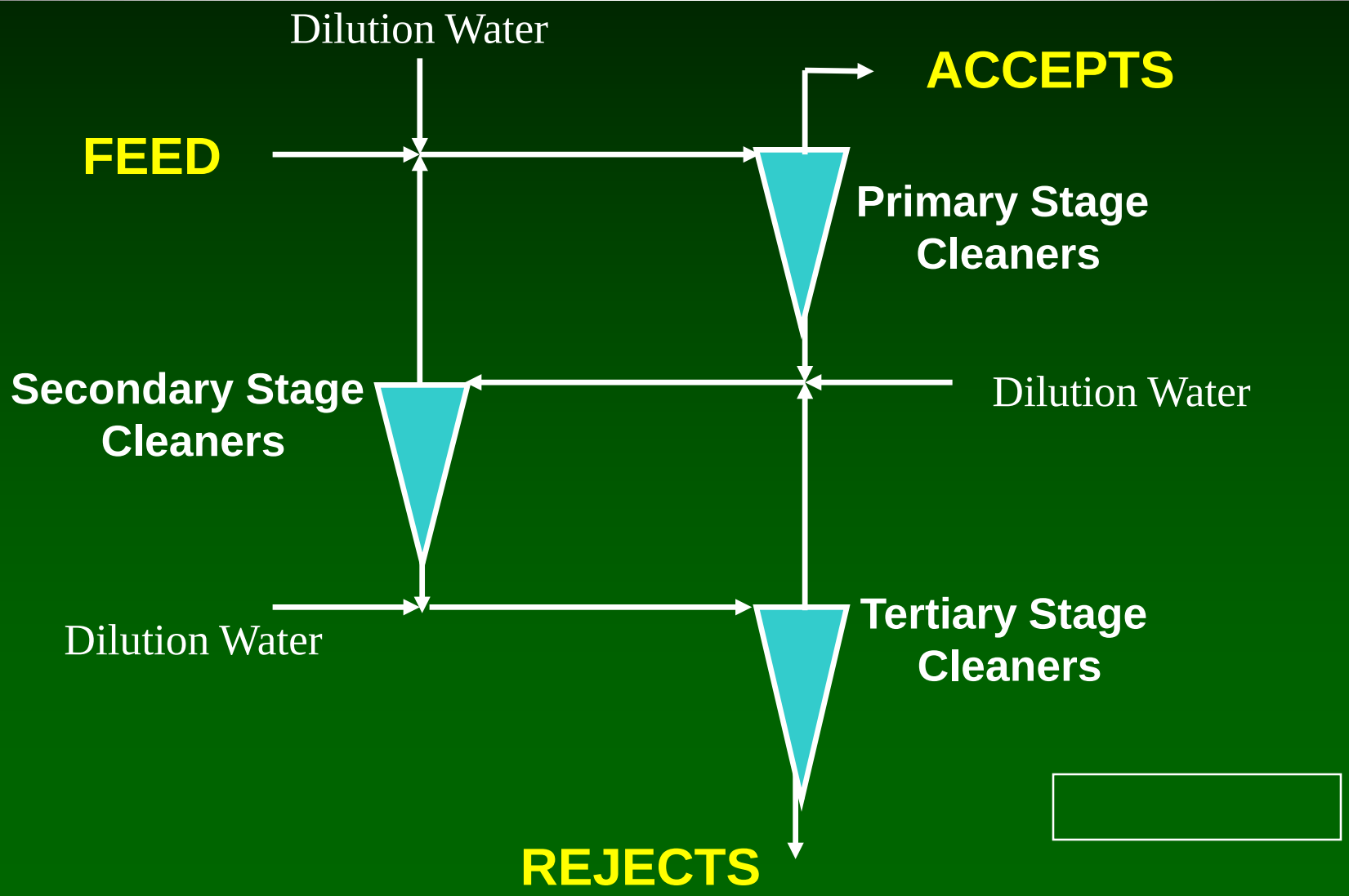
PPM(in) – PPM(acc) / PPM(in)

PPM= contaminant concentration



Reject Ratio: OD mass flow reject / OD mass flow inlet

Cascade Arrangement of Cleaners



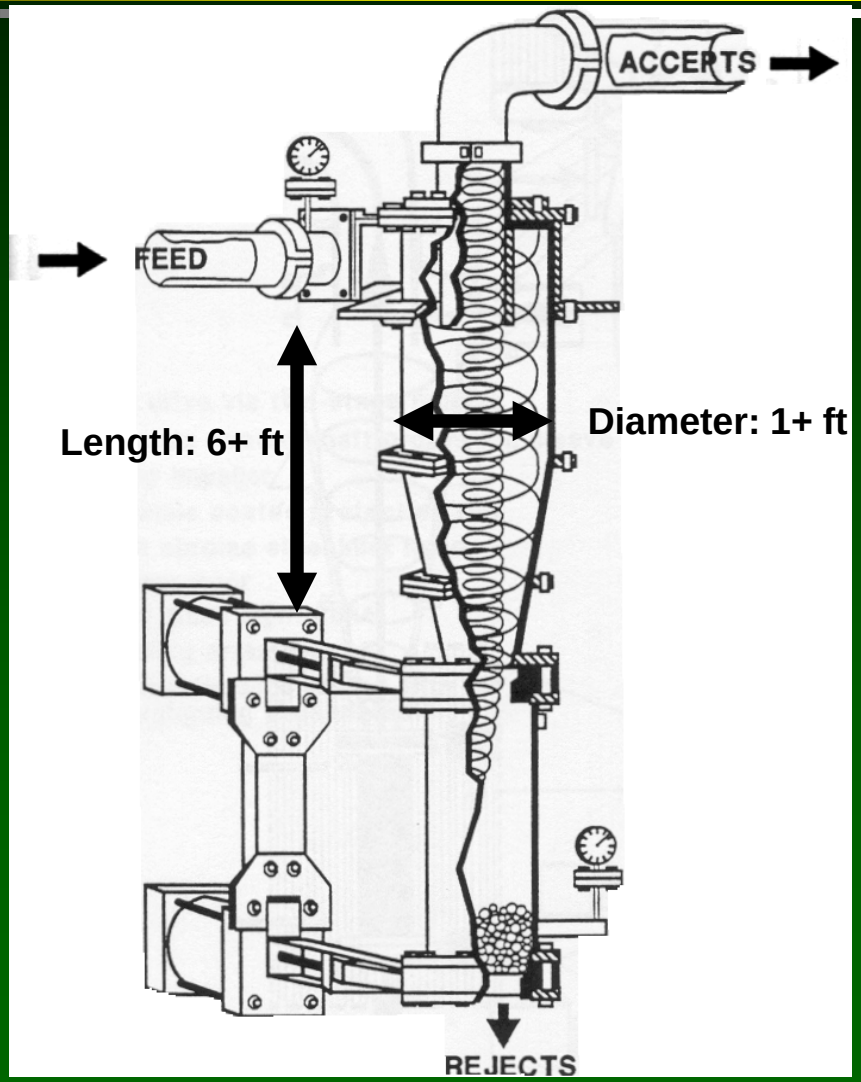
Three Basic Cleaner Types:

- **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.

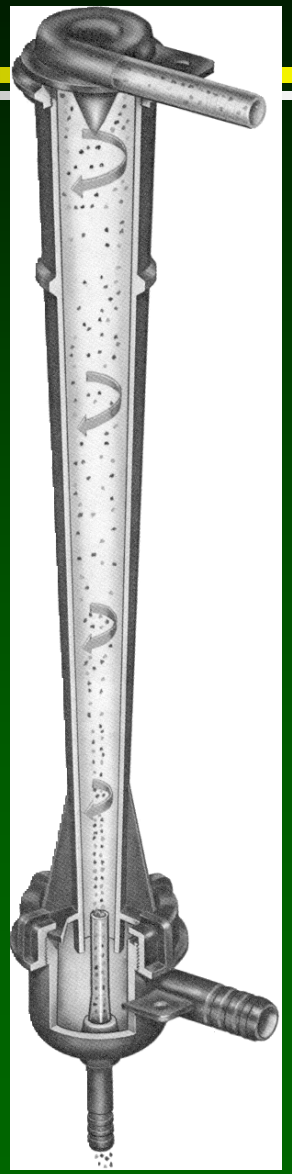
- **Forward Cleaners:** separates **fine, heavy** contaminants such as a sand and inks. Also called cyclones, hydrocyclones, or cleaners. (Described previously) Diameter = 70-400 mm

- **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

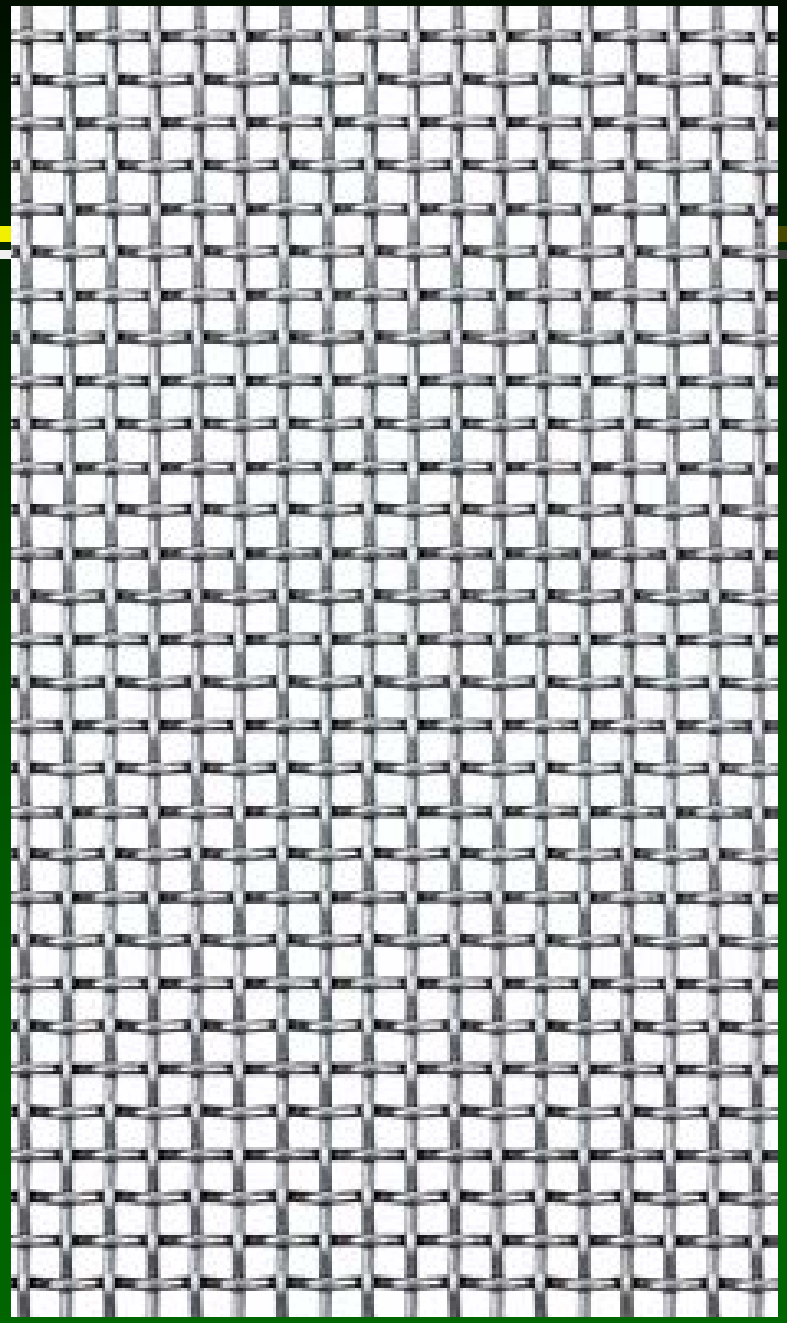
Accepts

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.

