Paper ID:FM-02

Determination of Maximum Solid Concentration by Using a Fluidized Bed

Md. Fazlur Rahman Akanda[1], Samiuzzaman[2]
[1,2] Department of Mechanical Engineering Bangladesh University of Engineering & Technology, Dhaka-1000, BANGLADESH

E-mail: md.fazlurrahmantonmoy@gmail.com[1], samiuzzaman14@gmail.com[2]

Abstract

Liquid-solid fluidization is characterized by the uniform expansion of bed particles; therefore, it is known as particulate fluidization. In liquid, solid fluidization, there is no bubbling phase that is the main cause of uniform bed expansion. The fluidized bed can be explained as it is a packed bed through which fluid (liquid or gas) flows at a high velocity such that the bed is loosened and the particle fluid mixture acts as a fluid. An experimental investigation has been carried out to estimate maximum solid concentration using a fluidized bed set up. Using this experimental setup pressure drop, superficial velocity, mass flow rate, void fraction- these parameters are measured. Sieve analysis are carried out for particle size distribution. For the measurement of drag for fully fluidized bed of particles and by using force and mass balances of the bed, a reasonable estimate of the maximum solid concentration can be obtained. For the experimental analysis, Ergun equation for flow through a randomly packed bed of spherical particles of diameter x, was used. Pressure drop is a required parameter to determine the energy losses and friction factor which are helpful in predicting the stable flow conditions necessary to efficiently operate the fluidized bed reactor for a given operation. The wall effects are believed to be absent in this situation. Variations in the result has been occurred due to particle size distributions.

Keywords: Fluidization, packed bed, superficial velocity, void fraction.

1. Introduction

An experimental investigation has been carried out to estimate maximum solid concentration and void fraction using a fluidized bed set up. The void fraction or voidage of packed beds of particles of continuous size distributions is of importance in many fields, e.g. for the prediction of pressure drops in packed bed reactors or packed columns, in soil mechanics and reservoir engineering, and for all industries that process or deliver products in powder form such as the metallurgical and ceramic industries, pigment industry, pharmaceutical industry, polymer industry, food and farming industries, etc. The another main application of fluidized bed in slurry pipeline design. In this experiment, we have measured maximum solid concentration from which we can obtain viscosity which is the main parameter of slurry pipeline design.

Fluidization is an operation by which fine solids are transformed into fluid like state with the help of gas or liquid. It is a state of a two-phase mixture of particulate solid material and fluid. It has both physical and chemical operations. The main objectives are to develop an experimental model for determining void fraction and maximum solid concentration and to interpret the effect of fluidization and particle size distribution and to compare the present model against a conventional laboratory method called settling method. Daniel P.Gillies et al [1] studied four methods of determining the maximum solid concentration .Settling bed method is one of them.

Ergun S et al. [2] has developed an equation to calculate the pressure drop, void fraction or voidage of packed bed of particles of continuous size distributions. For our experimental analysis, this Ergun equation for flow through a randomly packed bed of spherical particles of diameter x, was used. The pressure drop caused by the flow of fluid through column packed with granular material has been the subject of theoretical analysis and experimental investigation. This is due to the flow resistance in the packed bed and requires more energy input to maintain a given fluid flow.

For the sake of particle sized distribution [3], we have performed sieve analysis for the purpose of experiment three different sizes of sand particle (1mm,2mm and 3mm) are required which are gained through sieve analysis. Sieve analysis is laboratory test procedure in which particles will move vertically or horizontally through sieve mesh. Depending on the needs and particle material different sieving methods are available for the application. They are manual sieving method, mechanical sieving method, dry sieving method and wet sieving method.

