Consistency Example 1

Part A.

$$\%\ Consistency = \frac{OD\ solids\ grams}{Total\ \ grams} \times 100\%$$

$$\%\ Consistency = \frac{23.2\ grams}{385\ grams} \times 100\% = 6.0\%$$

Consistency Example 1

- Part B. Rearrange the consistency equation to solve for the Oven dry solids mass:

- $$OD\ solids\ in\ Tank = \frac{Total\ weight\ in\ tank \times Consistency\ (\%)}{100\%}$$

- $$OD\ solids\ in\ Tank = \frac{44{,}000\ lb \times 6\%}{100\%} = 2640\ OD\ lb\ solid\ in\ tank$$

Consistency Example 2

- How much of a fiber slurry at a consistency of 2.5 % must be weighed out in order to deliver an OD fiber sample (after drying) of 400 grams?

  - $$\textit{Total wt of slurry} = \frac{\textit{OD Solids weight} \times 100\%}{\textit{Consistency}\ (\%)}$$

- $$\textit{Total wt of slurry} = \frac{400\ \textit{OD grams} \times 100\%}{2.5\%} = 16,000\ \mathrm{g}$$

Types of Consistency Sensors

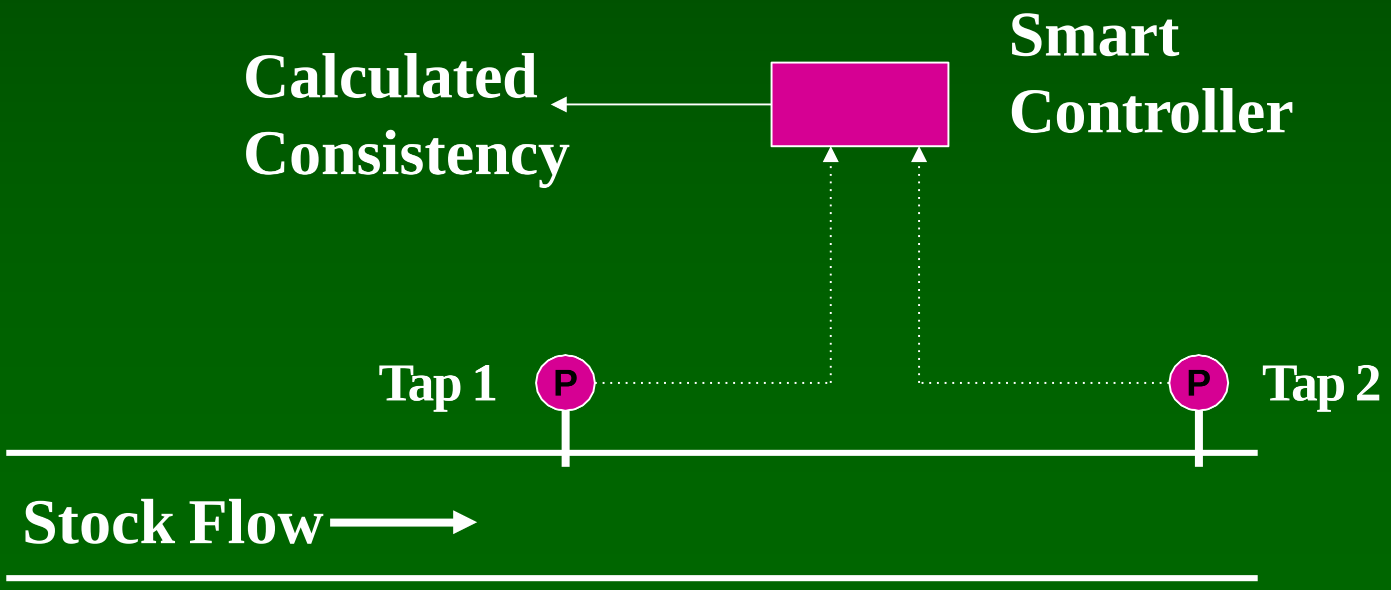
- Pressure Drop
- Mechanical – static or rotating
- Optical
- Microwave
- Sonar

Increasing accuracy

Increasing cost

Pressure Drop

- Locate two pressure taps some distance apart in stock line
- Thicker stock increases friction loss, causing higher pressure drop
- Correlate pressure drop with consistency
- Works only on thicker stock (2-10 % consistency)



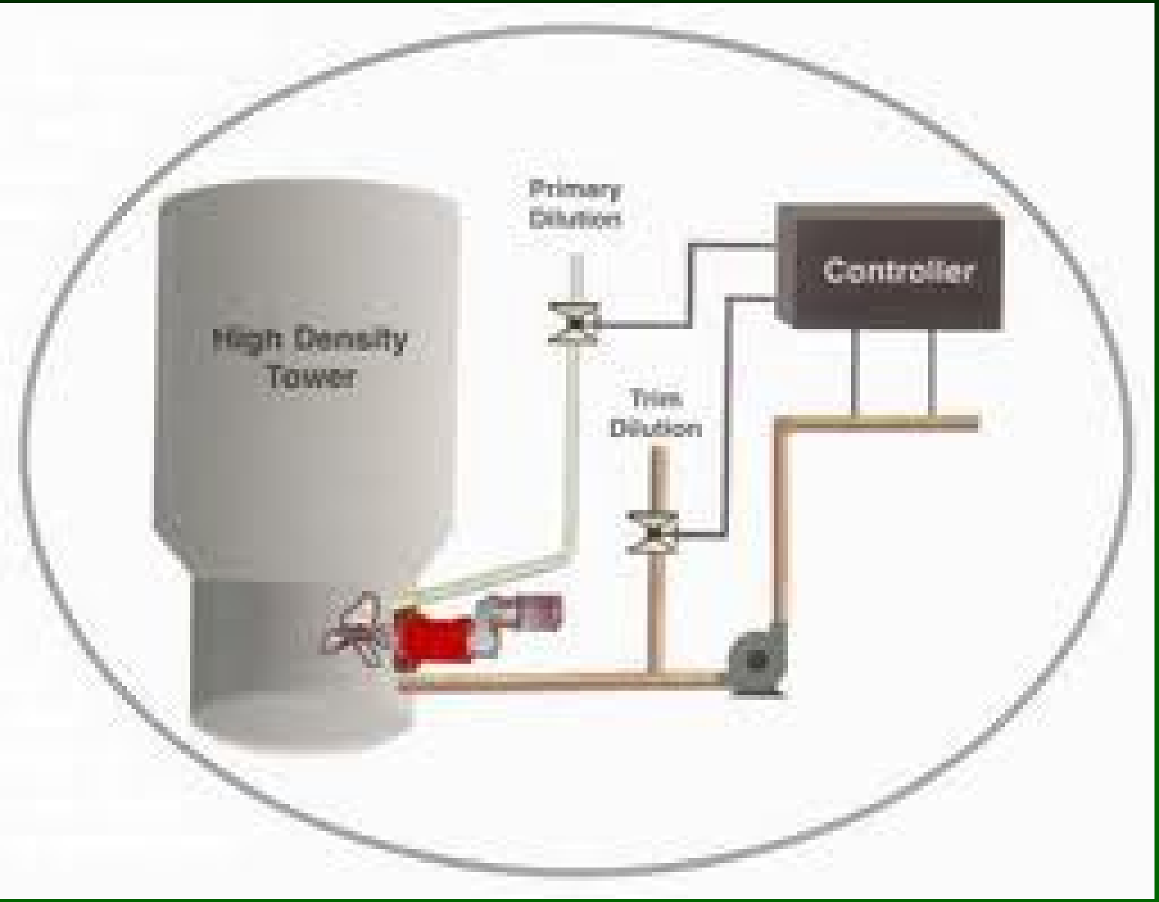
Mechanical -- Static

- As stock gets thicker, drag on items in line gets higher
- Insert wheel, paddle or other linkage into stock flow; attach to strain gauge; correlate drag/strain with consistency
- Good for thick stock
- Newer models very reliable and repeatable

Mechanical -- Rotating

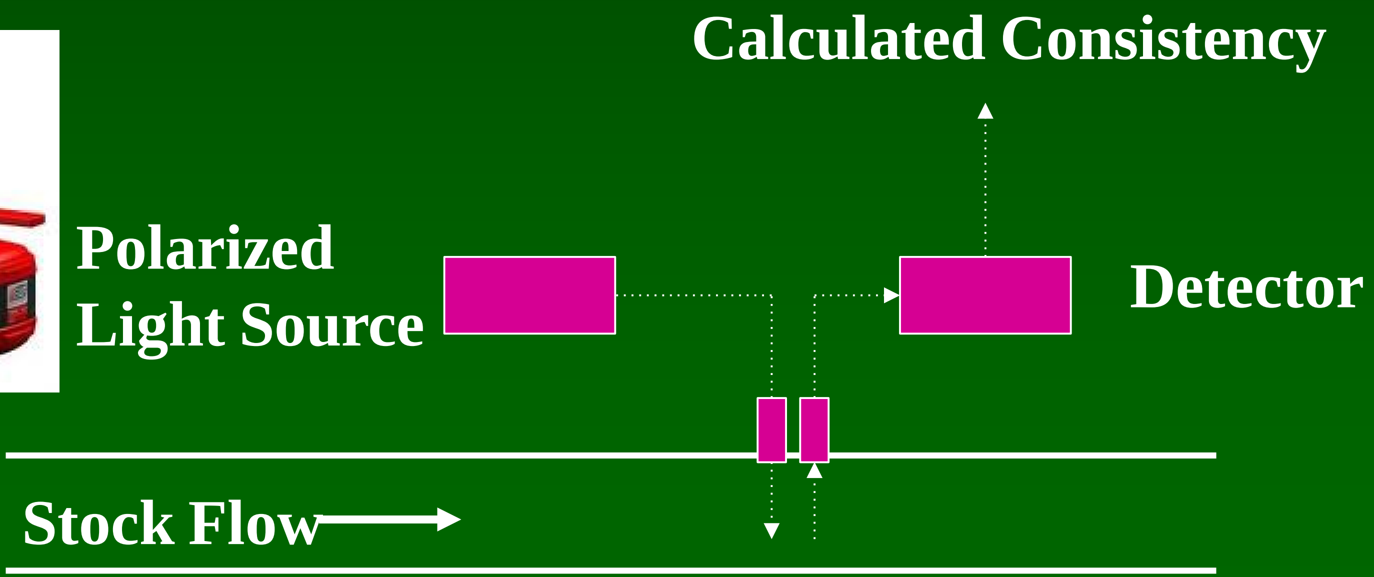
- A small impeller or wheel is driven in the stock stream
- The force required to drive it or the resistance is measured and correlated to consistency
- Reportedly more accurate and less prone to plugging/fouling than the static sensors

Mechanical -- Rotating



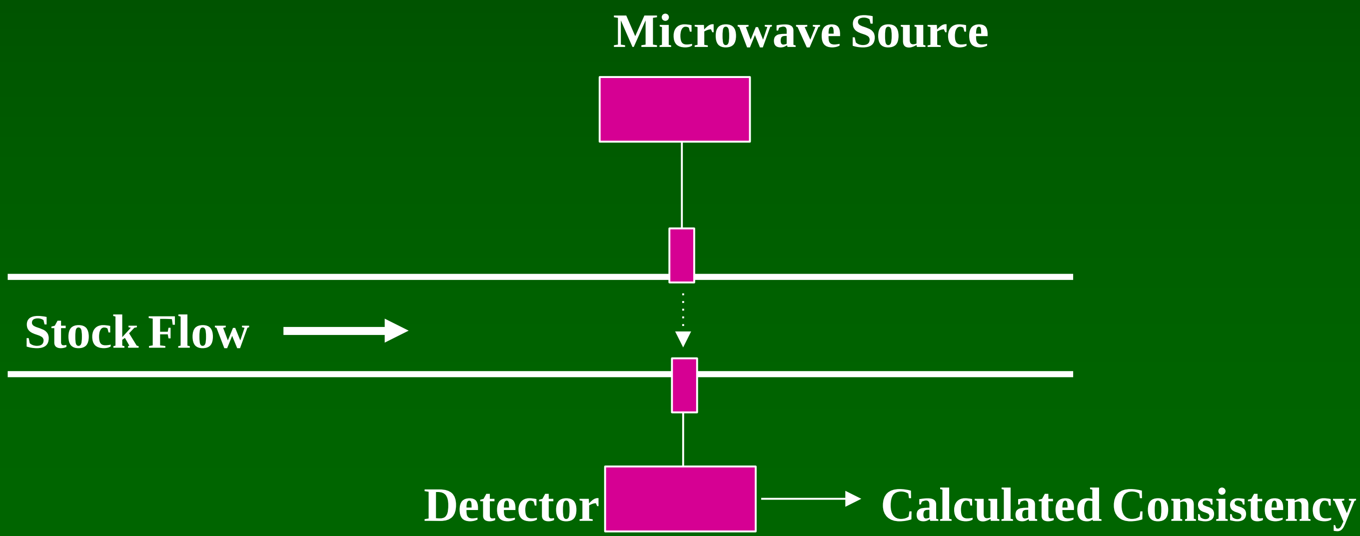
Optical

- Most popular method for bleached stock; very accurate
- Polarized light source directed into stock stream; detect how much reflected back
- As consistency rises, reflected light increases
- Works best on bleached stock and thin stock (down to 0.1 % consistency)



Microwave

- New sensor type -- even more accurate than optical, and reportedly more robust
- Works on bleached or unbleached stock
- Not sensitive to filler content
- Works on thicker stock
- Based on attenuation of microwave signal



Sonar

- Newest sensor type
- Emitter sends acoustic signal down pipeline
- Based on reflected signal, an amazing amount of information can be gained
  - Velocity
  - Volumetric flow
  - Consistency
  - Amount of entrained air

Consistency

Consistency, %	Moisture Content, %	Description	Where Found
0 – 6 %	100 – 94 %	**Known as low consistency stock – slurry behaves like water** **Is easily pumped with normal centrifugal pumps.**	**Pulp mill – blow tank, stock lines, screens, washer vats** **Paper mill – stock preparation, refining, headbox, after gravity drainage zone on fourdrinier**
6 – 18 %	94 – 82 %	**Known as medium-consistency stock – stock starts to behave more like a solid mush than water** **Little to no free liquid drains from it when held in the hand; must be pumped with special pumps**	**Pulp mill – washer discharge mat, bleaching reaction towers, storage tanks (known, unfortunately, as high-density storage tanks)** **Paper mill – after vacuum zone on fourdrinier**
18 % and higher	**82 % and lower**	**Known as high-consistency stock – stock behaves like a crumbly solid; feels damp** **No free liquid can be squeezed out by hand; usually move by conveyor or screw.**	**Pulp mill – high-consistency oxygen bleaching reactor (if used)** **Paper mill – after press section of paper machine (50 %), after dry section of paper machine (95 %)**

Relationship between Moisture Content and Consistency

- Consistency (%) + MC (%) = 100 %
- The *Moisture Content* of a sample is equal to (100 % - Consistency, %).
- The *Consistency* of a sample is equal to (100 % - Moisture Content, %).

DISSOLVED SOLIDS

- Consistency measures the amount of fibers and suspended solids is in the mixture
- Dissolved solids are used to measure the amount of solids that is dissolved in the liquor.
- $$\textbf{Dissolved solids}, \% = \frac{\textbf{Weight of dry dissolved solids}}{\textbf{Weight of the liquor}} \times \mathbf{100\%}$$

Stock

- **Fibers**
- **Liquor**
  - **Water**
  - **Dissolved solids**

MASS AND VOLUME IN PAPERMAKING

- In the paper industry, it is always important that we know how much dry fiber is either contained in a given place (a tank, a batch) or how much is flowing through a pipe or system.
- This means that we need to know the MASS of what is in the place or moving past some point in time.
- The funny thing is this: we don't normally measure mass or mass flow rate – it's much easier for us to measure volume or volumetric flow rate.
- We need to learn to <u>convert between volume and mass</u>

Convert Volume to Mass: EXAMPLE 3

- A papermaking slurry is flowing in a pipe at a measured flow rate of 15,000 gallons/minute.
- The consistency is tested and found to be 3.2 %.
- What is the <u>flow rate of dry fiber</u> through the pipe?
- Step 1: What should we do?

$$\text{Consistency, \%} = \frac{\text{Oven dry weight of sample}}{\text{Total weight of sample}} \; X\ 100$$

- But we don't have total mass flow…we have volumetric flow!
- But we find the mass flow using density

$$\boldsymbol{Density\ \left(\frac{lb}{ft^3}\right) = \frac{mass\ (lb)}{volume\ (ft^3)}}$$

Convert Volume to Mass: EXAMPLE 3

- A papermaking slurry is flowing in a pipe at a measured flow rate of 15,000 gallons/minute.
- The consistency is tested and found to be 3.2 %.
- What is the equivalent flow rate of dry fiber through the pipe?
- Step 2: Find total mass flow
- We will assume the density of the stock is 8.314 lb/gallon, this is used as an example, true densities of pulp stock can be found in Cameron's Handbook.

- $Mass\ flow = volumetric\ flow \times density$
- $Mass\ flow = 15{,}000\,\frac{gallons}{min} \times \frac{8.314lb}{gallon} = 124{,}700\,\frac{\text{lb}}{\text{min}}$

Convert Volume to Mass: EXAMPLE 3

- A papermaking slurry is flowing in a pipe at a measured flow rate of 15,000 gallons/minute.
- The consistency is tested and found to be 3.2 %.
- What is the equivalent flow rate of dry fiber through the pipe?
- Step 3: Find OD mass flow
- OD Flow = (Total Mass Flow) x (Consistency/100%)
- $\boldsymbol{OD\ Solids\ Flow} = \frac{124{,}700 lb}{min} \times \frac{3.2\%}{100\%} = 3990\ OD\ \frac{lb}{min}$

Charge on Pulp

- *Chemicals are added to pulp as a fraction (or percentage) of the oven dry solids in the pulp, which is called a "charge on pulp"*
- *For instance, a deinking chemical might be said to be charged at 2% on pulp*
- *What that means is that the mass of the deinking chemical to add is equal to 0.02*(OD mass of the fiber)*

- *Example, we have 1000 lbs of pulp stock at 10% consistency and we want to charge a bleaching chemical at 5% on pulp, how much of the bleaching chemical do we charge?*
- *Answer,*
  - *the amount of OD fiber is 0.1*1000 lb total pulp stock = or 100 lbs of OD fiber*
  - *If we charge 5% of the bleaching agent then we charge 0.05*100 lbs of OD fiber = 5 lbs of bleaching agent to add*

YIELD

- *Yield* is defined as the amount of product that comes out of some process, relative to the amount of material that went into the process.
- In the paper industry, yield is ALWAYS defined in terms of moisture-free material going in or out – that is, it is based on dry fiber (oven dry).
- Yield is important, because it helps us understand where our raw material is going – how much is lost during screening, how much is dissolved during bleaching, how much is lost during washing, etc.

$$Yield\ \% = \frac{Dry\ weight\ out\ of\ process}{Dry\ weight\ into\ process} \text{ X } 100$$

YIELD EXAMPLE

- 3 Tons of recovered paper at 5% MC is recycled, resulting in 45,000 lb of stock at 10% consistency, what is the process yield?

- OD IN: $\mathbf{3\ Tons} \times \frac{\mathbf{2000lb}}{\mathbf{Ton}} \times \frac{95\%}{100\%} \frac{\mathbf{solids}}{\mathbf{total\ weight}} = \mathbf{5700\ OD\ lb}$
- OD OUT: $\mathbf{45,000\ lb} \times \frac{10\%}{100\%} \frac{\mathbf{solids}}{\mathbf{total\ weight}}$ =4500 OD lb
- $\mathbf{Yield} = \frac{\mathbf{4500\ OD\ lb}}{\mathbf{5700\ OD\ lb}} \times \mathbf{100\%} = \mathbf{79\%}$

pH

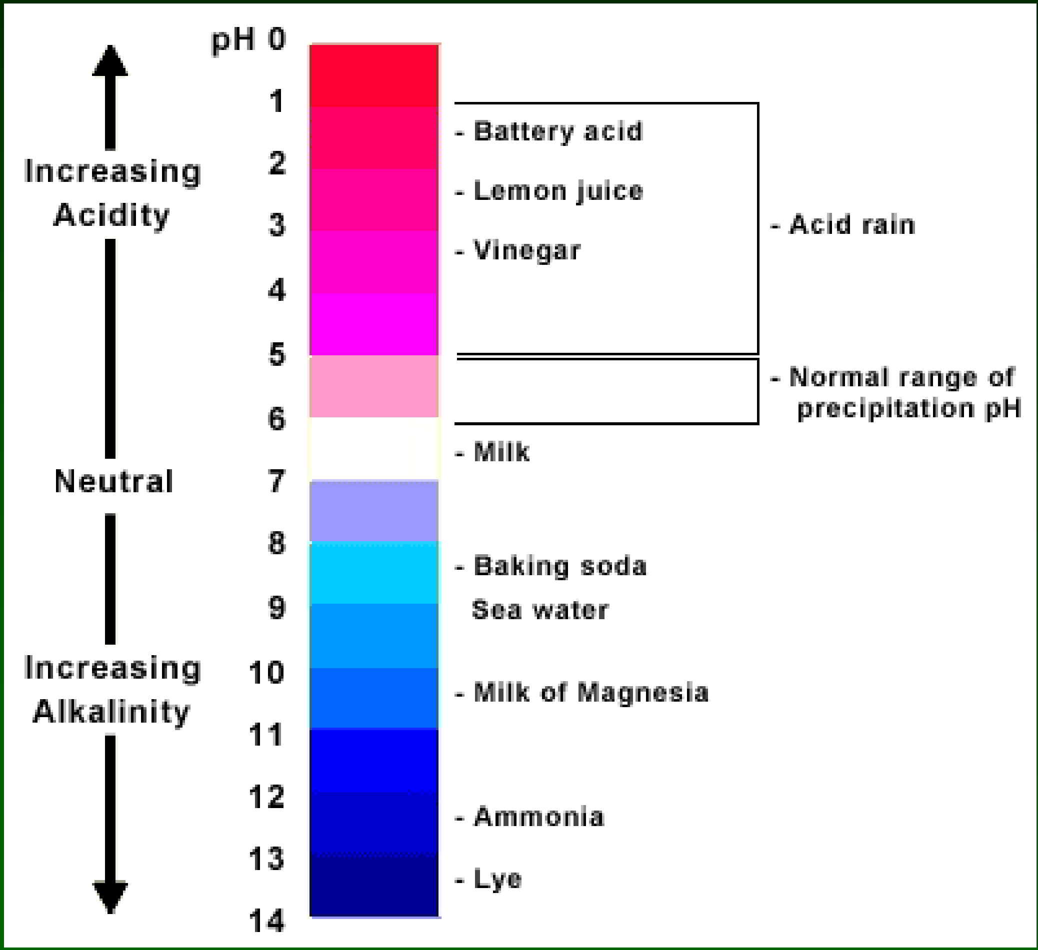
- pH stands for "potential of hydrogen" and refers to the concentration of hydrogen ions (H^+) in water or whatever liquid is being measured.

