# CENTRIFUGAL SEPARATION
## (Unit Operation-2)

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# TODAY'S TOPIC

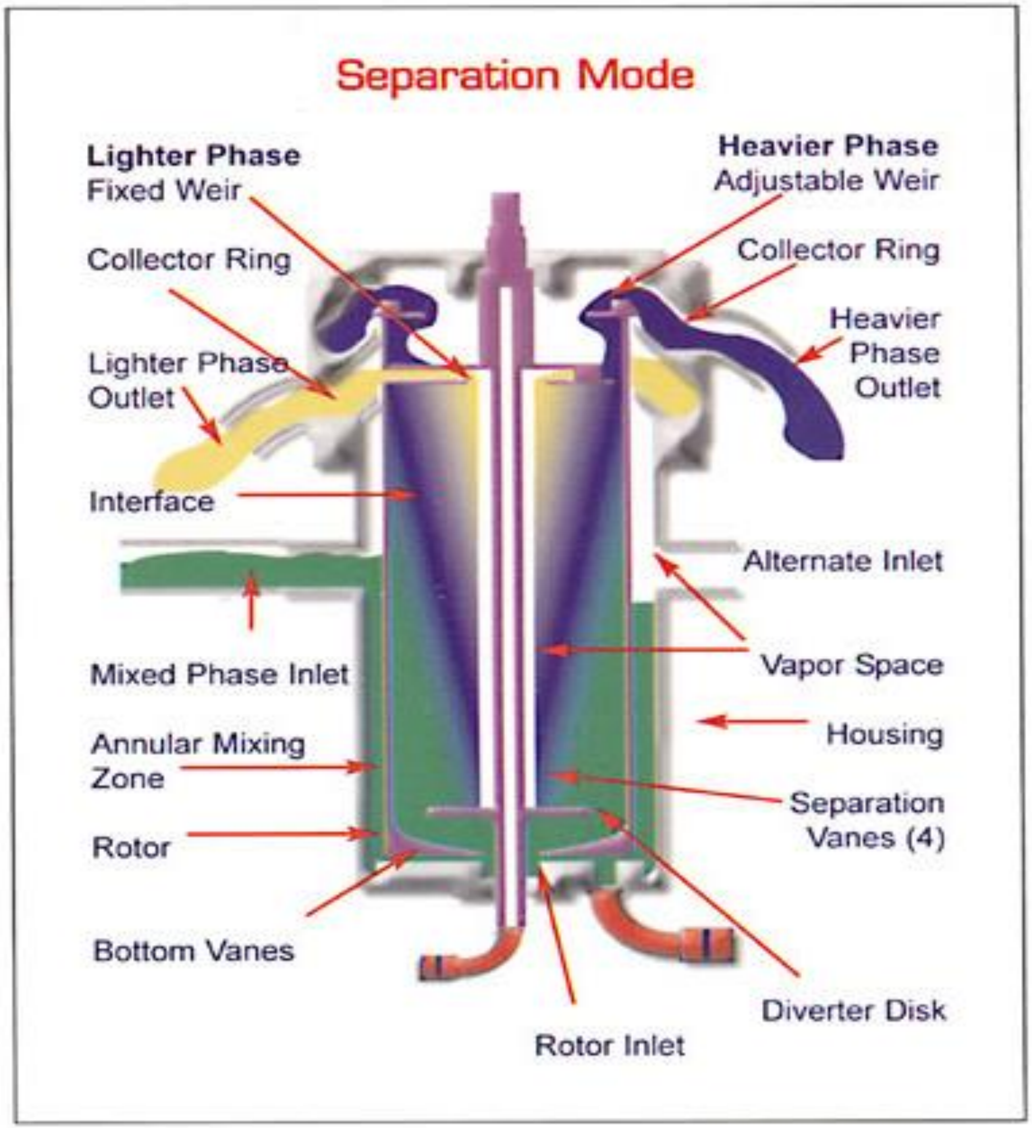
Today Topics :

- Centrifugal Separation
  - Introduction
  - Application
  - Equipment: Cyclone Separator
  - Theory
    - Centrifugal force
    - Rate of Settling
    - Critical Diameter

# LESSON OUTOMES

- Students should be able to
  - comprehend & discuss concept & theory on centrifugal separation
  - determine centrifugal force, critical diameter, rate of settling
  - analyze & design an application

