Module 9: Packed beds

Lecture 34: Examples on fixed and fluidized beds

- Fluidized bed condition:
- Ergun's equation:

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Example 1: Catalyst pellets 0.2" in diameter are to be fluidized with $100{,}000\ \mathrm{lb/hr}$ of air at 1 atm and $170°\mathrm{F}$ in a vertical cylindrical vessel. The density of the catalyst particles is $60\ \mathrm{lb/ft^3}$ and $\Phi s = 0.6$. If the given quantity of air is just sufficient to fluidize the solids, what is the vessel diameter? $\epsilon_{mf} = 0.45, \mu_f = 8.6 \times 10^{-6} \frac{\mathrm{lb}}{\mathrm{ft-s}}$

Answer: Assume $Re_{,p,mf} > 1000$ (inertial effects are dominant)

$$U_{mf}{}^2 = \frac{d_P\left(\rho_s - \rho_f\right)g}{1.75\,\rho_f}\,\epsilon_{mf}^3\,\Phi_s$$

$$\left(d_P = 0.2" = 0.2/12\ \mathrm{ft},\ \rho_s = 60\ \mathrm{lb/ft^3},\quad \rho_g = \frac{PM}{RT} = \frac{1\times 28}{630\times 730}\right.$$

$$\left. = 0.06\ \mathrm{lb/ft^3}, \qquad g = 32.2\,\frac{\mathrm{ft}}{\mathrm{s-s}}\right)$$

$$U_{mf}{}^2 = 23.7 \Rightarrow U_{mf} = 4.87\ \mathrm{ft/s}$$

Check, $\mathrm{Re\ (at\ minimum\ fluidization\ condition)} = \frac{U_{mf}\,d_P\,\rho_f}{\mu_f} = \frac{4.87\times\frac{0.2}{12}\times 0.06}{8.6\times 10^{-6}} = 5663 > 1000$

(So the assumption of inertial effects being dominant is correct)

As an exercise, the students can calculate
U_{mf} assuming $\mathrm{Re} < 20$:

$$U_{mf} = \frac{d_P{}^2\left(\rho_s - \rho_f\right)g}{150\,\mu}\left(\frac{\epsilon_{mf}^3\,\Phi_s{}^2}{1-\epsilon_{mf}}\right) = 50.47'/s$$

Check., $\mathrm{Re} = 50.47 \times \frac{0.2}{16} \times \frac{0.06}{8.6\times 10^{-6}} = 58684$

(So the flow is not viscous)

Vessel-Area (cross-section) $= \frac{\dot{m}}{\rho_f \times v_{mf}} = \frac{100{,}000}{3600\times .06} \times \frac{1}{4.87} = 95\ \mathrm{ft}^2$

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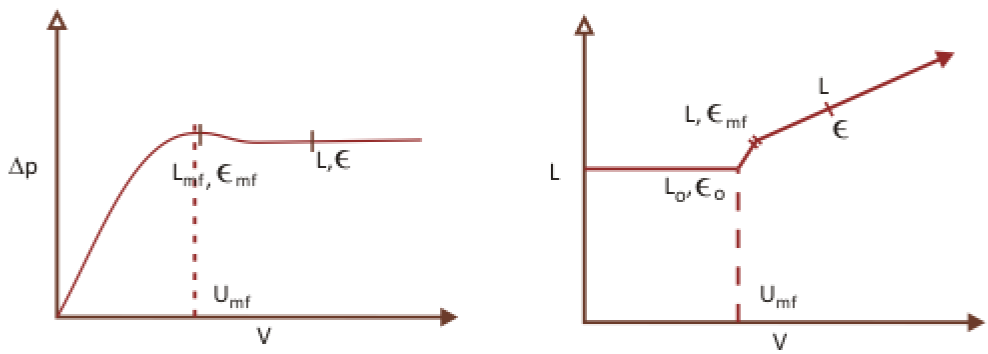
Example 2: We plan to pass air upward through a bed of solids resting on a screen. Will the solids fluidize?

Solids: $\rho_s = 3000\,\text{kg/m}^3,\ d_p = 2\text{ mm},\ \epsilon_{mf} = 0.36$

Air: $P_{inlet} = 130\text{ kPa},\ P_{outlet} = 100\text{ kPa},\ \overline{T} = 100°C$

Bed: 2m (Height); 0.5 m(ID)

Answer:



(Fig. 34a)

$$P_{air} = \frac{(130 + 100) \times 10^3}{2} \times \frac{0.029}{8.31 \times 373} = 1.075\ \text{kg/m}^3$$

$$\Delta p_{fluidized} = (1-\epsilon)\left(\rho_s - \rho_f\right) L\, g$$

$$= (1-0.36)(3000 - 1.075) 2 \times 9.8\ \ (L \simeq L_{mf}) = 37.7\text{ kPa}$$

$$> \text{Actual or observed } \Delta p\ (130 - 100) = 30\text{ kPa}$$

$$P_{outlet}\ (\text{theorecical}) < P_{outlet}\ (\text{observed})$$

Therefore, bed will not fluidize

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Example 3: A packed bed of spherical particles $(d_p = 50\mu m, \rho_s = 400\ kg/m^3)$ is fluidized using air at $870°C$ and pressure $= 2.76 \times 10^4\ N/m^2$. The packed–bed density is $1440\,kg/m^3$ and superficial air velocity is $0.3\ m/s$. Compare $'\Delta p'$ from Ergun's equation and fluidize bed condition-equation. $\mu_{air} = 1.28\,kg/m - s$

Solution:

Fluidized bed condition:

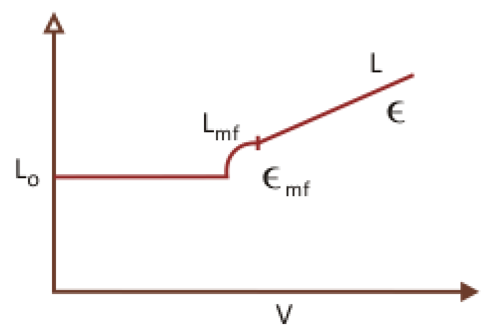
$$\frac{\Delta p}{L_{mf}} = (\rho_s - \rho_f)(1 - \epsilon_{mf})g$$

$$\epsilon = \frac{\rho_s - \rho_{balk}}{\rho_s} = \frac{4000 - 1440}{4000} = 0.64$$

$$\rho_f = \frac{PM}{RM} = \frac{28 \times 1.27}{1144 \times 0.082} = 0.38\ kg/m^3,$$

$$L_{mf}(1 - \epsilon_{mf}) = 20(1 - \epsilon_o) = L\ (1 - \epsilon)$$

$$\frac{\Delta p}{L_{mf}} = 14128\ N/m^3$$



(Fig. 34b)

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Ergun's equation:

$$\frac{\Delta p}{L} = \frac{150\,\mu\,V_o(1-\epsilon.)^2}{\phi_s{}^2\,d_p{}^2\,\epsilon^3} + \frac{1.75\,\rho_f\,v_o{}^2\,(1-\epsilon)}{\phi_s\,d_p\,\epsilon^3}$$

$$= \frac{150\times 1.28\times 10^5\times .3\,(1-.64)^2}{1\times(50\times 10^6)2\times 0.643} + \frac{1.75\times 1.10.38\times .30^2\times(1-.64)}{1\times(50\times 10^6)0.643}$$

$$= 115804\ \mathrm{N/m^3}$$

Therefore, there is a difference of one-order of magnitude

⇒ To sum–up, Ergun's equation is valid only for fixed–bed, when

$V_o < V_{mf}$ and $\epsilon < \epsilon_{mf}$

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