Unit Operation-II

SETTLING AND SEDIMENTATION I

OUTCOMES OF THE TOPIC

By the end of this lesson, students will be able to

- discuss Settling & Sedimentation
- describe equipment
- understand & discuss the theory
  - ✓ Gravitational force
  - ✓ Buoyant force
  - ✓ Drag force
  - ✓ Terminal (settling) velocity
  - ✓ Drag coefficient

LESSON OUTCOMES

After this Lesson Students should be able to

- ✓ comprehend what Settling & Sedimentation separation (S&S) is
- ✓ differentiate S & S with other techniques
  - ❑ Application of S&S
  - ❑ Theory of (S&S)
- ✓ be introduced to preliminary analysis of S&S

Introduction

WHAT IS SETTLING & SEDIMENTATION ?

It is separation of solid particles by gravitational forces acting on the particles present is a fluid

The particles can be

1. Particles as contaminants – removal from fluid stream
2. Particles as products – recovery
3. Particles as both

Driving forces on Settling and Sedimentation

What is the difference between filtration and settling & sedimentation process?

FOR FILTRATION – Driving Force is ΔP through a filter medium

FOR SETTLING & SEDIMENTATION – Driving Force is gravitational forces

Introduction

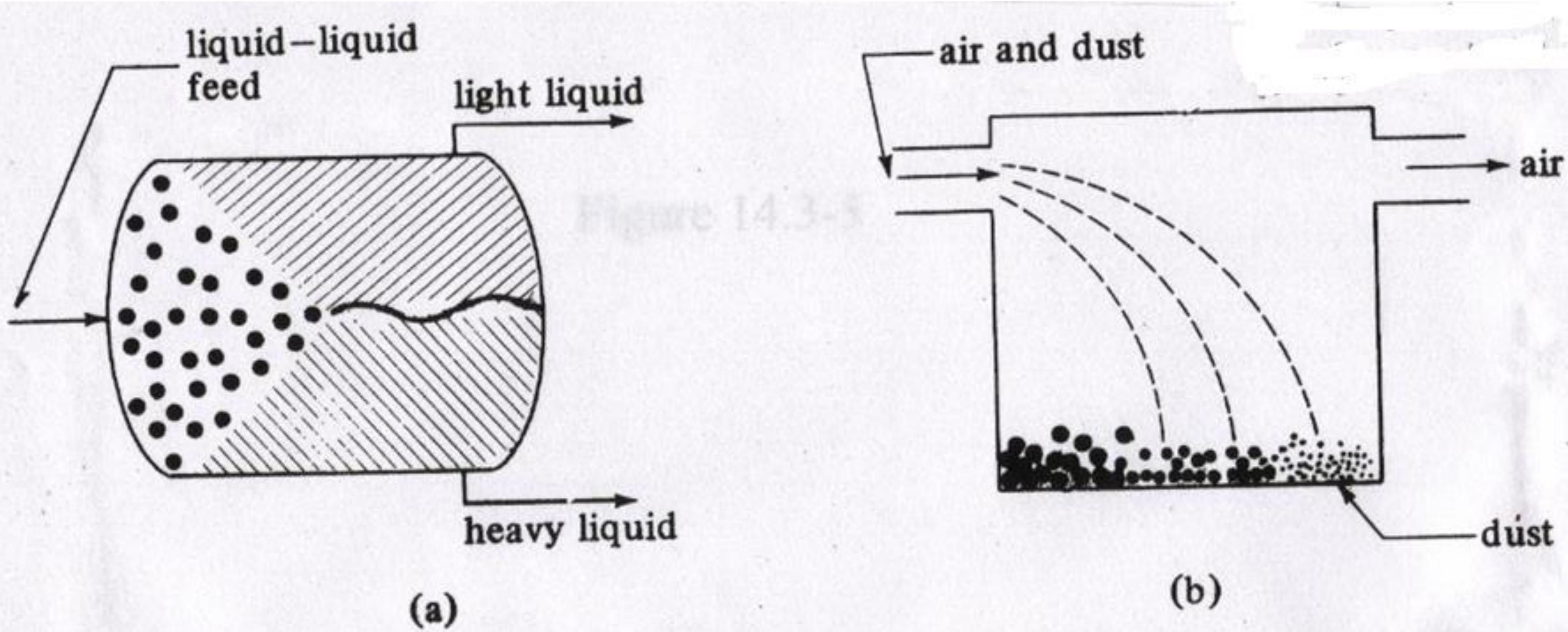
Free Settling – Falling of a particle is not affected by other particles and wall container/column.