2. Mathematical Formulation

Based on extensive experimental data covering a wide range of size and shape of particles, Ergun (1952) suggested the following general equation for any flow conditions:

$$\frac{\Delta P}{L} = \mathrm{A}\frac{(1-\varepsilon)^2}{\varepsilon^3}\frac{\mu U_0}{(\varphi d_p)^2} + B\ \frac{(1-\epsilon)}{\epsilon^3}\frac{\rho U_0^2}{\varphi d_p} \tag{1}$$

This is known as the Ergun equation for flow through a randomly packed bed of spherical particles of diameter x. Ergun’s equation additively combines the laminar and turbulent components of the pressure gradient. Now rearranging eqn. no.1 for the purpose of determining the value of voidage for the corresponding results in following equation,

$$\Delta P = C_1 U_0 + C_2 U_0^2 \tag{2}$$

Where,

$$C_1 = \mathrm{A}L\,\frac{(1-\varepsilon)^2}{\varepsilon^3}\frac{\mu}{(\varphi d_p)^2} \tag{2a}$$

$$C_2 = B\ L\ \frac{(1-\epsilon)}{\epsilon^3}\frac{\rho}{\varphi d_p} \tag{2b}$$

Once frictional pressure drops, ΔP are measured for different superficial fluid velocities and C1& C2 can be estimated from the data fit, which are then used to calculate voidage and solid concentration literally as follows:

$$\frac{1-\varepsilon}{\varphi} = \left(\frac{C_1}{C_2}\right)\left(\frac{B}{A}\right)\left(\frac{\rho}{\mu}\right) d_p \tag{3}$$

3. Experimental Setup and Methodology

3.1 Experimental Setup

A schematic diagram of the experimental apparatus is shown in Figure 01. A two-dimensional reactor model constructed of glass was used in the experiments. The bed section was 310 mm high and 100 mm outer diameter with a thickness of 5mm. A '100-mesh brass wire screen was used at the base of the two-dimensional bed to support the bed materials. Three auxiliary valves have been used two manually control the flow and control valve 3 had been used to control the inlet and outlet of liquid flow into the bed section. Main valve is connected to the reservoir section and an overflow section had been added in order to maintain the constant head criteria for the ease of experiment. Water was used as manometric fluid in order to measure the pressure drop in the bed section.

3.2 Experimental Procedure of Fluidization Process:

- Loading the bed with sand particles.
- Measuring bed height filled with particles.
- Starting flow of water from storage tank by opening valves through the packed bed.
- Increasing the flow slowly until the bed is at onset of fluidization.

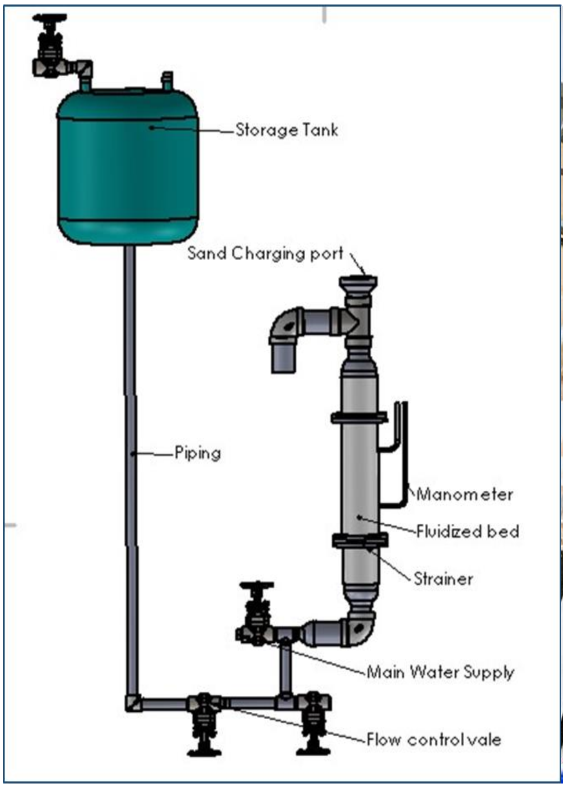


Fig 1: Schematic diagram of experimental setup   Fig 2: Experimental setup of fluidized bed

- Noting the range of variations of the manometric deflection, h..
- Measuring flow rate by collecting a certain amount of water at a specific time.
- Conducting same experiment two times to ensure repeatability.
- Unloading the particle by increasing flow carefully, avoiding overflow in the manometer tubes.