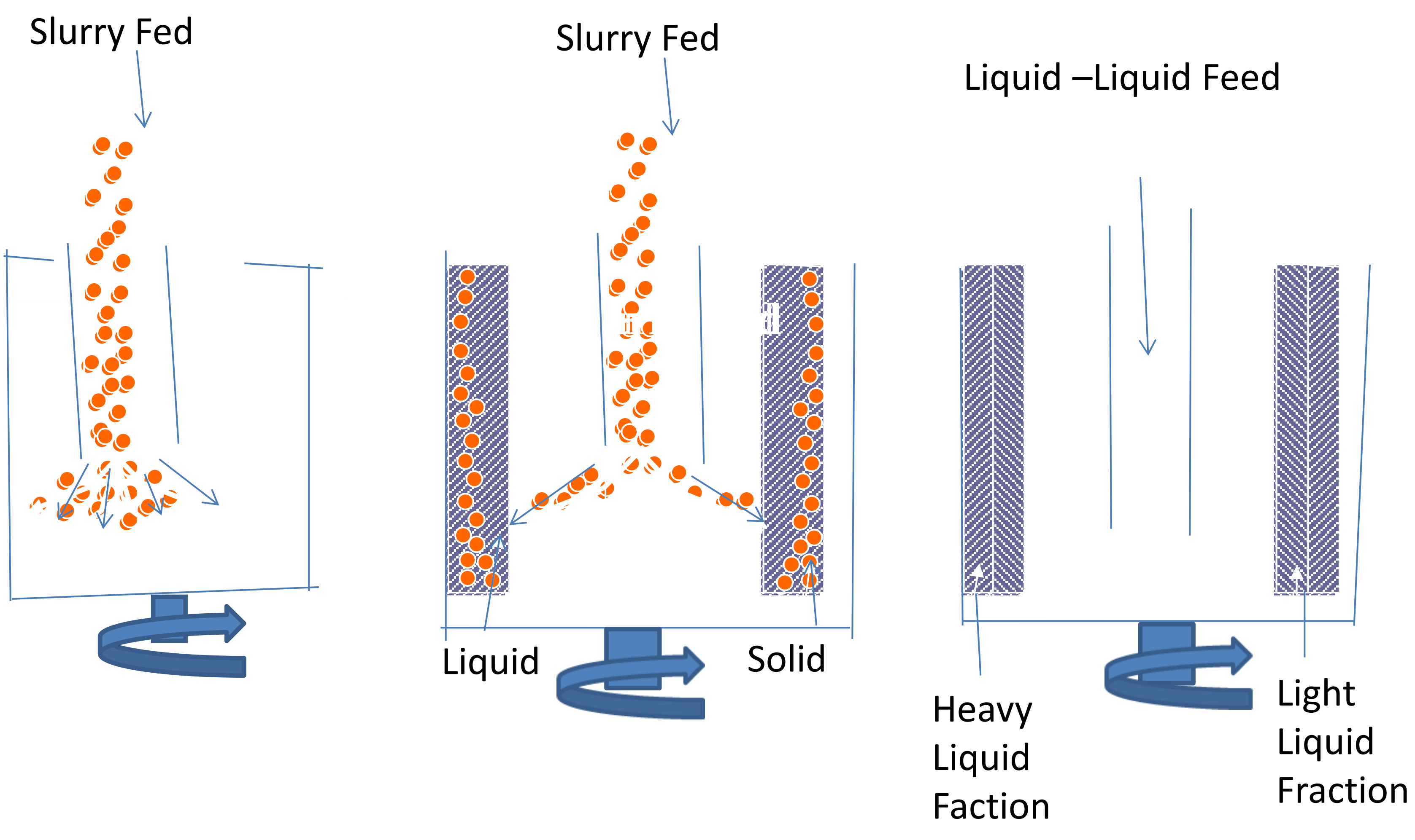
# Centrifugal Separation



# Introduction

- Centrifugal settling or sedimentation
  - separation of particles from a fluid by centrifugal forces acting on the particles
- used on particles that cannot be settled easily in gravity settling – smaller particles
- does not change relative settling velocities
- overcome
  - disturbing effect of Brownian motion
  - free convective currents
- gives faster results than gravity settling