- In more everyday terms, pH is a unit of measure for determining if a liquid is acidic or basic (alkaline). Something that is neither acidic nor basic is referred to as neutral.

- You may have encountered the term pH in relation to the water in a fish tank or swimming pool. Bad things can happen when pH levels are either too high or too low.

THE pH SCALE...

- How is pH measured in numbers?
- pH is measured on a scale of 0.0 to 14.0.
  - Numbers < 7.0 = acidic
  - Numbers > 7.0 = basic
  - A pH of 7.0 indicates a neutral liquid



pH= -log [H^+ concentration]

If the amount of H^+ goes up 10X, the pH only decreases by 1.
The power of the log scale

pH

- Adding acids or bases to water changes its pH.
  - Acids lower the pH of water by increasing the H+ concentration.
    - Acid examples: sulfuric acid (H_2SO_4), hydrochloric acid (HCl), vinegar (acetic acid, CH_3COOH)
  - Bases raise the pH of water by increasing the OH- concentration.
    - Bases examples: caustic (NaOH, sodium hydroxide), ammonia (NH_3)

Lecture:

Pulping of recovered paper

Pulping of recovered paper

Definition

Pulper : A device whose main objective is to convert recovered paper into a slurry of well separated fibers and other waste paper components.

Pulping of recovered paper

The pulping operation is the first and probably the most critical operation in paper recycling.

Proper pulping is a requirement if unit operations downstream (cleaning, screening, flotation…..) are to be effective.

Incorrect pulping conditions can irreversibly damage fibers making them inappropriate for papermaking uses.

Pulping

<u>**Main Function**</u> **: Disperse recovered paper into separated fibers.**

<u>**Several sub-objectives that are also important**</u>**:**

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.

Basic Pulping Categories : Batch vs. Continuos Pulping

Batch Pulping : The feed recovered paper, water and chemicals are all charged at the beginning of the process and are removed all at once at the end of the process. The batch process is repeated.

Continuos Pulping : The feed recovered paper, water and chemicals are continuously added to the pulper and at the same time, the pulped product is also being continuously removed.

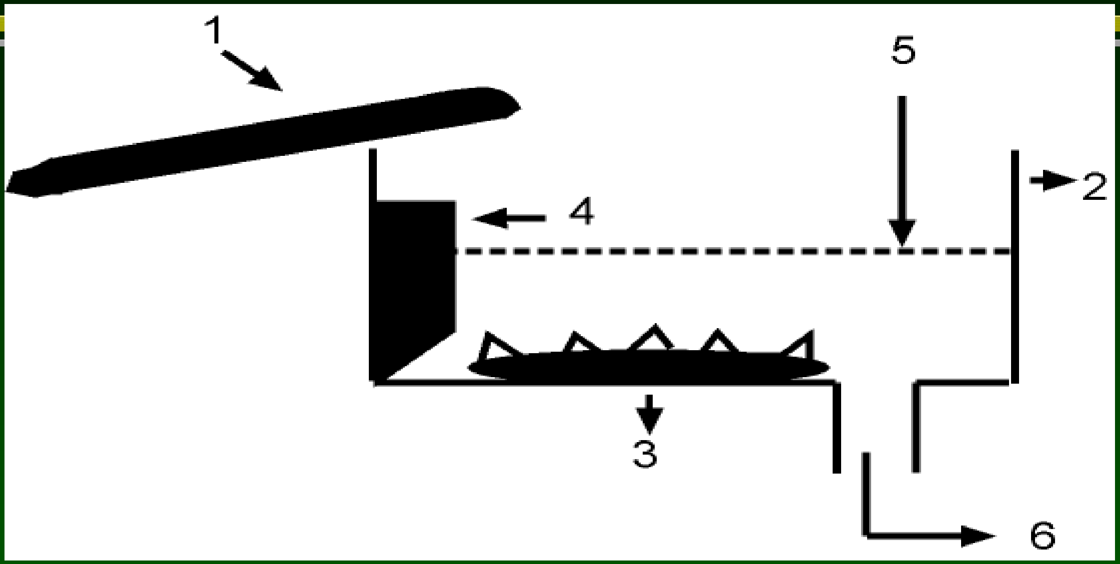
Basic Pulping Categories : Low vs High Consistency

$$\text{Consistency (solids)} \equiv 100 * \frac{\text{solids wt}}{\text{solids wt + liquid wt}} = \%\ K$$

Low Consistency Pulping: Typically from 3-6 % K. Produces a relatively easily pumpable fluid. The fluid is "pourable".

High Consistency Pulping: Typically from 8 - 18 % K. Produces a thick, slurry that will not flow under the influence of gravity alone.

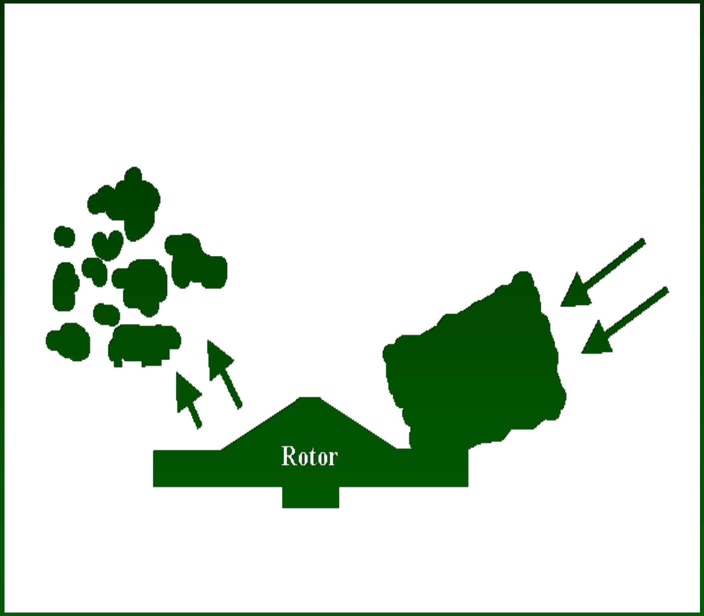
General Parts of a Pulper



- 1. Wastepaper feed method (conveyor).
- 2. Pulper tub.
- 3. Rotor - spinning device for agitation, mechanical energy input
- to the system.
- 4. Baffles - protrusions to assist in mixing and prevent swirling.
- 5. Dilution water.
- 6. Pulper exit.

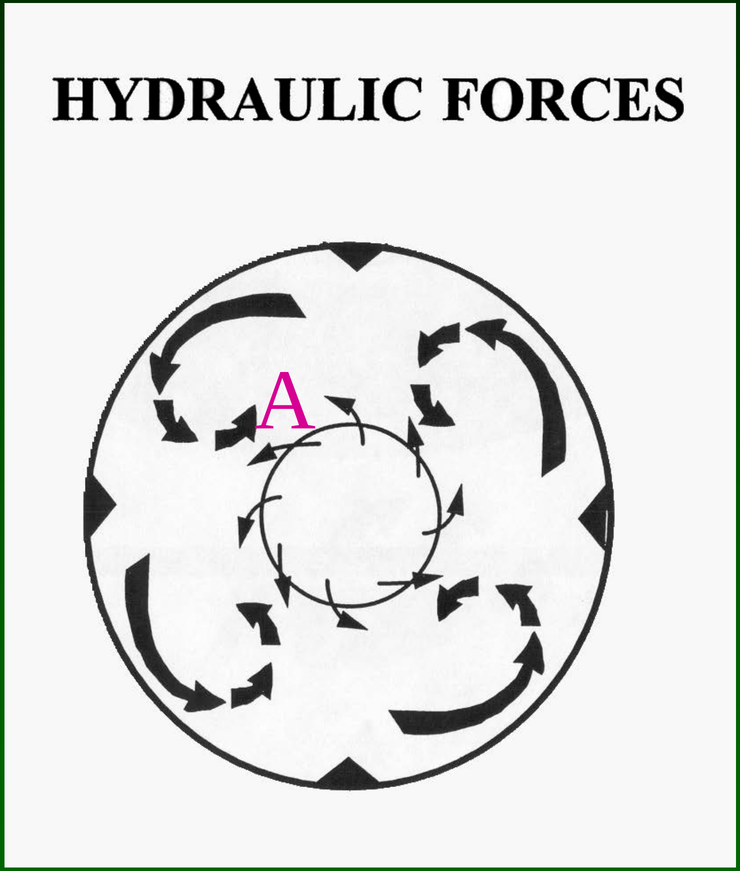
Forces in a Pulper

- <u>Mechanical Forces</u>
  These are caused when the fast moving rotor impacts material in the relatively slower body of pulp stock around it.
- Faster rotor speeds cause more intense mechanical forces in the pulper.



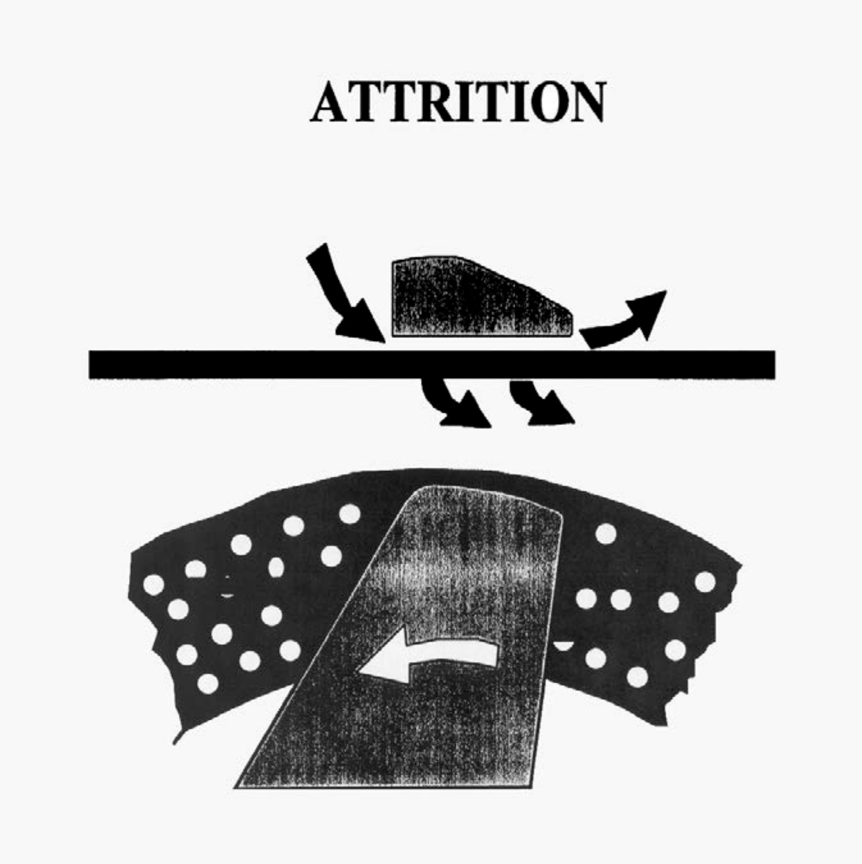
Pulper Forces

- Hydraulic Forces :
- These are caused by the motion of fluid that is caused by the spinning rotor (not by the direct impact of the rotors).
- When two adjacent portions of a fluid are moving in different directions (or at different speeds) a shear force is present. An example in the picture would be at point A.



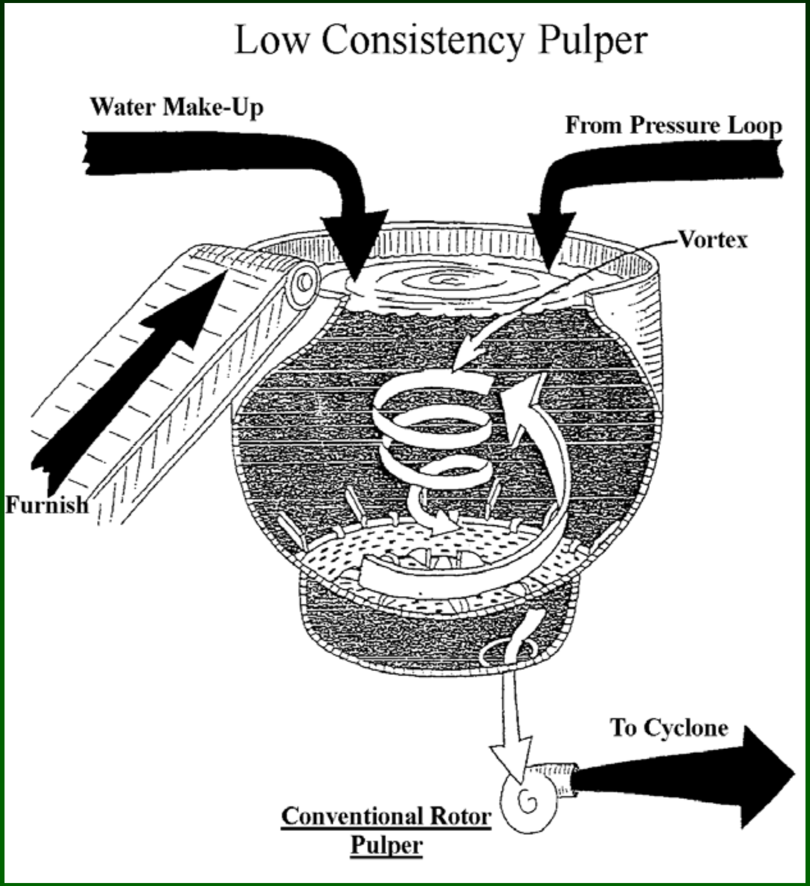
Forces in a Pulper

- **Attrition**
- **Mechanical shearing forces that occurs between the moving rotor and a static extraction plate near the rotor.**
- **The rotor forces fiber bundles between the rotor and extraction plate. Intense hydraulic forces act to cut the fiber bundles and fibers. This can cause significant damage to fibers.**
- **Used only for low % K pulping because the pulp must be screenable.**



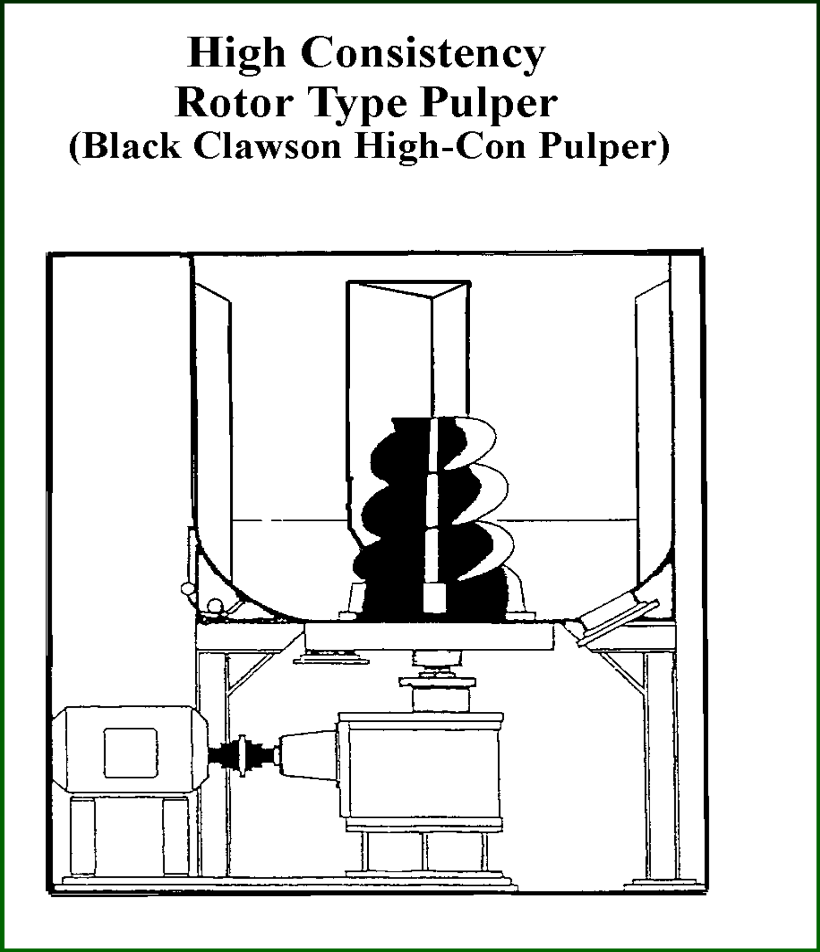
Low Consistency Pulping

- 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.



Pulper Types: High Consistency

- 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.



Comparison of Low vs High Consistency Pulping

- Rotor/ tank volume is much higher for high % K pulping. This is needed to maintain proper motion of non - fluid pulp stock at high % K.
- Specific power is higher for high % K due to the higher viscosity pulp stock that must be pulped.
- However, the specific power consumption per ton of paper is significantly lower for high % K pulping.This is due to high % K pulping having more tons of fiber for the amount of same pulping volume as a low % K pulper. Also, the relatively less amount of water at high % K pulping causes less energy to be expended on moving water.

	Low % K	High % K
Consistency %	3 - 6	8 -18
Rotor/Tank Vol %	0.1	8
Specific Power (KW)	6	22
No loadPower (%)	70 - 80	50 - 60
Rotor Speed m/s	16 - 21	8 - 15
Specific Power Consumption Kwh/ton	30 - 45	15 - 25

Comparison of Low vs High Consistency Pulping

- Rotor speed is slower for high % K, causing less damage to fibers via mechanical forces of rotor.
- Attrition forces are not used for high % K pulping. This decreases fiber cutting and contaminant breakage.
- RESULTS of above: higher tensile, burst and tear strength for high %K pulping
- High consistency pulping includes more fiber to fiber rubbing.
- RESULTS of above: This action increases detachment of contaminants from fiber surfaces. The detachment of ink from fibers is especially important for washing and flotation deinking.

Comparison of Low vs High Consistency Pulping

- Printing and writing grades consist of a high content of fully bleached hardwood and softwood fibers that are susceptible to damage => gentle high consistency pulping is preferred
- Further printing and writing grades need ink detachment => high consistency pulping with lots of fiber-fiber rubbing is preferred
- OCC recycling, a historically older technology, typically has low consistency pulping because unbleached fibers are less susceptible to damage

Screening and Junk Removal in Pulper

- One of the sub- objectives of pulping is to remove large debris that enters the system.
- Examples of large debris :
  - wood
  - wet-strength paper
  - plastics
  - baling wire
  - nails and bolts
- The removal of debris serves two important functions.
  - Protects equipment downstream from damage.
  - Prevents plugging of downstream equipment.

Examples of Debris Removal Methods

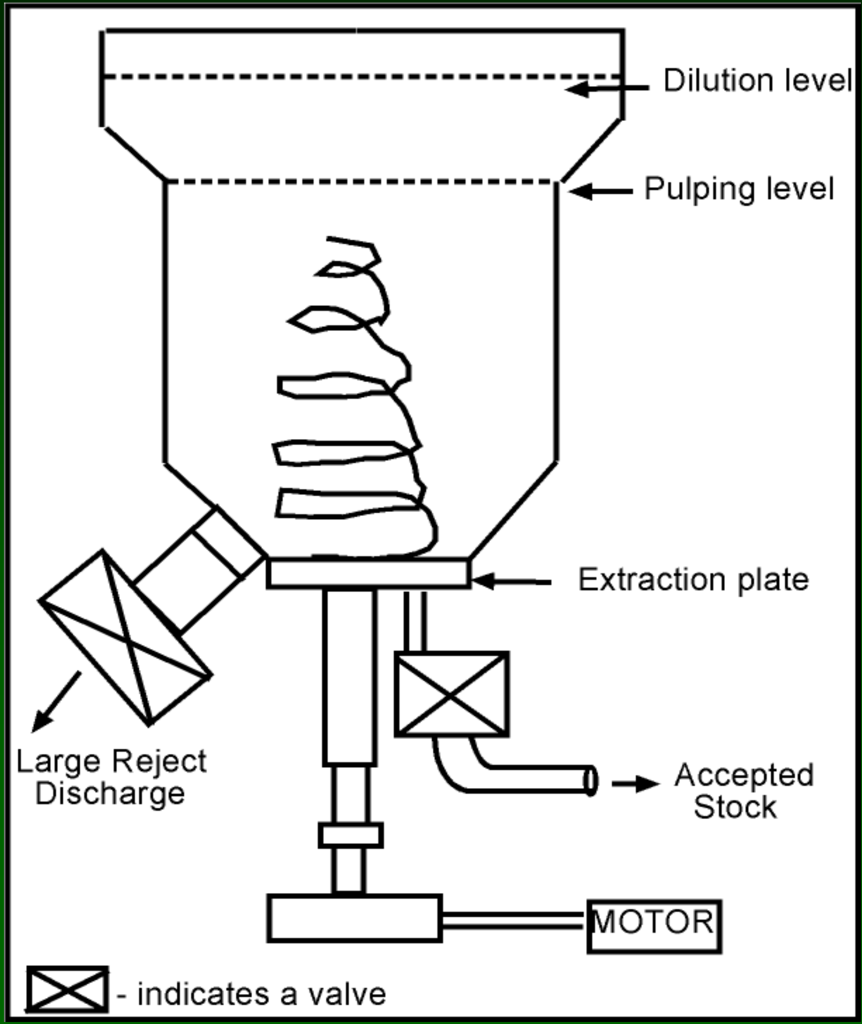
- Different pulpers have different methods to remove debris, examples of common methods follow.