3.2 Experimental Procedure for Conventional Process:

Though Fluidization process for measuring maximum concentration of packed bed is well-known for its accuracy, we've used conventional method of determining porosity by using graduated cylinder. Imbibition method comprises the following steps -

- Filling graduated cylinder with sand sample and drawing a line where sample comes up to
- Noting the bulk volume of sample
- Pouring water slowly and carefully into the cylinder until the water reaches the top of our sample
- Weighing the sample and determining mass difference before and after imbibition
- Obtaining pore volume of sample occupied by water from the mass difference divided by water density
- Calculating porosity from the ratio of pore volume to bulk volume

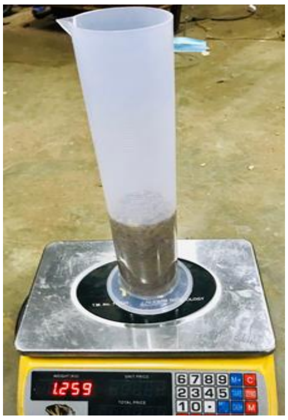
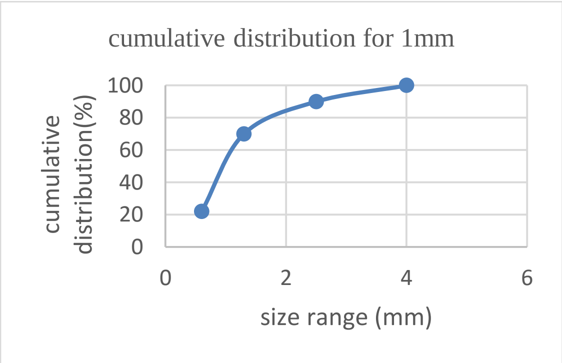


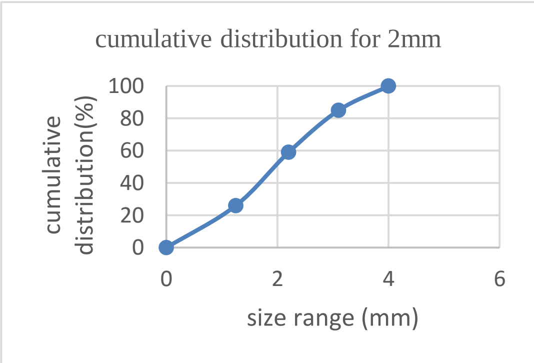
Fig 3: conventional method (Imbibition method)

3.3 Particle Size Distribution (Sieve Analysis):

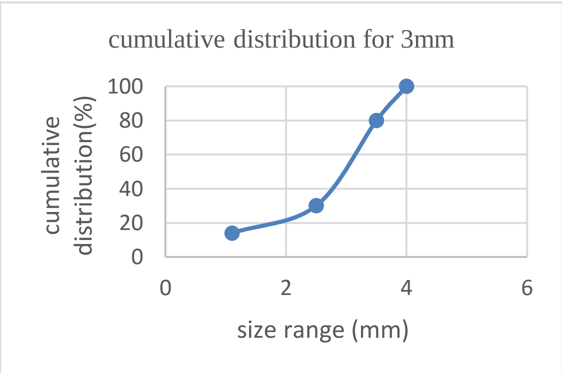
For selecting the bed particle three different sizes of sand particles has been chosen for the purpose of calculation of maximum concentration. For differentiation the size of the particles, sieve analysis had been carried out in Transportation Laboratory and Glass and Ceramics Laboratory in BUET. The following graphs represent cumulative distribution of different size of particles.



