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Fluidized Bed

Aim:

To study fluidization of a porous bed and graphically obtain the point of fluidization

Theory:

A packed bed expands when the pressure drop due to the upward flow of fluid through the bed equals the weight of packing. The individual particle moves under the influence of the passing fluid. The state is called fluidized. When a fluid passes upward through a bed of solids there will be a certain pressure drop across the bed to maintain the fluid flow depending upon the bed geometry and particle characteristics. The minimum fluid velocity at which the fluidization phenomenon occurs is called fluidization velocity.

A force balanced on a bed of length L when the pressure drop equals the gravitational force is as follows

$$\Delta P = L\left(1-\varepsilon\right)\left(\rho_p-\rho_f\right)g$$

where,

ρ_f is Fluid density

ρ_p is Solid particle density

$\varepsilon = 1 - Ws/LA\rho_p$ is porosity

Pressure drop across the fix bed (Ergun's equation)

$$\left(\frac{\Delta P}{\rho_f L}\right)\left(\frac{\varepsilon^3}{1-\varepsilon}\right)\left(\frac{d_p}{V^2}\right)=\frac{150(1-\varepsilon)\mu_f}{d_p V\rho_f}$$

At fluidization velocity,

$$\left(\frac{\Delta P}{\rho L}\right)\left(\frac{\varepsilon^3}{1-\varepsilon}\right)\left(\frac{d_p}{V_\varepsilon^{\ 2}}\right) = \frac{150(1-\varepsilon)\mu}{d_p V_\varepsilon \rho_f} + 1.75 = f_p \ = \frac{150(1-\varepsilon)}{(N_{\mathrm{Re}})_P} + 1.75$$

At the onset of fluidization, the pressure drop across the bed equals the weight of the bed per unit area of cross-section

$$\Delta P \big/ L = g(\rho_S - \rho_f)(1-\varepsilon)$$

The simplified expression for minimum fluidization velocity are as under.

$$V_{m_f} = \frac{d_p^2(\rho_s - \rho_f)g}{1650\mu_f} \qquad \mathrm{Re}_p \geq 20$$

