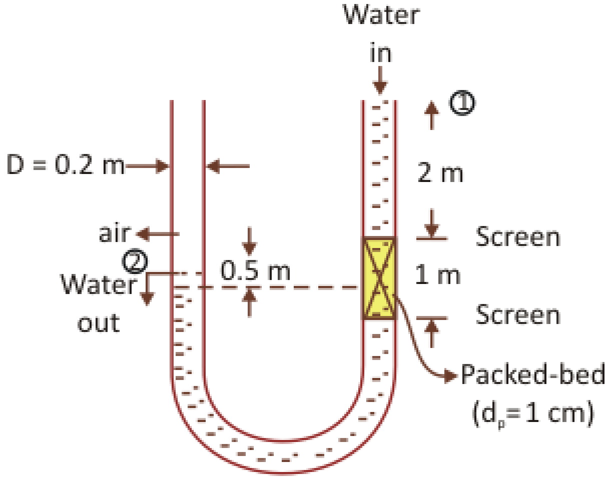
Module 9: Packed beds

Lecture 31: Examples on pressure drop calculations

- examples on packed bed calculation

Examples on packed bed calculation

Shown below is the schematic of a 0.2 m ID U-glass tube to a depth of 1m with 10,000 spherical quartz $\rho = 7800\ kg/m^3$ particles $(d_p = 1\ cm)$. What will be water ($\rho = 1000\,kg/m^3, \mu = 0.001\ kg/cm-s$) flow rate required through the bed if the water level is kept 2 m above the top of the packed bed? The particles are held between the two sieves.



(Fig. 31a)

Solution: Apply the ME balance between (1) and (2) incorporating frictional loss in the packed–bed:

$$J/kg : g\Delta z + \Delta\left(\frac{u^2}{2}\right) + \left(\frac{\Delta p}{\rho}\right) + w_p + w_s = 0$$

Here, $u_1 = u_2 =$ constant;, $P_1 = P_2 = 1\ atm$, $w_p = 0$

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Therefore, $g\,(Z_1 - Z_2) = w_s$

Or,

$$w_s = 9.8 \times (2 + 0.5) = 24.5\ \text{J/kg}$$

$$w_s \equiv \frac{150\,(1-\epsilon)^2\,\mu_f\,v_o L}{\epsilon^3 d_p^2\,\phi_s^2\,\rho_f} + \frac{1.75\,(1-\epsilon) v_o^2 L}{\epsilon^3\,d_p\,\phi_s}$$

$$\epsilon = \text{bed - porosity} = \frac{V_{\text{Packed-bed}} - V_{\text{particles}}}{V_{\text{Packed-bed}}}$$

$$= \frac{\pi/4\,(0.2)^2 \times 1 - 1000\,\frac{4}{3}\,\pi\left(\frac{0.01}{2}\right)^3}{\pi/4\,(0.2)^2 \times 1}$$

$$= 0.833$$

$\phi_s = 1$: Spherical particle

$d_p = 0.01\text{m}$

$\mu_f = 0.001\ \text{kg/m} - \text{s}$

$\rho_f = 1000\ \text{kg/m}^3$

Substitute,

$$24.5 = \frac{150 \times (1-0.833)^2 \times 0.001 \times V_o \times 1}{0.833^2 \times (0.01)^2 \times 1^2 \times 1000} + \frac{1.75(1-0.833) V_o^2 \times 1}{0.833^2 \times 0.01}$$

Or

$$24.5 = 0.0723\ v_o + 50.56\ V_o^2$$

$$V_o = 0.69\ \text{m/s}$$

$$Q = \pi/4\,D^2 \times V_o = \frac{\pi/4\,(0.2)^2 \times 0.69}{1000} \times 10^6 \times 60$$

$= 1300$ liters per min.