- High Consistency Batch Pulping
  - HC pulper with Dilution Zone
  - HC pulper with Detrasher

- Low consistency Pulping
  - Continuos Low consistency pulper with Ragger and junk tower.
  - Continuos Low consistency pulper with a de-trashing system

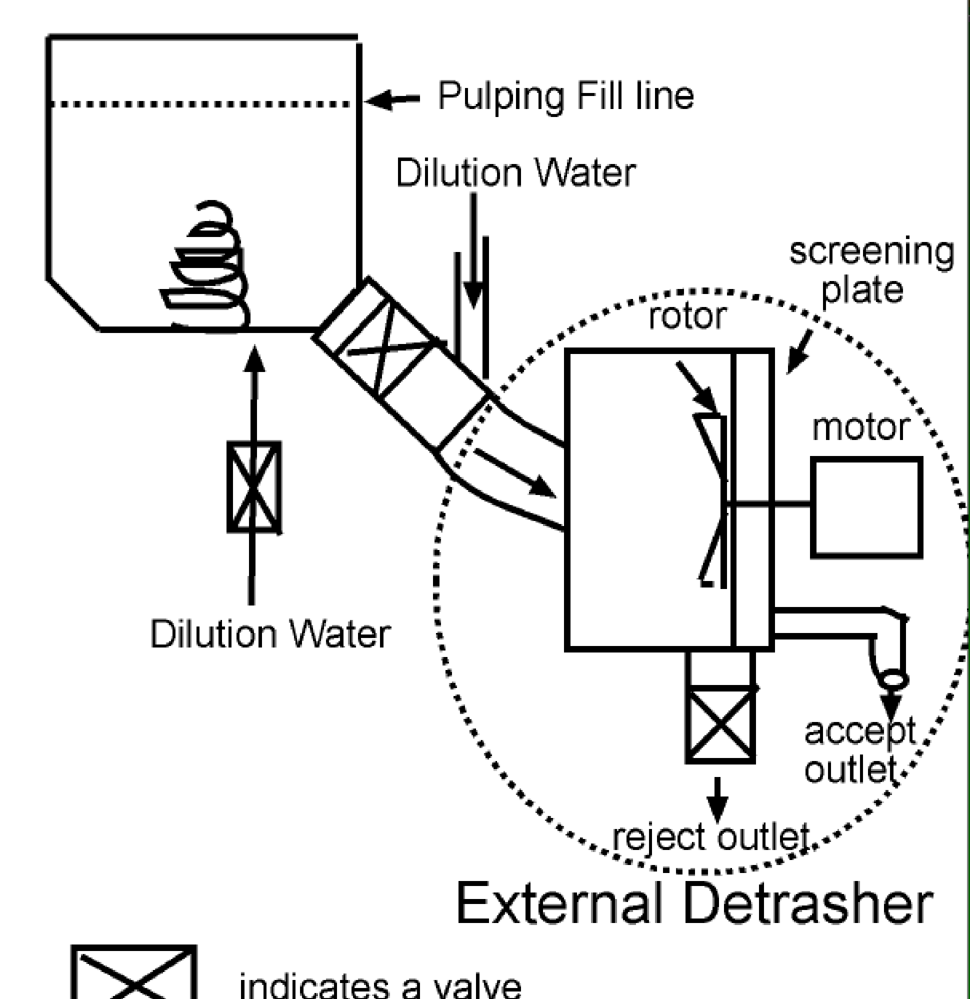
High Consistency Batch Pulper with Dilution Zone

- The pulper is designed so that during pulping at 15 - 18% K the pulper volume is only partially full.
- At the end of the pulping cycle, dilution water is added to achieve a 5 - 6 % K.
- After dilution, accepted stock passes through an extraction plate with holes about 3/4 - 1 inch diameter.
- Finally, large debris is flushed from the pulper through a large rejects opening on the side.



High Consistency Batch Pulper with External Detrasher

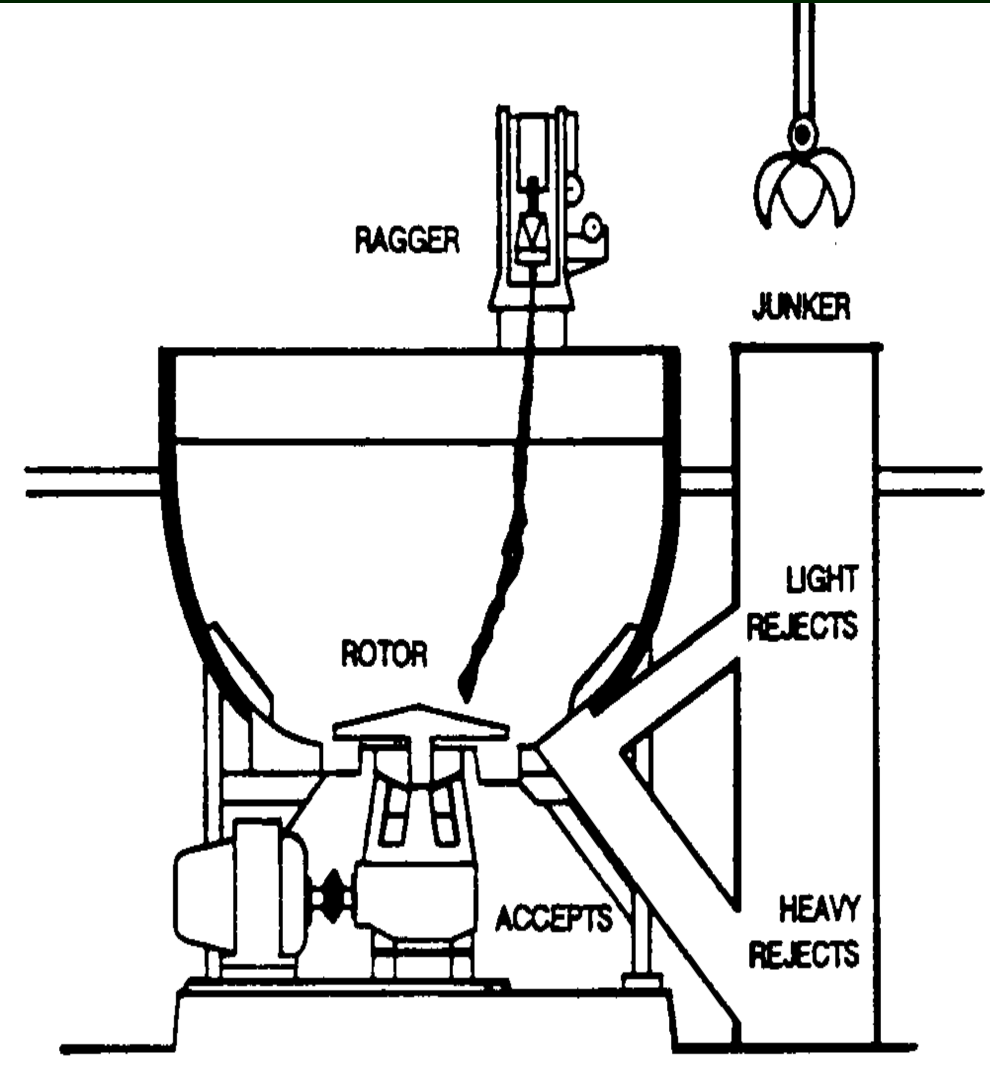
- The pulper is “full” at high consistency during pulping.
- At the end of the pulping dilution water is added at the bottom of the pulper diluting the pulp in the bottom to less than 6 %.
- A large opening on the bottom/side of the pulper is used as the exit for the pulper contents.
- The pulp and debris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



Note: drawing not to scale.

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.

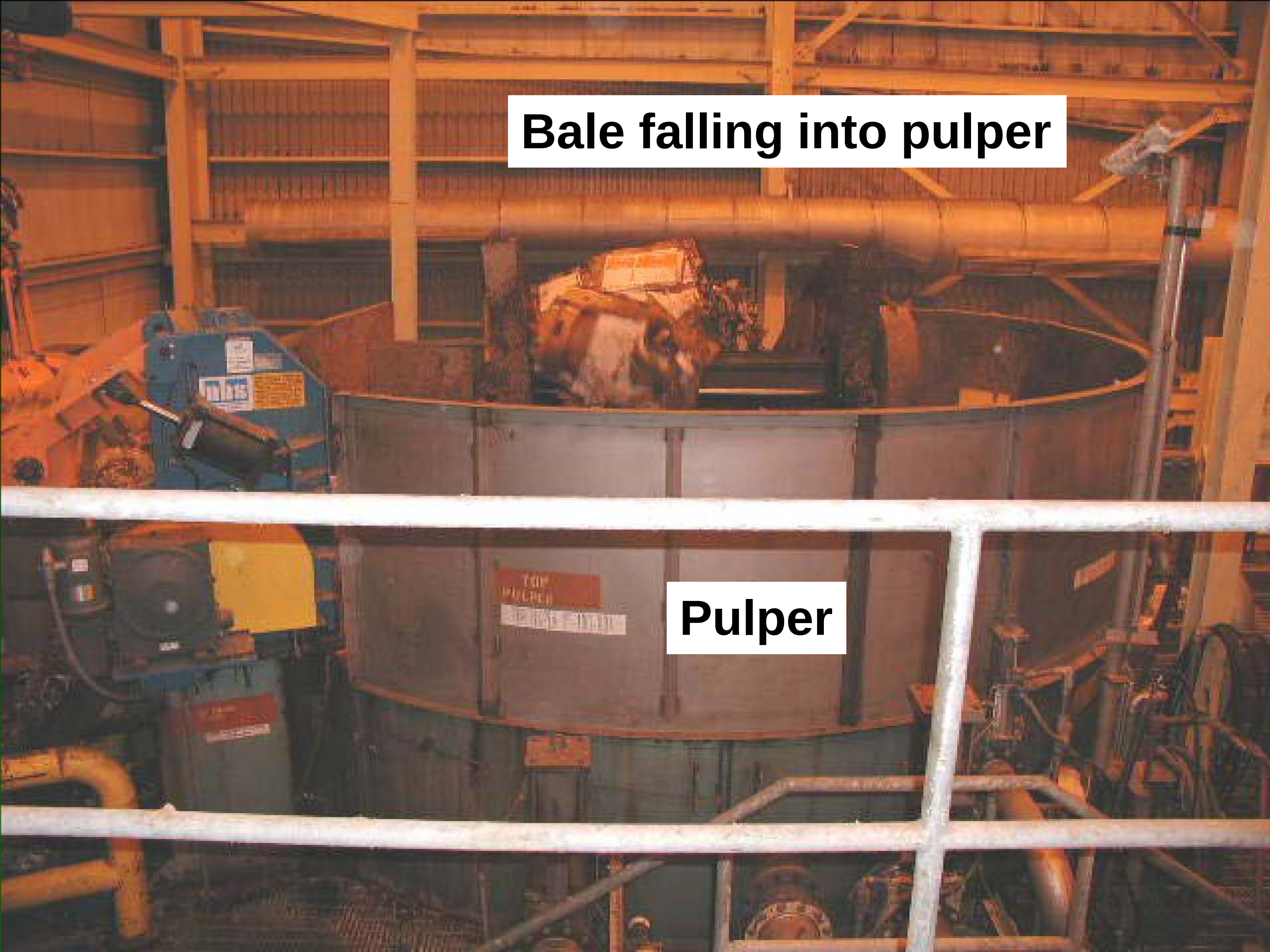


Recovered OCC bale storage

Loading OCC bales on pulper conveyor


Wire bale cutter


Pulper conveyor


Bale falling into pulper
TOP PULPER
Pulper

Ragger removing debris from the pulper surface


Ragger pulling rejects
out of pulper


Junker Claw

Continuos Low Consistency Pulper with Ragger and Junk Tower

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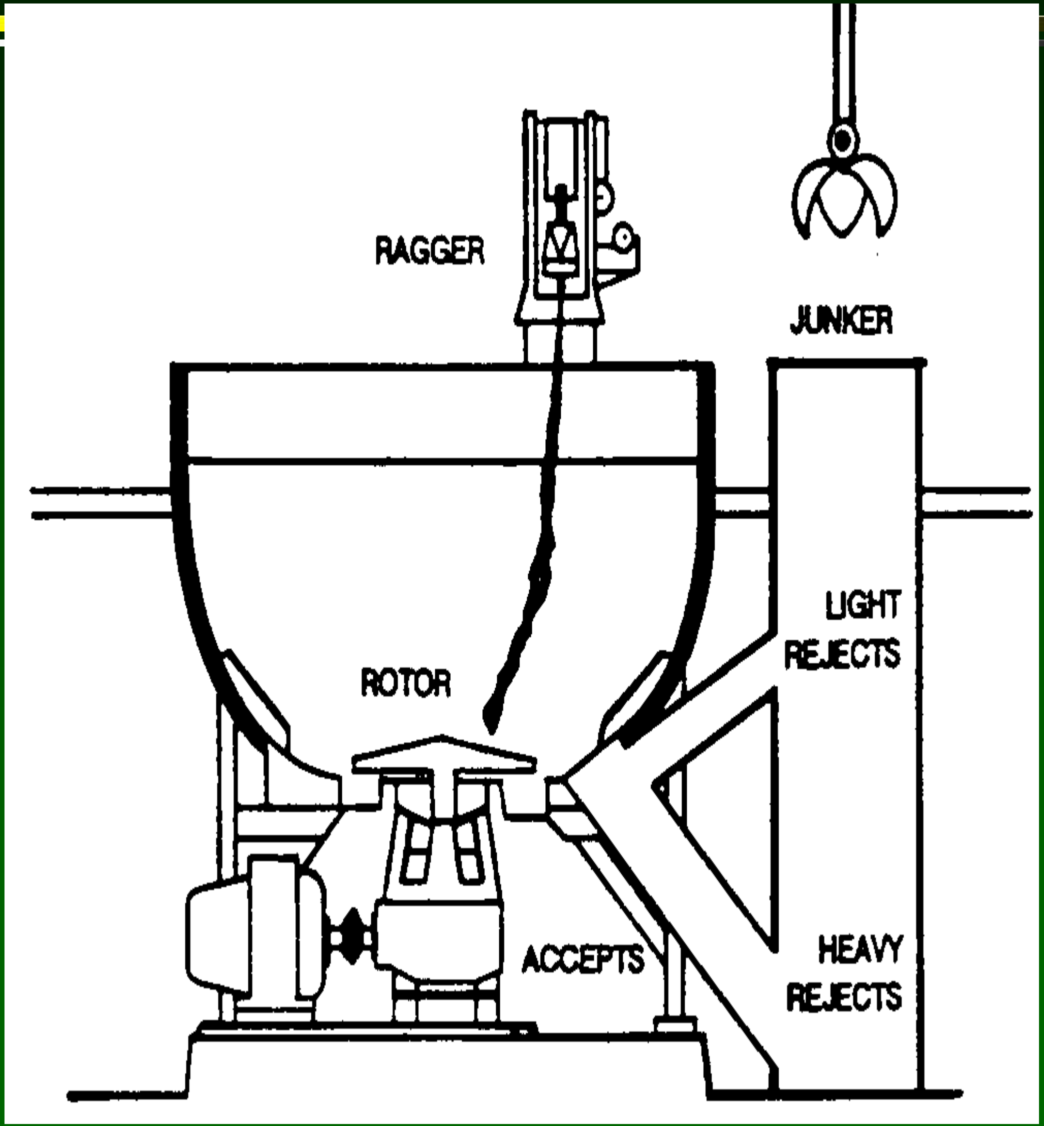
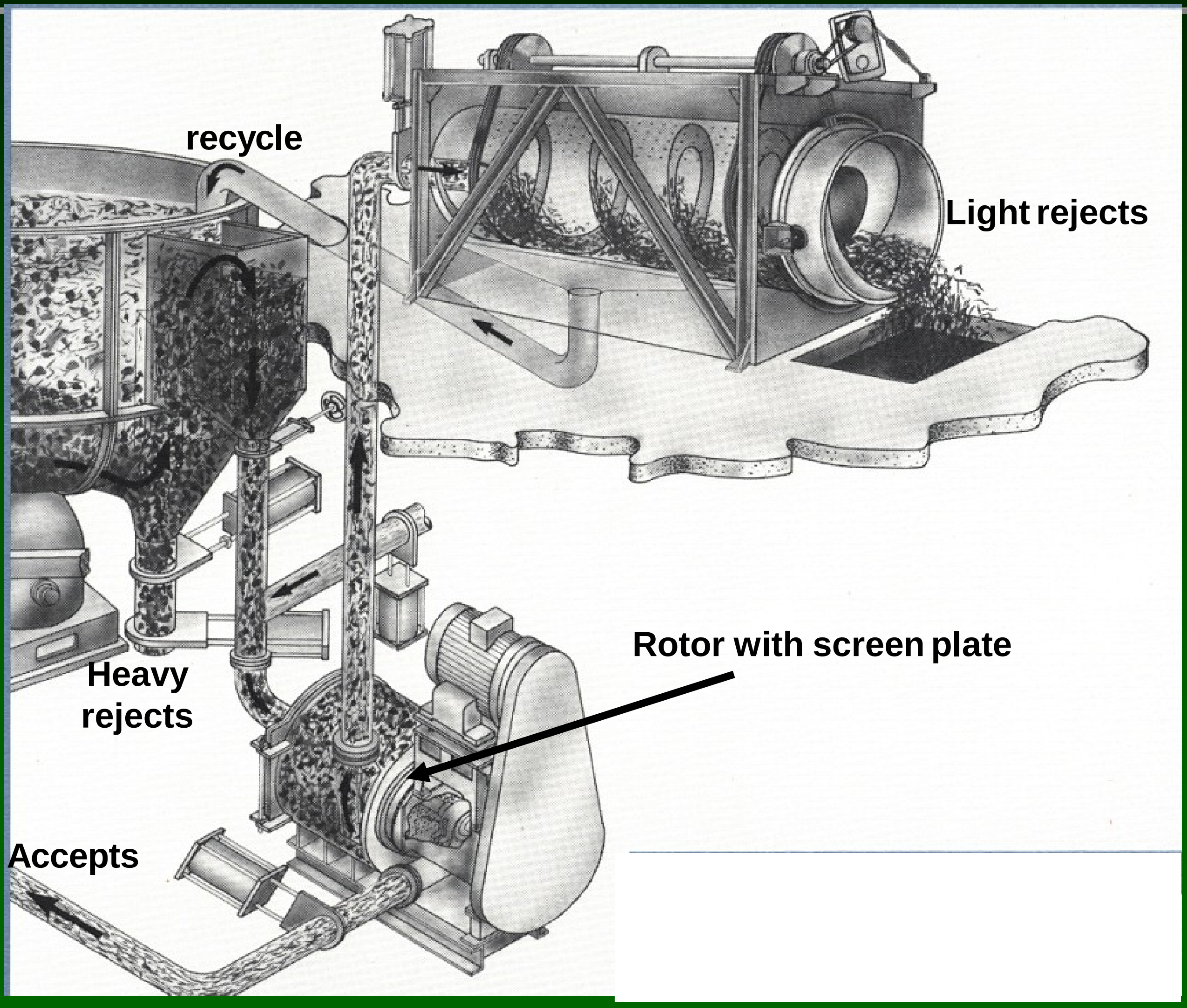


