Module 9: Packed beds

Lecture 29: Drag, particles settling

- Flow through a packed bed of solids
- Drag
- Criteria of settling
- Hindred settling

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Flow through a packed bed of solids

- Packed–beds of catalyst–particles are extensively used in chemical industries. Packed beds of solid particles are also used in absorption, adsorption, and distillation columns to increase interfacial area of contact between gas and liquid. In the next couple of lectures, we will address pressure–drop in packed beds of solids. Before that there are some definitions:

$$\phi_s = \text{sphericity} = \left(\frac{\begin{array}{c}\text{surface} - \text{area of}\\ \text{a sphere}\end{array}}{\begin{array}{c}\text{surface area of}\\ \text{particle having the same volume}\\ \text{as that of the sphere}\end{array}} \right)$$

a' = Specific surface area of a particle

$$= \left(\frac{\text{surface area of a particle}}{\text{volume of a particle}} \right)$$

$$= \frac{\left(\pi\, d_{sPh}^2\right)/\phi_s}{\left(\pi\, d_{sPh}^3\right)/6} = \frac{6}{\phi_s\, d_{sph}}$$

where the subscript ‘sph’ refers to the sphere having the same volume as that of the particle

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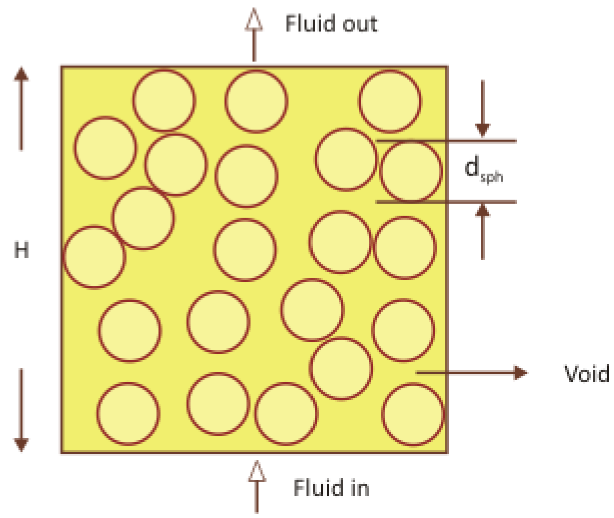
Table

Particles	Φ	
Spheres	1	
Cubes, cylinder	$(L = D) \approx 1$	
Berl saddle	0.3	$\left\{\begin{matrix} \text{coal dust } 0.73 \\ \text{crush glass } 0.65 \end{matrix}\right\}$
Ranching rings	$(L = Do, Di = 0.5\ Do)$	

a = specific area of the bed $= \dfrac{\text{surface area of all particles}}{\text{Total volume of the bed}} = \dfrac{6\,(1-\epsilon)}{\Phi_s\ d_{sph}}$

$$\epsilon \equiv \text{packed bed void (bed - porosity)} = \frac{V_{ved} - V_{particles}}{V_{ved}}$$



(Fig. 29a)

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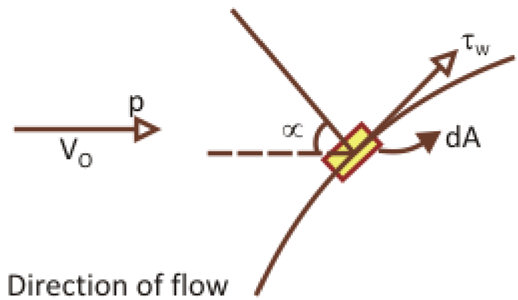
Drag: We have already introduced this term in the previous lecture. There are two types of drag: form drag and wall or shear drag. The former is because of the fluid–pressure on the solid–surface and acts perpendicular to the surface wall. Drag is because of shear–forces and acts parallel to the surface.



(Fig. 29b)

- A horizontal plate parallel to fluid flow will experience drag only because of wall shear.

$$F_D \int_o^A (\underbrace{p\ cost\alpha}_{\text{form drag}} + \underbrace{\tau_w sin\alpha}_{\text{wall drag}})dA$$

$= C_D \left({}^1/_2\, \rho V_o^2\right) A_p$ (already defined in previous lectures)

$= 3\pi\ \mu_f\, V_o\ \rho_f$ (Stoke's Law for Rep < 1)

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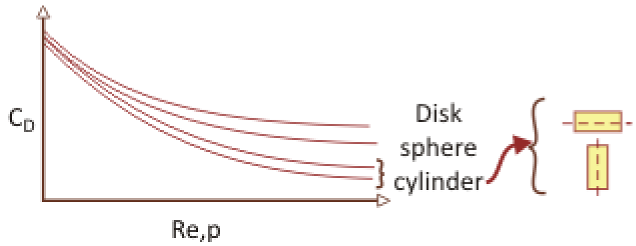
- C_D in general depends upon Reynolds number, but is also dependent on the shape and orientation of the particle with respect to the flow. Charts are available to determine drag coefficient.



(Fig. 29b)

- Terminal or settling velocity of a single particle in fluid may be calculated as

$$U_t = \sqrt{\frac{2g(\rho_p - \rho_f)m}{A_p C_D \rho_p \rho_f}}$$

- If the fluid moves–up with velocity U_f, velocity of the particle with respect to a stationary observer,
  $U_p = U_t + U_f$, so that the relative velocity or drag remains the same.

- C_D depends on $Re_{,P}$ which cannot be directly calculated because the velocity (settling) is not known. Therefore, iteration is required to determine U_t. In the previous lecture, we took-up such an example. However, there is a criterion to check if the settling is in the Stoke's regime (creeping flow) or in Newton's region (high flow when inertial effects are important), which is calculated independent of velocity:

Criteria for settling

$$\text{y } K = D_p\left[\frac{g\rho_f(\rho_p-\rho_f)}{\mu f^2}\right] < 2.6 \text{ (Stoke's regime)}$$

$2360 > K > 68.9 \Rightarrow \text{Newton} - \text{regime}$

- (As an exercise, substitute C_D in the expression for terminal velocity with $24/Re_{,P}$, and use the criterion $Re_{,P} < 1$ to obtain the above expression, $K < 2.6$ for the Stoke's regime)

Hindered settling

If there are particles in the fluid, then the settling of a single particle will be influenced by the presence of the neighboring particles. In such case, the settling velocity is larger than that of a single–particle.

$U_{hindered} = U_t\ (\epsilon)^n$, where ϵ is the volume–fractions (not bed–porosity) of fine–suspension of particles in fluid,

$R_{e,\rho}$	n
0.1	4.6
1	4.3
10	3.7
100	3.0
1000	2.5

The viscosity of a suspension is also affected by the presence of the dispensed phase and should be accordingly used in the calculation of Reynolds number:

$$\frac{\mu_s}{\mu_f} = \frac{1+0.5(1-\epsilon)}{\epsilon^n}$$

μ_s = viscosity of suspension; μ_f = viscosity of pure fluid

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