Hindered Settling – Particles settling at low falling rate due to the high solid concentration.

Sedimentation – Separation of a dilute slurry by gravity settling into a clear fluid and a slurry of higher solid content.

Equipment for Settling and Sedimentation

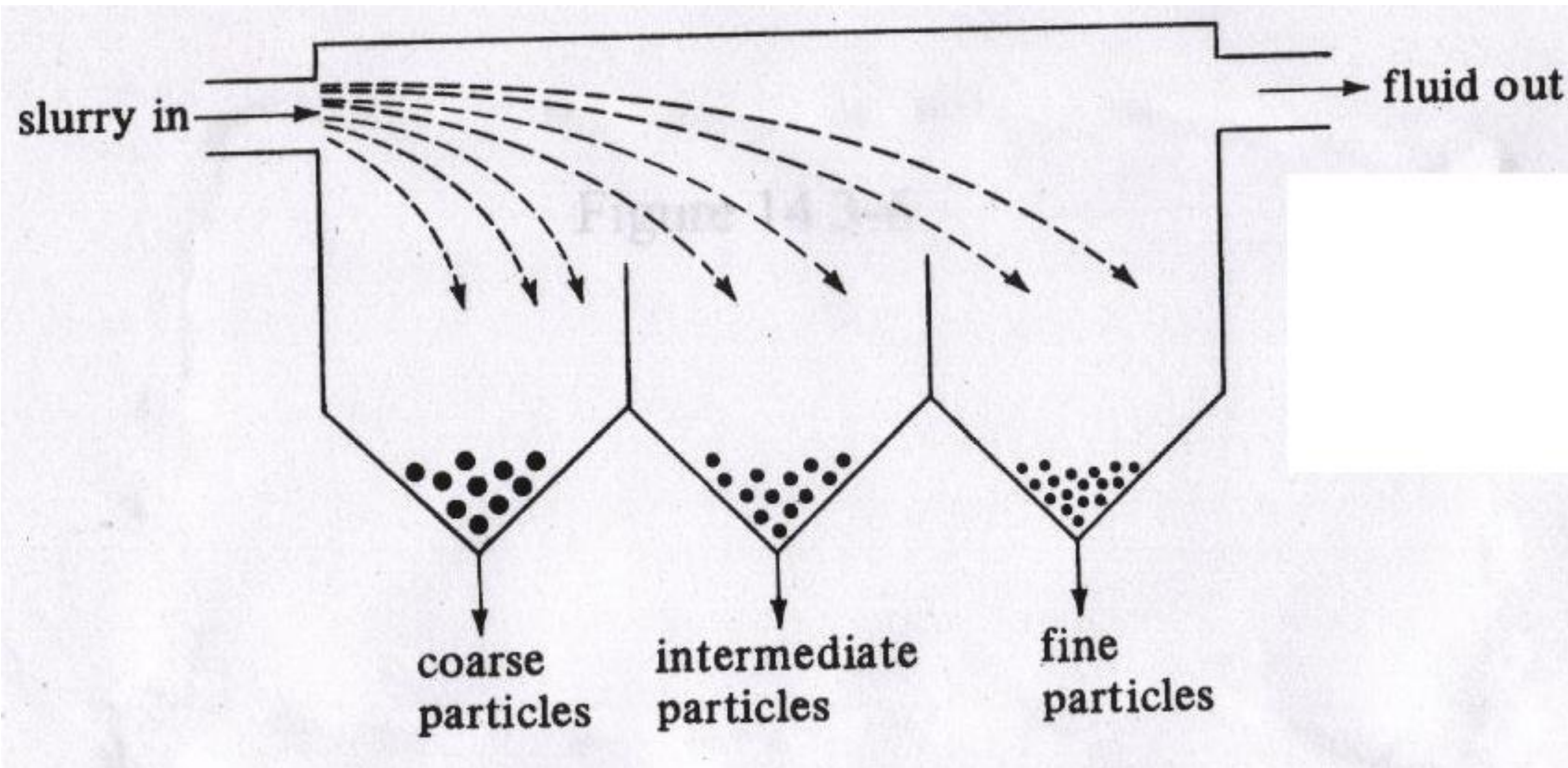
1. Simple gravity settling tank



Gravity settling tanks : (a) settler for liquid–liquid dispersion, (b) dust-settling chamber.