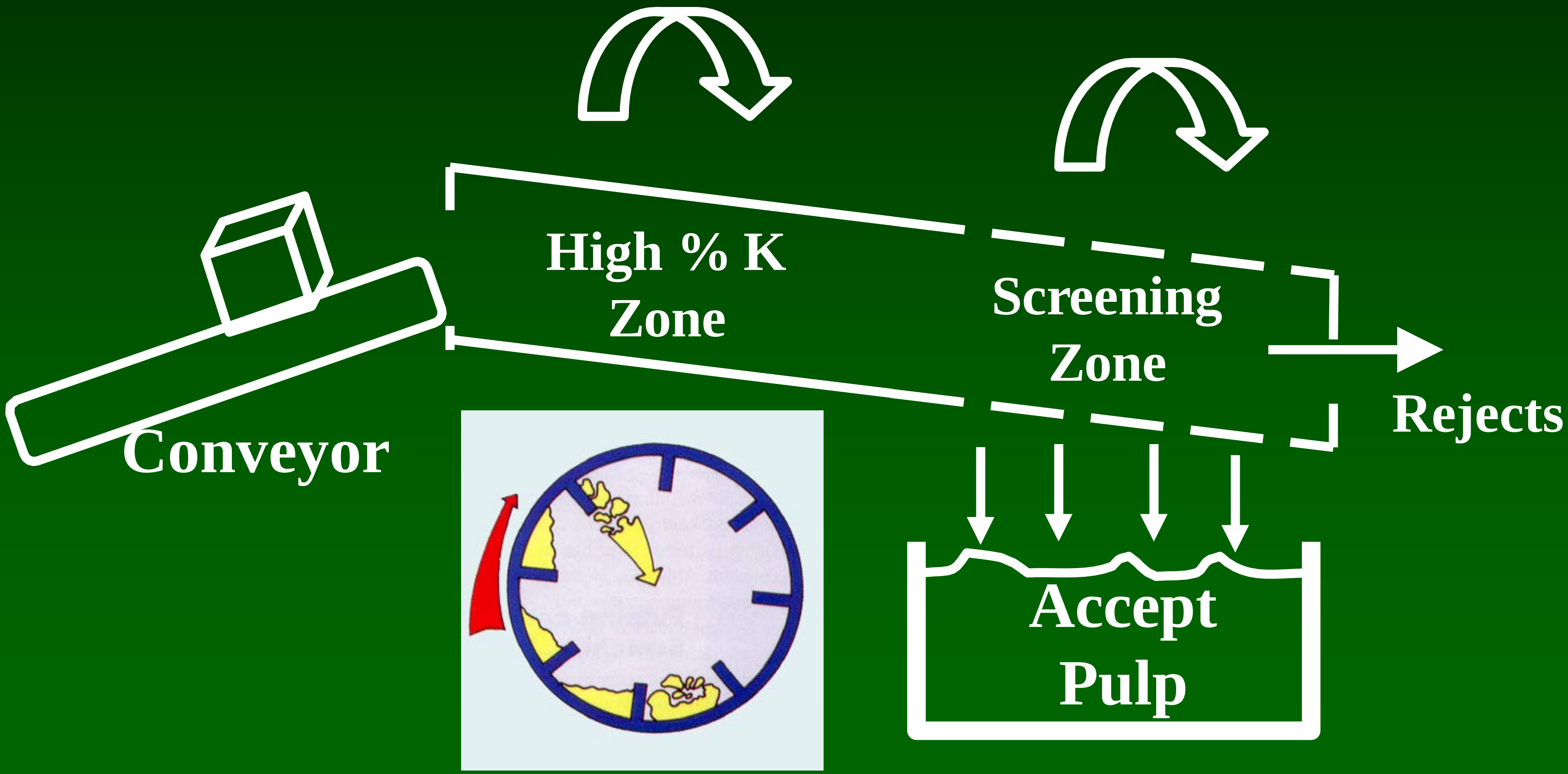
Example Detrashing Process



Drum Pulping

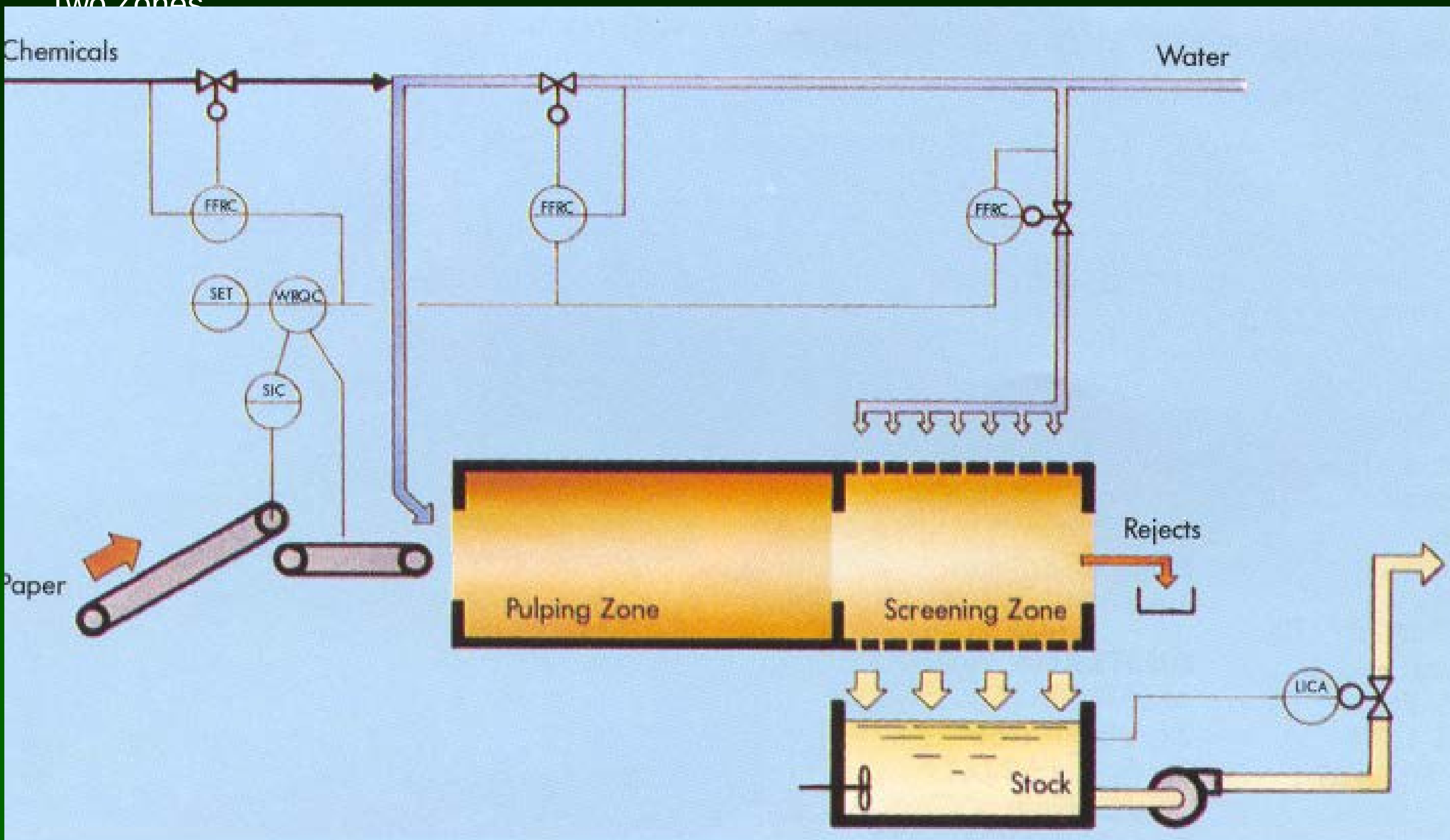
- A continuos, high consistency pulping method.
- Most often used for pulping old newsprint.
- Consists of an inclined rotating drum 11 -17 rpm through which the paper/ pulp travel down. The drum is very large approximately 10 feet high and 100 feet long.

High Consistency Drum Pulper



Drum Pulping

- Two Zones



Drum Pulping

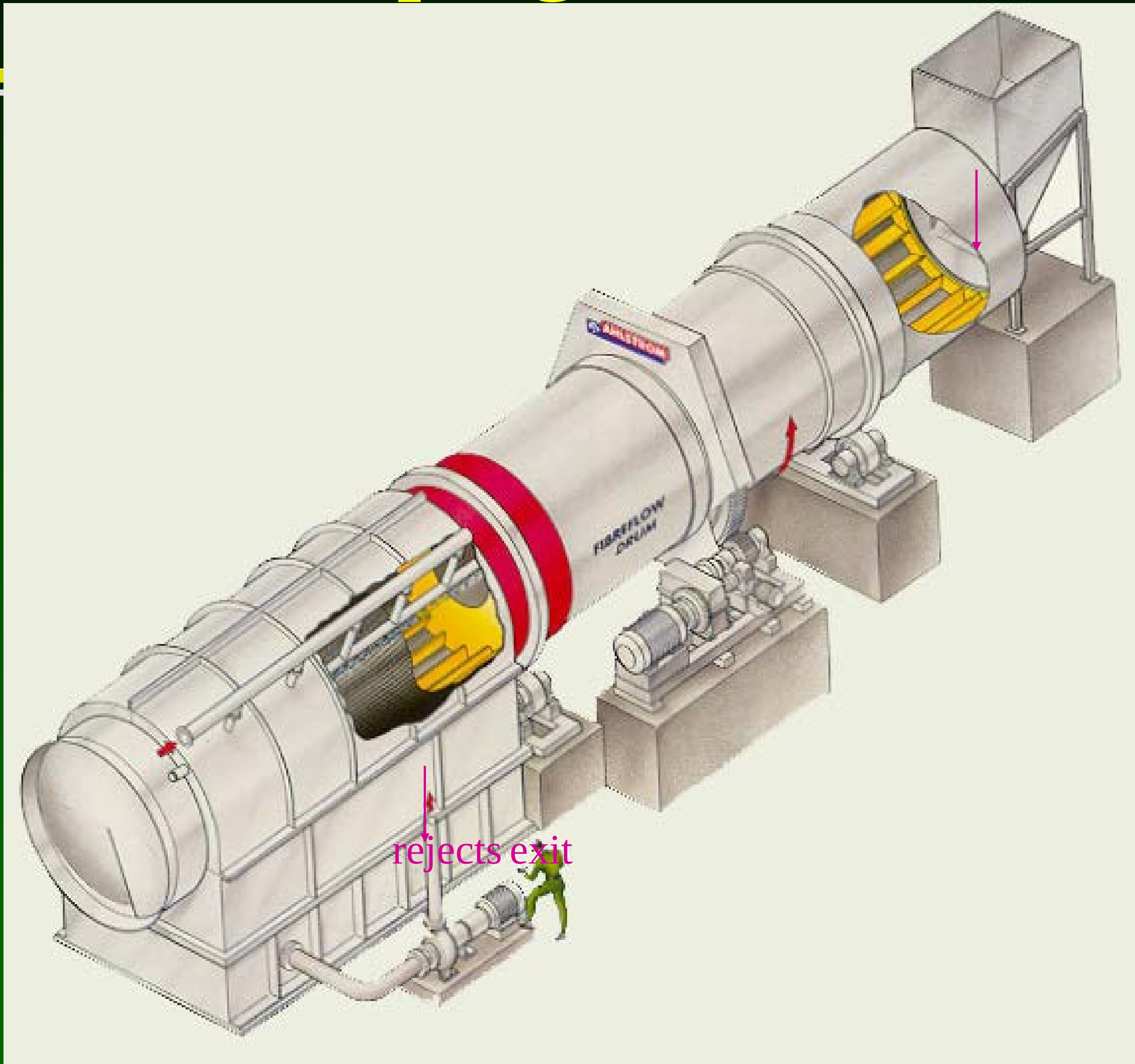
- Two Zones
  - High Consistency pulping zone
  - Low consistency pulping zone.
- High Consistency Pulping Zone
  - Paper ,water and chemicals added to ^ 15% K.
  - Baffles on the walls of the drum lift the paper and drop causing defibering in a gentle manner.
- Low Consistency Screening zone
  - Water is added to dilute stock 3-4% K.
  - Pulped fibers pass through 6 mm holes and are accepted from the pulper.
  - Large rejects continue through the pulper and are4 discharged at the end.

Overview

Rejects

Drum Pulping

- Advantages
  - Gentle pulping keeps contaminants large and minimizes fiber degradation.
  - Simple operation that includes screening.
- Disadvantages
  - High capital cost.
  - Not an aggressive pulping method (example: cannot pulp wet strength papers).

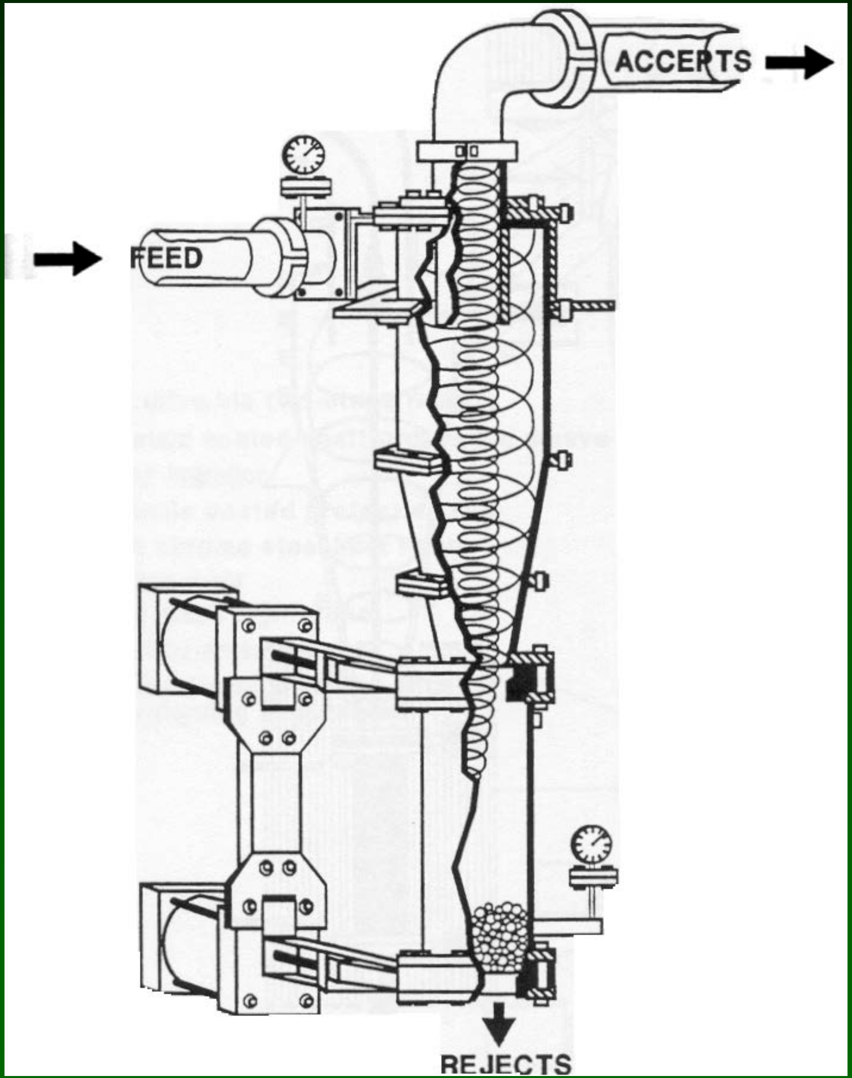


External Pulping Complementary Equipment

- Often the pulper is within a loop
- Some operations may send back material to the pulper to be further pulped
- Some operations aid in the removal of large debris
- Other operations add more mechanical action to assist in pulping

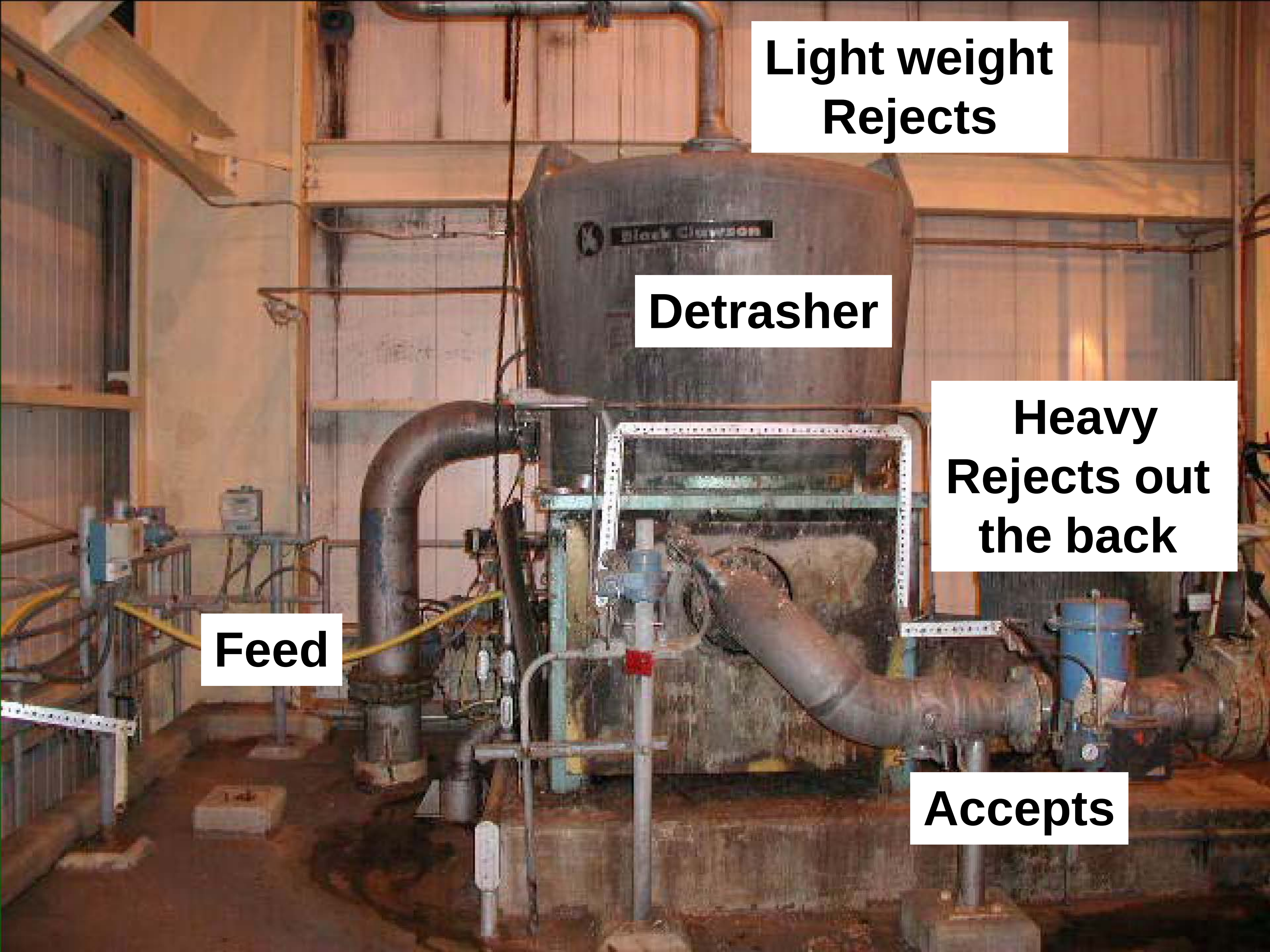
High density cleaners

High Density Cleaner: removes large heavy rejects from pulp



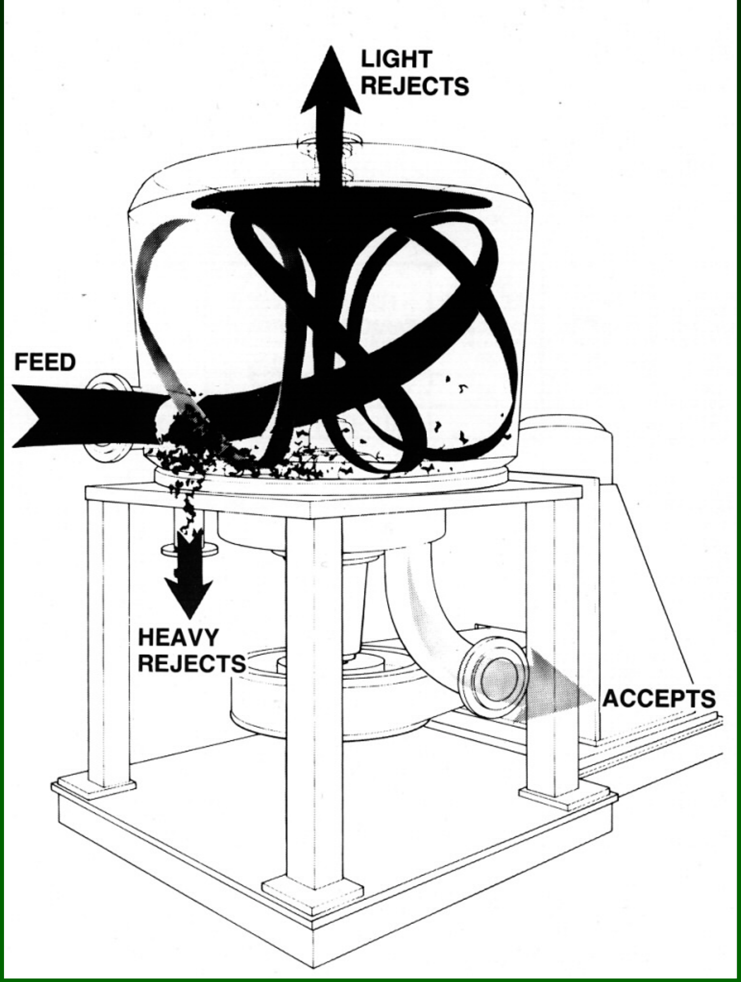
Objective: separate large heavy contaminants from fibers to protect downstream equipment from damage and pluggage

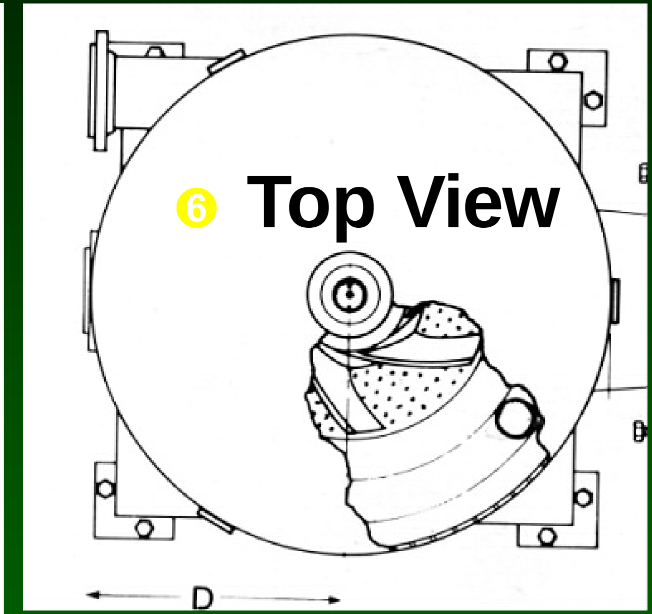
How it works: centrifugal forces separate materials mainly due to density/size