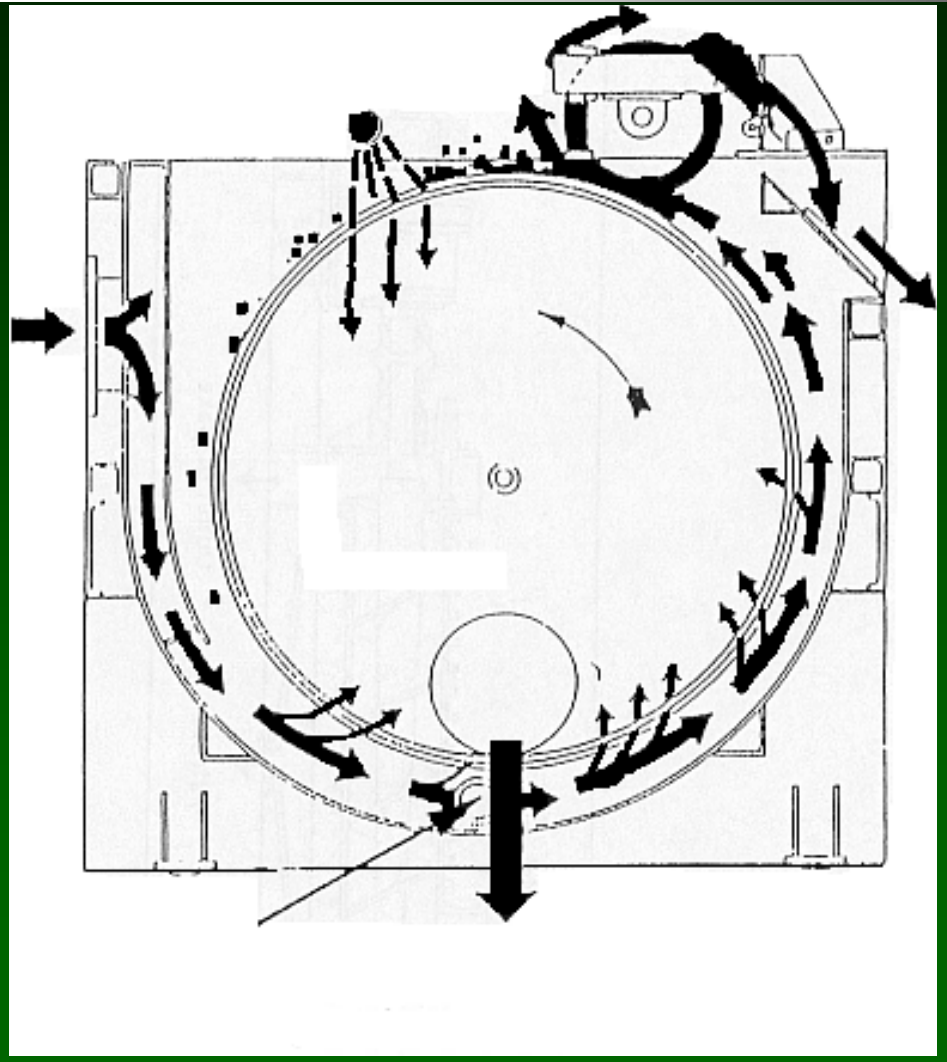
Washers

- 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

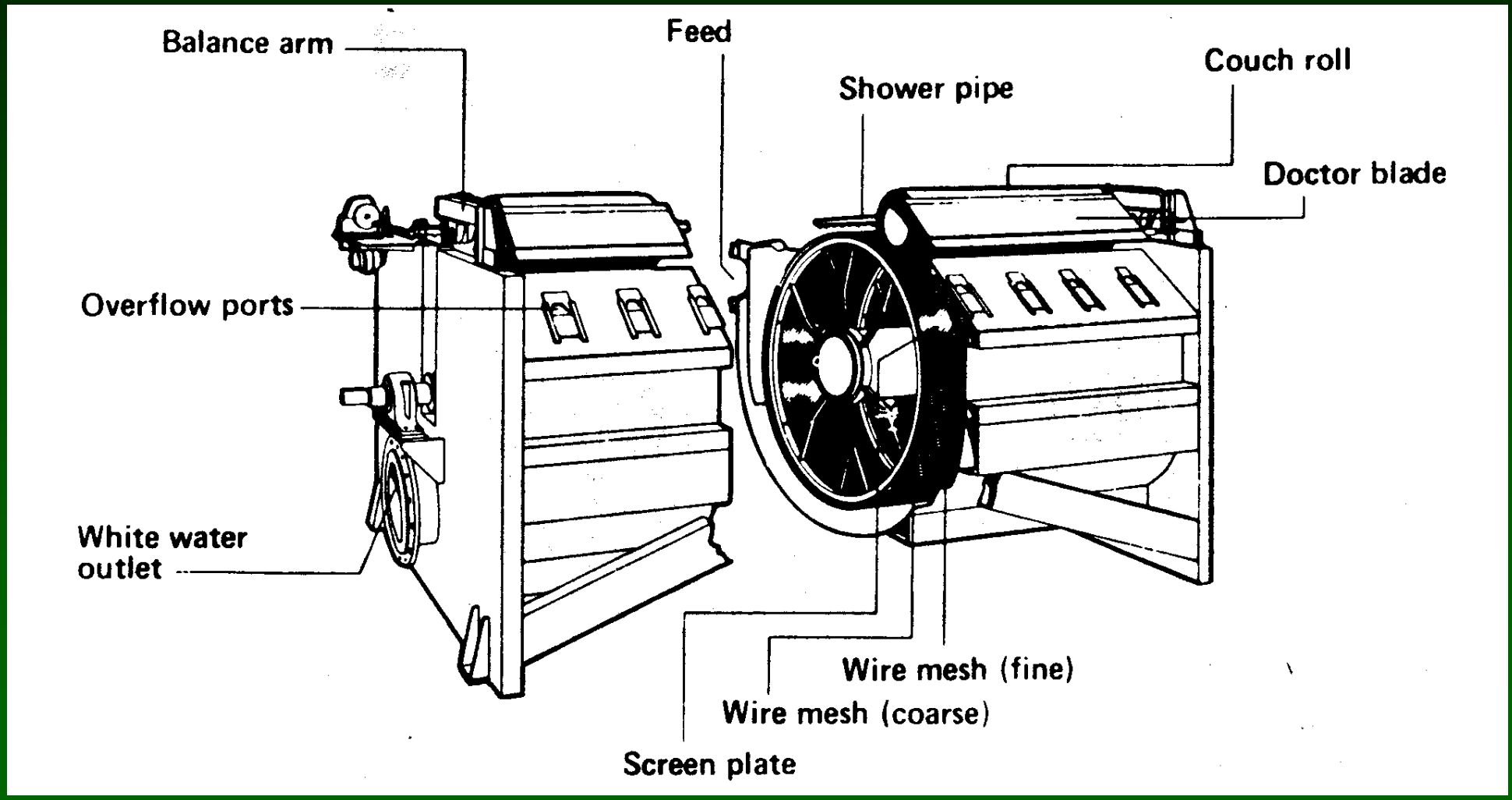


Gravity Decker

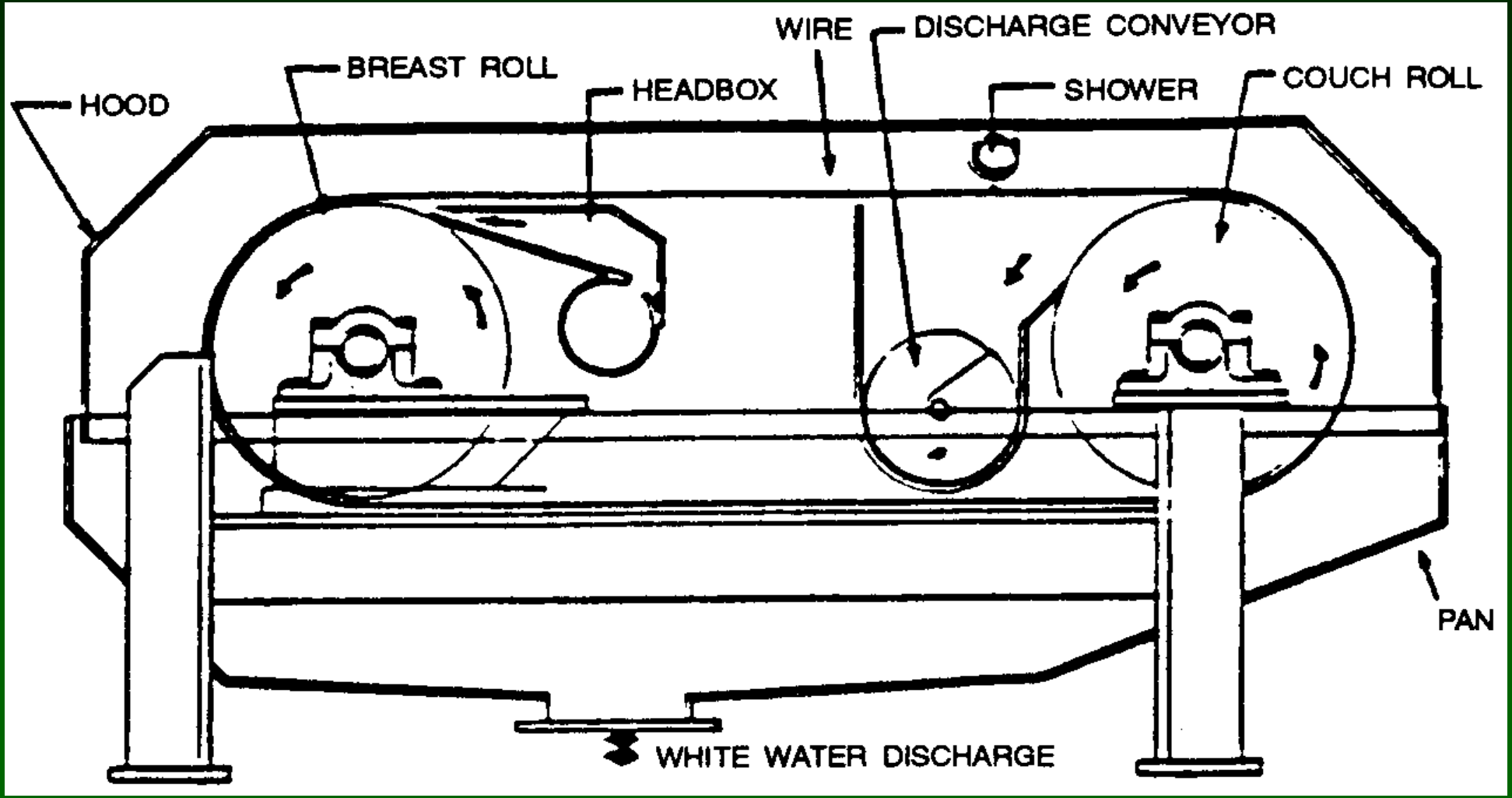
- Pulp enters at 0.8% and leaves at 5%
- Water (and ink) passes through wire mesh cylinder
- Vacuum created by liquid falling increases water removal



