SOLID LIQUID SEPARATION: CENTRIFUGATION

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DOWNSTREAM PROCESSING COURSE

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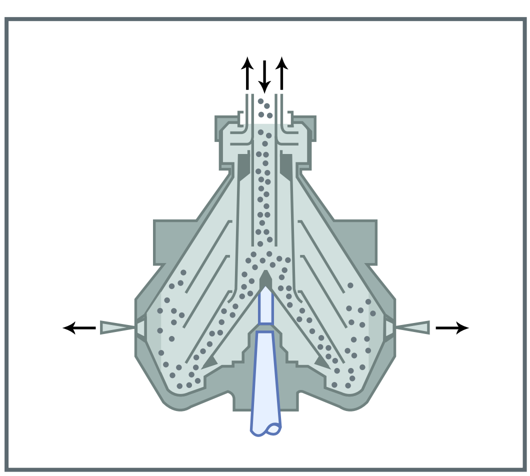


Figure by MIT OCW.

Centrifugation is Effective in Volume Reduction

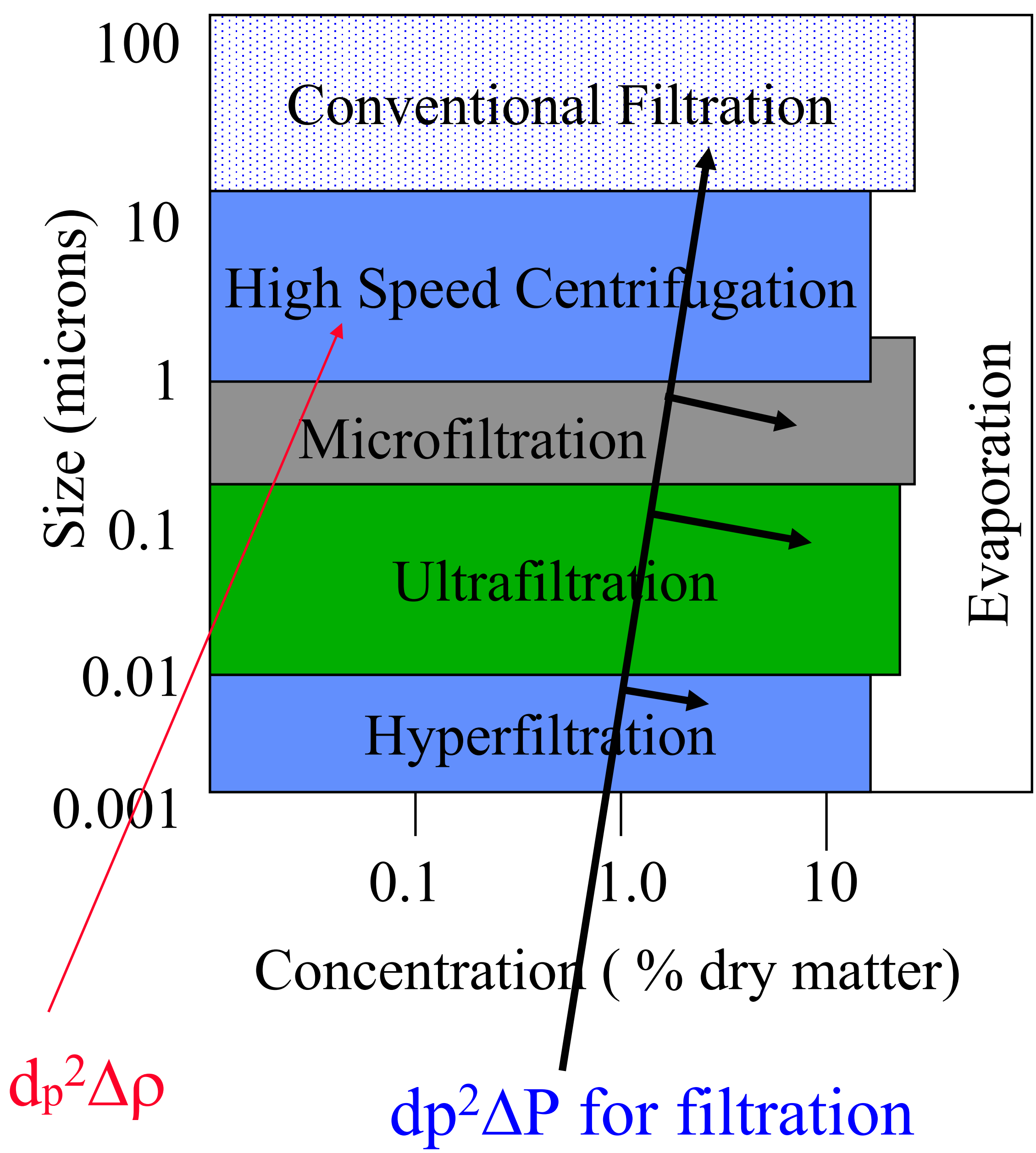
Characteristics of process streams in primary recovery