Equipment for Settling and Sedimentation

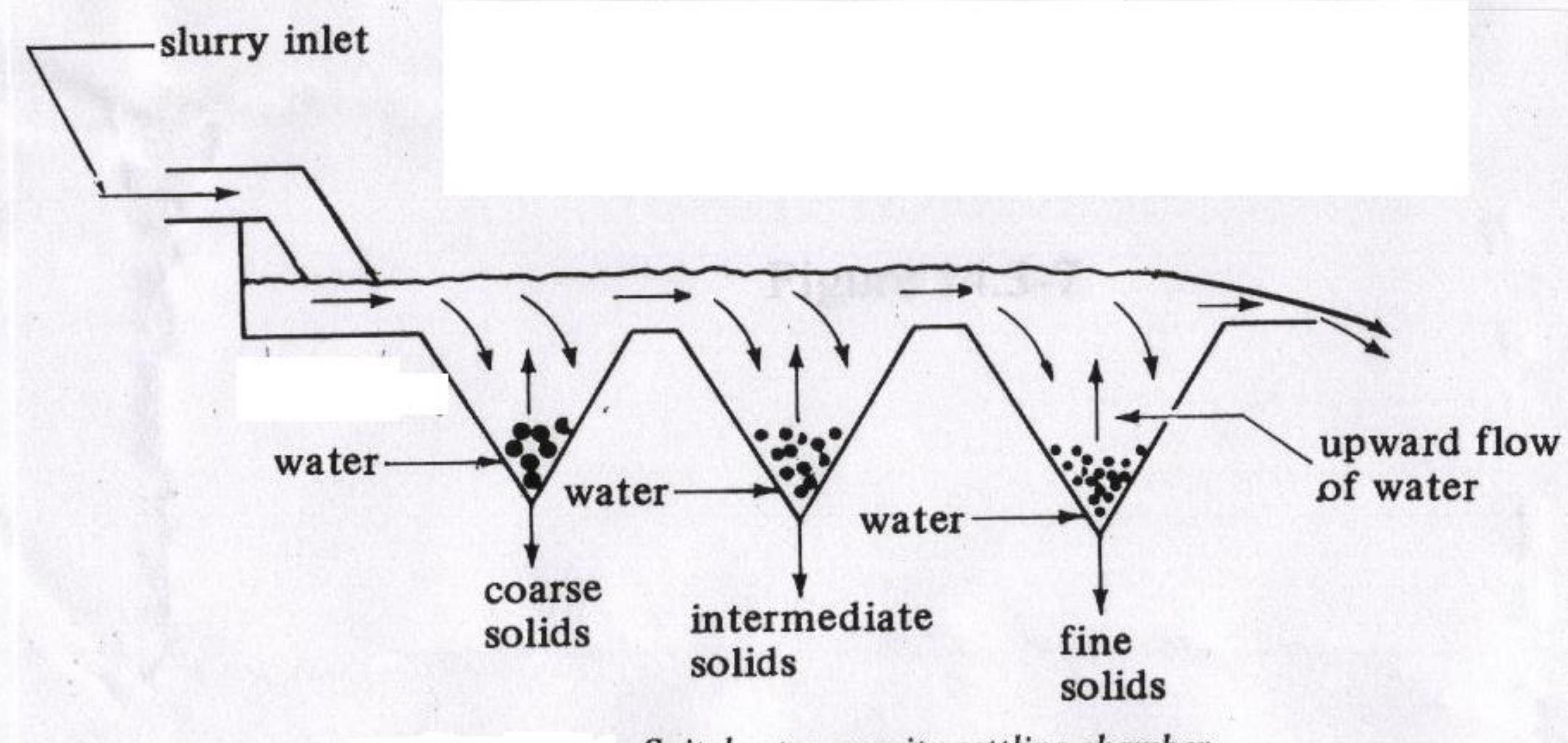
2. Gravity settling classifier



Simple gravity settling classifier.