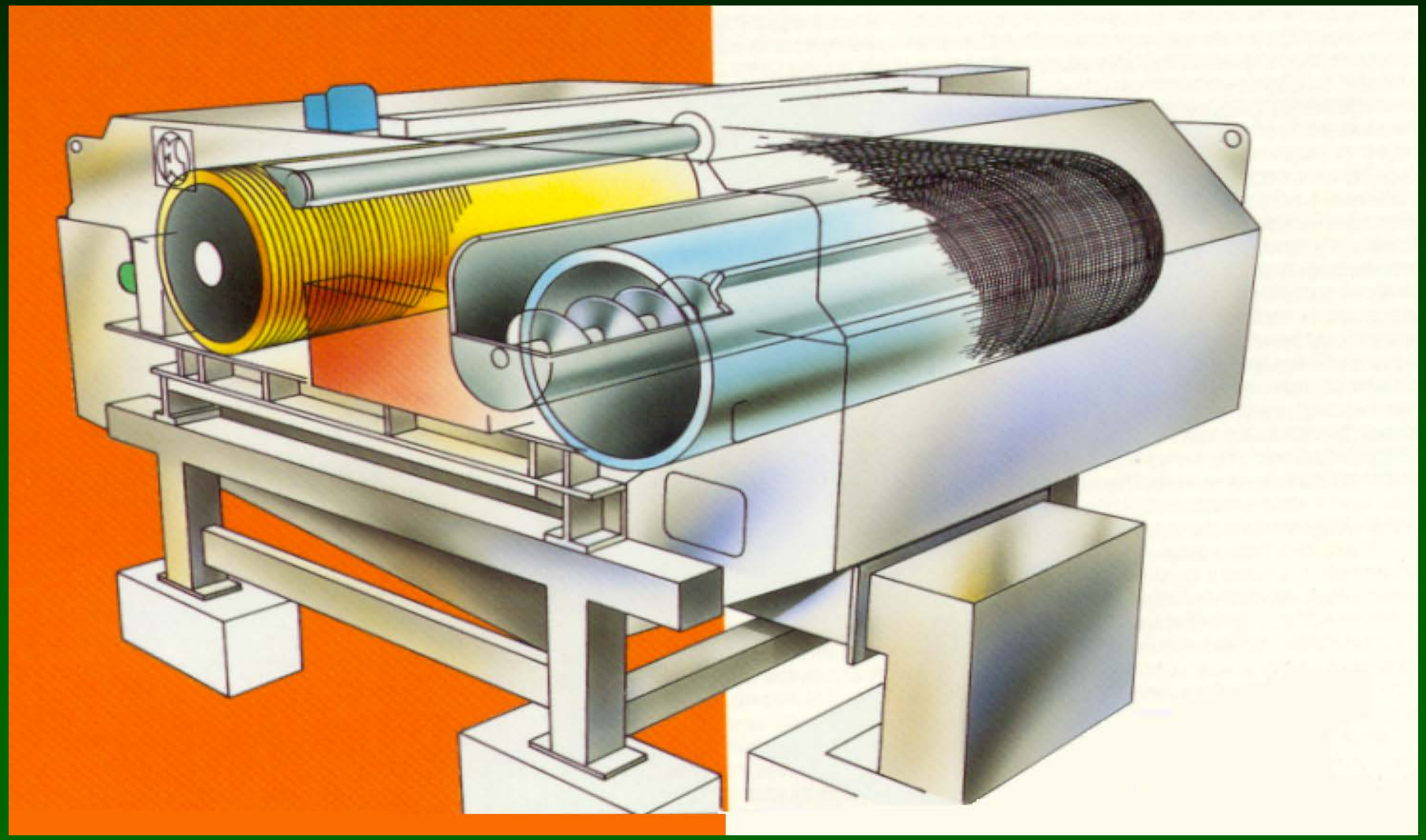
Gravity Decker



Double Nip Thickener (DNT)

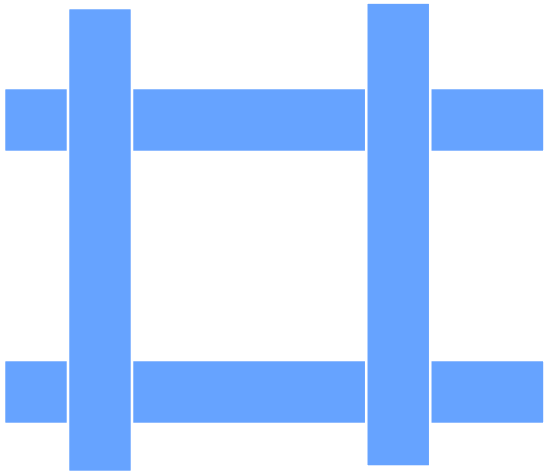


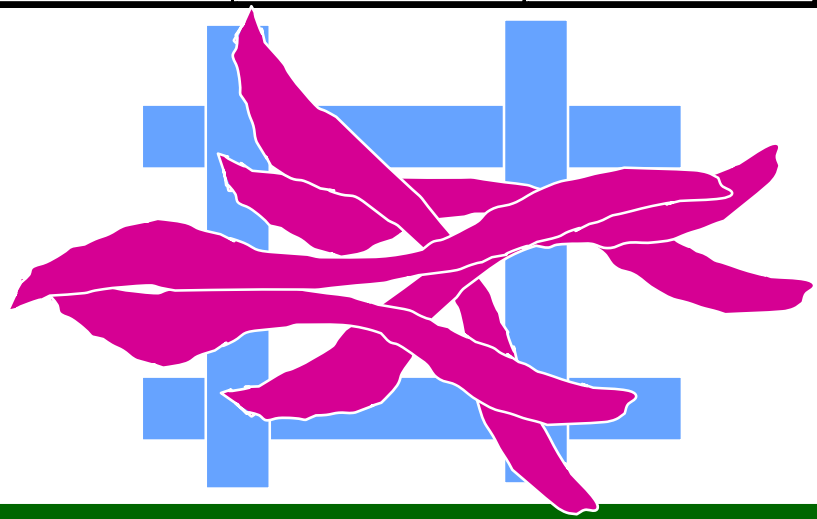
Double Nip Thickener (DNT)



Pulp mats prevent the removal of small particles in washing!!!!!

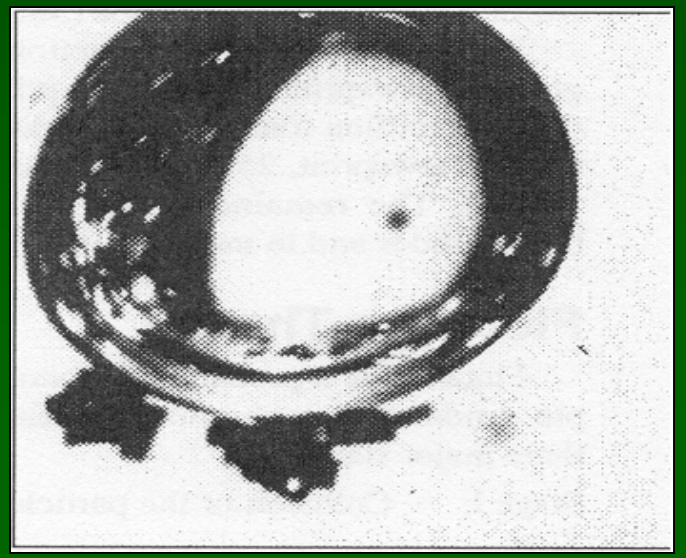
Type	Inlet % K	Outlet % K	Ash Removal %, Theoretical	Ash Removal %, Actual	Pulp Mat Formation
Sidehill Scrn	0.8	3	74	60	Minimal
Grav Decker	0.8	5	85	55	Yes
Incl. Screw	3.0	10	72	45	Extensive
Horiz. Screw Press	4.0	28	89	35	Extensive
Belt Washer	1.0	10		80	Minimal
Vario Split	0.8	10	85	80	Minimal





Flotation

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



Ink particles attached to air bubble

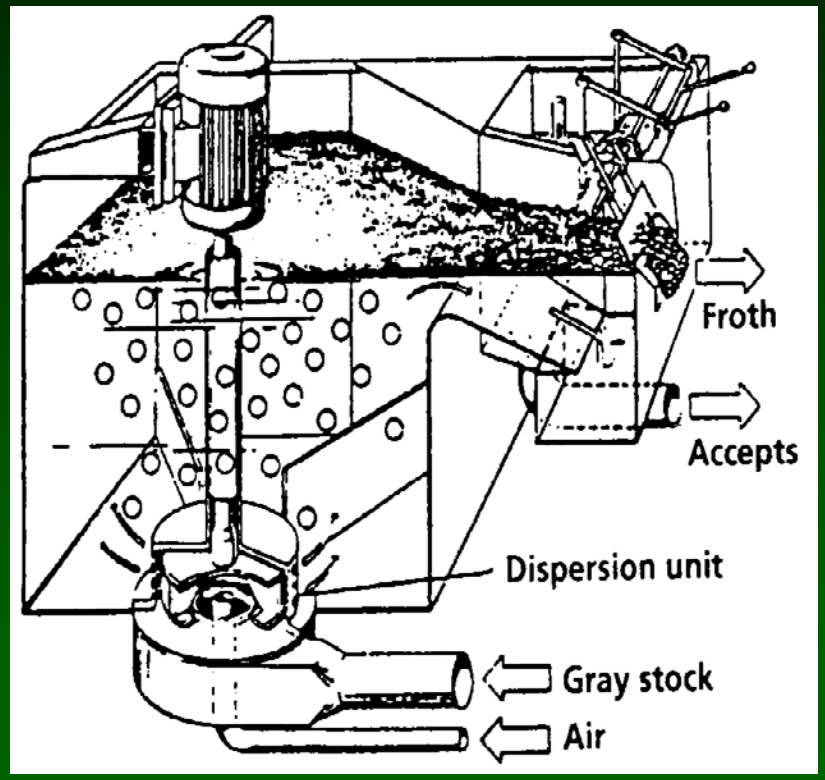
Contaminant Characteristics: Hydrophobicity

- 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 hydrophillic material (fiber).

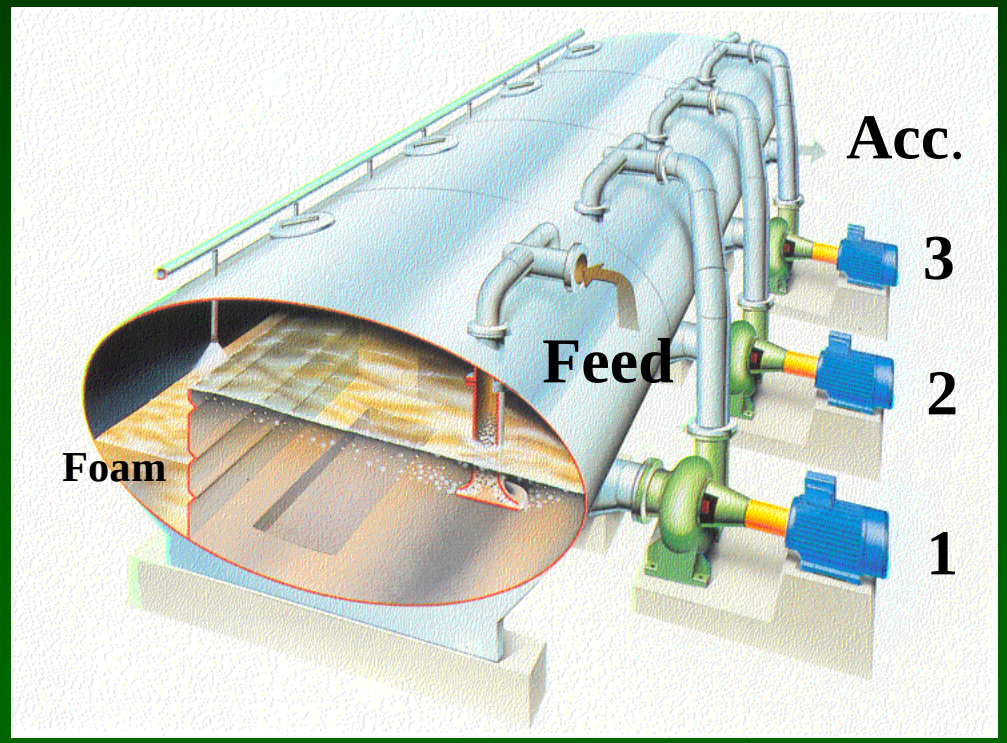
Flotation

- 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

	Flotation	Washing
Chemistry-Sensitive	more	less
Water Use	lower	higher
Yield	higher	lower
Ash Removal	No	Yes
Tensile Str.	Lower	Higher
Opacity	Higher	Lower