Light weight Rejects
Detrasher
Heavy Rejects out the back
Feed
Accepts

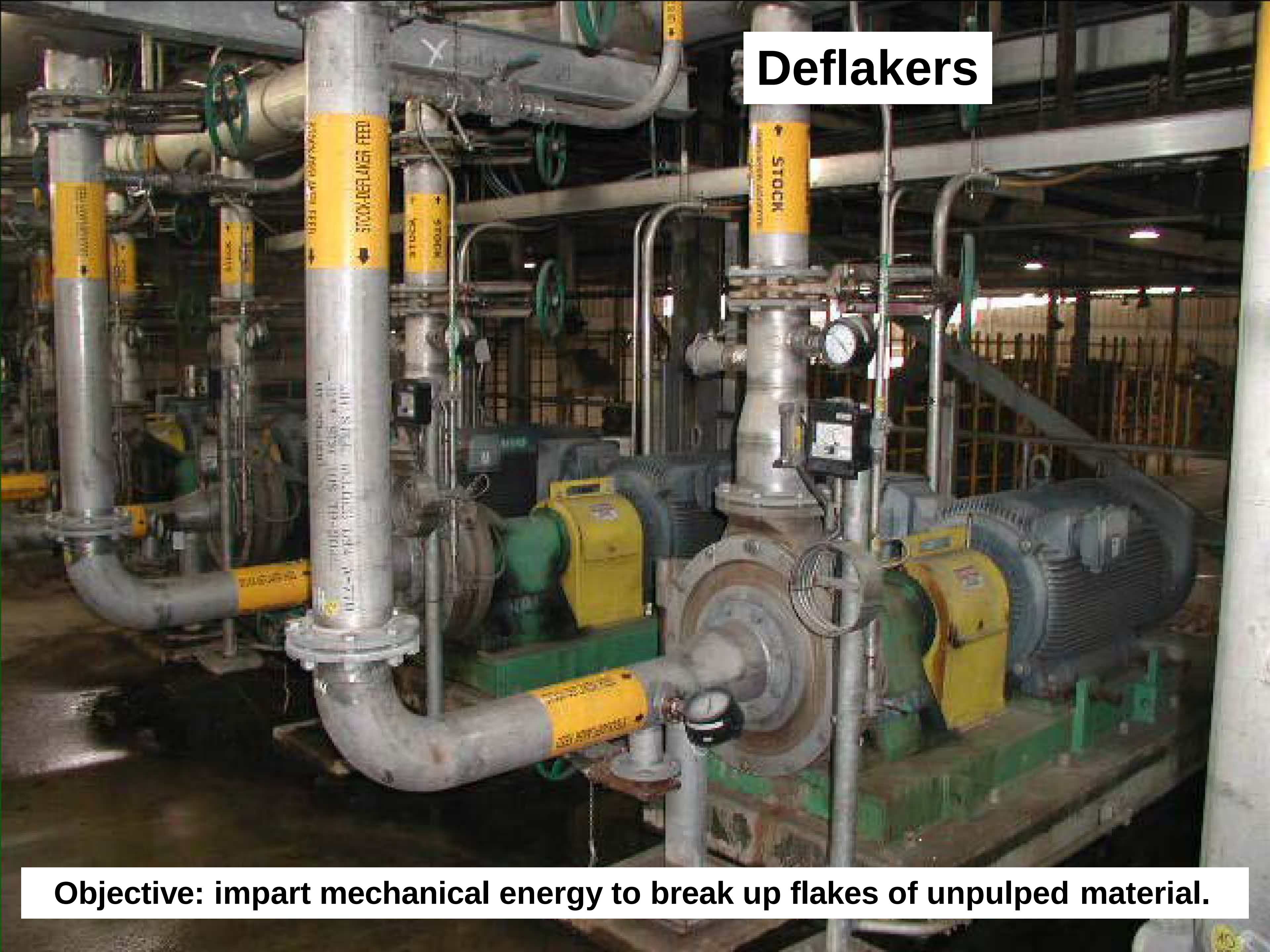
Example detrashing unit





Objective: pulp unpulped pieces of paper/board and separate contaminants using a screen or centrifugal forces to protect downstream equipment from damage and pluggage

Deflakers



Objective: impart mechanical energy to break up flakes of unpulped material.

Pulping Summary

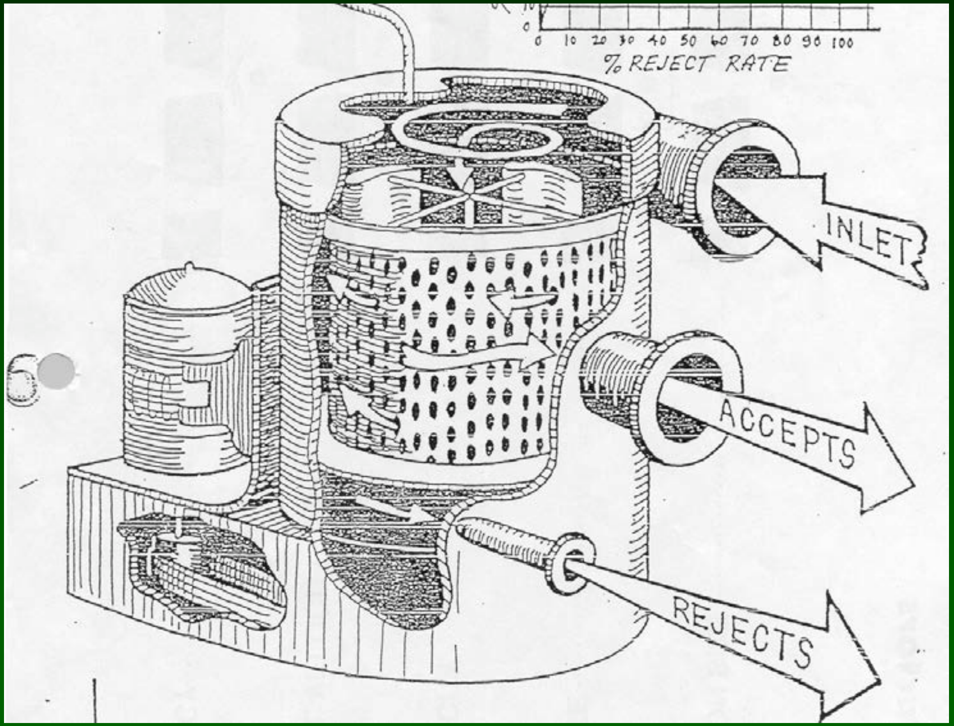
- Several methods to pulp
- Main objective: defiberize
- Secondary Objectives:
  - Remove Large Debris
  - Detach contaminants
  - Not destroy fibers
  - Mix
- Final Thought: If pulping is not done properly, subsequent processing steps will be ineffective and product quality will be unacceptable

Lecture:

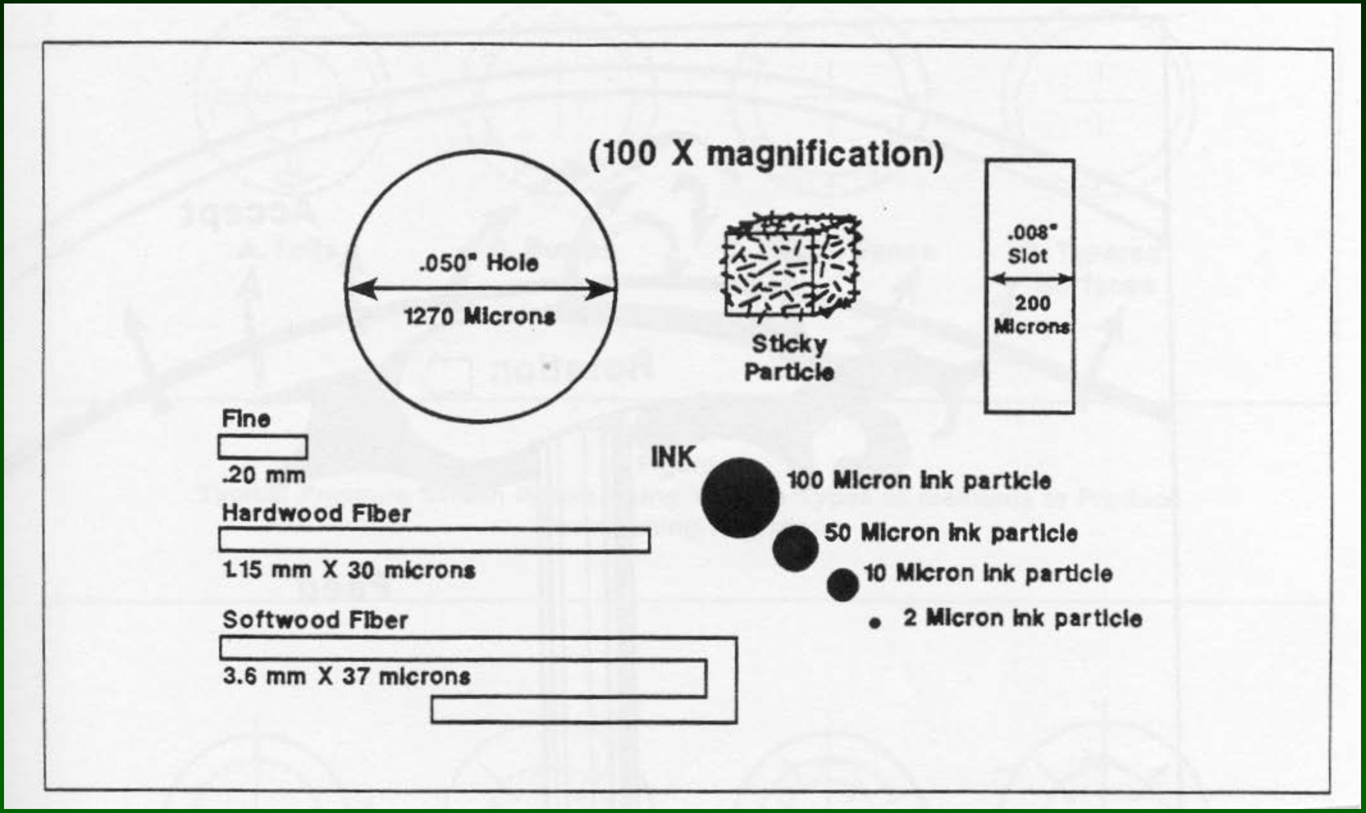
Screening

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

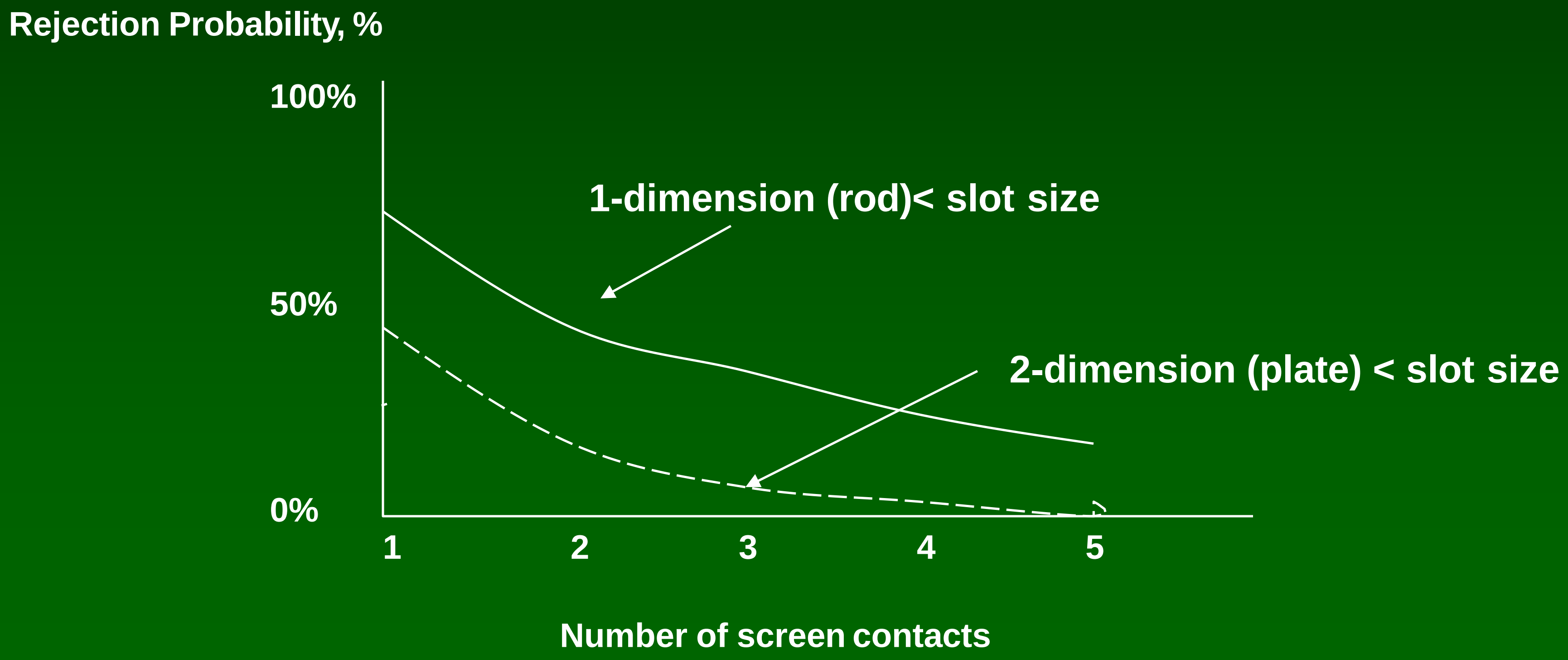


0.001 inch = 1 Mil = roughly 25 microns = .025 mm

Modes of Removal

1. Stiff particles with all 3 dimensions larger than width of slot or diameter of hole are rejected

2. Stiff particles with one or two dimensions smaller than width/diameter have a probability of rejection.



Screening Types and Conditions

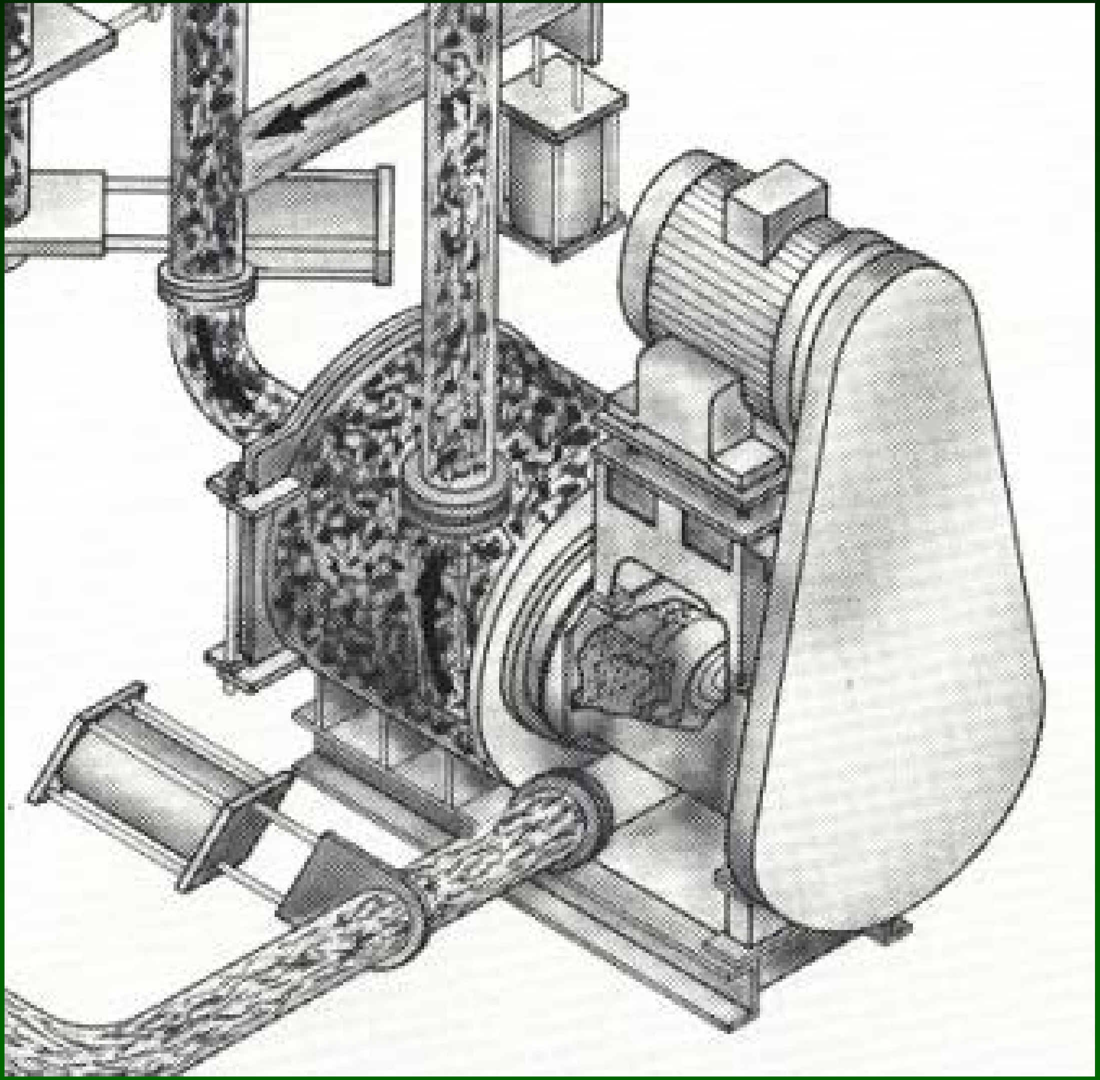
Screen Type	Screen Openings, mm	Rotor circumference speed,m/s	Consistency Range		
			MC <6%	MC <4.5%	LC <1.5%
Disk	Hole 2-3	20-30	Yes		
Cylindrical	Hole 0.8-1.5	10-30		Yes	
Cylindrical	Slot 0.1-0.4	10-30		Yes	Yes

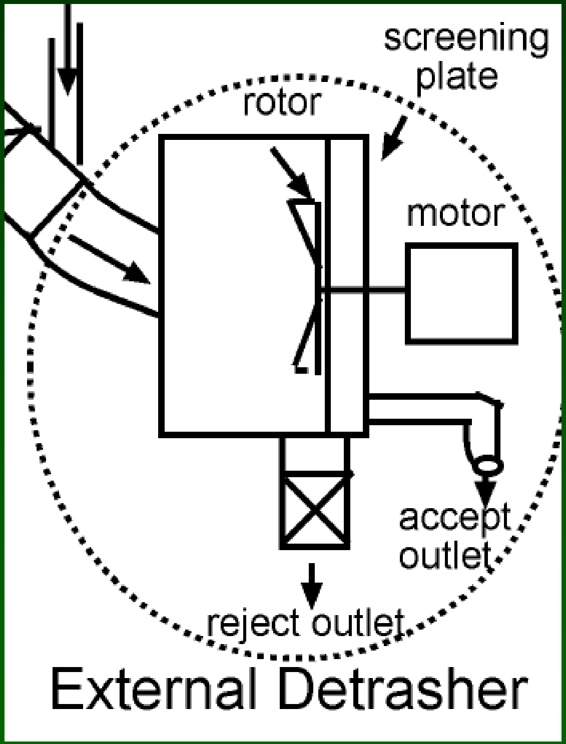
Screening

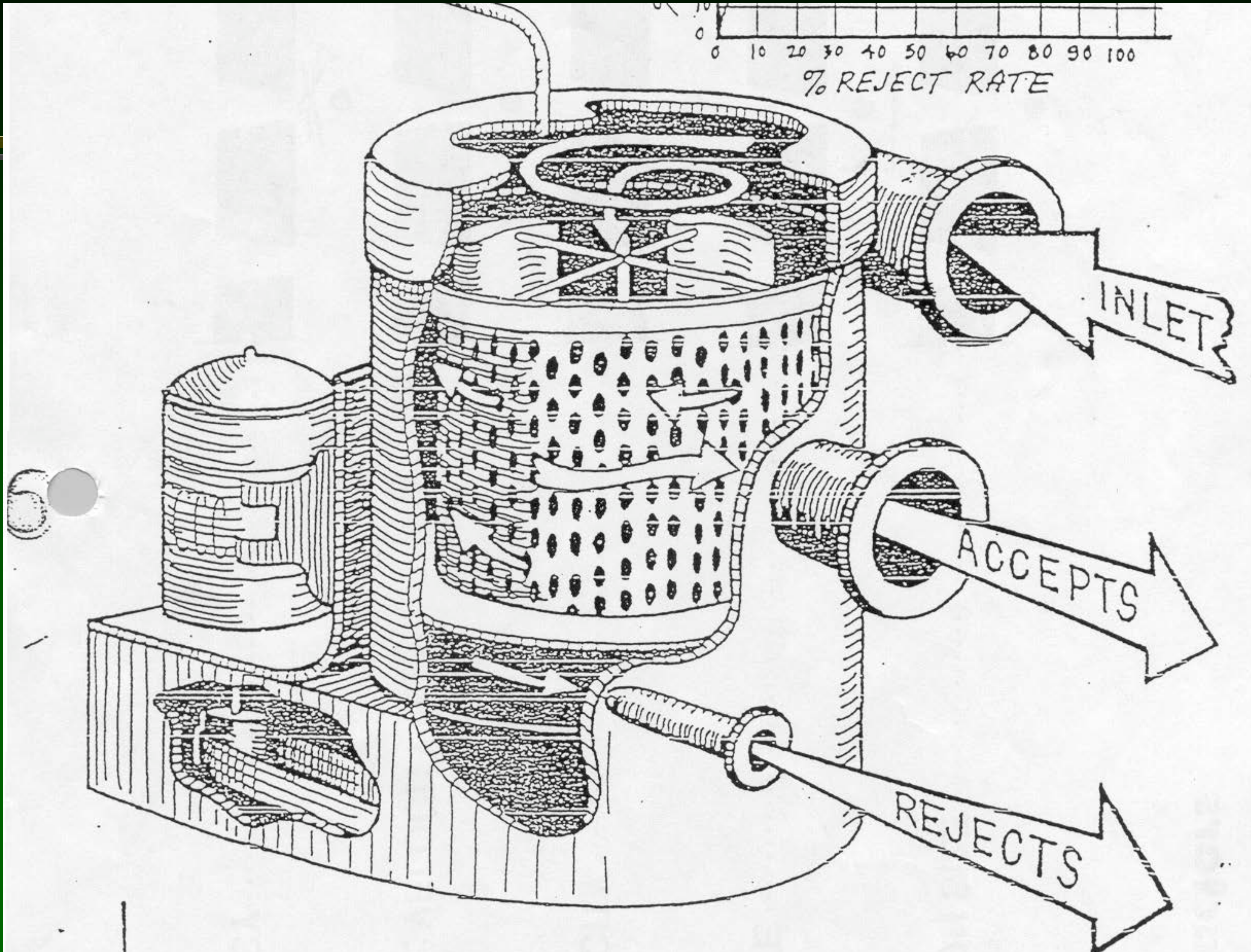
- Types of perforations
  - coarse holes .110 in or 2.7 mm
  - fine holes .060 in or 1.52 mm
  - coarse slots .010 in or .254 mm
  - fine slots .006 in or .152 mm