# Basic Theory of Centrifugal Separation



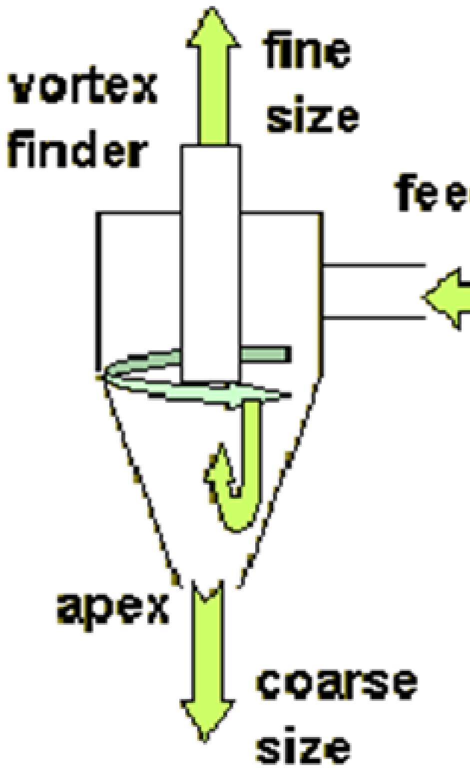
# Application

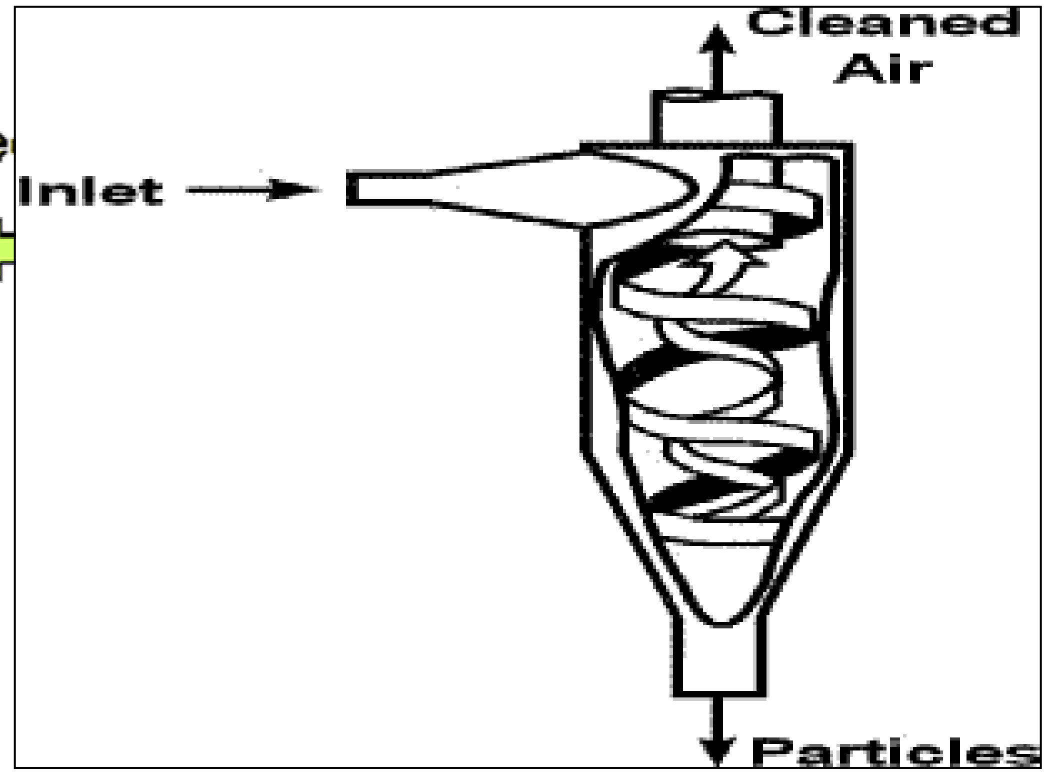
- separation of cream from whole milk
- separation of cellular materials
  - beers
  - vegetable oil
  - fish-protein-concentration
  - fruit juice
- drying crystals
- separation of emulsion into liquids or solid-liquid
- remove dust particles from air
  - vacuum cleaner

# Equipment: Cyclone Separators

vertical

conical




Size classification

- Centrifugal force

$$a_e = r\omega^2$$

$a_e$= acceleration from a centrifugal force (m/s$^2$)