Challenge question: why is the tensile strength lower for pulps that have been floated relative to those that have been washed? _____

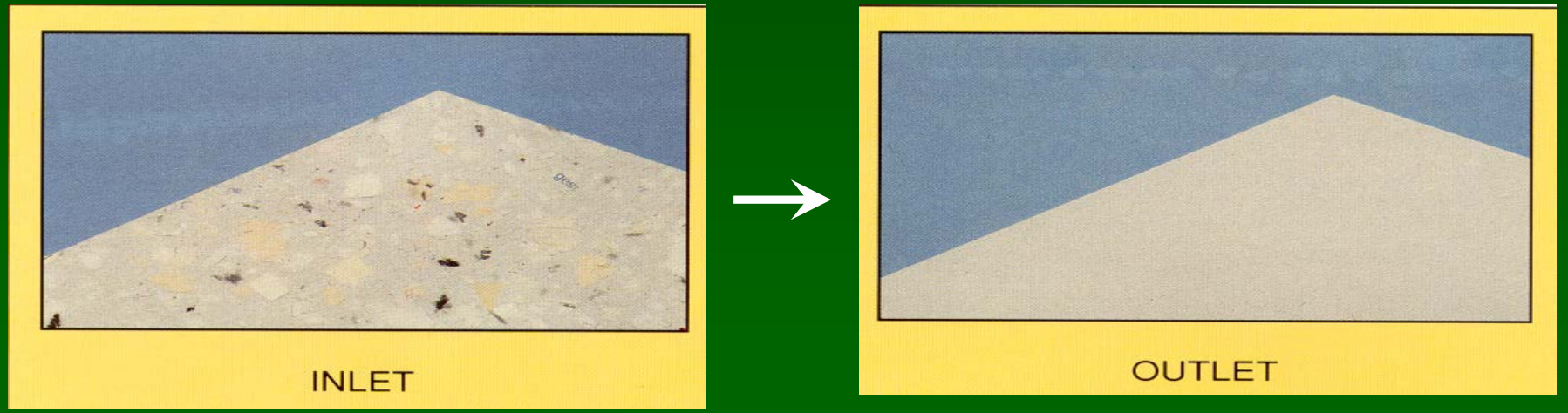
Flotation and Washing Summary

- Washing: removes _____ contaminants
- Flotation: removes contaminants based on _____ differences relative to fibers

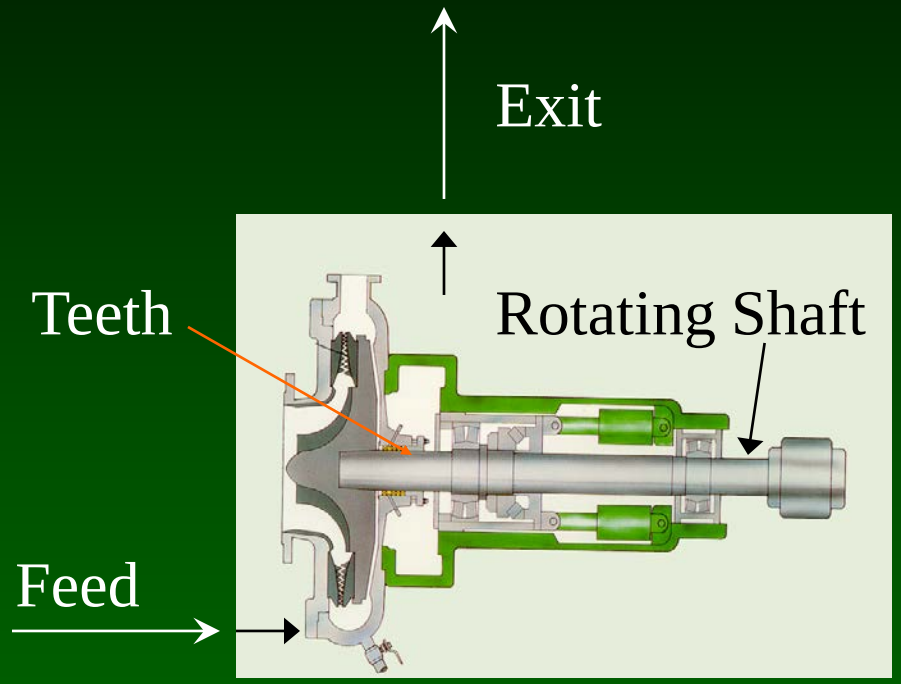
- Pulp mat formation _____ the efficiency of de-inking washers
- Flotation / Washing retains more of the smaller particles (fillers) and has higher yield.

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).



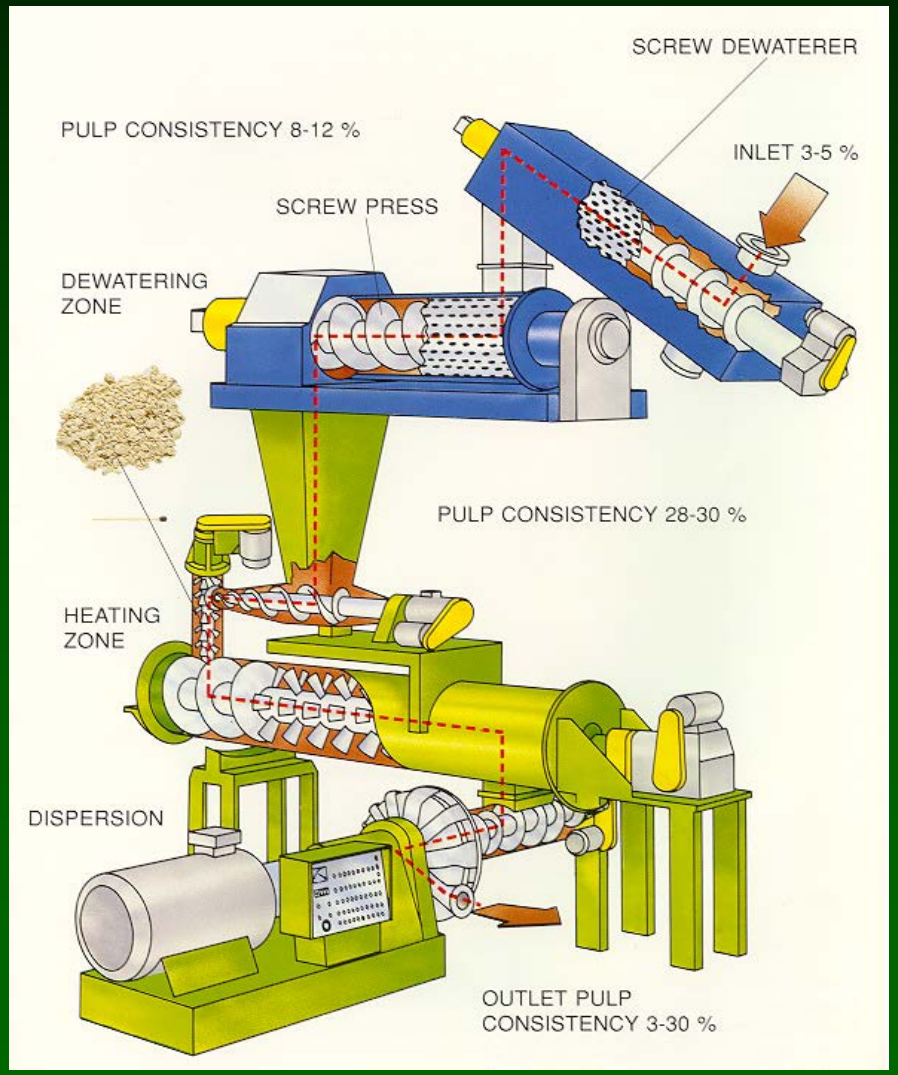
Dispersion



- 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

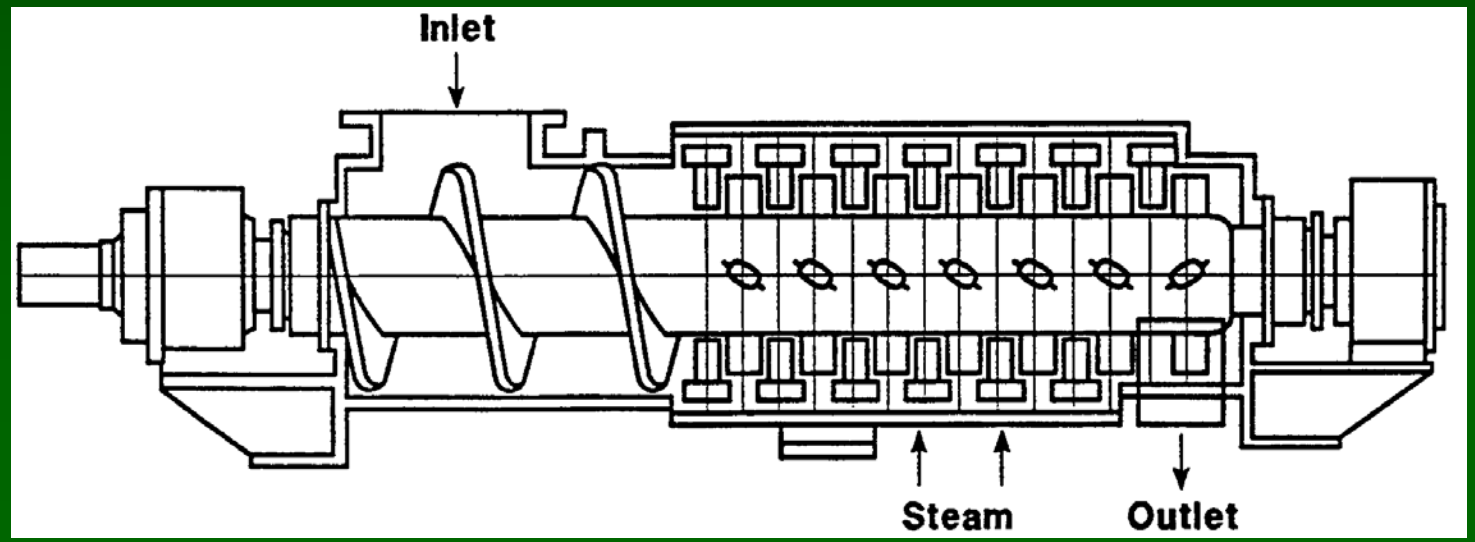
Dispersion

- 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



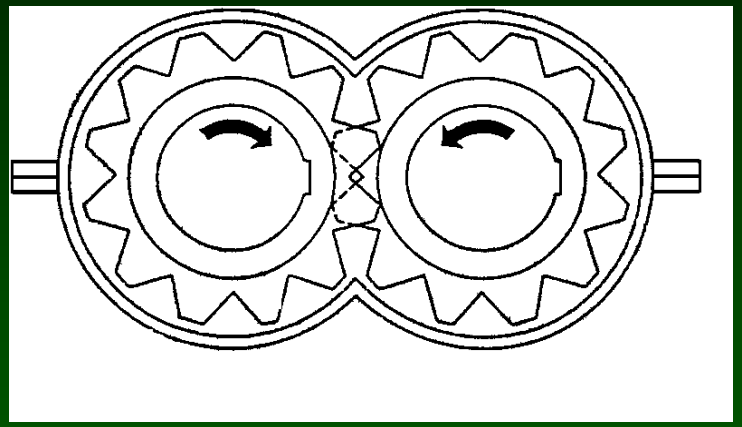
Kneading

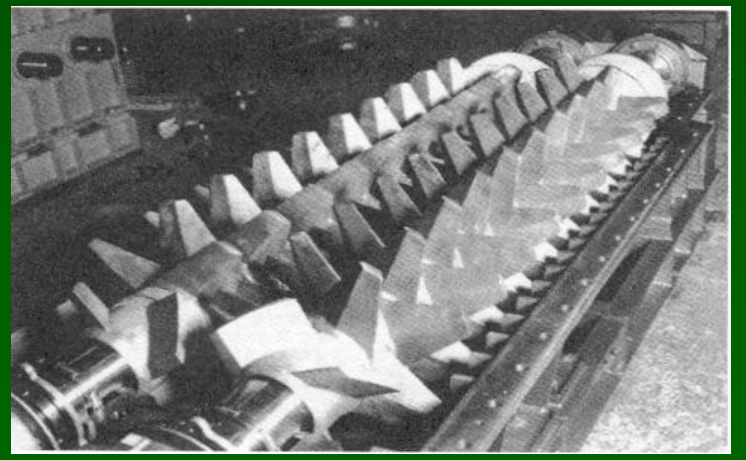
- How does it work?
  - Pulp at high consistency is mixed between moving bars on a slow-rotating shaft and stationary bars attached to the housing.
  - Strong shear forces (mainly fiber-fiber rubbing) break the contaminants.
- Typical Conditions
  - Consistency = 30% K
  - Temperature = 50 C
  - Retention 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.