- Also, the fibers offer a resistance to passage, related to the consistency

Example of Disk Screen

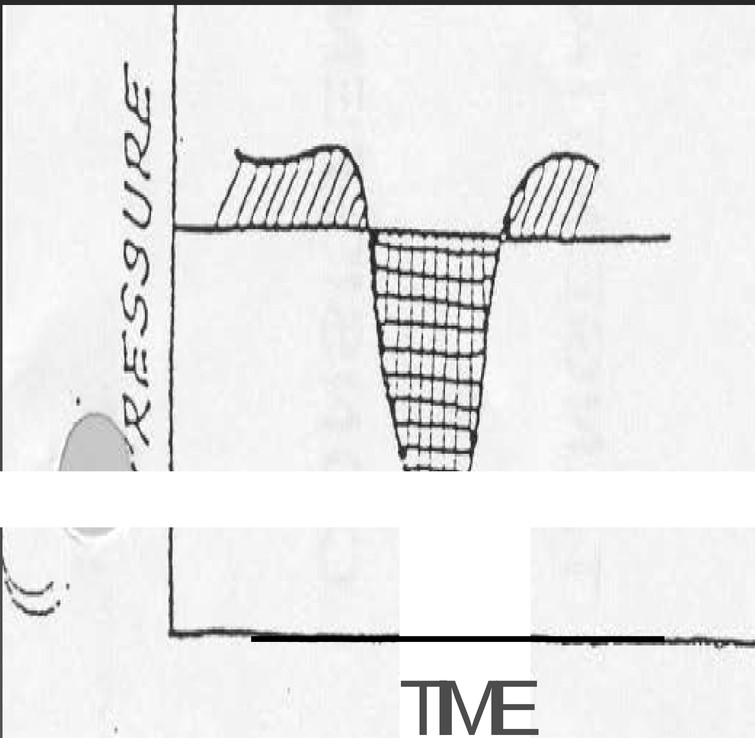


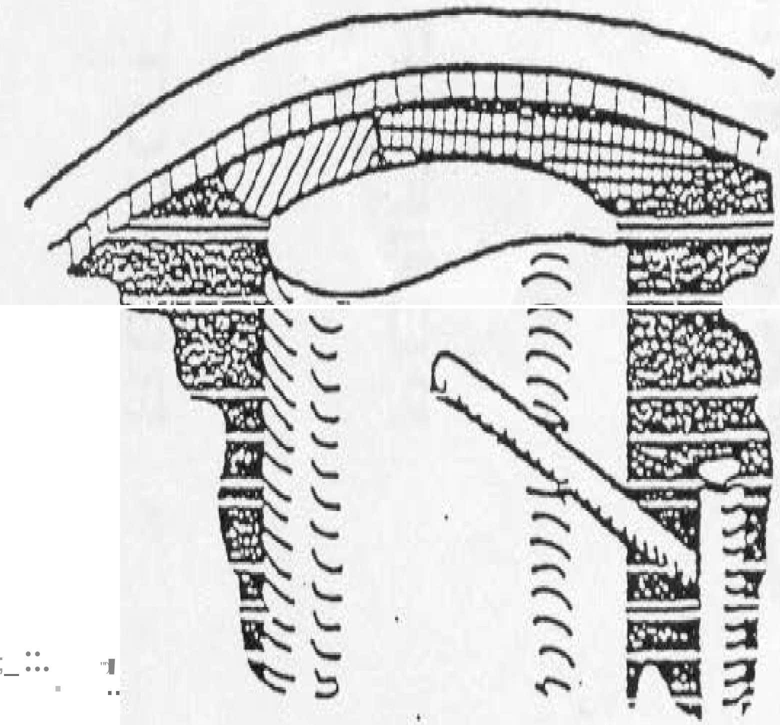




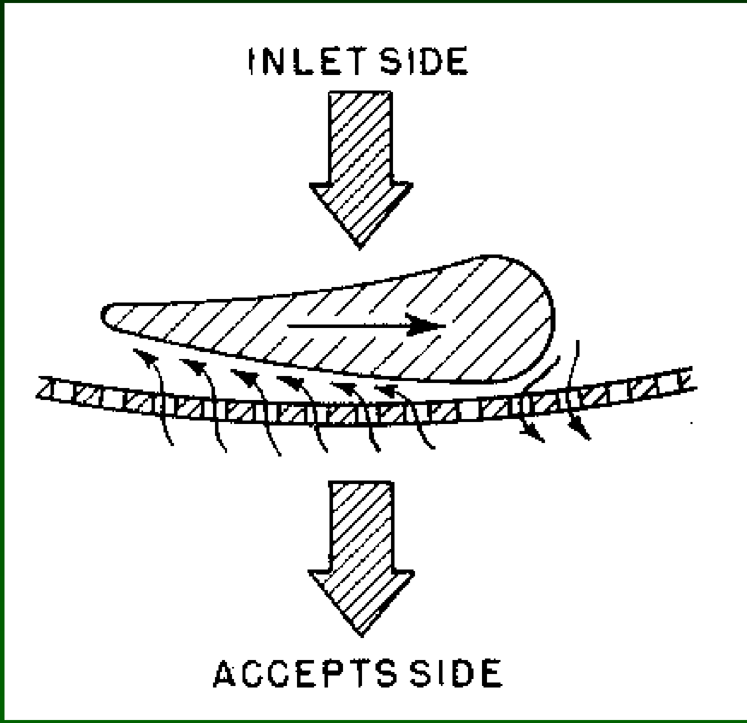
0
0 10 20 30 40 50 60 70 80 90 100
% REJECT RATE
INLET
ACCEPTS
REJECTS

Pressure screen


PRESSURE
TIME



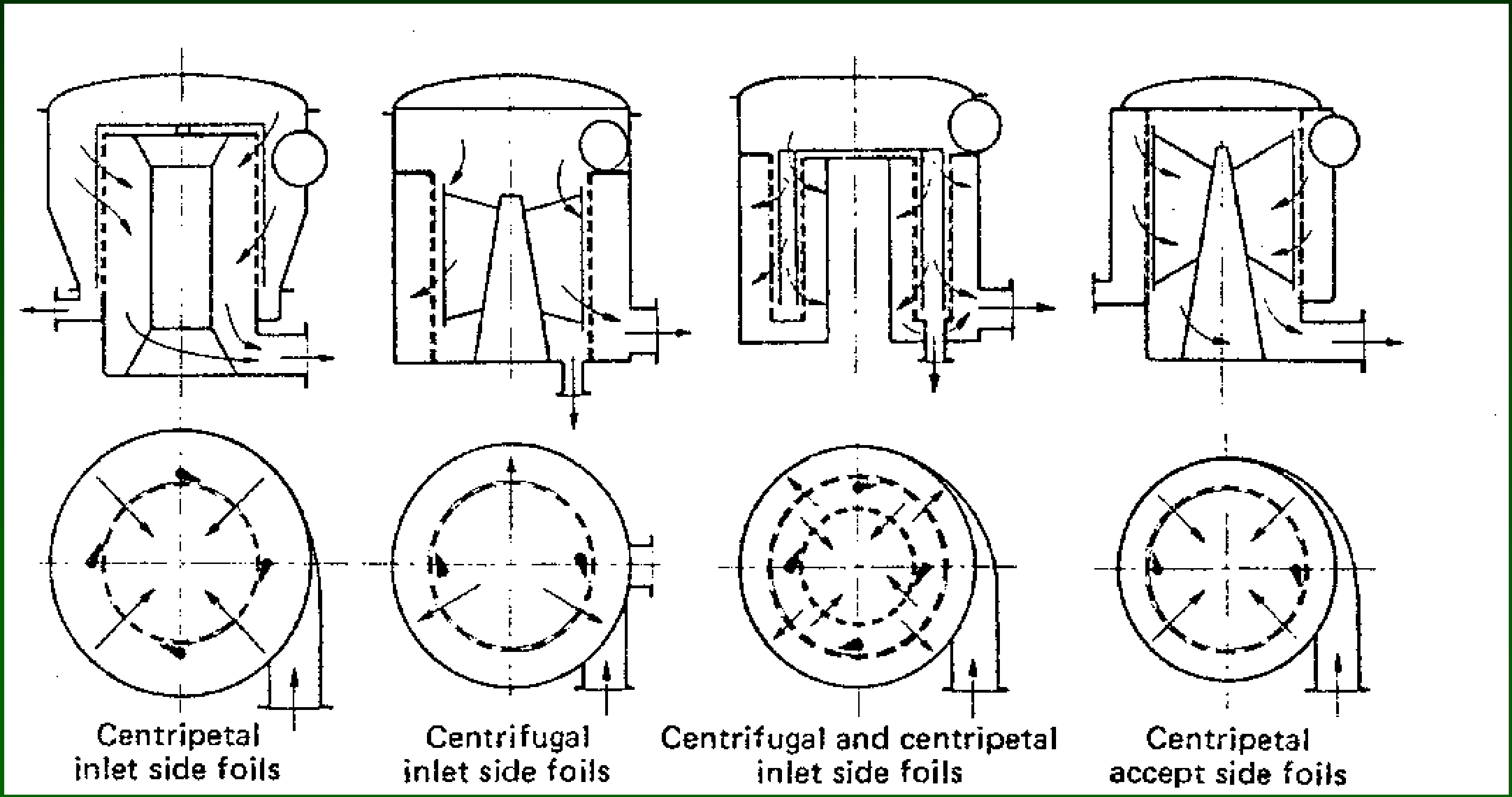
Pressure Screen Principle to Prevent Blinding of Screen



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.

Pressure Screen Flow Configurations



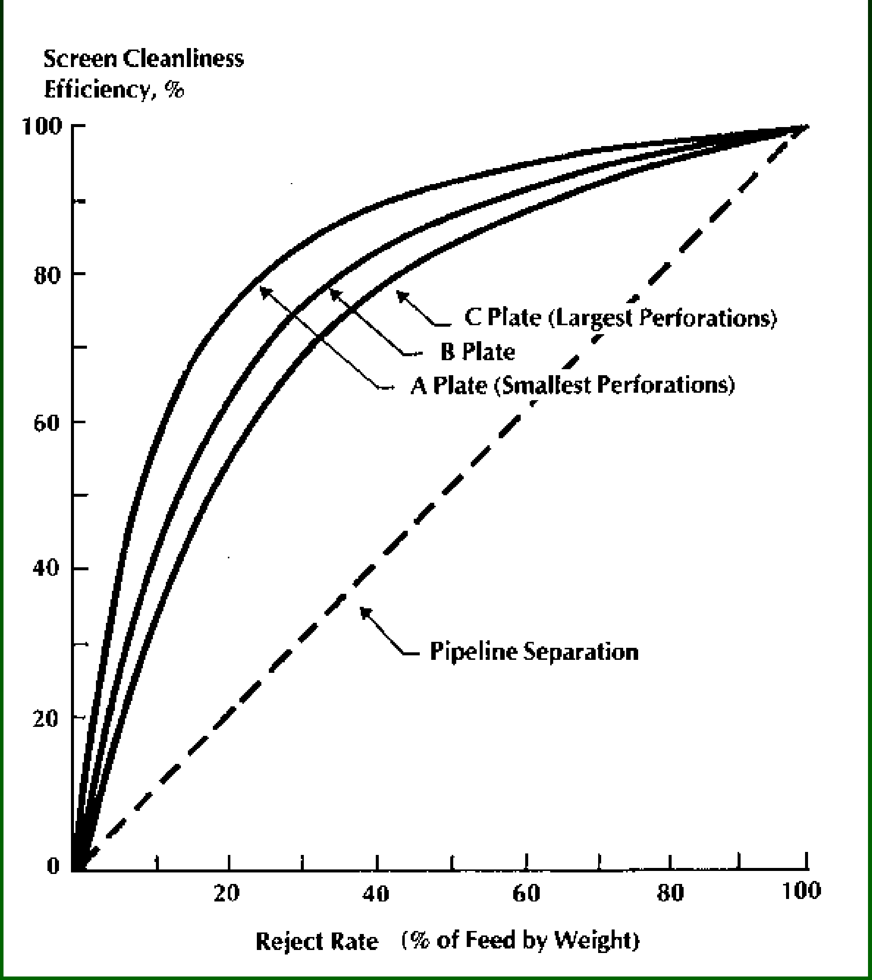
Screen Plates

- Holes

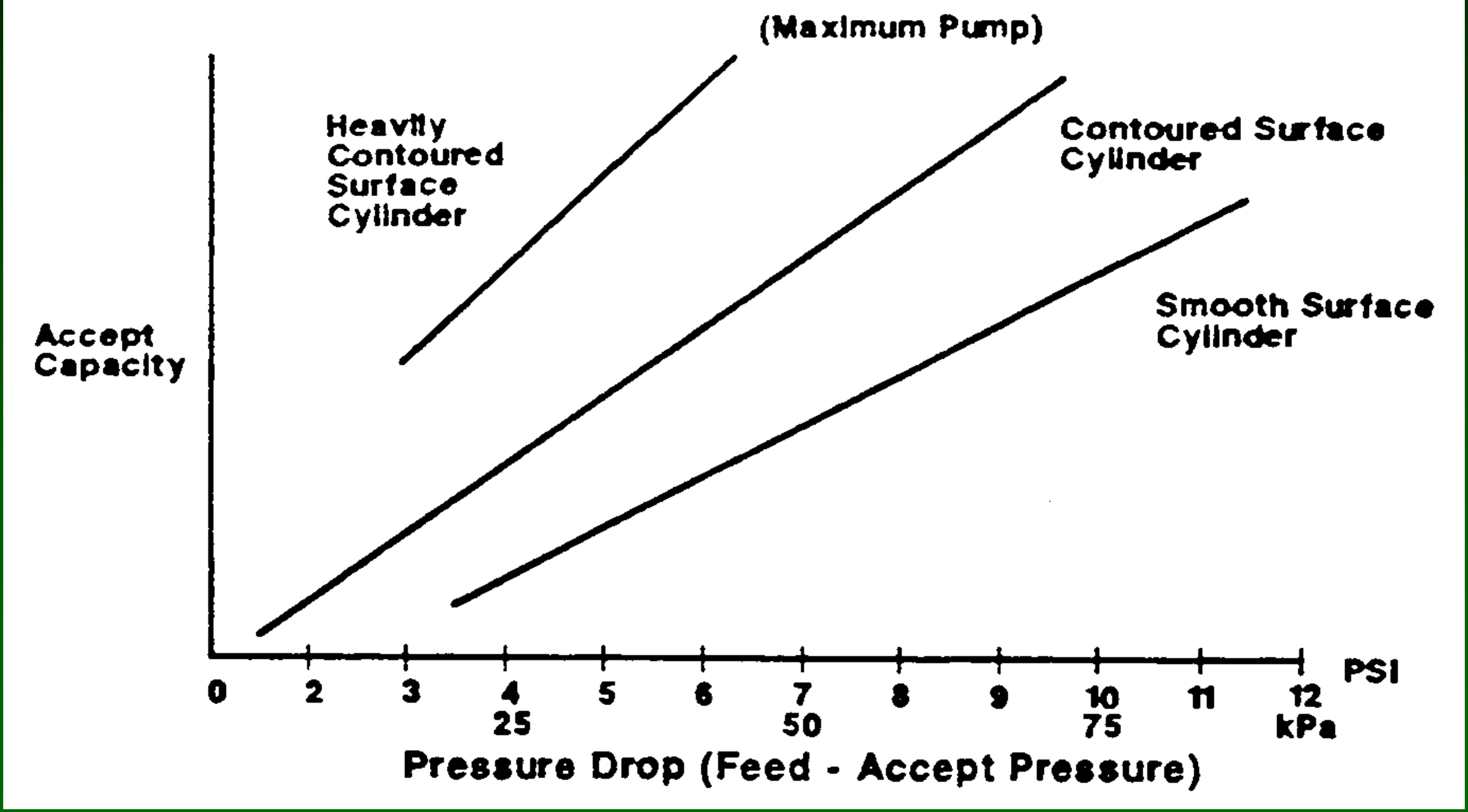
- Slots

- Contoured

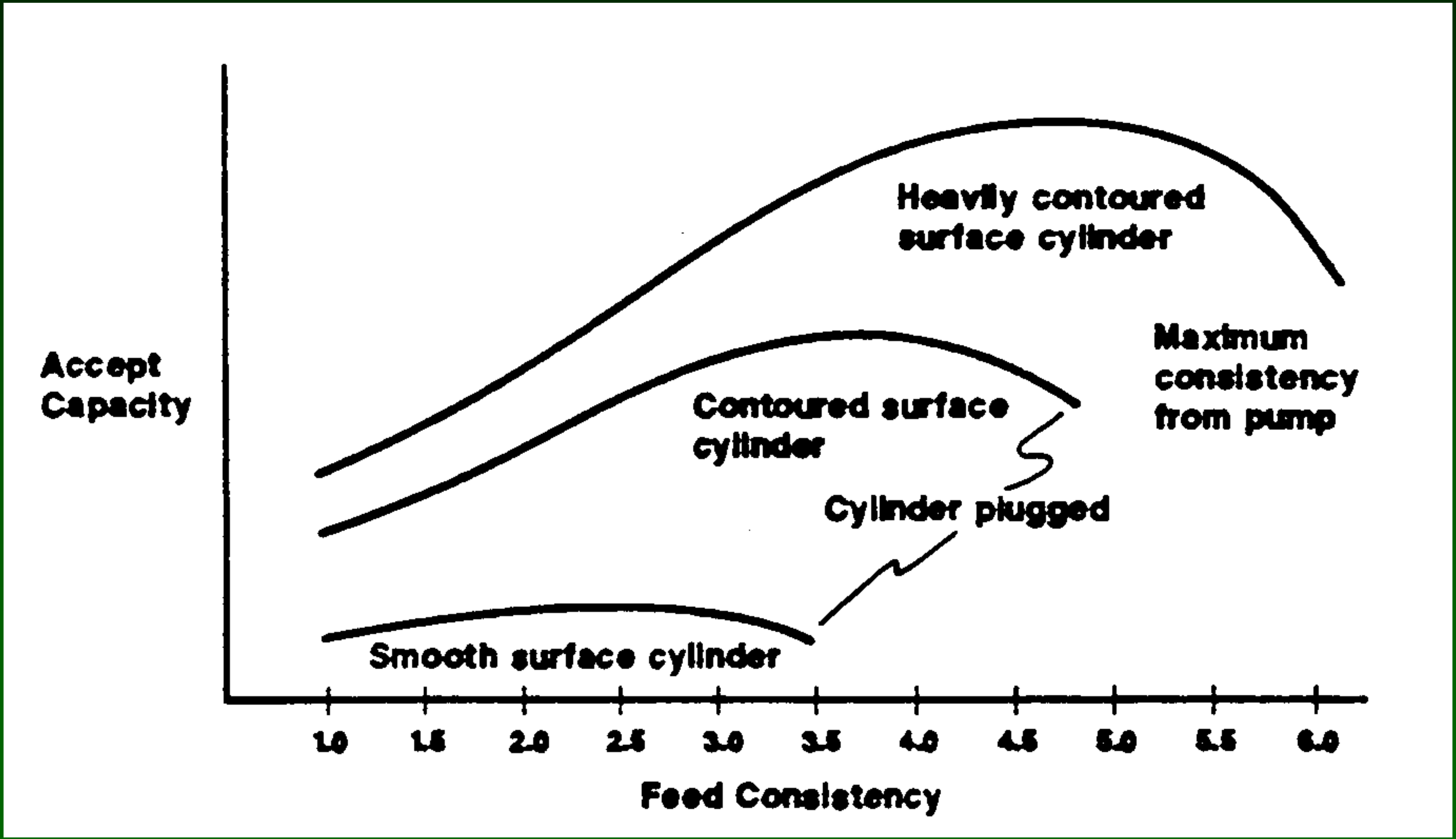
Effect of Reject Rate & Plate Opening on Screen Cleanliness