- 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 <u>and</u> 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



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)

Vs=Sedimentation velocity (cm/s)

dp=particle diameter (cm)

ρp=particle density (g/cm^3)

ρs=solvent density (g/cm^3)

μ=solvent viscosity (g/cm-s)

gc=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

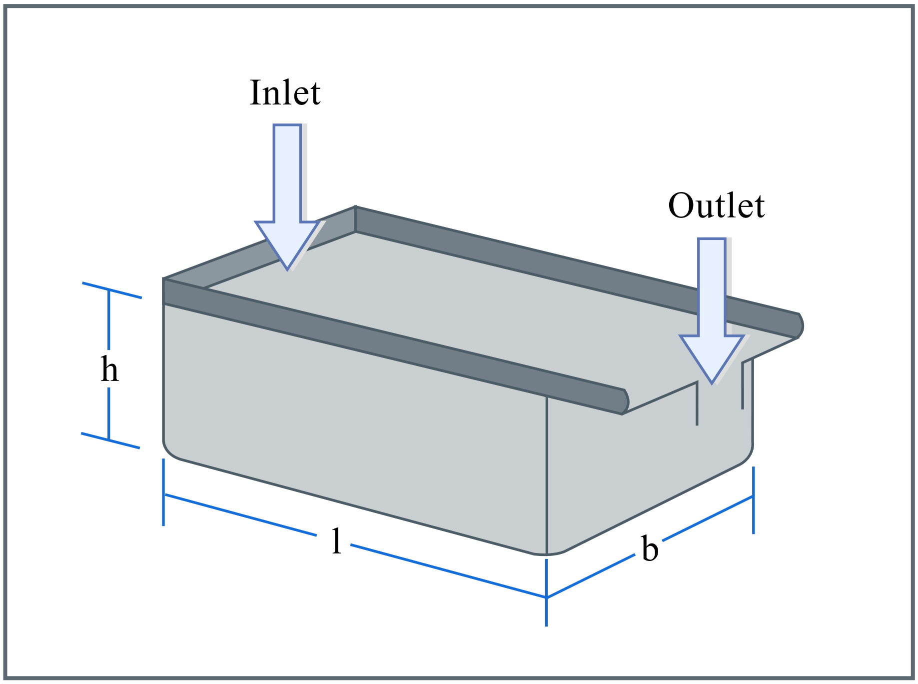


Figure by MIT OCW.