	Dispersion	Kneading
Mechanism	Shear	Rub
Consistency	30%	30%
Temp.	95	50
RPM	1200-1800	100-900
Retent. Time	2 s	10-60 s
Gap, mm	.5-1.5	10-40

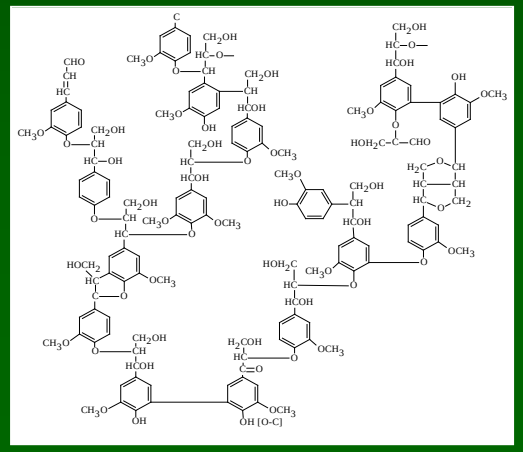
Kneading vs. Dispersion

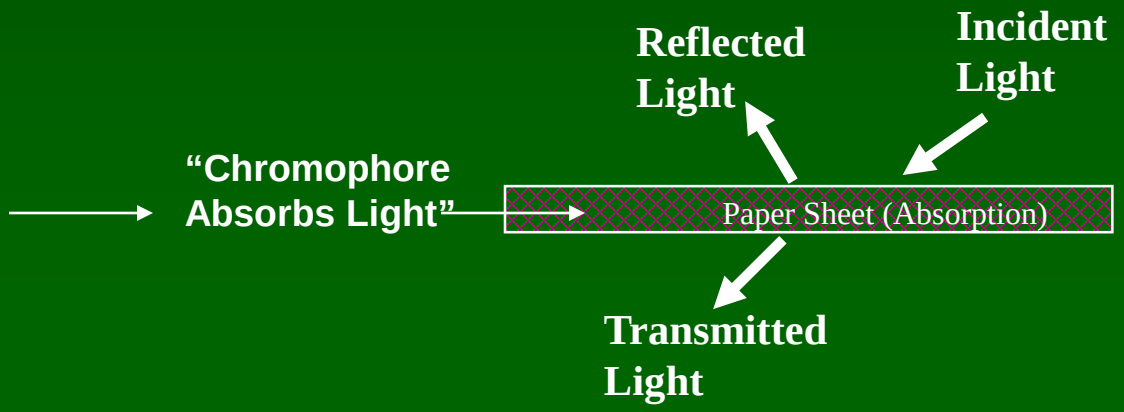
Methods to decrease contaminant size.

Effect	Dispersion	Kneading
Tappi Dirt Reduct.	75%	85%
Toner Reduct.	yes	better
Stickies Reduct.	better	no effect
Fiber Cutting	substantial	none
Fines Generation	yes	no

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





Bleaching

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

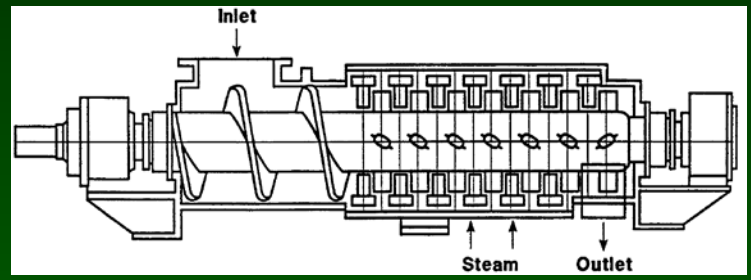
- Issues:
  - chlorine free effluent
  - operations concerns
    - consistency
    - pH (avoid acidic state)
  - furnish/product characteristics

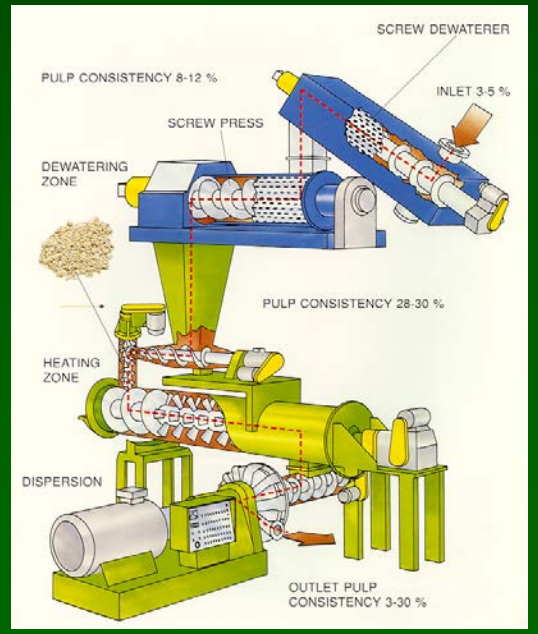
  - Can you bleach ink? _____

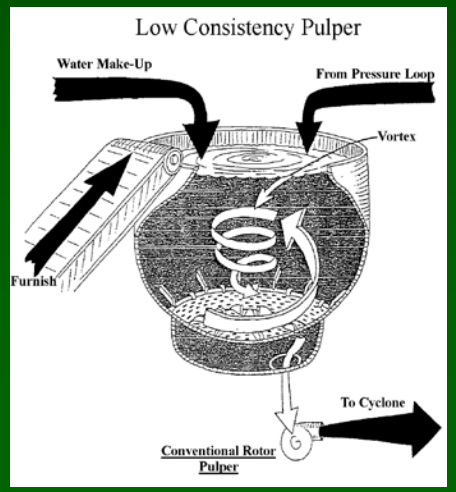
  - Can you bleach blue cotton fabrics? _____

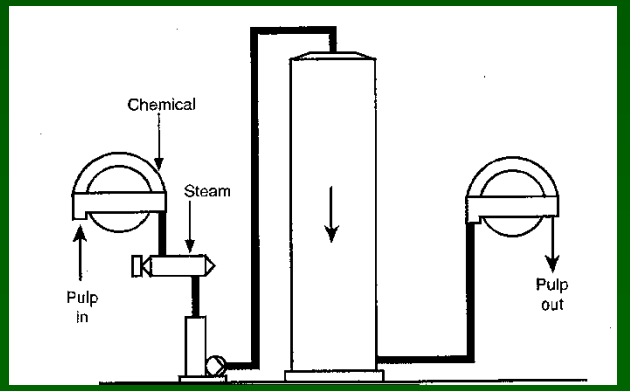
Bleaching: Where is it done?

- 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 = _____

Produced paper	Recovered paper grade	Amount of total waste	Amount of waste [% by dry weight]			
			Rejects		Sludges	
		[% by dry weight]	Heavy-weight & coarse	Light-weight & fine	Flotation deinking	White water clarification
Graphic paper	News, magazines	15–20	1–2	3–5	8–13	2–5
	Superior grades	10–25	< 1	≤ 3	7–16	1–5
Hygienic paper	Files, office paper, ordinary, medium grades	28–40	1–2	3–5	8–13	15–25
Market DIP	Office paper	32–40	< 1	4–5	12–15	15–25
Liner, fluting	Sorted mixed recov. paper, supermarket waste	4–9	1–2	3–6	–	0–(1)
Board	Sorted mixed recov. paper, supermarket waste	4–9	1–2	3–6	–	0–(1)

Implications of yield:

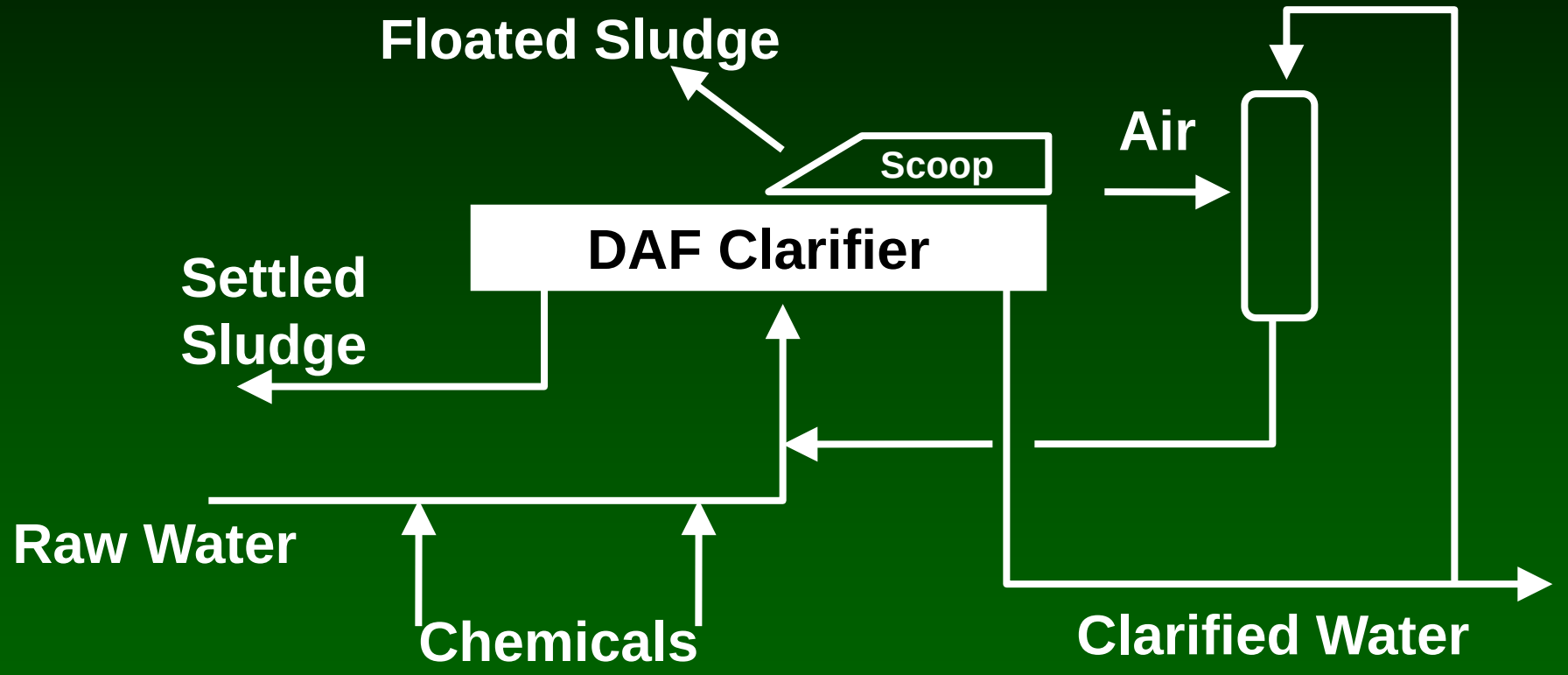
- If a mill takes in 400 tons per day of paper and has a fiber yield of 70 % how much dry paper does it make?