$r$ = radial distance from centre

$\omega$ = angular velocity (rad/s)

$$F_c = ma_e = mr\omega^2$$

$$\omega = \frac{v}{r}$$

$$F_c = \frac{mv^2}{r}$$

# Basic theory of centrifugal separation

- Rotational speed, $N$ rev/min

$$\omega = \frac{2\pi N}{60} \qquad N = \frac{60v}{2\pi r}$$

$$F_c = mr\left(\frac{2\pi N}{60}\right)^2$$

- Gravitational Force,

$$\boxed{F_g = mg}$$

- Centrifugal force in terms of gravitational force

$$\frac{F_c}{F_g} = \frac{r\omega^2}{g} = \frac{v^2}{rg} = \frac{r}{g}\left(\frac{2\pi N}{60}\right)^2$$

# Example

## Force in a centrifuge

A centrifuge having a radius of the bowl of 0.1016 m is rotating at $N = 1000$ rev/min.

a) Calculate the centrifugal force developed in terms of gravity forces.
b) Compare this force to that for a bowl with a radius of 0.2032 m rotating at the same rev/min.

# Example

**Force in a centrifuge**

A centrifuge having a radius of the bowl of 0.1016 m is rotating at $N = 1000$ rev/min.

a) Calculate the centrifugal force developed in terms of gravity forces.

b) Compare this force to that for a bowl with a radius of 0.2032 m rotating at the same rev/min.

# Example : Problem Statement

Given: (a) r = 0.1016 m (a)