Equipment for Settling and Sedimentation

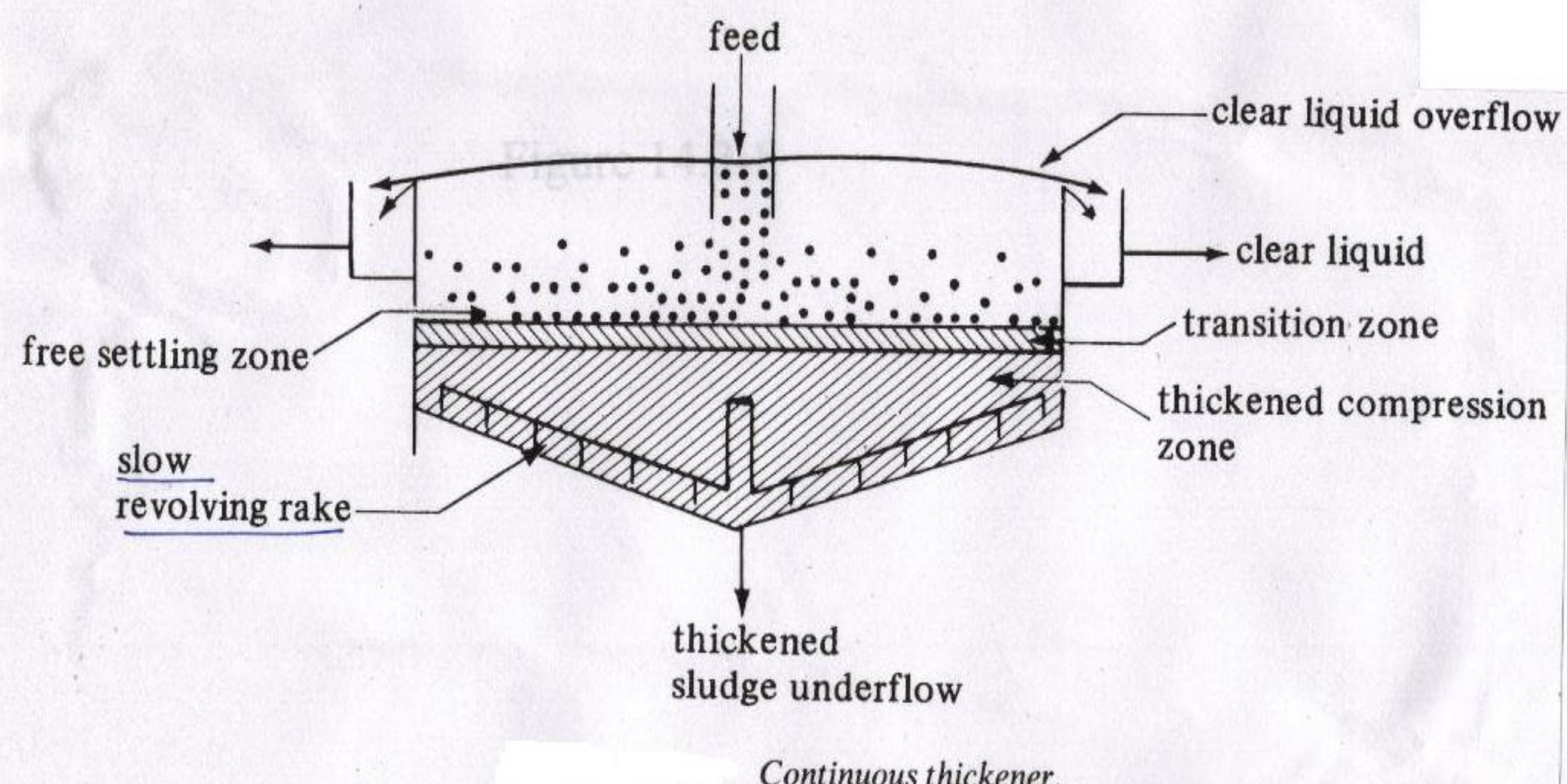
3. Spitzkasten classifier



Spitzkasten gravity settling chamber.

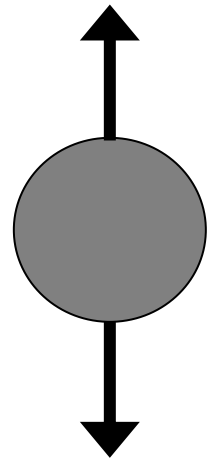
Equipment for Settling and Sedimentation

4. Sedimentation Thickener

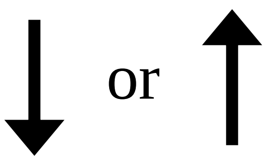


Continuous thickener.

Theory of particle movement through fluid



Buoyant force
-Due to density difference between particle and fluid



Resistance drag force
-Opposite motion

- What are the forces involved when a rigid particle is moving through a fluid?

  -buoyant force (F_b)
  -gravitational force (Fg)
  -resistance drag force (F_D)

Theory of particle movement through fluid

- Buoyant force F_b (N)

$$F_b = \frac{m\rho\ g}{\rho_p} = V_p \rho g$$

m = mass of particle (kg), v = velocity (m/s), ρ_p = density of particle (kg/m^3), ρ = density of liquid (kg/m^3)

$\rho = \rho_p$ ⇨ particle will not move relative to fluid

$\rho < \rho_p$ ⇨ particle will move downwards relative to fluid

$\rho > \rho_p$ ⇨ particle will move upwards relative to fluid