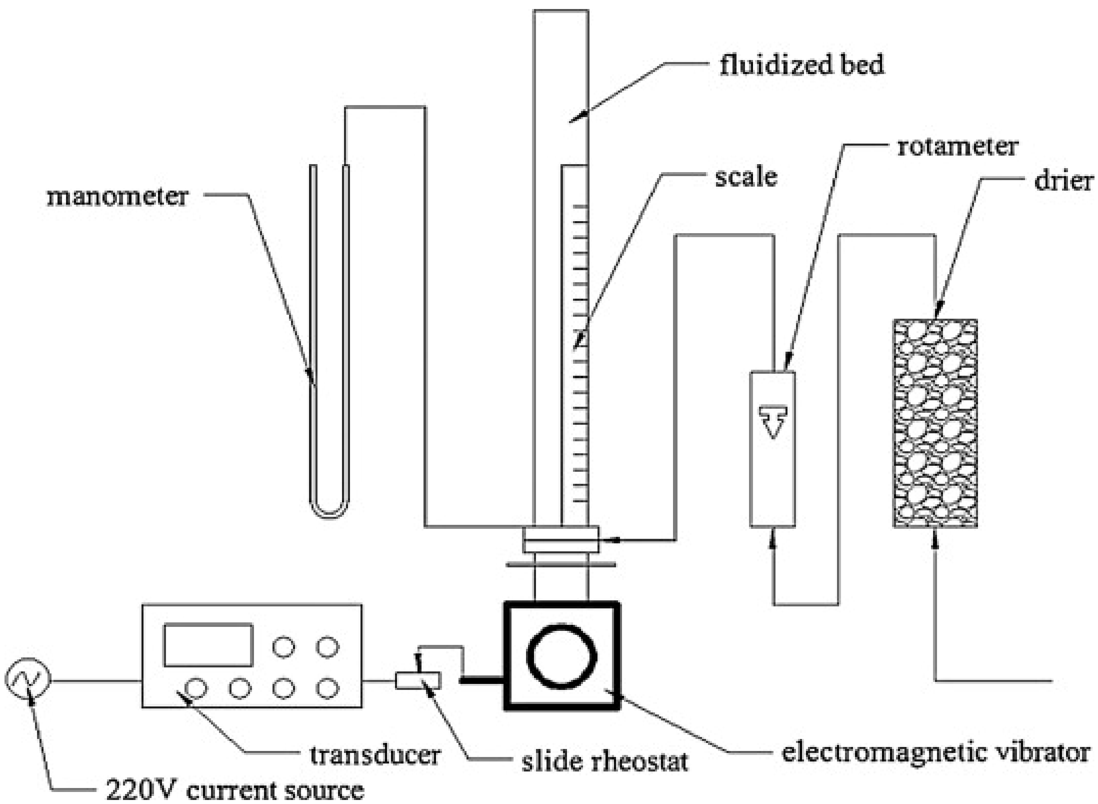
And for large particles

$$V_{m_f} = \frac{d_p^2(\rho_s - \rho_f)g}{24.5\mu_f} \qquad \mathrm{Re}_p \geq 1000$$

Where

V_{m_f}	=	superficial velocity at minimum fluidization
d_p	=	particle diameter
W_S	=	mass of solid in bed
L	=	height of bed
A	=	area of cross section of the bed
μ	=	fluid viscosity
Re_p	=	Reynolds number based on particle diameter
	=	$d_p V \rho_f \big/ \mu$

Schematic



fluidized bed
rotameter
manometer
scale
drier
transducer
slide rheostat
electromagnetic vibrator
220V current source

Observation Table

Sr.No.	Flow Rate (LPM)	Superficial Velocity(Vo) (cm/s)	Bed Height (cm)	Pressure Drop - ΔH (mm-hg)	Pressure drop (ΔP) (Pa)
1.	0.5	0.411	30.4	14	1866.51
2.	1.00	0.823	30.5	18	2399.8
3.	1.50	1.23	31.5	24	3199.74
4.	1.15	0.946	32.4	25	3333.06
5.	2.0	1.645	33.8	26	3466.38
6.	2.25	1.851	34.9	24	3199.74
7.	2.50	2.057	36.5	24	3199.74
8.	3.00	2.468	39.6	23	3066.41
9.	3.35	2.756	42.5	23	3066.41
10.	4.00	3.291	49.9	23	3066.41
11.	4.45	3.661	51.7	23	3066.41
12.	5.00	4.113	57.0	23	3066.41

Given:

Density of water - 1000 kg/m3

Viscosity of water at 20 °C – 1 centipoise

Diameter of the pipe – 2 inch = 5.08cm

Area of cross section of the pipe = $\pi D^2 /4$ = 20.26834 cm

Calculations

Consider the following cases,

$Q_1 = 0.5$ LPM

$Q_2 = 1$ LPM

$d = 2$ inch
$= 2 \times 2.54$ cm
$= 5.08$ cm

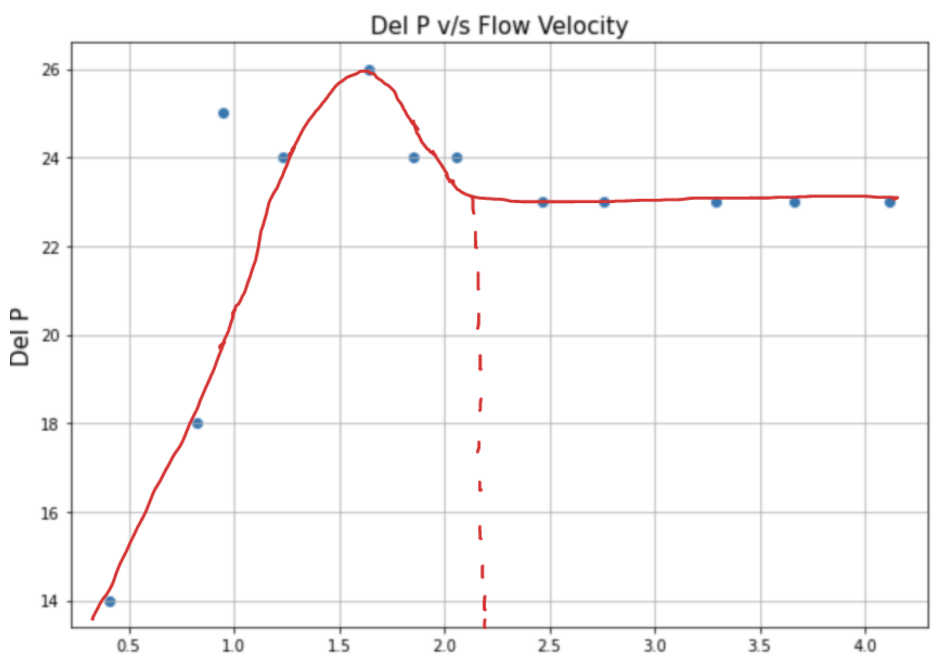
$Q_1 = 16.67\ cm^3/s$
$Q_2 = 8.33\ cm^3/s$

