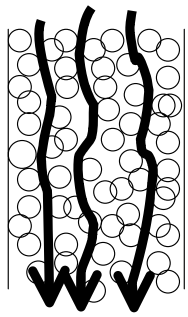
Chapter 4 Fluid Flow through Packed Bed of Particles

4.1 Pressure Drop - Flow Relationship

(1) Laminar Flow

Fluid flow through a packed bed: simulated by fluid flow through a hypothetical tubes



$$\therefore \frac{(-\Delta p)}{H} = \frac{32\mu U}{D^2}$$

$$\Rightarrow \frac{(-\Delta p)}{H_e} = \frac{K_1 \mu U_i}{D_e^2}$$

Hagen-Poiseille equation

Substituting suitable relations

$$\therefore \frac{(-\Delta p)}{H} = 180 \frac{\mu U}{x^2} \frac{(1-\varepsilon)^2}{\varepsilon^3}$$

Carman-Kozeny equation

(2) General Equation for Turbulent and Laminar Flow

Ergun equation

$$\frac{(-\Delta p)}{H} = 150 \frac{\mu U}{x^2} \frac{(1-\varepsilon)^2}{\varepsilon^3} + 1.75 \frac{\rho_f U^2}{x} \frac{(1-\varepsilon)}{\varepsilon^3}$$

Laminar Turbulent

Laminar flow for $Re* = \frac{xU\rho_f}{\mu(1-\varepsilon)} < 10$

Turbulent flow for $Re* = \frac{xU\rho_f}{\mu(1-\varepsilon)} > 2000$

or

$$f* = \frac{150}{Re*} + 1.75$$

where $f* \equiv \frac{(-\Delta p)}{H} \frac{x}{\rho_f U^2} \frac{\varepsilon^3}{(1-\varepsilon)}$

Friction factor

Figure 4.1

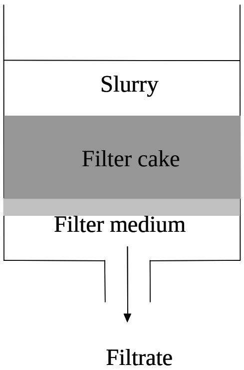
(3) Nonspherical Particles

x_{sv} (surface-volume diameter) instead of x

Worked Example 4.1

4.2 Filtration

For filtration theory and practice, see http://coel.ecgf.uakron.edu/~chem/fclty/chase/FILTRATION%20FUNDAMENTALS_files/frame.htm



(1) Introduction

Filter media : Canvas cloth, woolen cloth, metal cloth, glass, cloth, paper, synthetic fabrics

Filter aids : To avoid cake plugging

- Diatomaceous silica, perlite, purified woolen cellulose, other inert porous solids
- By either adding slurry (increasing cake permeability) or precoating the filter media surface

Types of liquid filters

	Batch	Continuous
Pressure Filtration	Filter Press Shell-and-Leaf Filters	Automatic Belt Filters
Vacuum Filtration	Discontinuous Vacuum Filters	Rotary Drum Filters Horizontal Belt Filters
Centrifugal Filtration	Batch Types	Continuous Types

(2) Incompressible Cake

For cake filter

From laminar part of Ergun equation

$$\frac{(-\Delta p)}{H} = \frac{150\mu U(1-\varepsilon)^2}{x^2\varepsilon^3}$$

where L : cake thickness

x : surface-volume diameter of particle

* For *compressible* filter cake,

$$\frac{dp}{dL} = r_c \mu U$$

where r_c: a function of pressure difference

By defining cake resistance r_c

$$r_c = \frac{150(1-\varepsilon)^2}{x^2\varepsilon^3},$$

$$\frac{(-\Delta p)}{H} = r_c \mu U$$

where $U = \frac{1}{A}\frac{dV}{dt}$

V: volume of slurry fed to filter

Also defining ϕ(volume formed by passage of unit volume filtrate)

$$\phi = \frac{HA}{V},$$

$$\frac{dV}{dt} = \frac{A^2(-\Delta p)}{r_c \mu \phi V}$$

Including the resistance of filter medium,

since the resistances of the cake and the filter medium are in series,

$$(-\Delta p) = (-\Delta p_m) + (-\Delta p_c)$$

$$\downarrow$$

$$\frac{1}{A}\frac{dV}{dt} r_c \mu H_c$$

By *analogy* for the filter medium

$$(-\Delta p_m) = \frac{1}{A}\frac{dV}{dt} r_m \mu H_m$$

$$\therefore\ (-\Delta p) = \frac{1}{A}\frac{dV}{dt}(r_m \mu H_m + r_c \mu H_c)$$

Defining equivalent height of filter cake and volume of filtrate

$$r_m H_m = r_c H_{eq} \text{ and } H_{eq} = \frac{\Phi V_{eq}}{A}$$

where V_{eq}: volume of filtrate passing to create a cake of thickness H_{eq}

$$\therefore\ \frac{1}{A}\frac{dV}{dt} = \frac{(-\Delta p)A}{r_c \mu (V + V_{eq})\Phi}$$

Constant rate filtration

$$\frac{1}{A}\frac{dV}{dt} = \frac{(-\Delta p)A}{r_c \mu (V + V_{eq})\Phi} = constant$$

Constant pressure filtration

Integrating

$$\frac{t}{V} = \frac{r_c \Phi \mu}{A^2(-\Delta p)}\left(\frac{V}{2} + V_{eq}\right)$$

Worked Example 4.2

(3) Washing the Cake

Figure 4.2