Theory of particle movement through fluid

- Gravitational force, F_g (N)

$$F_g = mg$$

- Drag force (frictional resistance), F_D

$$F_D = C_D \frac{v^2}{2} \rho A$$

C_D = proportionality constant, dimensionless

Theory of particle movement through fluid

- Resultant force = force due to acceleration

$$m\frac{dv}{dt} = F_g - F_b - F_D$$

$$m\frac{dv}{dt} = mg - \frac{m\rho g}{\rho_p} - \frac{C_D v^2 \rho A}{2}$$

Theory of particle movement through fluid

- Falling
  - Period of accelerated fall
    - Very short – 1/10 sec
  - Period of constant-velocity fall
    - \- Free settling velocity or terminal velocity, v_t

$$\frac{dv}{dt} = 0$$

$$v_t = \sqrt{\frac{2g(\rho_p - \rho)m}{A\rho_p C_D \rho}}$$

Theory of particle movement through fluid

- For spherical particles

$$m = \frac{\pi D_p^3 \rho_p}{6}$$

$$A = \frac{\pi D_p^2}{4}$$

$$\therefore \qquad v_t = \sqrt{\frac{4(\rho_p - \rho) g D_p}{3 C_D \rho}}$$

Theory of particle movement through fluid

Drag Coefficient C_D, for rigid spheres

- In laminar-flow region (Stokes' law region for $N_{Re} < 1$), the drag coefficient is