A = Surface area

V = Volume

Q = Throughput – independent of height & proportional to area

V_{lim} = Sedimentation velocity

T = Time

$$\left.\begin{array}{l} t = \dfrac{V}{Q} = \dfrac{bhl}{Q} \\ t = \dfrac{h}{\vartheta_{\lim}} \\ A = bl \end{array}\right\} \Rightarrow Q = \vartheta_{\lim} A$$

Comparison of Sedimentation in a Tank and Centrifuge

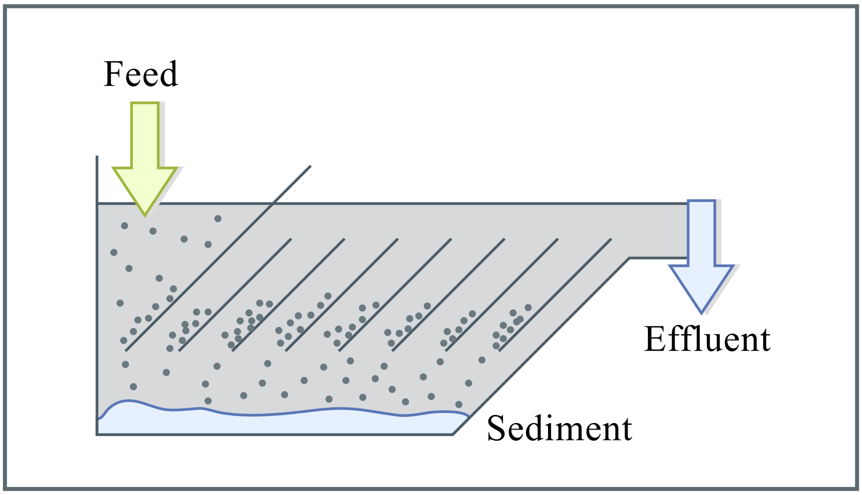


Figure by MIT OCW.

Increase **AREA** to increase **Q**

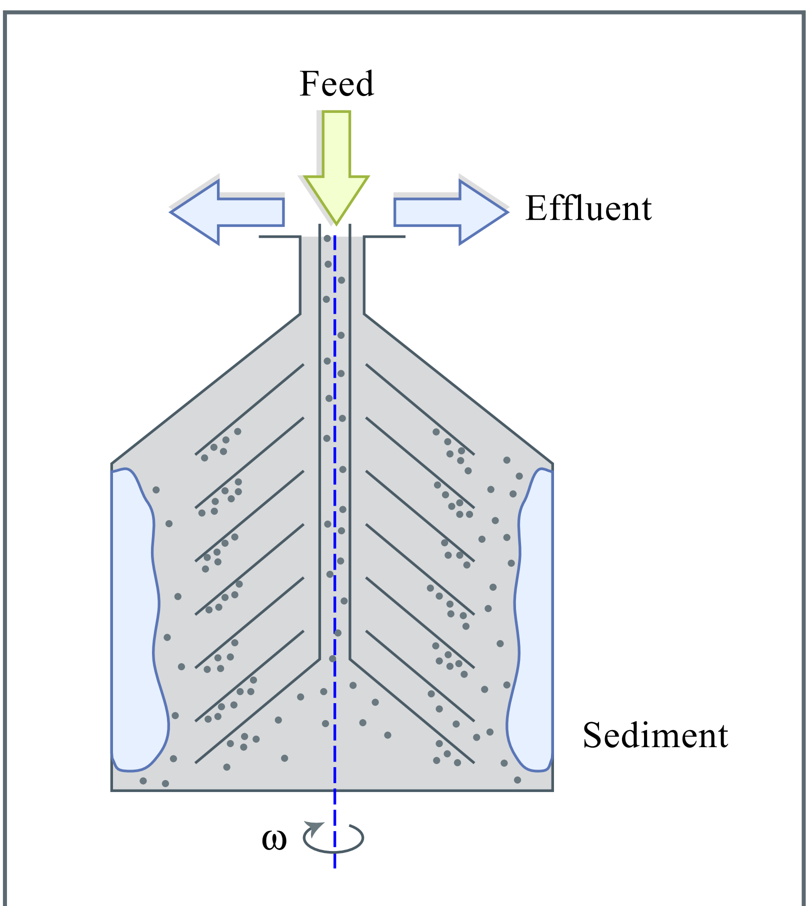


Figure by MIT OCW.