- 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

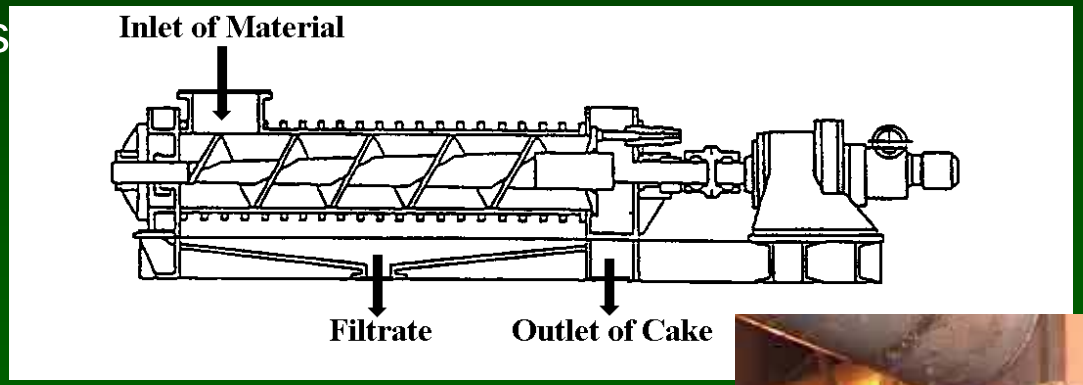
Dissolved Air Flotation (DAF) Clarifier



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



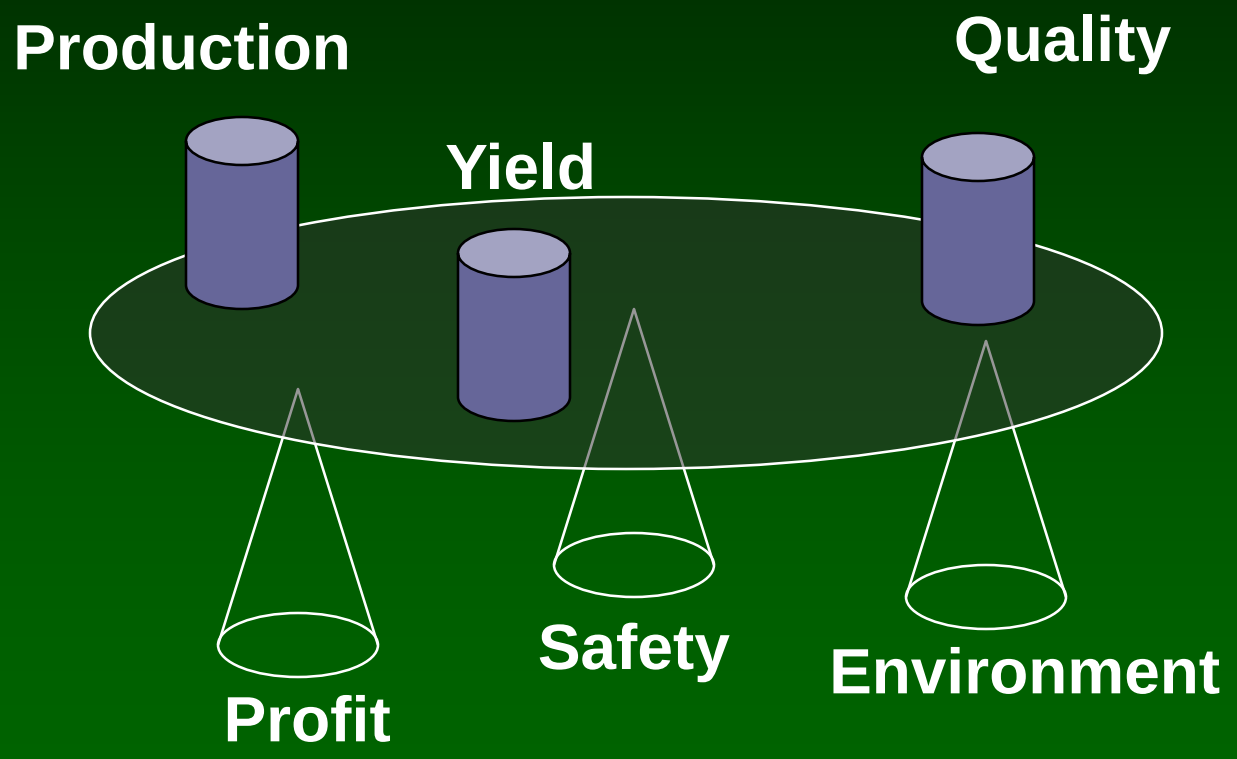
Learning objectives

- 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

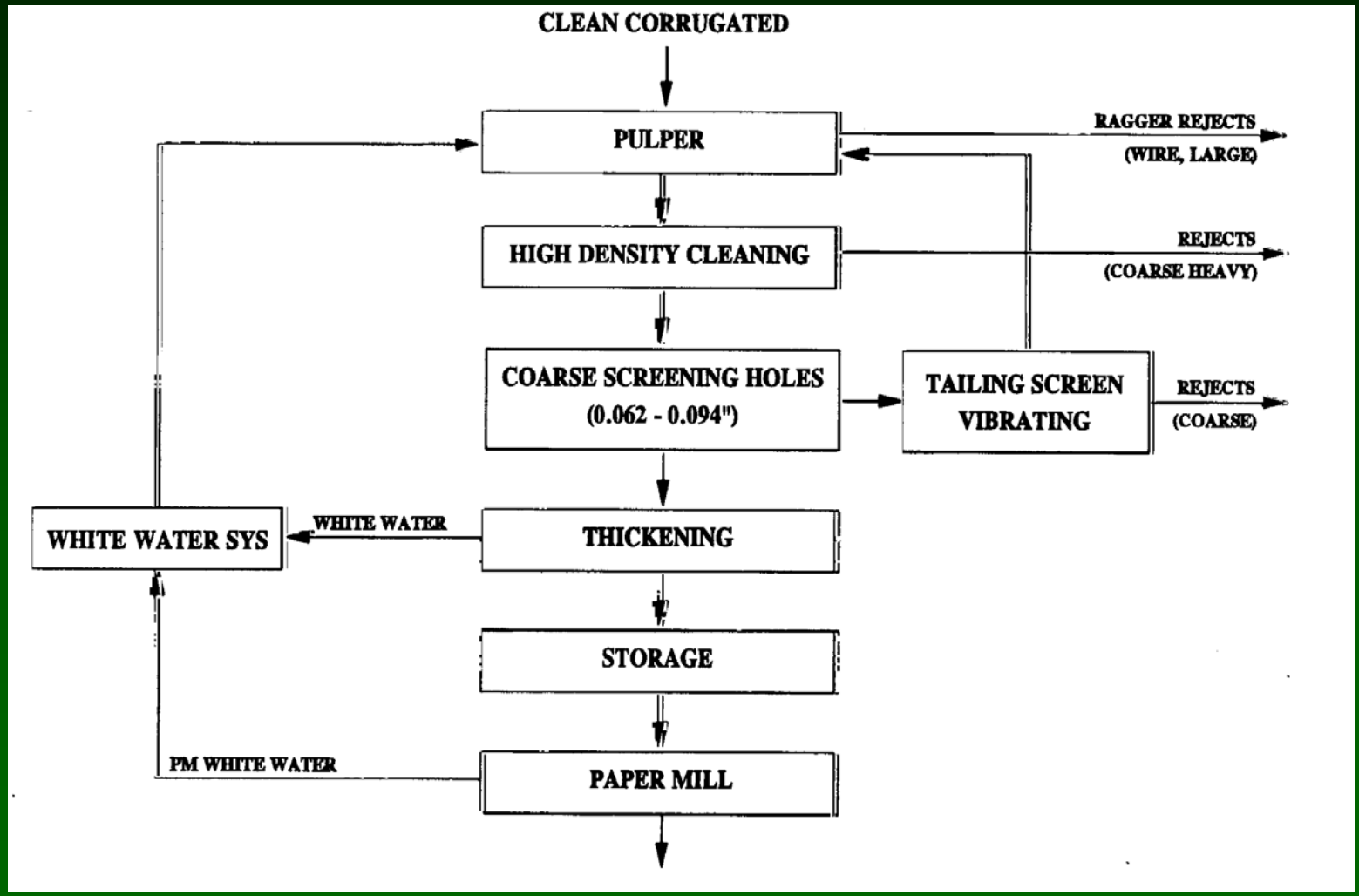
Paper Recycling Operations: A Balancing Act



Crude Cleaning System for Packaging Product

- Used to produce liner, medium, folding board, tube stock
- Often used with a continuous pulper

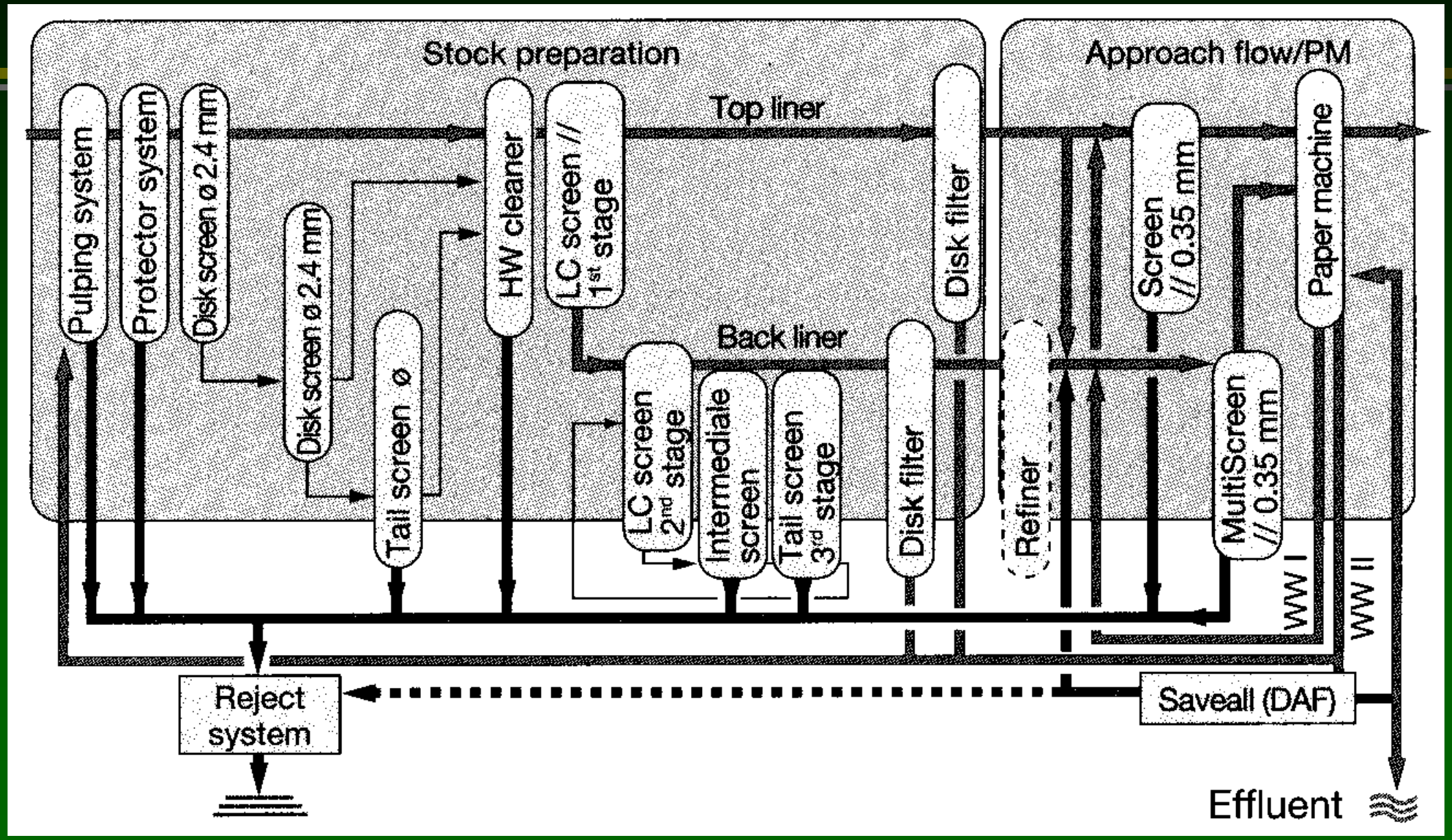
- Yield?
- Contaminant removal?
- Ink removal?



