SOLID LIQUID SEPARATION: CENTRIFUGATION

CHARLES L. COONEY
DOWNSTREAM PROCESSING COURSE
MIT Professional Institute
August 1-5, 2005

Figure by MIT OCW.
Centrifugation is Effective in Volume Reduction

Characteristics of process streams in primary recovery

• Volume at or near process maximum
• Heterogeneous solid/liquid mixture
• Particle size distribution
• Typical particle sizes:
  • Bacteria 1 to 2 μ
  • Yeast 3 to 5 μ
  • Actinomyces 2 to 30 μ
  • Molds 4 to >30 μ
  • Microbial flocs 10 to >100 μ
  • Cell debris <1 μ
  • Solids content: 1-10% dry basis
    5-50% wet basis
• Time variable product and stream quality
• Viscosity: 1 to >5,000 cp
• Temperature: 4-40 C
• Mechanically (shear) sensitive materials
• Temperature and pH sensitive materials
• Potentially toxic materials
Centrifuge Equipment
Process Needs

• Cleaning in place (CIP)
• Steam in place (SIP)
• Automation for start-up and operation
• Short process times
• Flexibility in process stream properties
• Temperature control
• Containment to prevent entry of contaminants and release of solvents or toxic materials
• Corrosion resistance
• Small footprint
• Fail safe system in case of off-balance
• Continuous operation for long times
• Interface with upstream and downstream operations
OPERATING REGION FOR SOLID/LIQUID SEPARATION AND SOLUTE CONCENTRATION

Conventional Filtration
High Speed Centrifugation
Microfiltration
Ultrafiltration
Hyperfiltration
Evaporation

Concentration (% dry matter)

Size (microns)

$dp^2\Delta\rho$

$dp^2\Delta P$ for filtration
STOKE’S LAW
CALCULATION OF
CENTRIFUGE THROUGHPUT, \( Q \)

\[ Q = V_S A \]

\[ V_S = \frac{d_p^2 (\rho_p - \rho_s)}{18 \mu g_c} \]

\( Q = \) Volumetric throughput (cm\(^3\)/s)
\( V_S = \) Sedimentation velocity (cm/s)
\( d_p = \) particle diameter (cm)
\( \rho_p = \) particle density (g/cm\(^3\))
\( \rho_s = \) solvent density (g/cm\(^3\))
\( \mu = \) solvent viscosity (g/cm-s)
\( g_c = \) gravitational constant (cm/s\(^2\))
Implications of Stoke’s Law

Causes for deviation
• Non-spherical particles
• Non-Newtonian rheology
• Hindered settling
• Non-uniform flow

Opportunities to improve
• Increase particle size
• Increase density difference
• Reduce viscosity
• Increase gravitational force
Continuous Separation in a Tank

A = Surface area
V = Volume
Q = Throughput – independent of height & proportional to area
\( V_{lim} \) = Sedimentation velocity
T = Time

\[
t = \frac{V}{Q} = \frac{bhl}{Q}
\]
\[
t = \frac{h}{\vartheta_{lim}}
\]
\[
A = bl
\]

\[\Rightarrow Q = \vartheta_{lim} A\]
Comparison of Sedimentation in a Tank and Centrifuge

Increase AREA to increase Q

Figure by MIT OCW.
Centrifugal Coefficient & Stoke’s Law

\[ C = \frac{r \cdot \omega^2}{g} \approx \frac{D \cdot n^2}{1800} \]

\[ V = \frac{d^2 (S - S') g}{18 \eta} \]

\( C = \) centrifugal coefficient
\( R = \) radius of rotor
\( \omega = \) angular velocity
\( D = \) rotor diameter
\( N = \) rotor speed
\( V = \) settling rate
\( D = \) particle diameter
\( S = \) particle density
\( S_1 = \) medium density
\( N = \) medium viscosity
\( g = \) gravitational constant
Sedimentation Velocity

\[ Q = V_{\text{lim}} A \]

Tank

\[ v_{\text{lim}} = \frac{d^{2}_{\text{lim}} \Delta \rho g}{18 \mu} \]

Disc-Stack Separator

\[ v_{\text{lim}} = \frac{d^{2}_{\text{lim}} \Delta \rho}{18 \mu} r \omega^{2} \]

What is different?

\[ r \omega^{2} \]
The area of interest is the projected area perpendicular to the centrifugal force.
THROUGHPUT Q

\[ Q = V_{\text{lim}}A \]

\[ Q = \int_{r_2}^{r_1} \frac{\mathcal{G}_{\text{lim}} \Delta P}{18\eta} r \omega^2 \frac{2}{3} \pi \omega^2 N \cot a \frac{r_1^2 - r_2^2}{r_1 r_2} \, dr \]

\[ \equiv \]

\[ Q = \left[ \frac{\mathcal{G}_{\text{lim}} \Delta P}{18\eta} \right] \left[ \frac{2}{3} \pi \omega^2 N \cot a \frac{r_1^2 - r_2^2}{r_1 r_2} \right] \]

Figure by MIT OCW.
Area Equivalent $= \Sigma$

Throughput $= Q$ =

\[
Q = \left[ \frac{g \Delta P}{18\eta} \right] \left[ \frac{2\pi}{3} \omega^2 N \cot a\left( r_1^2 - r_2^2 \right) \right]
\]

Note the gravitational force constant

Sedimentation velocity for a particle

$\Sigma = $ surface area required for sedimentation in a tank to achieve same result as centrifuge

\[
\frac{Q_2}{Q_1} = \frac{\Sigma_2}{\Sigma_1} \quad \implies \quad Q_2 = Q_1 \frac{\Sigma_2}{\Sigma_1}
\]
Process Objectives

**CONCENTRATION**

Solid product in feed

Light phase – any solids are lost product

Heavy phase – any liquid is an impurity

**CLARIFICATION**

Dissolved product in feed

Light phase – solids are impurities

Heavy phase – any liquid is lost product
# Choosing the right separator

**Primary Selection – Solids content**

<table>
<thead>
<tr>
<th>SEPARATOR TYPE</th>
<th>SOLIDS CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber bowl centrifuge</td>
<td>0</td>
</tr>
<tr>
<td>Solid bowl centrifuge</td>
<td>0</td>
</tr>
<tr>
<td>Self cleaning separator</td>
<td>0</td>
</tr>
<tr>
<td>Nozzle bowl separator</td>
<td>20</td>
</tr>
<tr>
<td>Centrifugal decanter</td>
<td>80</td>
</tr>
</tbody>
</table>

Blue squares indicate the primary selection based on solids content.