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
W = angular velocity
D = rotor diameter
N = rotor speed
V = settling rate
D = particle diameter
S = particle density
S1 = medium density
N = medium viscosity
g = gravitational constant

Sedimentation Velocity

$$Q = V_{\lim} A$$

Tank $$v_{\lim} = \frac{d_{\lim}^2 \Delta\rho g}{18\mu}$$

Disc-Stack Separator

$$v_{\lim} = \frac{d_{\lim}^2 \Delta\rho}{18\mu} r\omega^2$$

What is different?

$r\omega^2$

AREA

$$Q = V_{lim}A$$

$$dA = N2\pi r\,(\cot a)\,dr$$

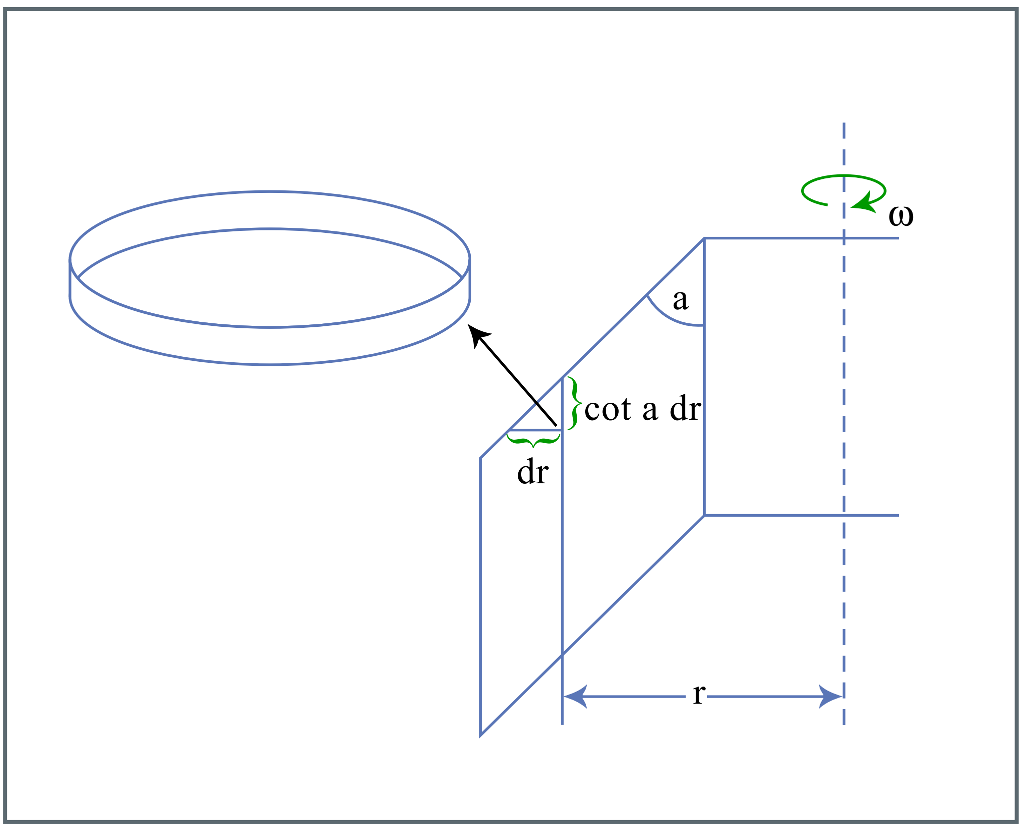


Figure by MIT OCW.