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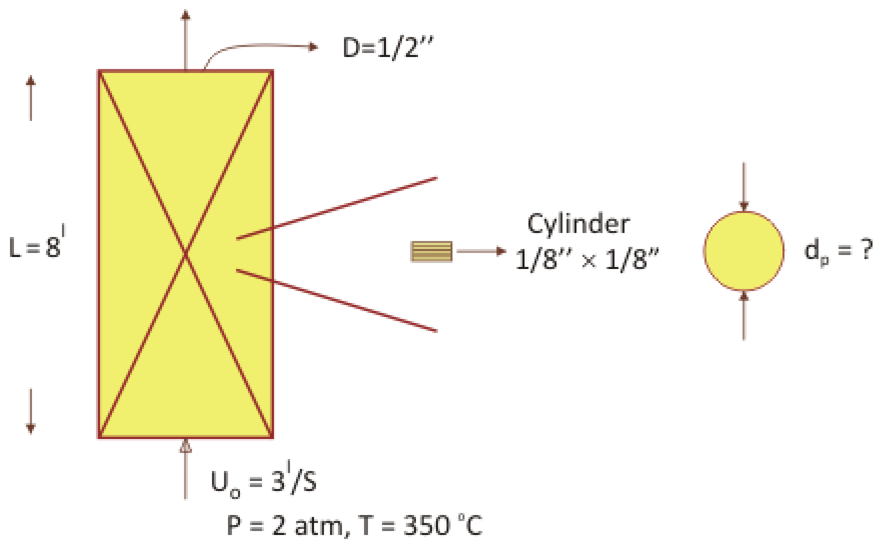
Example 2:

Partial oxidation is carried out by passing air with 1.2 mol percent hydrocarbons through $\frac{1}{2}''$ ID tube packed with 8' of $1/8'' \times 1/8''$ cylindrical catalyst pellets. The air enters at $350°C$ and 2.0 atm with a superficial velocity of 3 ft/s. Calculate the pressure–drop because of friction.

Assume, $\epsilon = 0.40, \mu(air) = 16 \times 10^{-5} \frac{gm - cm}{s}$.

Answer:



(Fig. 31b)

First calculate ϕ_s of the packed material (pellet).

$\phi_s \equiv \dfrac{4\pi\left(\frac{d_p}{2}\right)^2}{\underbrace{\left(\pi d^2 + 2\frac{\pi d^2}{4}\right)}}$; $d_p \equiv$ diameter of a sphere having the same volume as that of cylindrical pellet.

$= \frac{2}{3}\left(\frac{d_p}{d}\right)^2$, surface area of cylindrical pellet, d =length or diameter of the pellet . And,

$\frac{4}{3}\pi\left(\frac{d_p}{d}\right)^3 = \underbrace{\frac{\pi}{4}d^2.d}$ (= volume of the pellet)

$$d^3 = {}^2/_3\, d_p{}^3 \Rightarrow \left({}^{d_p}/_d\right)^3 = {}^3/_2 \Rightarrow d_p = 0.363\text{cm}$$

Therefore,

$$\phi_s = \frac{2}{3}\left({}^{3}/_{2}\right)^{2/3} = 0.667\ (1.5)^{2/3}$$

Calculate $Re_{,P} = \dfrac{v_o d_p \rho_f}{\mu_f} = \dfrac{(3 \times 12 \times 2.54) \times 0.363 \times 0.0011}{16 \times 10^{-5}}$

$$\left(\rho_f = \frac{PM}{RT} = \frac{2 \times 28 \times 10^{-3}}{623 \times .082 \times 10^{-6}}\right)$$

$$= 228$$

Therefore, both viscous and inertial terms are important and Ergun's equation should be written as:

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

Substitute, $\Delta p = \dfrac{150 \times\ (1-0.4)^2 \times 16 \times\ 10^{-5} \times (3 \times 12 \times 2.54) \times (8 \times 12 \times 2.54)}{0.4^3 \times .363^2 \times 0.667\ (1.5)^{2/3}}$

$$+ \frac{1.75 \times\ (1-0.4) \times (3 \times 12 \times 2.54)^2 \times (8 \times 12 \times 2.54)}{0.4^3 \times\ 0.363 \times 0.667\ (1.5)^{2/3}}$$

$$= 124225\ \text{Dyne/cm}^2$$

(Note: It is assumed that the variation in gas–velocity because of variation in pressure is negligible. v_o and ρ_f are calculated at the inlet conditions).