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

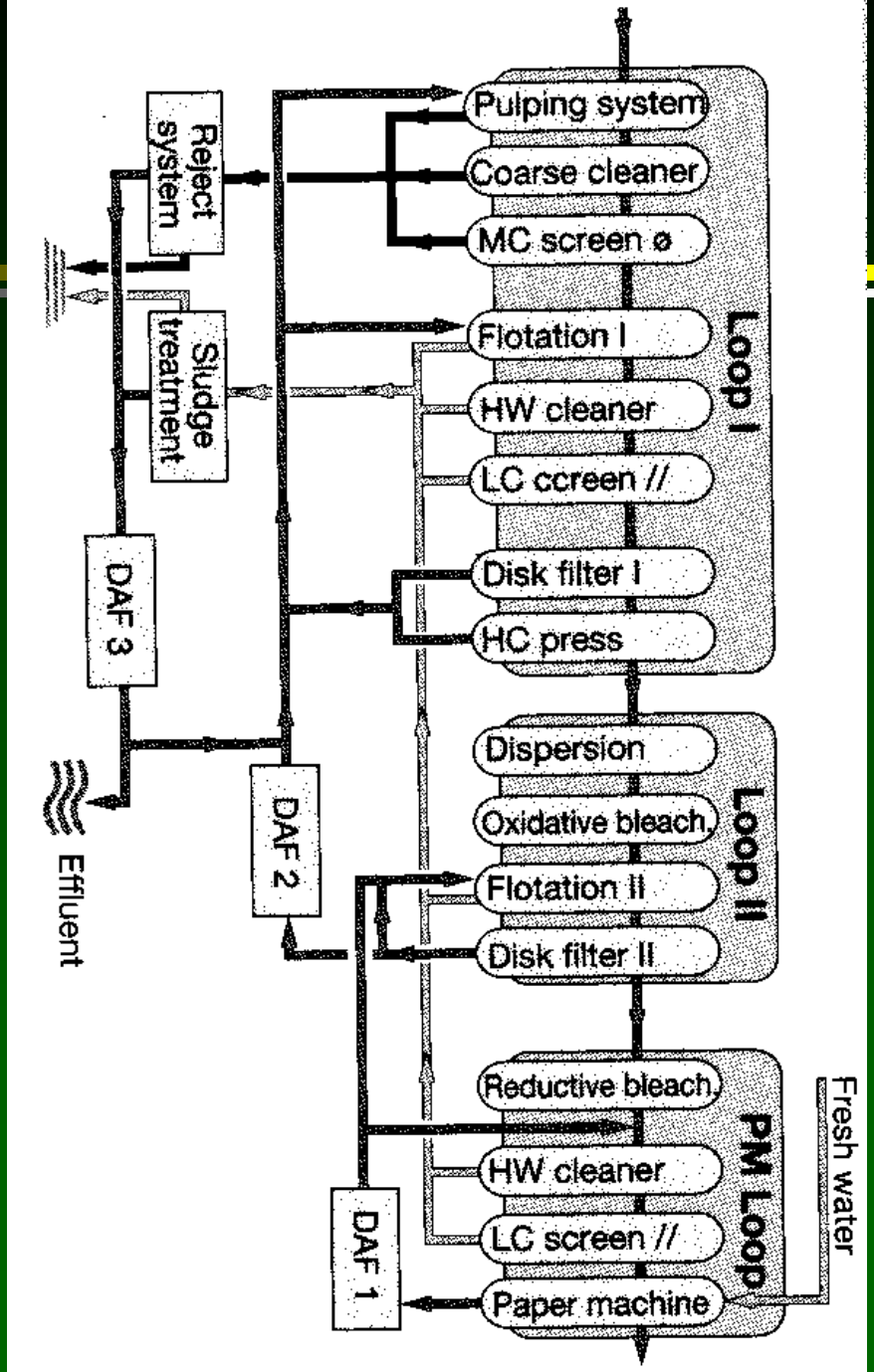
Test Liner Production



ONP-OMG Recycling

- Used to produce recycled newsprint
- May have batch, continuos 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?

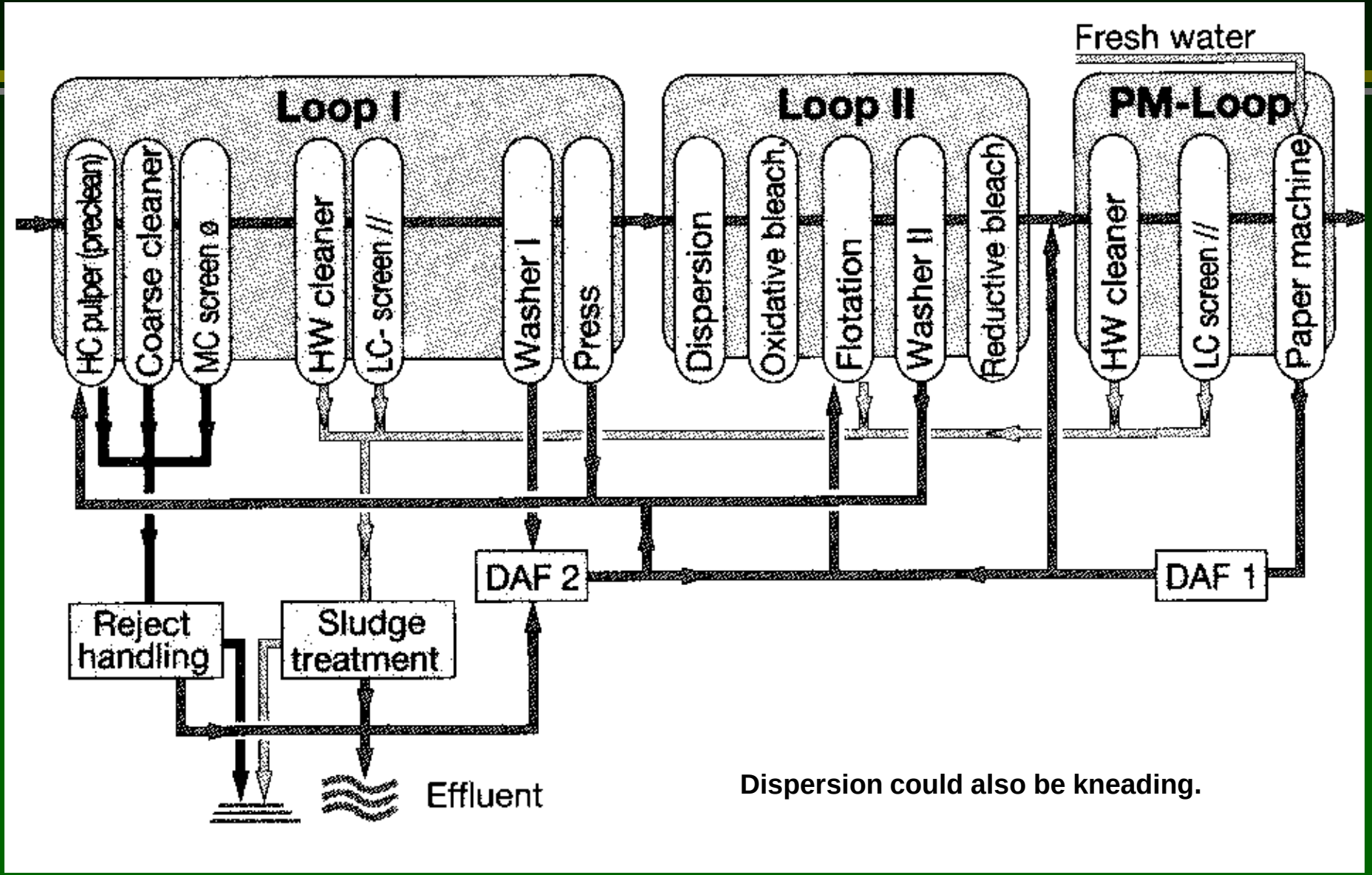
Why 3 DAF's, not just one?

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

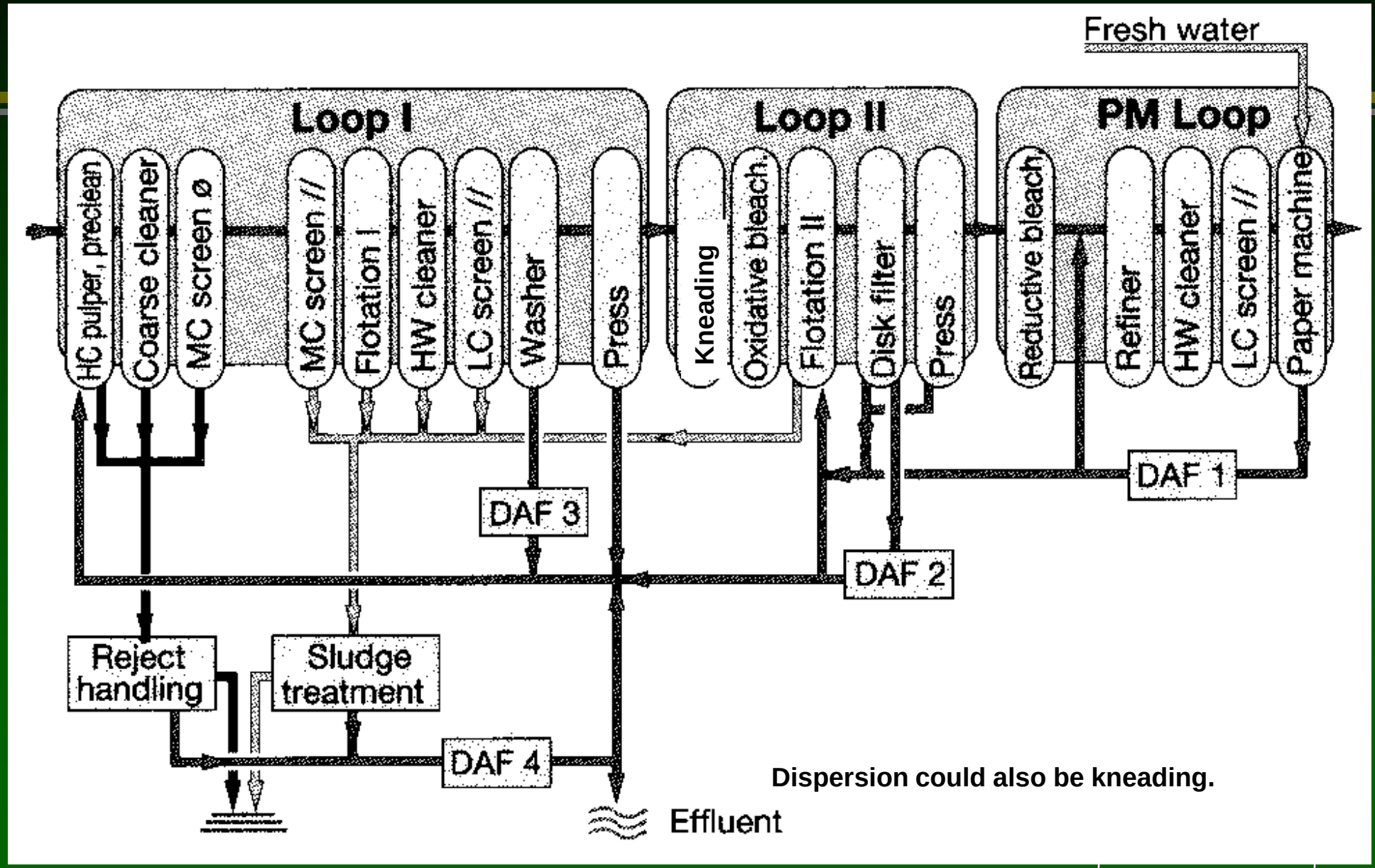


Dispersion could also be kneading.