Using $V = \frac{Q}{A}$

$$v_1 = \frac{8.33 \times 4}{\pi \times 5.08^2} = 0.411\ cm/s$$

$$v_2 = \frac{16.67 \times 4}{\pi \times 5.08^2} = 0.82\ cm/s$$

Plot



Flow velocity (cm/s)

The point of fluidization occurs around the range of 2.2cm/s. Hence the fluidization velocity can be approximated to 2.2cm/s.

Packed Bed

Aim:

a) To plot pressure drop per unit length of the packed($\Delta P/L$) vs the Mass velocity of the fluid (G) on a log-log scale.
b) Compare the ΔP values obtained experimentally with the calculated values using Ergun's equation.

Theory

As a fluid passes through the bed, it does so through empty spaces (VOIDS) in the bed. The voids form continuous channels throughout the bed. These channels need not be of the same length and diameter. While the flow may be laminar through some channels, it may be turbulent in other channels. The resistance due to friction per unit length of the bed can be taken as the sum of two terms:

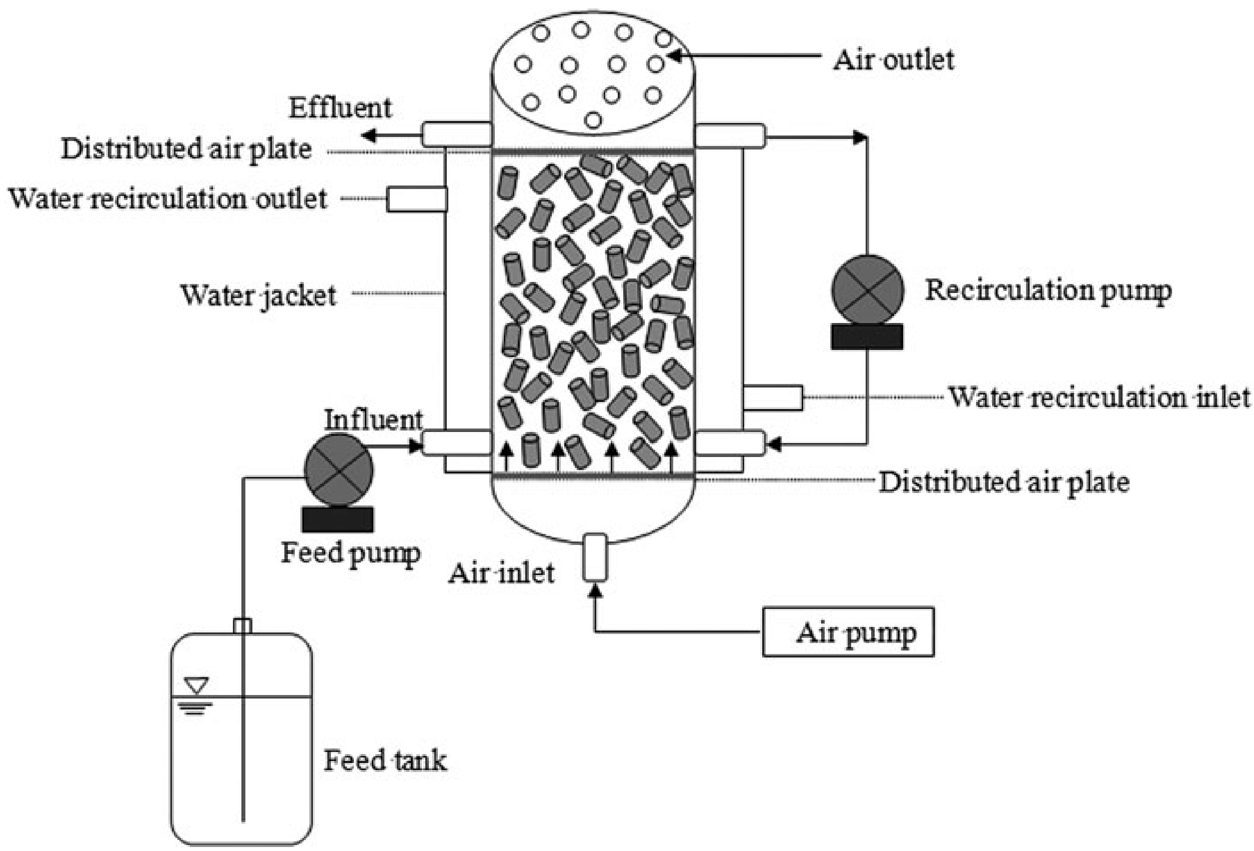
- Viscous drag force which is proportional to the first power of fluid velocity VCH; and
- Inertial forces are proportional to the square of the fluid velocity.