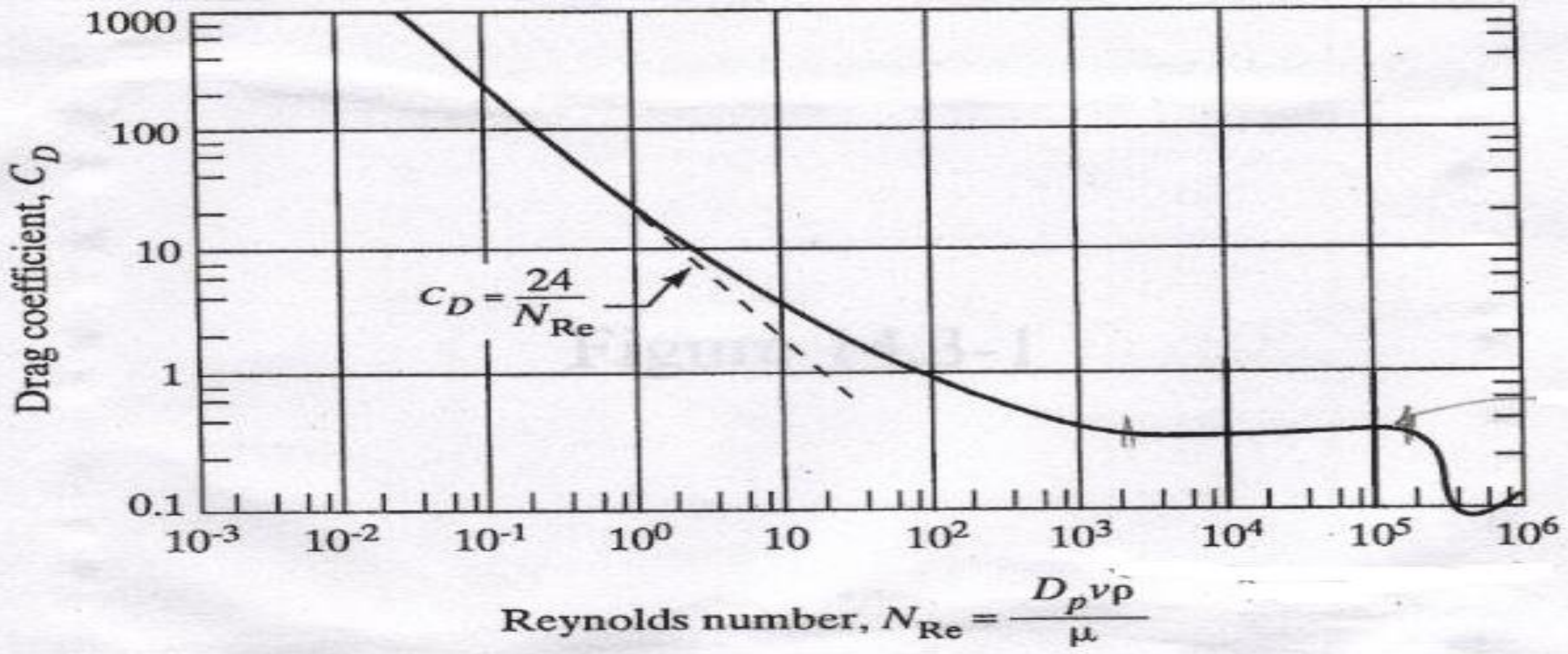
$$C_D = \frac{24}{D_p v \rho / \mu} = \frac{24}{N_{\mathrm{Re}}}$$

- Substituting this into above equation for laminar flow

$$v_t = \frac{g D_p^2 (\rho_p - p)}{18\mu}$$

Theory of particle movement through fluid

- In the turbulent Newton's law region above Reynolds number of about 1000 to 2.0 x 10^5; $C_D = 0.44$.



Drag coefficient for a rigid sphere.

Settling velocity of oil droplets

Oil droplets having a diameter of 20 μm are to be settled from air at temperature of 37.8°C and 101.3 kPa pressure. The density of the oil is 900 kg/m^3. Calculate the terminal velocity of the droplets.

