Objective

To remove contaminants that degrade the physical and optical properties of the pulp
Pulp Cleaner Questions

• What do pulp cleaners do?
• What are the main flow structures in a cleaner?
• What controls the motion of particles in a cleaner?

Hydrocyclones

• Separates high and low density contaminants
• Removal of dirt, grit, sand
• Shive, bark, and stone cell removal
• Plastic contaminant removal
• Removal of waxes, stickies and adhesives from recycled pulp stock
• Pulp stock deaeration
• Fibre fractionation
What are the Main Flow Structures in a Centrifugal Cleaner?

- Inlet/outlets
- Vortex finder
- Air core
- Mantle
- Short circuit path

Axial Velocities

LINE OF ZERO VERTICAL VELOCITY
Radial Velocity

AIR CORE

VOREX FINDER

POSITIVE VALUES = INWARD FLOW
What Controls the Motion of Particles in a Cleaner?

- Centrifugal force
  - Angular velocity of the fluid
  - Diameter of the hydrocyclone
  - Density of particle

- Drag
  - Steady state drag (i.e. Pressure gradient/Inertial)
  - Added mass, lift, etc.

Radial Force Balance

\[
m \frac{dv}{dt} = (m - m^*)a - C_D A_p \frac{\rho v^2}{2}
\]

\[
a = r \omega^2
\]

\[
m = \frac{\pi}{6} d_p^3 \rho_p
\]

\[
v = \frac{(\rho_p - \rho)}{18 \mu} r \omega^2 d_p^2
\]

\[
C_D A_p \frac{\rho v^2}{2} = 3 \pi d_p \mu v
\]
Fluid-particle interactions (Newtonian fluid)

Fluid-particle interactions (Non-Newtonian)
**Cleaner Total Efficiency \( (E_T) \)**  
*reflects contaminant removal*

\[
E = \frac{M_{C.R}}{M_{C.F}}
\]

- \( M_{C.R} = \text{mass flow (contaminants/reject)} \)
- \( M_{C.F} = \text{mass flow (contaminants/feed)} \)

**Reject Rate \( (R) \)**  
*reflects loss of pulp*

\[
R = \frac{M_R}{M_F}
\]

- \( M_R = \text{total mass flow (reject)} \)
- \( M_F = \text{total mass flow (feed)} \)
E-R Performance Curve

![E-R Performance Curve Diagram]

Cleaner Performance - OPERATING PARAMETERS

![Cleaner Performance Diagram]

- **OPERATING PARAMETERS**
  - **Pressure Drop**
  - **Efficiency**

- **C1 < C2 < C3**
- **C1 = Feed Consistency**
- **1 = 1, 2, 3**

- **FLOW SPLIT**
- **ACCEPT FLOW**
  - HIGH
  - MEDIUM
  - LOW

- **REJECT RATE (%)**
- **EFFICIENCY (%)**

- **0.5% Consistency**
Overflow/Underflow Mass Measurements

<table>
<thead>
<tr>
<th>Particle size x (microns)</th>
<th>Overflow $F_f(x)$ (% oversize by mass)</th>
<th>Underflow $F_c(x)$ (% oversize by mass)</th>
<th>Feed $F(x)$ (% oversize by mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>0.28</td>
<td>32.50</td>
<td>11.60</td>
</tr>
<tr>
<td>20</td>
<td>19.00</td>
<td>92.00</td>
<td>44.60</td>
</tr>
<tr>
<td>2</td>
<td>68.00</td>
<td>96.00</td>
<td>77.80</td>
</tr>
</tbody>
</table>

Total Efficiency

$$E_T = \frac{F(x) - F_f(x)}{F_c(x) - F_f(x)}$$

- Correction needed due to “dead flux” of solids being carried to the overflow or underflow from the fluid axial velocity.

$$RR = \frac{Q_{\text{underflow}}}{Q_{\text{feed}}} \quad E'_T = \frac{E_T - RR}{1 - RR}$$
Cleaner Performance - REMOVAL EFFICIENCIES AS FUNCTION OF PARTICLE DENSITY