Since V_{CH}, velocity in the channel is difficult to estimate, V_{CH} is substituted by $V\varepsilon$, the velocity through the empty cross-section of the column. $V\varepsilon$ is related to V_{CH} by the expression $V\varepsilon = \varepsilon V_{CH}$, where 'ε' is the BED VOIDAGE or POROSITY. The total surface area of the particles in the bed which come in contact with the fluid is a function of the SPECIFIC SURFACE of the particles, its SPHERICITY and the voids in the bed. Taking all these facts into consideration, equation (1) has been derived to estimate the pressure drop for the flow of fluid through a packed bed.

$$\left(\frac{\Delta P}{\rho L}\right)\left(\frac{\varepsilon^3}{1-\varepsilon}\right)\left(\frac{d_p}{V_\varepsilon^{\,2}}\right) = \frac{150(1-\varepsilon)\mu}{d_p V_\varepsilon \rho_f} + 1.75 = f_p \; = \frac{150(1-\varepsilon)}{(N_{\mathrm{Re}})_P} + 1.75$$

At very low values of (NRe)P the term 150(1-ε)/ (NRe)P is very large compared to 1.75. In other words, viscous drag force predominates. As (NRe)P increases, fp approaches 1.75. For any range of (NRe)P, the total friction loss is additive of resistance due to viscous forces and resistance due to inertial forces.

<u>Schematic</u> :



Observation Table:

Sr.No.	Mass of fluid (Kg)	Time (s)	Flow rate (Kg/s)	Pressure drop Left Limb (cm)	Pressure drop Right Limb (cm)	Pressure drop Difference (cm)	delP/L (Pa/m)	G(Kg/m2-s)
1.	2.25	60	0.0375	10.7	9.9	0.8	55.9498	18.473
2.	5.00	60	0.08333	11.5	9.0	2.5	174.8431	41.051
3.	6.00	60	0.1	12	8.5	3.5	244.7803	49.261
4.	4.00	30	0.133	13	7.5	5.5	384.6547	65.681
5.	5.00	30	0.167	14	6.5	7.5	524.5292	82.102
6.	5.50	30	0.183	15	5.5	9.5	664.4036	90.312
7.	6.00	30	0.2	16	4.5	11.5	804.2780	98.522
8.	6.75	30	0.225	16.5	4.0	12.5	874.2153	110.837
9.	7.00	30	0.233	17	3.5	13.5	944.1525	114.943
10.	7.50	30	0.25	17.5	3.0	14.5	1014.0897	123.153

Values Given:

Length of Packed bed – 37 inch =0.9398 m

Column id – 2 inch=0.0508 m

Weight of packing – 900 g

Volume of empty space – 1275 cm3

Size of packing OD – ¼ inch=0.00635 m=do

Size of packing ID – 3/16 inch=0.0047625 m=di

Packing material type – PVC

Void fraction – 0.67

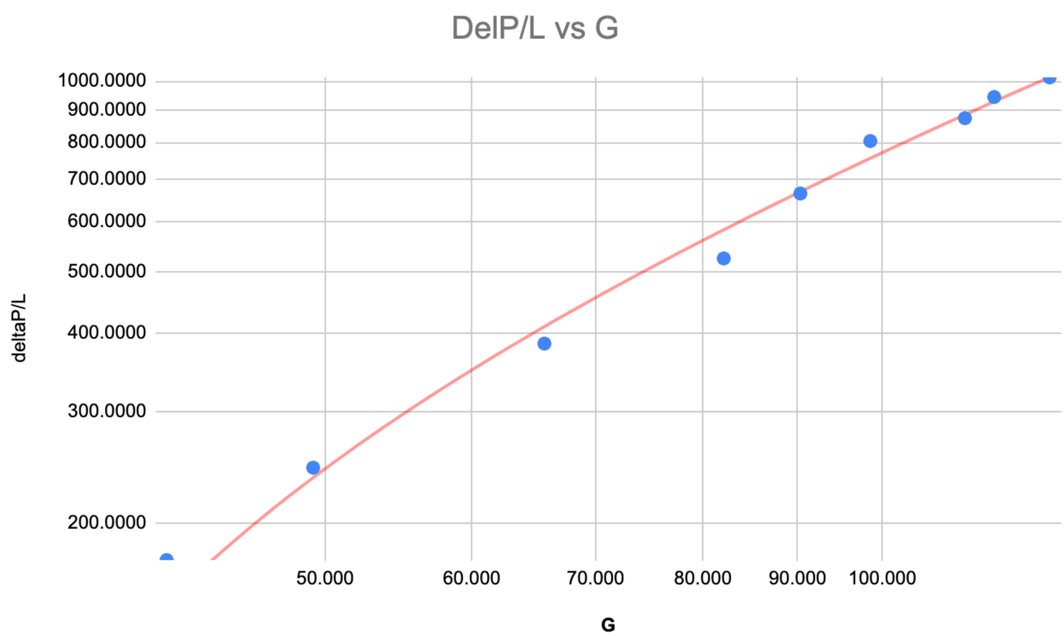
Density of water - 1000 kg/m3

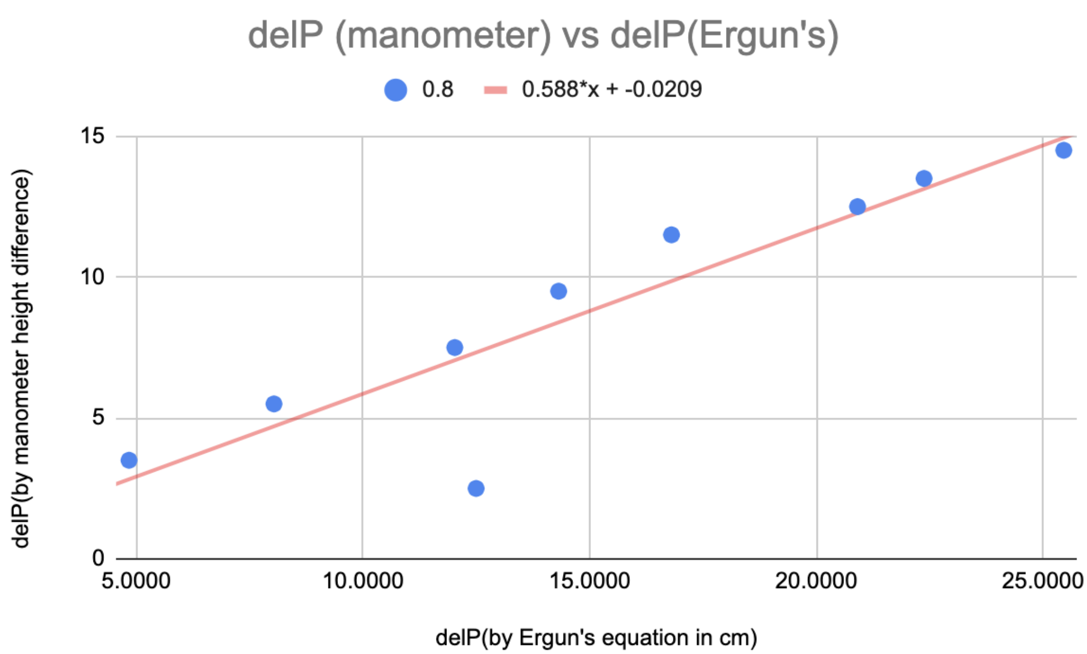
Viscosity of water at 20 °C – 1 centipoise

