WATER FILTRATION

I. Introduction
A. Filtration: a unit operation used for the removal of particulates from water and wastewater.
B. Particles are removed at the surface and within the filter medium.
C. Types of particles that are removed are listed below:
   1. Algae
   2. Humic colloidal compounds
   3. Viruses
   4. Asbestos fibers
   5. Clay particles
D. Types of media used are listed below:
   1. Polyethylene, stainless steel, or cloth screens with openings ranging from 1 to 100 micrometers.
   2. Diatomaceous earth filters consisting of siliceous fossil remains with openings ranging from 7 to 50 micrometers.
   3. Granular media consisting of sand, anthracite, coal, magnetite, garnet sand, coconut shells with openings ranging from 0.1 to 10 mm.
E. As particulates build up in and on the filter media, the pressure drop builds up to a level that exceeds the available head. The filter is then taken out of service and backwashed or regenerated.
F. Treatment Flow Schemes
   1. Conventional Filtration
      a. Coagulation/flocculation, sedimentation followed by filtration
   2. Direct Filtration
      a. Coagulation/flocculation followed by filtration

II. Filtration Hydraulics
A. Derivation of Headloss through a clean filter bed

1. Darcy-Weisbach Equation for headloss in a pipe

\[ h_L = f \frac{L V^2}{D 2 g} \]

\( h_L \) = Head loss, ft (m)
\( f \) = Dimensionless friction factor
\( L \) = Length of pipe, ft (m)
\( D \) = Pipe diameter, ft (m)
\( V \) = Mean velocity in pipe, fps (mps)
\( g \) = Acceleration of gravity

2. Hydraulic radius: is the cross-sectional area divided by the wetted perimeter.
\[ R_H = \frac{X - \text{Sectional area}}{\text{Wetted Perimeter}} = \frac{\forall}{A_S} \]

\[ V = \text{volume of filter medium and } A_S \text{ is the filter surface area.} \]

For a pipe flowing full or half full, the hydraulic radius is given below.

\[ R_H = \frac{\pi D^2/4}{\pi D} = \frac{D}{4} \]

Therefore, \( D = 4 \, R_H \).

3. Velocity of approach: \( V_A = Q/A_S \)
4. Velocity through the filter bed: \( V = V_A/\varepsilon \)
   \[ \varepsilon = \frac{\text{Volume of voids}}{\text{Volume of media}} = \text{Bed porosity} \]
   \[ \varepsilon = \frac{\text{Volume of Voids}}{\text{Volume of Voids} + \text{Volume of Media}} = \frac{V_v}{V_v + V_M} \]

4. The volume of voids is equivalent to the total channel volume for the water to flow through.
5. \( V_v = \text{Total Volume (V) } \times \text{Porosity (\varepsilon)} \)
6. Volume of media divided by the total volume = 1 - \( \varepsilon \)
   \[ 1 - \varepsilon = \frac{V_M}{V} \]
   \[ V = \frac{V_M}{1 - \varepsilon} \]
   \[ V = \frac{V_v}{\varepsilon} \]
   \[ \frac{V_v}{\varepsilon} = \frac{V_M}{(1 - \varepsilon)} \]

7. Volume of Media Particles : \( V_P \)
8. Number of Media Particles: \( N \)
9. Surface area of Each Media Particle: \( A_P \)
10. Shape factor for non-spherical particles: $\phi$
11. Volume of spherical particle: $\pi \frac{d^3}{6}$
12. Surface area of spherical particle: $\pi d^2$

B. Derivation of Carman-Kozeny Equation

1. Hydraulic radius through filter bed:

\[
R_H = \frac{V_v}{A_s}
\]

\[
\frac{V_v}{\varepsilon} = \frac{V_M}{(1 - \varepsilon)}
\]

\[
V_v = \frac{\varepsilon}{1 - \varepsilon} \frac{V_M}{V_v}
\]

\[
V_v = \varepsilon N \frac{V_p}{(1 - \varepsilon)}
\]

\[
\frac{\varepsilon}{1 - \varepsilon} \frac{V_p}{N A_p}
\]

\[
R_H = \left( \frac{\varepsilon}{1 - \varepsilon} \right) \left( \frac{V_p}{A_p} \right)
\]

\[
\frac{V_p}{A_p} = \left( \frac{\pi \frac{d^3}{6}}{\pi \frac{d^2}{2}} \right) = \frac{d}{6}
\]

\[
R_H = \left( \frac{\varepsilon}{1 - \varepsilon} \right) \left( \frac{\phi d}{6} \right)
\]

\[
h_L = f \left( \frac{L}{4 R_H} \right) \left( \frac{V^2}{2 g} \right) = f \left( \frac{L}{4 \varepsilon} \right) \left( \frac{1 - \varepsilon}{\phi d} \right) \left( \frac{6 V^2}{2 g} \right)
\]

\[
V = V_A / \varepsilon
\]
\[ h_L = f \left( \frac{L}{4 \eta} \right) \left( \frac{1 - \varepsilon}{\varepsilon^3} \right) \left( \frac{6 V_A^2}{2 \varepsilon^2 g} \right) \]

\[ h_L = f \left( \frac{L}{\phi d} \right) \left( \frac{1 - \varepsilon}{\varepsilon^3} \right) \left( \frac{V_A}{g} \right) \left( \frac{6}{8} \right) \]

\[ h_L = f' \left( \frac{L}{\phi d} \right) \left( \frac{1 - \varepsilon}{\varepsilon^3} \right) \left( \frac{V_A^2}{g} \right) \]

\[ f' = 150 \left( \frac{1 - \varepsilon}{N_{Re}} \right) + 1.75 \]

\[ N_{Re} = \frac{\phi \rho V_A d}{\mu} = \frac{\phi V_A d}{\nu} \]

C. Media shape factors (\( \phi \))
   1. Pulverized coal 0.73
   2. Angular sand 0.73
   3. Rounded sand 0.82
   4. Ottawa sand 0.95

D. Carman-Kozeny Equation: Bed of porous media of mixed particle size.

\[ h_L = \left( \frac{L}{\phi} \right) \left( \frac{1 - \varepsilon}{\varepsilon^3} \right) \left( \frac{V_A^2}{g} \right) \sum f' \frac{x_i}{d_i} \]

\( x_i \) = Weight fraction of particles retained between any two sieves.
\( d_i \) = Geometric mean diameter between adjacent sieves.

E. Carman-Kozeny Equation: Bed of porous media of uniform particle size.

\[ h_L = \left( \frac{L}{\phi d} \right) \left( \frac{1 - \varepsilon}{\varepsilon^3} \right) \left( \frac{V_A^2}{g} \right) \]

F. Rose Equation: Bed of porous media of mixed particle size.
\[ h_L = \left( \frac{1.067}{\phi} \right) \left( \frac{L}{g} \right) \left( \frac{V_A^2}{\varepsilon^4} \right) \sum \frac{C_D \times_i}{d_i} \]

\[ C_D = \frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34 \]

G. Rose Equation: Bed of porous media of uniform particle size.

\[ h_L = \left( \frac{1.067}{\phi} \right) \left( \frac{C_D}{g} \right) \left( \frac{L V_A^2}{\varepsilon^4} \right) \left( \frac{1}{d} \right) \]