Screening Factors



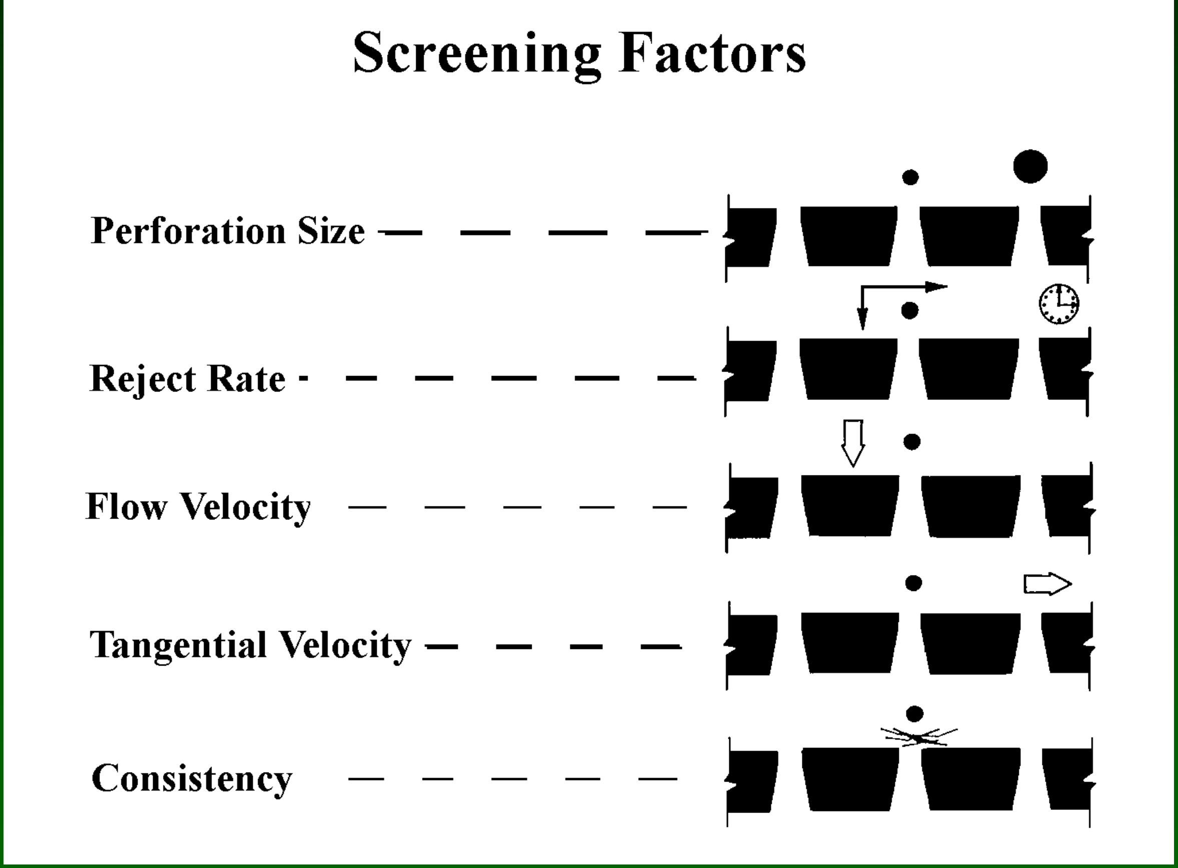
Screening Factors



Screen Performance Variables

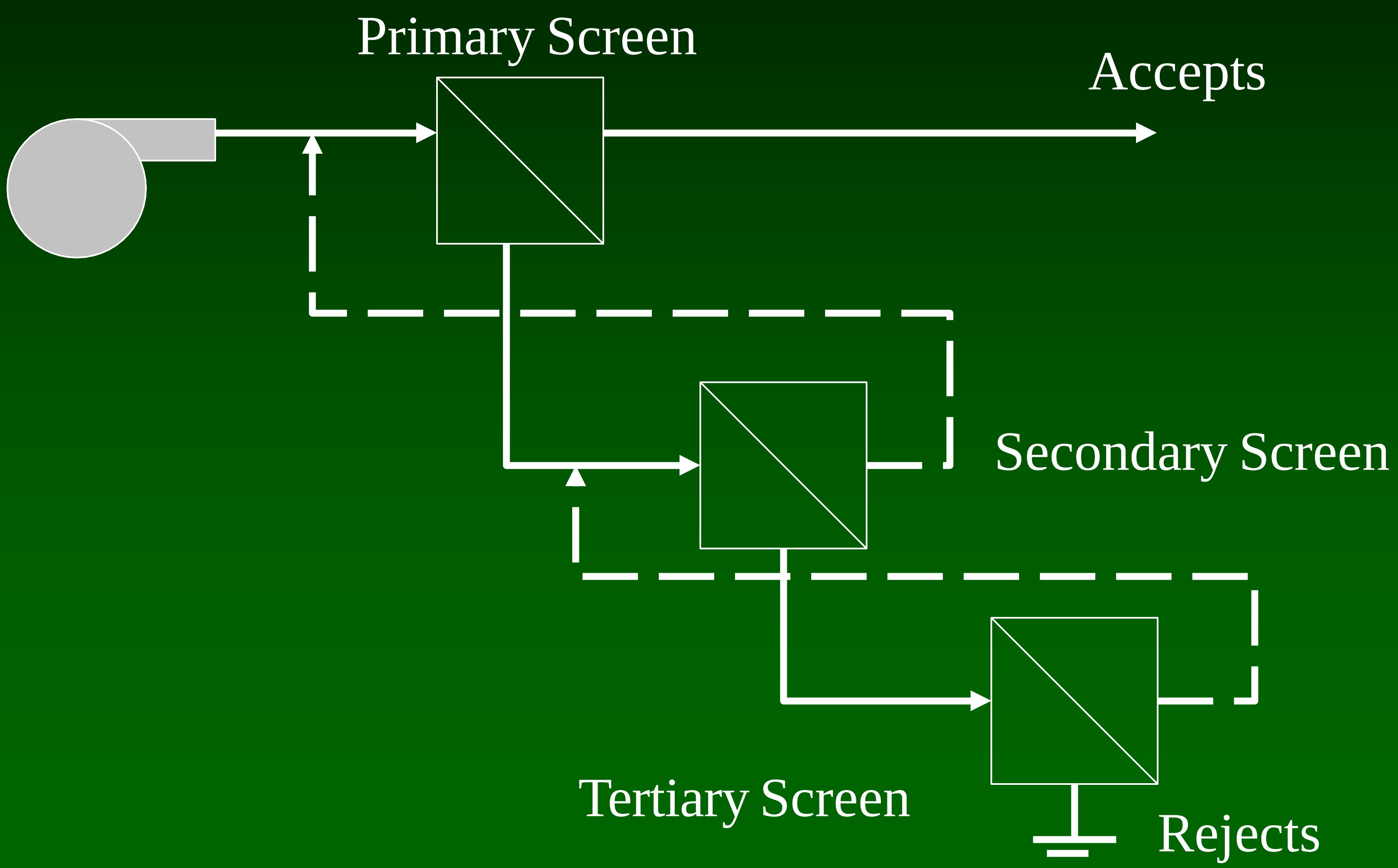
- Stock characteristics
  - fiber type, debris characteristics, debris level
- Screen design
  - flow configuration, plate cleaning mechanism, perforation type (holes or slots), rotor speed
- Operating variables
  - stock flow rate (pressure drop across screen), feed consistency, reject rate, screen plate perforation size, stock temperature, dilution flow to screen

Screening

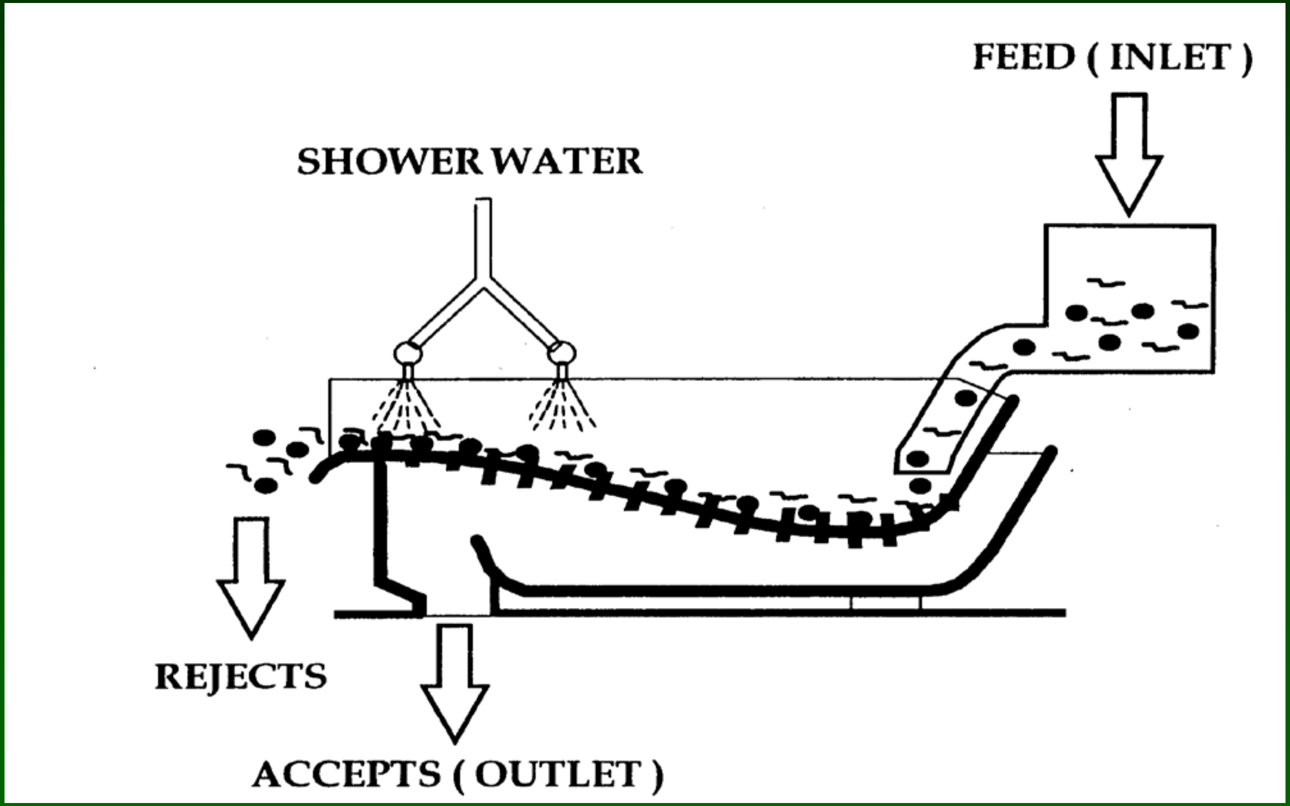

Screening Factors
Perforation Size
Reject Rate
Flow Velocity
Tangential Velocity
Consistency

Screen Layout:

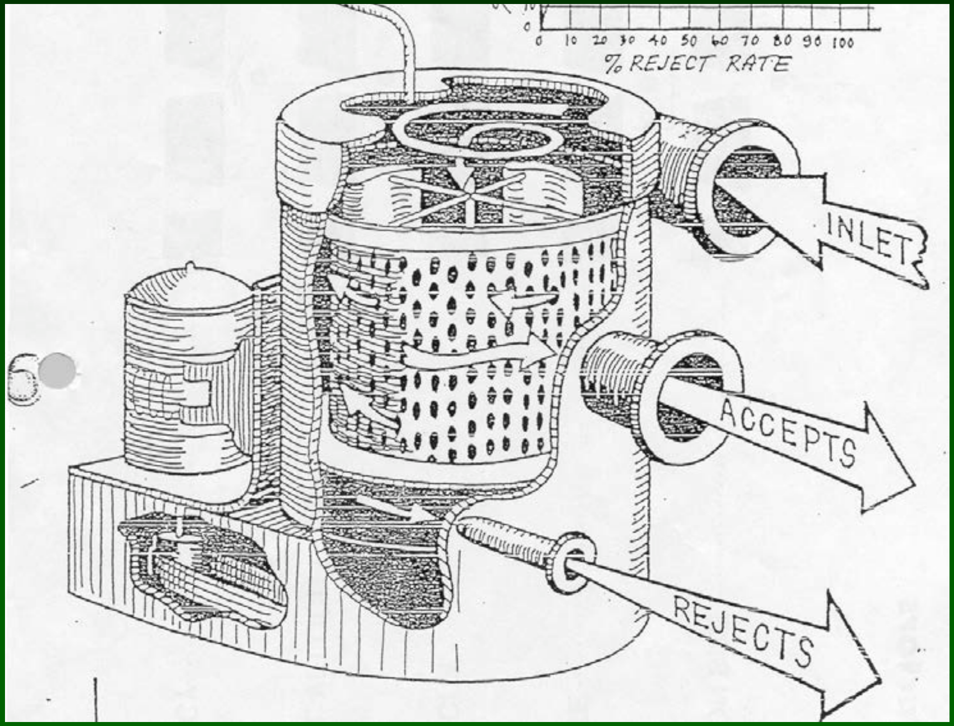
Always have cascaded screens to save fiber.



Open Gravity Screen



Summary Pressure Screen:



Objective: separate large contaminants from fibers

Can act as barrier screen or probability screen

Typically cascaded to save fiber

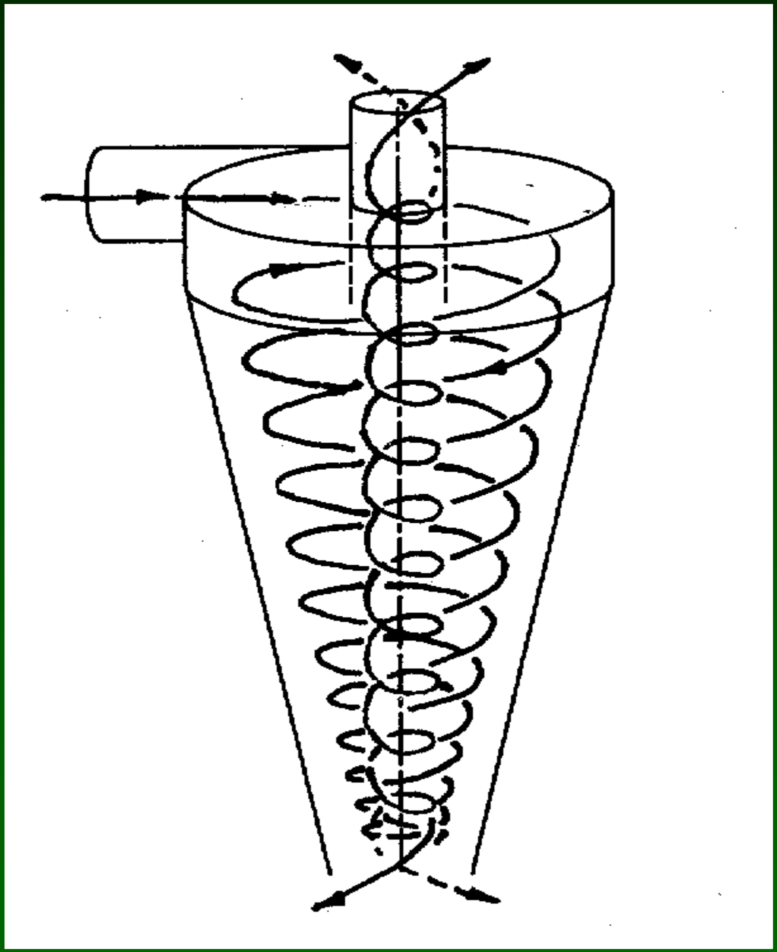
Typical conditions to promote increased throughput can have negative impact on cleanliness efficiency.

Lecture:

Centrifugal cleaning

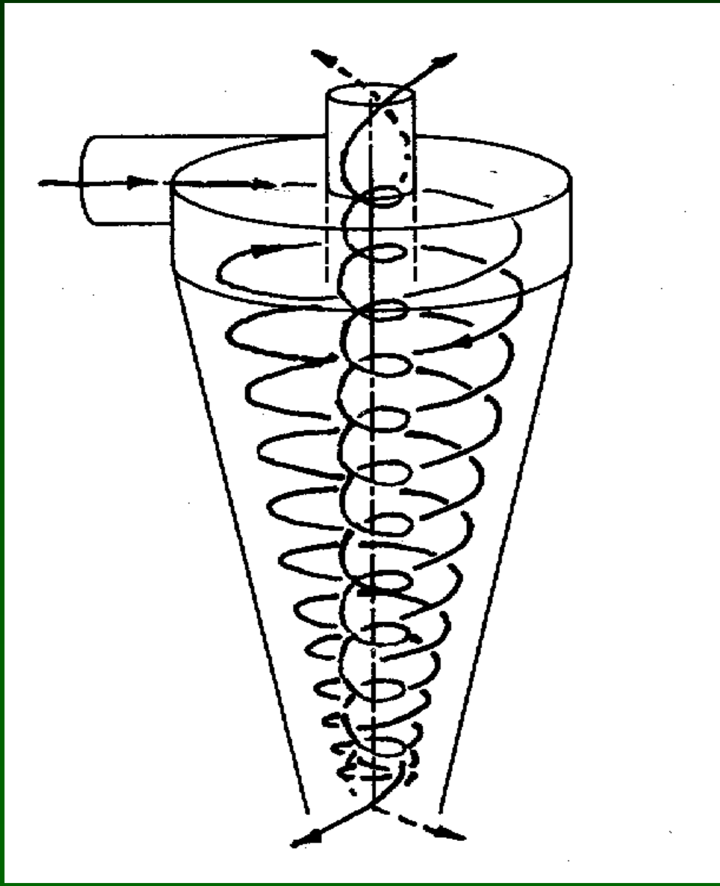
Centrifugal Cleaning

- Remove impurities from the pulp stream based mainly on density
- Centrifugal cleaners remove
  - metals
  - inks
  - sand
  - bark
  - dirt
  - etc.,



Centrifugal Cleaning

- Principles of operation
  - Centrifugal cleaner uses fluid pressure to create rotational fluid motion in a tapered cylinder
  - Rotational movement causes denser particles to move to the outside faster than lighter particles
  - Good fibers carried inward and upward to the accepted stock inlet
  - Dirt held in the downward current and removed from the bottom



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 above) 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
- Many other variations…………

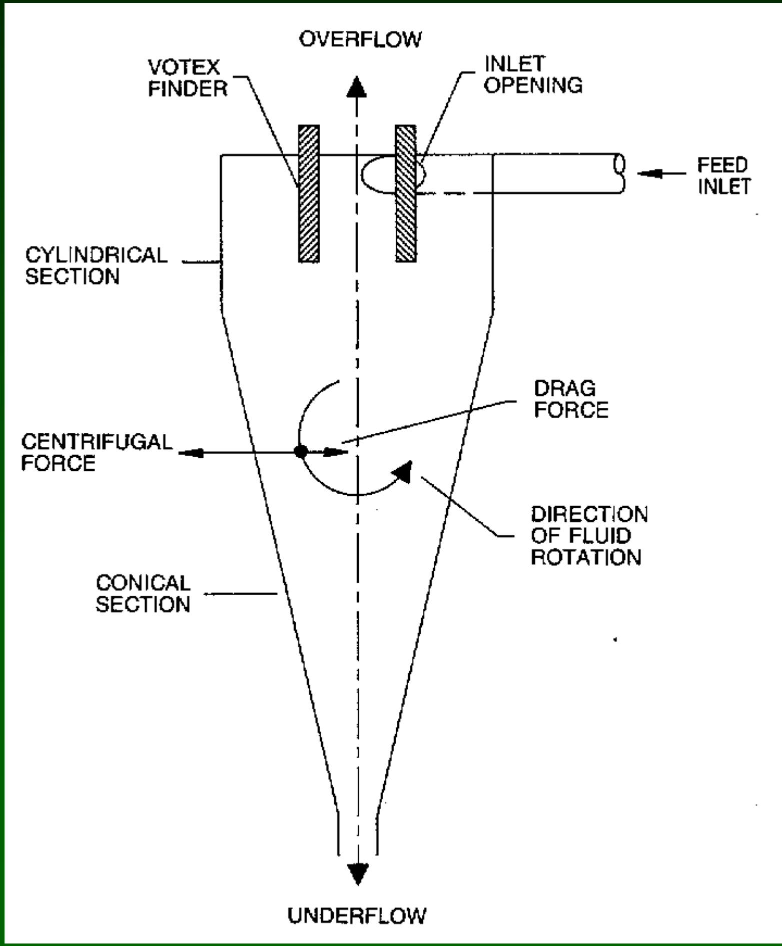
Types of Cleaners: Functional Differences

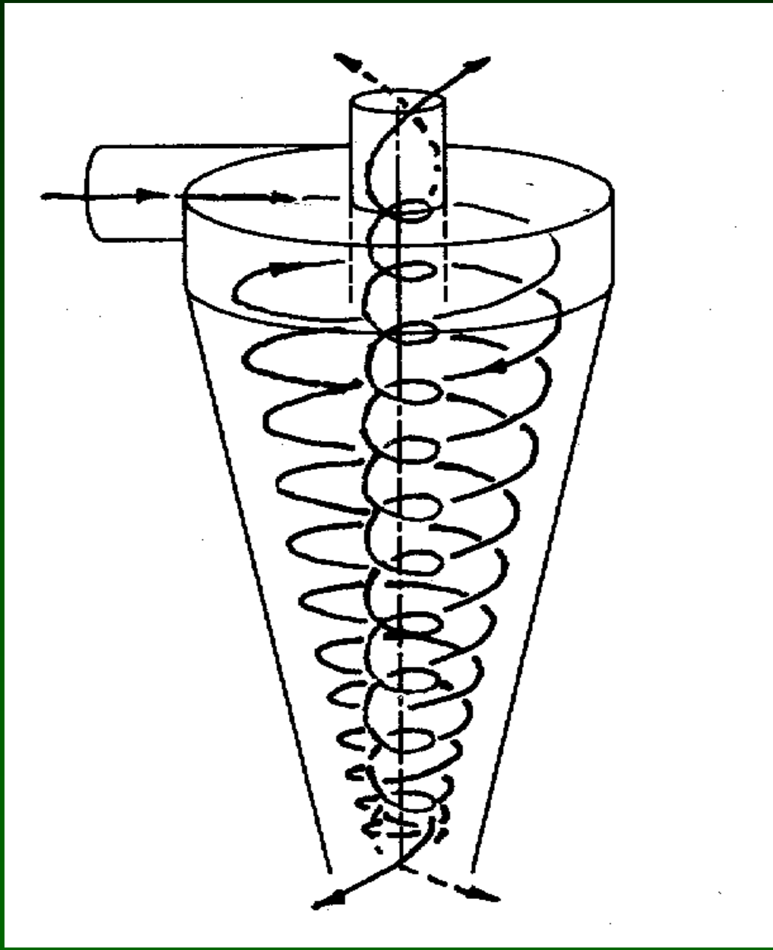
- Consistency
- HC cleaner: 2-4.5% K, MC: 1-2, LC: 0.5-1.5