(b) r = 0.2032 m

$N$ = 1000 rev/min

Calculate: centrifugal force

# Example : Solution

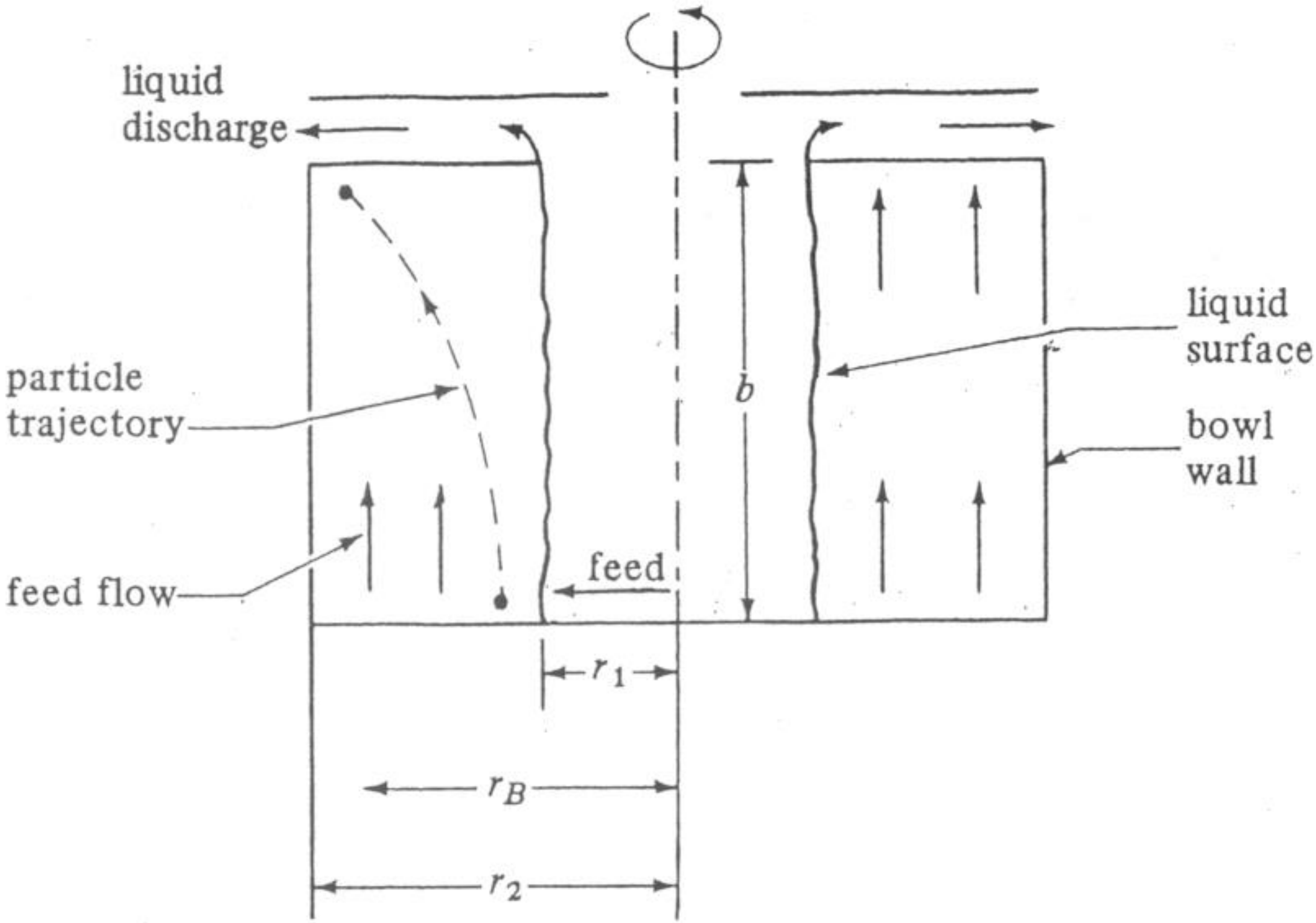
$$\frac{F_c}{F_g} = 0.001118 r N^2$$

$$= 113.6 g$$

$$\frac{F_c}{F_g} = 0.001118 r N^2$$

$$= 227.2 g$$

# Rate of settling in centrifuges



# Rate of settling in centrifuges

- Settling in Stoke's law range,

$$v_t = \frac{\omega^2 r D_p^2 (\rho_p - \rho)}{18\mu}$$

$$v_t = \frac{dr}{dt}$$

$$dt = \frac{18\mu}{\omega^2 (\rho_p - \rho) D_p^2} \frac{dr}{r}$$

- Integrating between the limits $r = r_1$ at $t = 0$ and $r = r_2$ at $t = t_T$

$$t_T = \frac{18\mu}{\omega^2 (\rho_p - \rho) D_p^2} \ln \frac{r_2}{r_1}$$

# Rate of settling in centrifuges

$$q = \frac{\omega^2 (\rho_p - \rho) D_p^2}{18 \mu \ln \frac{r_2}{r_1}} V$$

$$V = \pi b \left( r_2^2 - r_1^2 \right)$$

$$q = \frac{\omega^2 (\rho_p - \rho) D_p^2}{18 \mu \ln \frac{r_2}{r_1}} \left[ \pi b \left( r_2^2 - r_1^2 \right) \right]$$

- Critical diameter, $D_{pc}$ – diameter of particle that reaches half the distance between $r_1$ and $r_2$.

$$q_c = \frac{\omega^2 (\rho_p - \rho) D_{pc}^2}{18 \mu \ln \frac{2 r_2}{r_1 + r_2}} \left[ \pi b \left( r_2^2 - r_1^2 \right) \right]$$

# Example

## Settling in a centrifuge

A viscous solution containing particles with a density 1461 kg/$m^3$ is to be clarified by centrifugation. The solution density is 801 kg/$m^3$ and its viscosity is 100 cp. The centrifuge has bowl with $r_2$ = 0.02225 m, $r_1$ = 0.00716 m and height b = 0.1970 m. Calculate the critical particle diameter of the largest particles in the exit stream if N=23000 rev/min and the flowrate q = 0.002832 $m^3$/h.

Given: viscous solution containing particles

$\rho_p = 1461$ kg/m3

$\rho = 801$ kg/m3, $\mu = 100$ cp

bowl: $r_2 = 0.02225$ m, $r_1 = 0.00716$ m

$N = 23000$ rev/min

$q = 0.002832\ \text{m}^3/\text{h}$

Calculate: critical diameter

$$q_c = \frac{\omega^2 (\rho_p - \rho) D_{pc}^2}{18 \mu \ln \dfrac{2r_2}{r_1 + r_2}} \left[ \pi b \left( r_2^2 - r_1^2 \right) \right]$$

# Example : Solution

- Convert rotation into rad/s

$$\omega = \frac{2\pi N}{60}$$

- Bowl volume

$$V = \pi b(r_2^2 - r_1^2)$$

- Convert flow rate

$$q_c = \frac{0.002832}{3600}$$

- Use Eqn. to find $D_{pc}$

# RECAP

- comprehend & discuss concept & theory on centrifugal separation
- determine
  - centrifugal force, $F_C$
  - critical diameter, $D_{PC}$
  - rate of settling, $q_C$
- analyze & design an application

**References:**

[1] Geankoplis C. J., Transport Processes and Unit Operations, 4th Edition, Prentice Hall, 2003.

[2] Perry, R.H. and Green, D. Perry's Chemical Engineers' Handbook, $6^{th}$ ed. New York, McGraw-Hill Book Company, 1984.

# Question & Answers

# THANK YOU