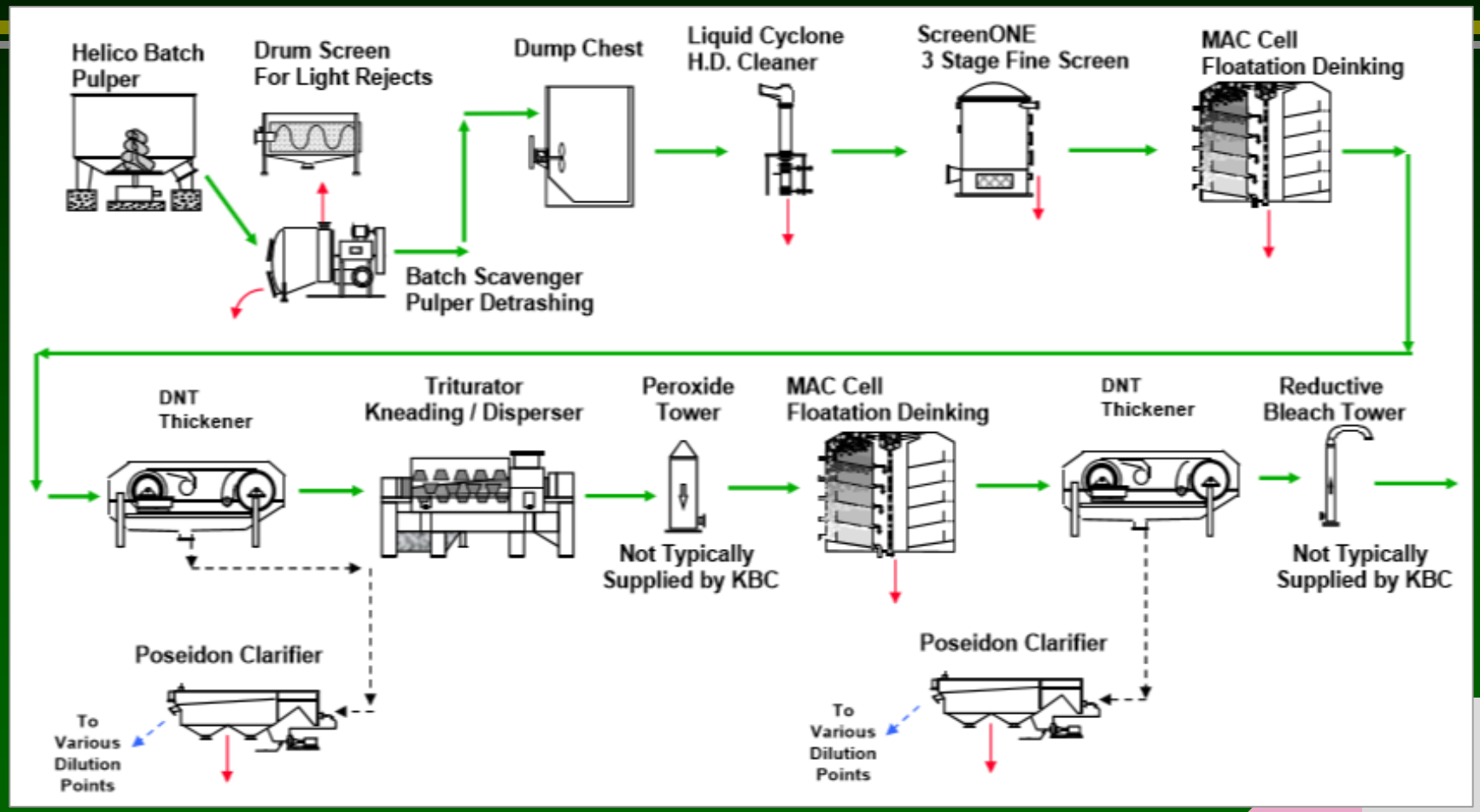
Deinking of Printing Grades for Printing/Writing

- 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

High Grade Printing and Writing Grades



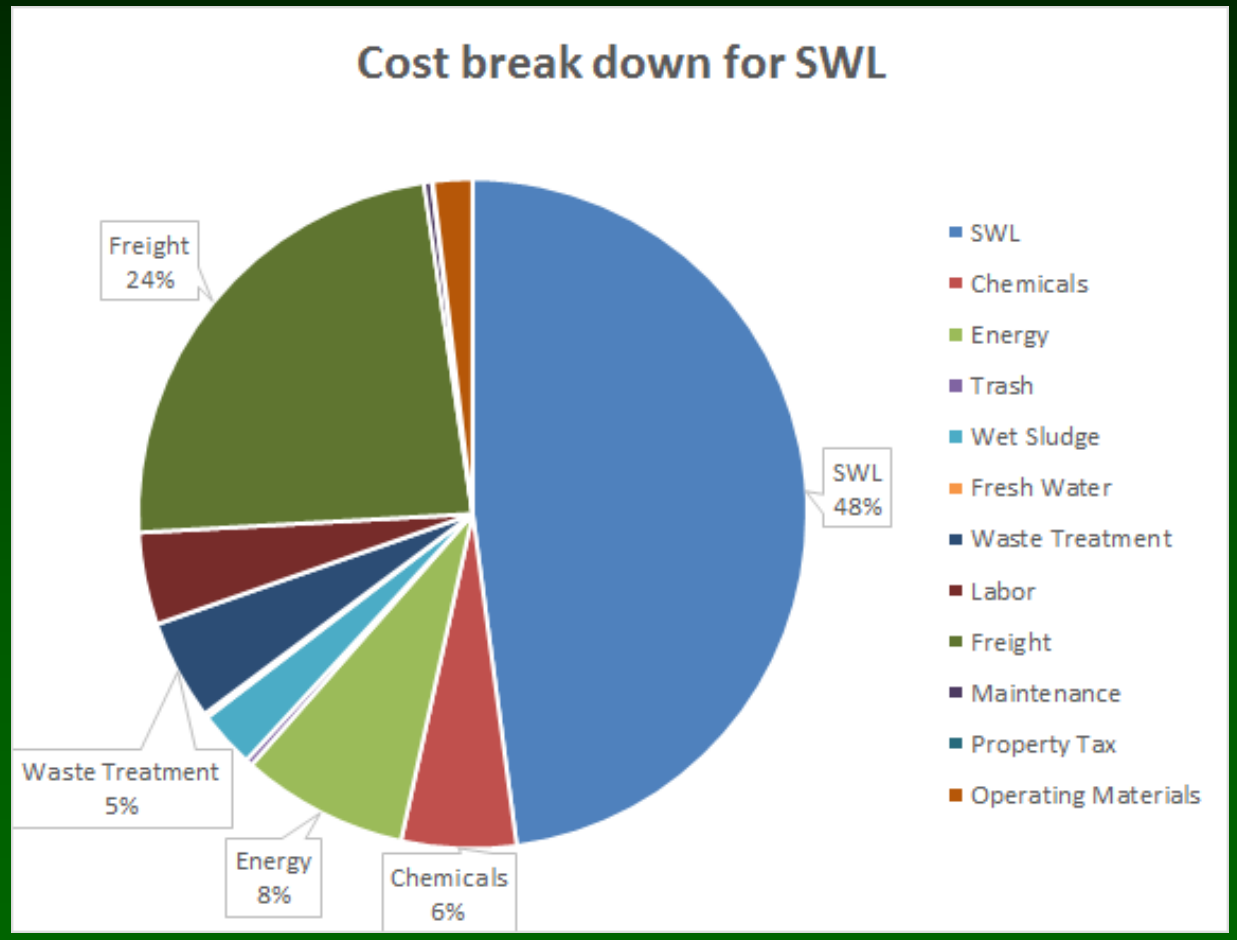
Process Flow to Produce 100 TPD Deinked Pulp



Capital Equipment Required

Description	Delivered Cost, $	Estimate Source	Installed Cost, $	Factor
1- Kadant Deinking Facility (150 ODT/day)	$ 4,290,000	Kadant Black-Clawson	$ 17,252,000	4.01
1- HD Storage Tank (75 ODT @ 4%)	N/A	Jacobs Engineering	$ 1,960,000	3.69
1- Peroxide Bleach Tower (7.5 ODT @ 10%)	$ 64,000	Matche	$ 235,000	3.69
1- Dithionite Bleach Tower (6.4 ODT @ 4%)	$ 83,000	Matche	$ 306,000	3.69
1- H_2O_2 Tank (5,000 Gal)	$ 15,000	Matche	$ 54,000	3.69
1- $NaHSO_3$ Tank (7,000 Gal)	$ 18,000	Matche	$ 67,000	3.69
1- NaOH Tank (7,000 Gal)	$ 18,000	Matche	$ 67,000	3.69
1- Raw Material Warehouse (15,000 sq. ft.)	$ 180,000	General Steel	$ 503,000	2.80
Total Cost			**$ 20,444,000**	

Cost Breakdown- SWL



Cost Component	$/ton DIP
SWL	294.1
Chemicals	34.1
Energy	49.5
Trash	2.1
Wet Sludge	16.9
Fresh Water	1.3
Waste Treatment	29.8
Labor	27.3
Freight	144.6
Maintenance	2.4
Property Tax	0.4
Operating Materials	11.7
Total	614.0

Cost Breakdown- Comparison

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

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? _____

Paper Recycling: Effect on Environment

	Uncoated free sheet	100% Post consumer
Wood Use	3,467 tons	0 tons
		3,467 tons less
Total Energy	38,364 million BTU's	21,658 million BTU's
		16,707 million BTU's less
Purchased Energy	18,206 million BTU's	21,658 million BTU's
		3,452 million BTU's more
Sulfur dioxide (SO2)	26,088 pounds	25,557 pounds
		530 pounds less
Greenhouse Gases	5,690,196 lbs CO_2 equiv.	3,582,112 lbs CO_2 equiv.
		2,108,084 lbs CO_2 equiv. less
Nitrogen oxides (NOx)	18,417 pounds	14,414 pounds
		4,003 pounds less
Particulates	12,433 pounds	7,345 pounds
		5,088 pounds less
Hazardous Air Pollutants (HAP)	2,150 pounds	151 pounds
		1,999 pounds less
Volatile Organic Compounds (VOCs)	5,559 pounds	1,826 pounds
		3,733 pounds less
Total Reduced Sulfur (TRS)	340 pounds	0 pounds
		340 pounds less
Wastewater	19,075,196 gallons	10,325,000 gallons
		8,750,196 gallons less
Biochemical Oxygen Demand (BOD)	6,288 pounds	6,060 pounds
		228 pounds less
Total Suspended Solids (TSS)	10,143 pounds	6,900 pounds
		3,243 pounds less
Chemical Oxygen Demand (COD)	91,744 pounds	27,600 pounds
		64,144 pounds less
Adsorbable organic halogens (AOX)	932 pounds	0 pounds
		932 pounds less
Solid Waste	2,278,349 pounds	1,154,701 pounds
		1,123,648 pounds less

Papercalculator, Basis of 1000 tons of paper

Effects of Recycling on Pulps