Calculation Table

Sr.No.	Vε	Modified Re	Friction Factor	ΔP	Pressure drop(in cm) Using Ergun's equation
1.	0.012377	29.4569	3.43042	227.675	3.4640
2.	0.027504	65.4598	2.50619	821.404	12.4972
3.	0.033005	78.5517	2.38016	318.280	4.8425
4.	0.044007	104.7356	2.22262	528.379	8.0390
5.	0.055008	130.9195	2.12809	790.481	12.0267
6.	0.060509	144.0115	2.09372	941.034	14.3173
7.	0.066010	157.1034	2.06508	1104.587	16.8057
8.	0.074261	176.7414	2.03007	1374.293	20.9091
9.	0.077011	183.2874	2.02007	1470.695	22.3758
10	0.082512	196.3793	2.00206	1673.251	25.4576

Plots:


DelP/L vs G
1000.0000
900.0000
800.0000
700.0000
600.0000
500.0000
400.0000
300.0000
200.0000
deltaP/L
50.000
60.000
70.000
80.000
90.000
100.000
G


delP (manometer) vs delP(Ergun's)
0.8
0.588*x + -0.0209
15
10
5
0
delP(by manometer height difference)
5.0000
10.0000
15.0000
20.0000
25.0000
delP(by Ergun's equation in cm)

Calculations:

Q (flow rate) = 0.1833 kg/s

L (length of packed bed) = 37 in

= 0.94 m

μ (Dynamic Viscosity) = 1 cp

= 0.001 kg/ms

ε (void fraction) = 0.67

D_i (inner diameter) = 2 inch = 0.0508 m

ρ (density of water) = 1000 kg/m^3

g = 9.81 m/s^2

Flow rate, $q = \frac{Q}{\rho} = 1.833 \times 10^{-4}$ m^3/s

$V = \frac{q}{A_{cr}} = \frac{1.833 \times 10^{-4} \times 4}{\pi \times 0.0508^2} = 0.0904$ m/s

V_0 (superficial velocity) = $V * \varepsilon$

$= 0.0904 * 0.67$

$= 0.0605$ m/s

$$\frac{S_p}{V_p} = \frac{6}{d_p}$$

where V_p is volume of one particle

S_p is cross sectional area of particle

d_p is effective diameter of particle

d_p = 2.38 mm

$$Re = \frac{\rho V_0 L}{\mu} = 9.72$$

$$Gr_p \text{ (modified reynold's number)} = \frac{Re}{1-\varepsilon} = 29.457$$

$$f_p \text{ (friction factor)} = \frac{150}{Gr_p} + 1.75 = \frac{150}{29.457} + 1.75$$

$$f_p = \frac{\Delta P}{L} \times \frac{d_p}{\rho V_0^2} \times \frac{\varepsilon^3}{1-\varepsilon} = 3.43092$$

$$\Delta P = \frac{f_p * L}{\left(\frac{d_p}{\rho V_0^2} \times \frac{\varepsilon^3}{1-\varepsilon}\right)} = 227.675 \text{ cm}$$

$$\frac{\Delta P \times 100}{(\rho_m - \rho) g} = 3.464 \text{ cm}$$

Result:

1.delP/L is increasing with the increase in G(kg/m2-s).
2.Pressure drop calculated by Ergun's equation is close to what we get from the manometer.
3.The slope of the graph is 0.588.
4.The pressure drop obtained experimentally was 3.464 cm which is close to the calculated value and hence our calculations are verified and Ergun's equation is applicable.

Conclusion:

The values calculated using Ergun's equation and manometer can see from the graph. The slope is close to 1, the error is due to the error in taking the readings. Hence, Ergun's equation is verified.