At 37.8°C the ρ of air = 1.137 kg/m^3; μ = 1.90 x 10^{-5} Pa.s.

Problem Statement

Given:

diameter = 20 μm

T_{air} = 37.8°C

P_{air} = 101.3 kPa pressure.

density of oil, ρ_p = 900 kg/m^3

fluid = air, solid particle = oil

Calculate: terminal velocity

Solution

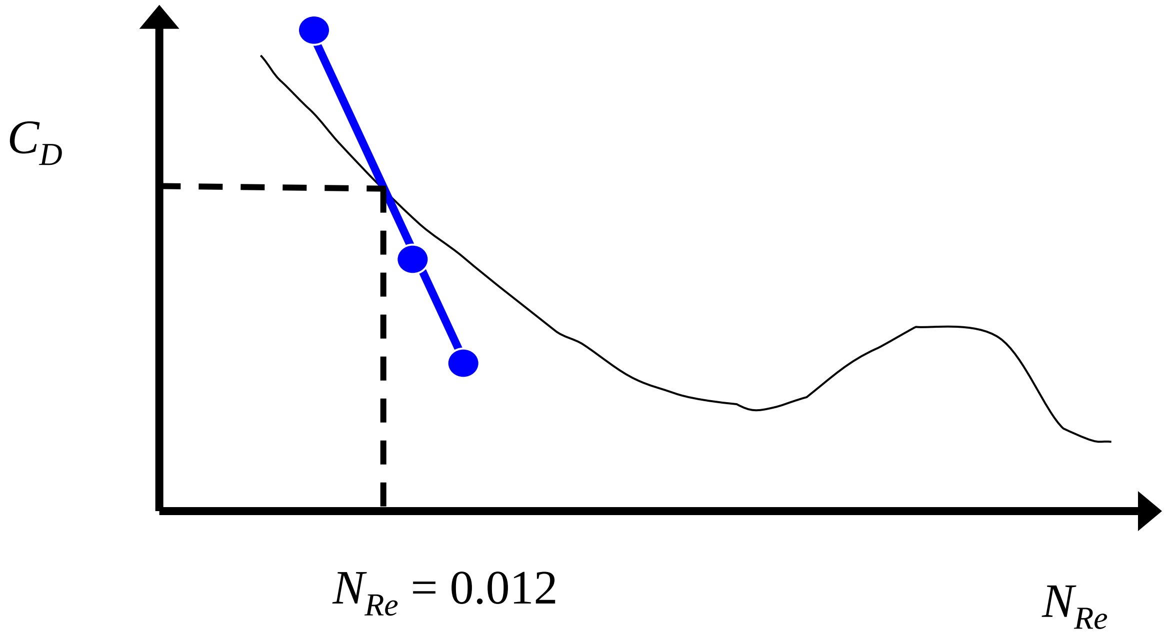
$$N_{\mathrm{Re}} = \frac{D_p v_t \rho}{\mu} = 1.197 v_t \qquad (1)$$

$$v_t = \sqrt{\frac{4(\rho_p - \rho) g D_p}{3 C_D \rho}} \rightarrow C_D = \frac{0.2067}{v_t^2} \qquad (2)$$

- Try 3 values of v_t:

v_t (m/s)	N_{Re} (using 1)	C_D (using 2)
0.305	0.365	2.22
0.0305	0.0365	222
0.0035	0.00365	22200

Solution



Using (1)

$$N_{\mathrm{Re}} = 0.012 = 1.197 v_t$$

$$v_t = 0.01 \text{ m/s}$$

or using (2) for laminar flow ($\mathrm{N_{Re}} < 1.0$)

$$\mathrm{v_t} = 0.0103 \text{ m/s}$$

Recap

- introduced to Settling & Sedimentation
- briefed on industrial application
- discussed theory
- tried out an example question

References:

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

Question & Answers

THANK YOU