The area of interest is the projected area perpendicular to the centrifugal force

THROUGHPUT Q

$$Q = V_{\lim} A$$

$$Q = \int_{r_2}^{r_1} \frac{\vartheta_{\lim} \Delta P}{18\eta} r \omega^2 N 2\pi r \cot a \, dr$$

$$\Leftrightarrow$$

$$Q = \underbrace{\left[\frac{\vartheta_{\lim} \Delta P}{18\eta}\right]}_{1} \underbrace{\left[\frac{2\pi}{3} \omega^2 N \cot a \left(r_1^2 - r_2^2\right)\right]}_{2}$$

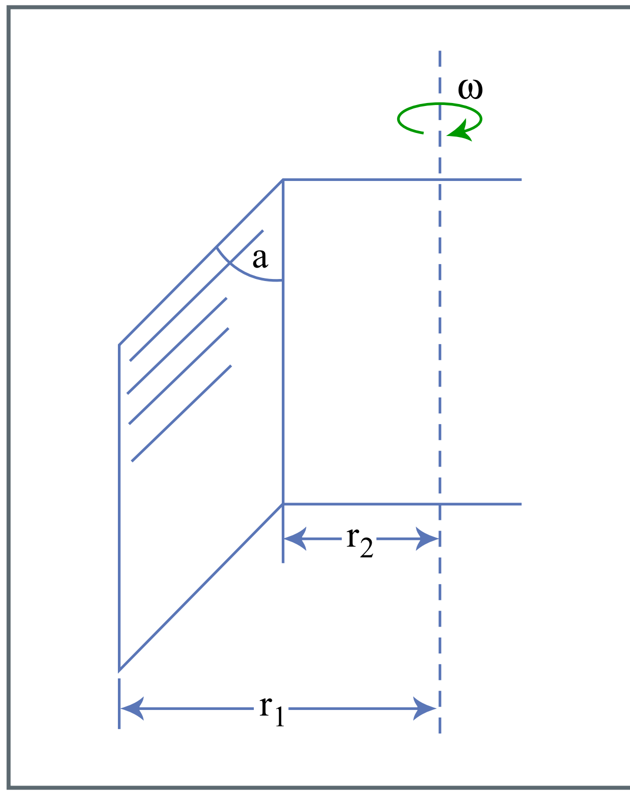


Figure by MIT OCW.

Process Medium

Separator Design

Area Equivalent = Σ

Throughput = Q=

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

$$Q = \underbrace{\left[\frac{\vartheta_{\lim}\Delta P}{18\eta}g\right]}_{1}\underbrace{\left[\frac{2\pi}{3g}\omega^2 N \cot a\left(r_1^2 - r_2^2\right)\right]}_{2}$$

Note the gravitational force constant

Sedimentation velocity for a particle

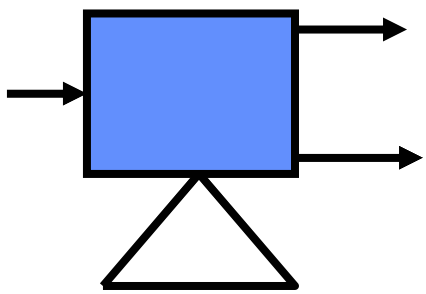
$\Sigma =$ surface area required for sedimentation in a tank to achieve same result as centrifuge

$$\frac{Q_2}{Q_1} = \frac{\Sigma_2}{\Sigma_1} \Rightarrow Q_2 = Q_1\frac{\Sigma_2}{\Sigma_1}$$

Process Objectives

CONCENTRATION

Solid product in feed

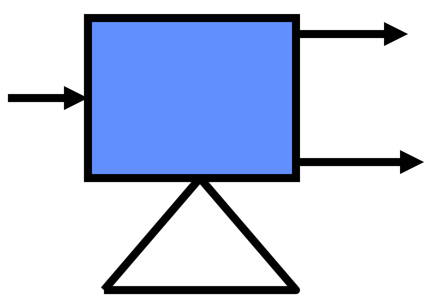


Light phase – any solids are lost product

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

	SOLIDS CONTENT										
SEPARATOR TYPE	**0**		**20**		**40**		**60**		**80**		**100**
Chamber bowl centrifuge											
Solid bowl centrifuge											
Self cleaning separator											
Nozzle bowl separator											
Centrifugal decanter											