Grade Efficiency – Raw Data

<table>
<thead>
<tr>
<th>Particle size (microns)</th>
<th>Underflow Fe(x) (% undersize)</th>
<th>Overflow Ff(x) (% undersize)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>19.2</td>
<td>54.2</td>
</tr>
<tr>
<td>3</td>
<td>29.5</td>
<td>75.4</td>
</tr>
<tr>
<td>4</td>
<td>40.7</td>
<td>86.9</td>
</tr>
<tr>
<td>5</td>
<td>50.2</td>
<td>93.1</td>
</tr>
<tr>
<td>6</td>
<td>58.1</td>
<td>96.3</td>
</tr>
<tr>
<td>8</td>
<td>70.2</td>
<td>99.0</td>
</tr>
<tr>
<td>10</td>
<td>78.6</td>
<td>99.7</td>
</tr>
</tbody>
</table>
Grade Efficiency – Calculation

\[
\frac{1}{G(x)} = 1 + \left( \frac{1}{E_T} - 1 \right) \frac{\partial F_f(x)}{\partial F_c(x)}
\]

Slope of \( F_f(x) \) vs. \( F_c(x) \) curve

<table>
<thead>
<tr>
<th>Particle size (microns)</th>
<th>dFf/dFc</th>
<th>G(x) (%)</th>
<th>G’(x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.12</td>
<td>53.6</td>
<td>33.4</td>
</tr>
<tr>
<td>6</td>
<td>0.29</td>
<td>81.8</td>
<td>74.0</td>
</tr>
<tr>
<td>8</td>
<td>0.12</td>
<td>91.3</td>
<td>87.5</td>
</tr>
<tr>
<td>10</td>
<td>0.05</td>
<td>96.1</td>
<td>94.5</td>
</tr>
</tbody>
</table>

Cleaner Performance - EFFECT OF PARTICLES SIZE ON EFFICIENCY
Types of Hydrocyclones Used in the Pulp and Paper Industry

- Forward Cleaners
  - high density
  - medium density
  - fine forward cleaners
- Core Bleed Cleaners
- Reverse Cleaners
- Through Flow Cleaners

FORWARD

Accepts

Feed 0.6%

Dp = 140 - 200 kPa (20 - 30 psi)

Rejects (dirt, sand)

REVERSE

Rejects (wax, hot melts, rejects)

Feed 1.0%

Dp = 140 - 280 kPa (20 - 40 psi)

Accepts

THROUGH FLOW

Feed 1.0%

Dp = 70 - 100 kPa (10 - 15 psi)

Accepts

Rejects (wax, hot melts, plastics)
Forward Cleaners -
HIGH DENSITY CLEANERS

- 2-6% Feed Consistency
- 25-120 cm Diameter
- 2-6 m Height
- Stainless Steel
- Located prior to pressure screens and refiners

Forward Cleaners - MEDIUM DENSITY

- 20-65 cm diameter
- 2-6 m in height
- 1-3% Consistency
- Stainless steel with ceramic cone
- Located before pressure screens and fine forward cleaners
- Similar in design to high density
Fine Forward Cleaners

- 7.5-30 cm diameter
- 0.6-2.4 m height
- 0.5-1.5% consistency
- Injection molded plastic or stainless steel
- Located in paper machine approach systems

Light Contaminant Removal Hydrocyclones

Feed
0.6 - 0.8% consistency

Light rejects
(plastic, wax)
< 10% of feed flow
< .01% consistency
< 1.0% of feed solids

Heavy rejects
(sand, grit)
3 - 8% of feed flow
1.5% - 3.0% consistency
10 - 25% of feed solids

Light rejects
_light_,
< 10% of feed flow
< .01% consistency
< 1.0% of feed solids

Accepts

Rejects

Light rejects
Accepts

< 10% of feed flow
< .01% consistency
< 1.0% of feed solids

Rejects

Accepts

Feed
Hydrocyclone Systems

Diagram showing the components of a hydrocyclone system:

- Headbox
- Pressure screen
- Stock
- Primary
- Fan pump
- Secondary
- White water silo
- Tertiary
Advantages / Disadvantages

- Simple in construction
- Easy to install
- Small in size
- Inflexible to process changes
- Separations are rarely perfect
- Many plugging problems associated in using hydrocyclones
- High pumping and dewatering costs