- Centrifugal Acceleration (acceleration due to gravity =9.8 m/s2)
- HC cleaner: <60 g, MC: <100g, LC: <1000 g

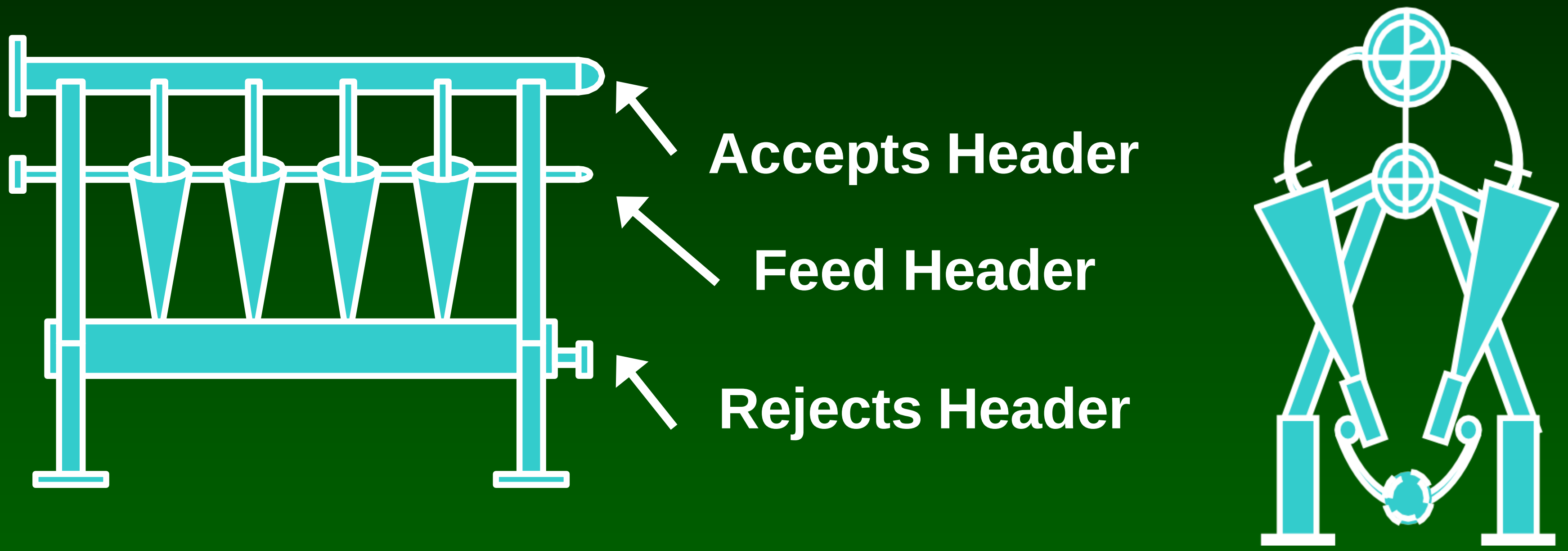
- Reject Rate by mass/stage
- HC cleaner: 0.1-1% , MC: 0.1-1%, LC: 3-30%

Centrifugal Cleaner: Features and Flow





“Bank Arrangement” of Cleaners

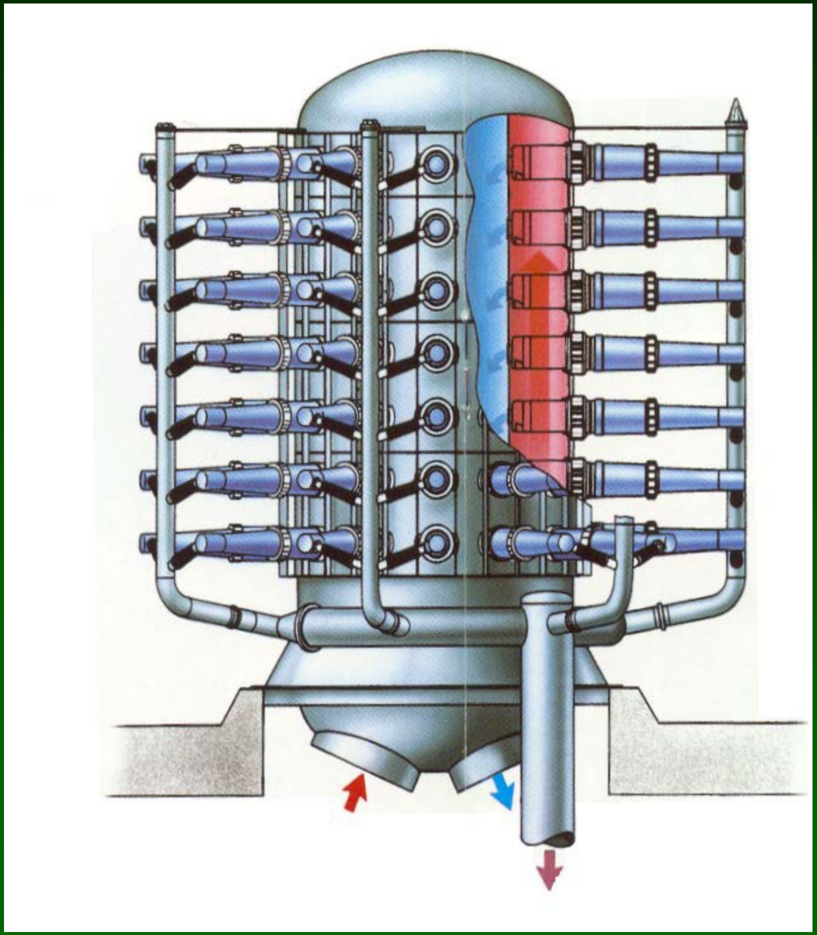


Several cleaners are piped in parallel fashion.
A single cleaner is not capable of providing enough through put for typical industrial flows.

Forward Cleaners

Cleaners

- Canister



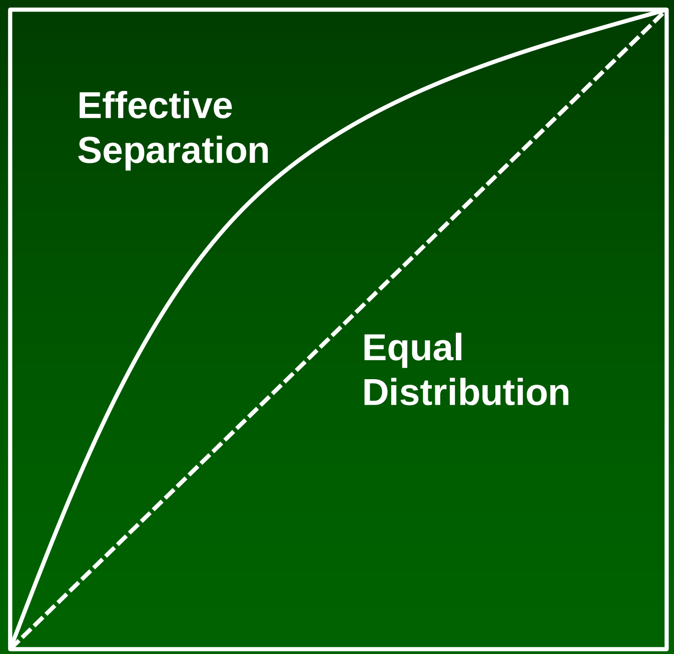

Cleaners Pump
PRIMARY SCREEN ACCEPT

Typical Cleaner "Curve"

Separation Ratio:

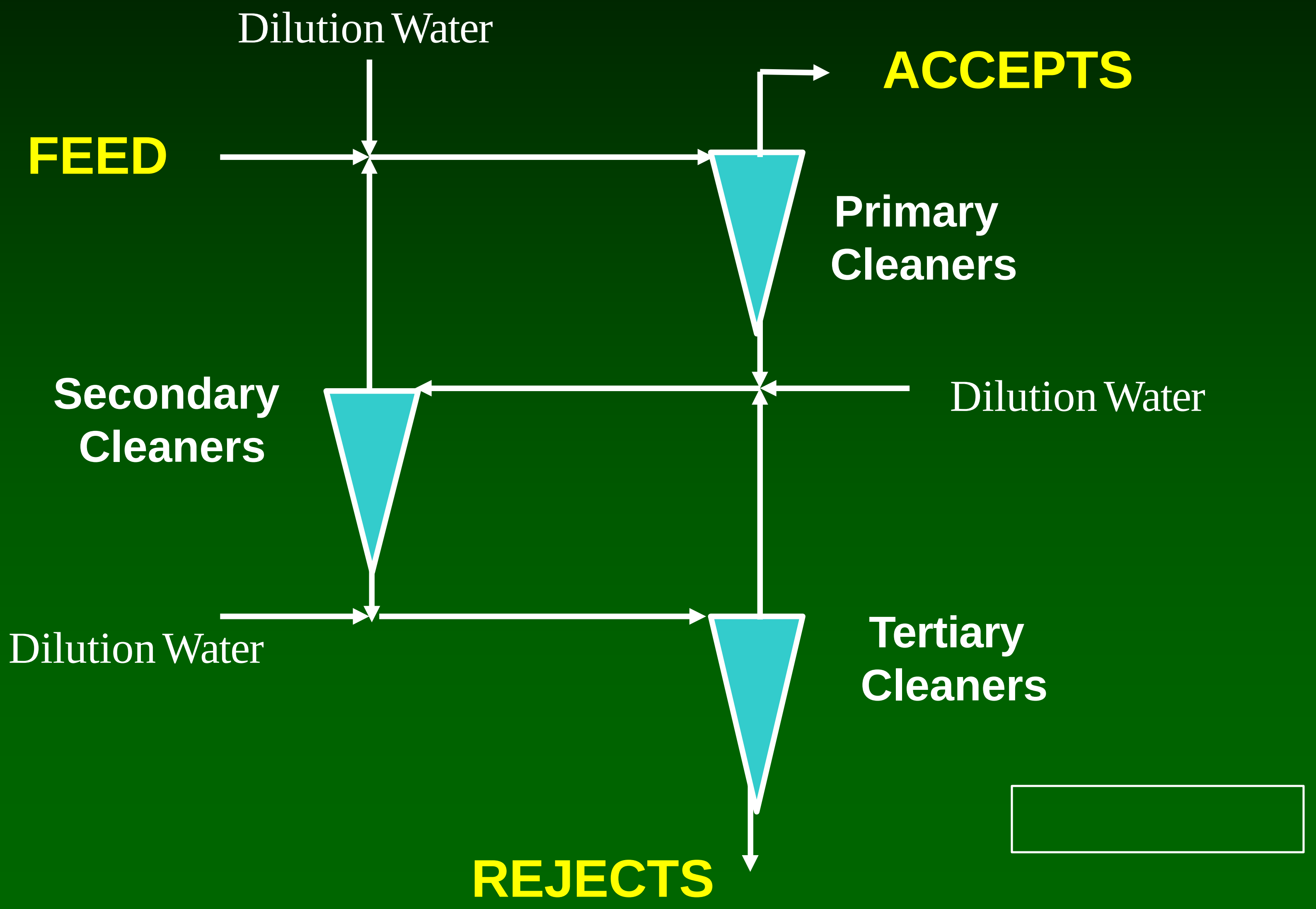
m(in) – m(acc) / m(in)

m= mass flow contaminant

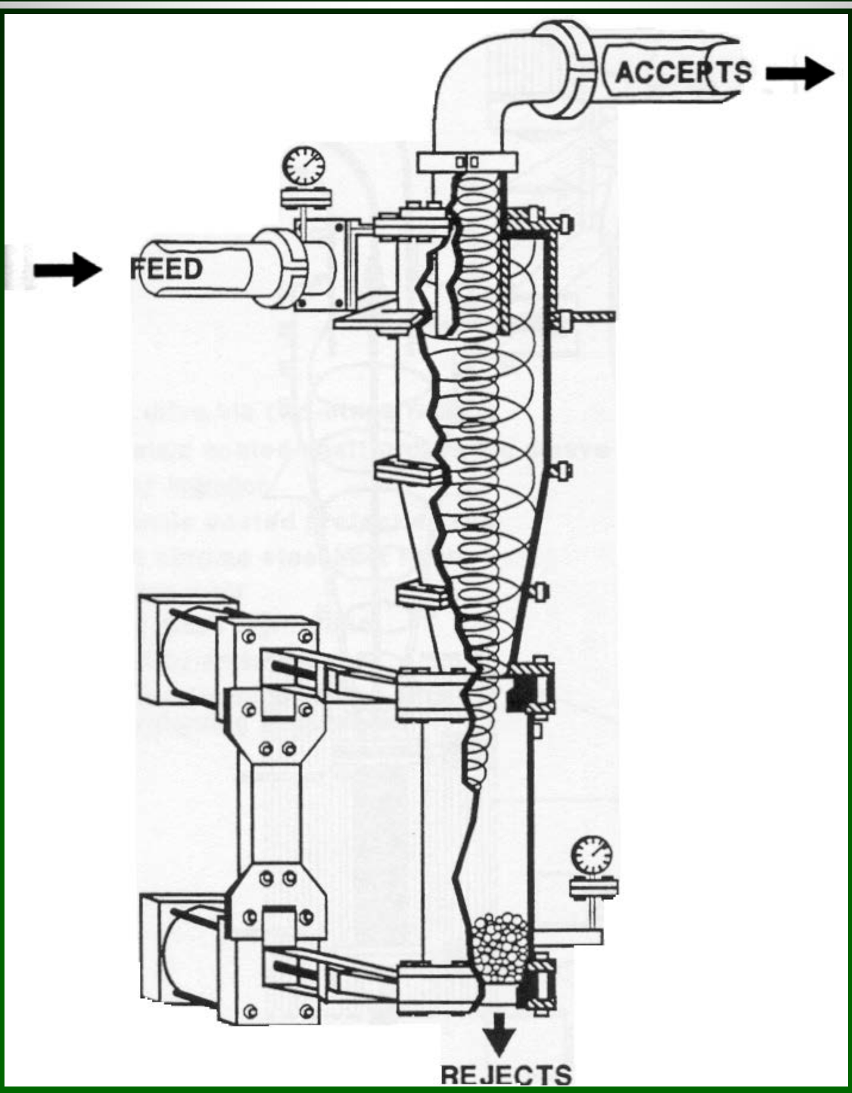


Reject Ratio: OD mass flow reject / OD mass flow inlet

Cascade Arrangement of Cleaners

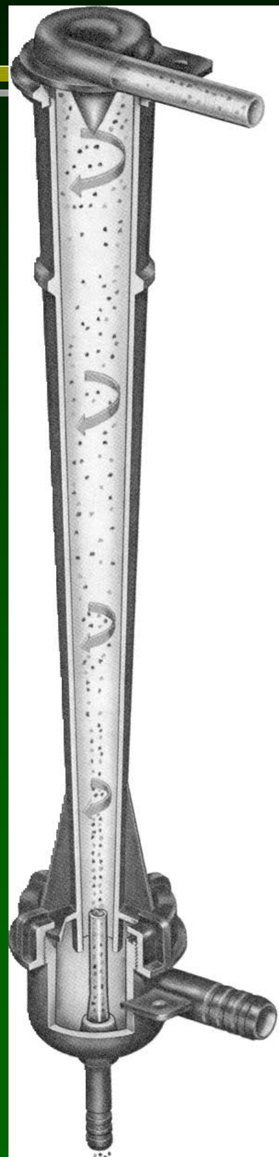


High Density Cleaner



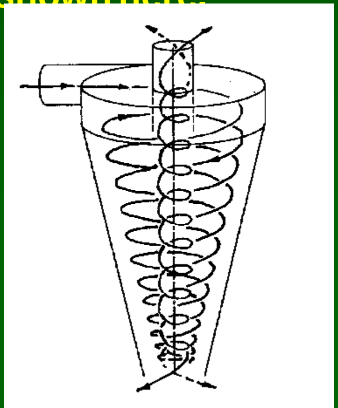
High density cleaners

Through Flow Cleaner: removes low density contaminants



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

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



Thru-flow cleaners

Centrifugal Cleaner Performance Variables

- Stock Characteristics
  - fiber type
  - contaminant characteristics (size, shape, density), dirt level
- Cleaner Design
  - body diameter, feed inlet configuration, accept diameter, cylindrical section height, cone angle, spiral grooves application, reject rate control method (fixed orifice and back pressure)

Parameters Affecting Hydrocyclone Cleanliness Efficiency

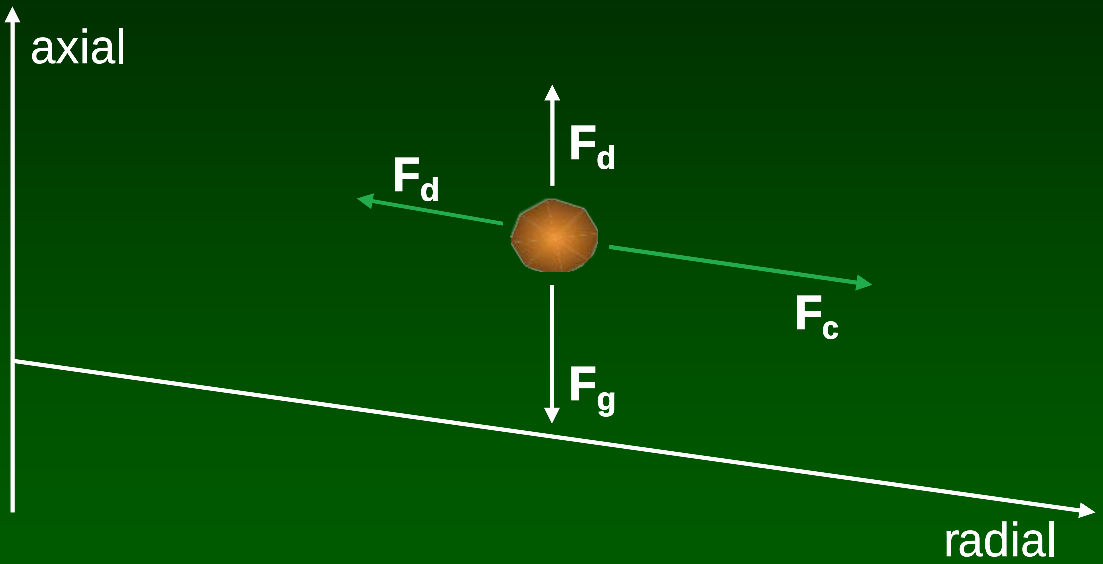
Operating Variable increase in:	Cleanliness Efficiency	Sensitivity to Variable
Pressure Difference	Incr/Decr	High
Volumetric Flow	Incr/Decr	Medium
Cyclone Diameter	Decrease	High
Consistency	Decrease	High
Flake Content	Decrease	Medium
Temperature	Increase	Low
Reject Rate	Increase	Medium
Flushing Flow	Decrease	Medium

Effect of Particle Properties on Separation

- Particles with large density differences wrt water are removed more effectively
- Particles with density near 1 g/cm^3 may separate from fibers
- Larger particle at same density will be removed more effectively than smaller particle
- Particles of the same density but with favorable hydrodynamic shape ($c_w A_p$) separate more effectively, eg, a sphere is better than a flat plate, since rejected particles must swim against the main currrent towards the accepts

Fundamentals

- Force balance on a single particle in a hydrocyclone



- Radial direction:
  - Net centrifugal force ↔ Drag force
- Axial direction:
  - Net gravitational force ↔ Drag force
- Tangential direction:
  - Assume: particles move along with fluid

❻ One dimension analysis of single particle

Assume the time for particle to reach its terminal velocity is very brief

$$m \cdot \frac{dU_s}{dt} = F_c (or\, F_g) - F_d$$

$$0 = F_c (or\, F_g) - F_d$$

$$F_c (or\, F_g) = F_d$$

❻ Particle slip velocity,

U_s = velocity of water – velocity of particle

Net centrifugal force

Drag force

$$\left(\rho_p \frac{u_t^2}{r} - \rho_l \frac{u_t^2}{r}\right) V_p = \frac{1}{2} \rho_l U_s^2 A_p C_d$$

$$U_s = \sqrt{2 \frac{u_t^2}{r} \frac{V_p}{A_p} \left(\frac{\rho_p - \rho_l}{\rho_l}\right) \frac{1}{C_d}}$$

for radial direction

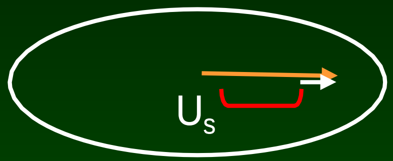
C_d = drag coefficient	ρ_p, ρ_l = density of particle and fluid
r = radial position	u_t = tangential velocity of fluid
V_p = volume of particle	A_p = projected area of particle

Fundamentals

$$U_s = \sqrt{2\frac{u_t^2}{r}\frac{V_p}{A_p}\left(\frac{\rho_p-\rho_l}{\rho_l}\right)\frac{1}{C_d}}$$

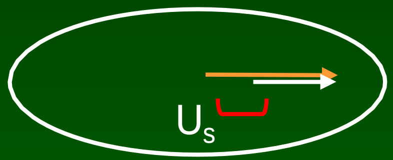
- Why is the slip velocity important ?

  - For high U_s



⇒ "Reject stream"

  - For low U_s



⇒ "Accept stream"

- High u_t (tangential velocity)
- High ρ_p (particle density)
- Low C_d (drag coefficient)

} Object tends to be rejected

Cleaner Summary

- Several types of cleaners
- Objective: remove high/low density contaminants
- Must reject material to operate effectively
- Several forces/operational variables/particle characteristics that combine to determine effectiveness in removal