(a)



(b)



(c)

Fig 4: Particle size distribution for d_{50}=1mm(a), d_{50}=2mm(b) & d_{50}=3mm(c)

4. Results and Discussion

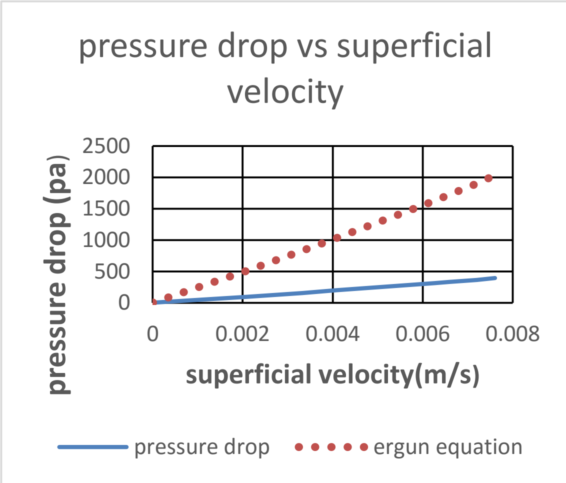


Fig5: pressure drop vs superficial velocity (1mm)

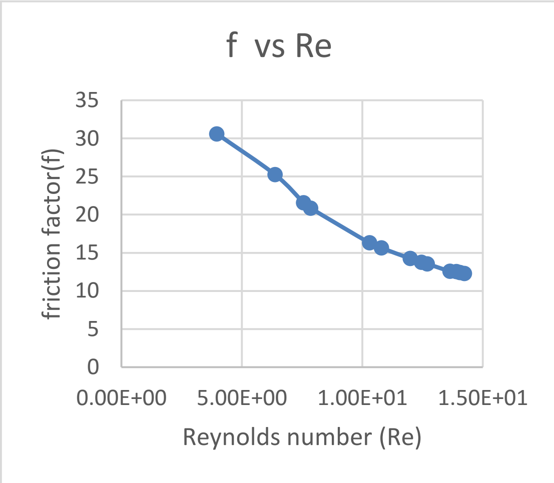
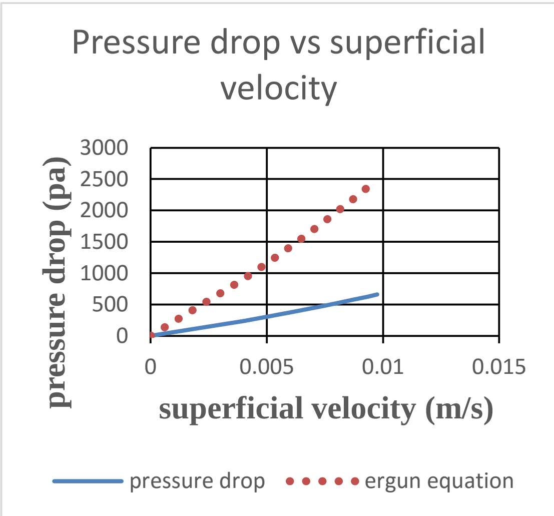


Fig 6: friction factor vs Reynolds number



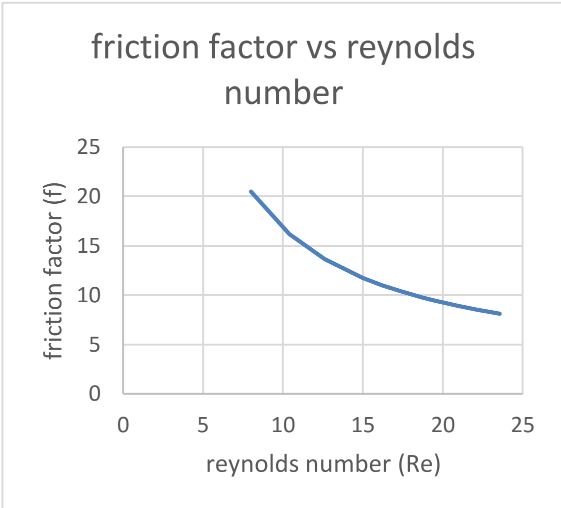


Fig 7: pressure drop vs superficial velocity(2mm) Fig 8: friction factor vs Reynolds number

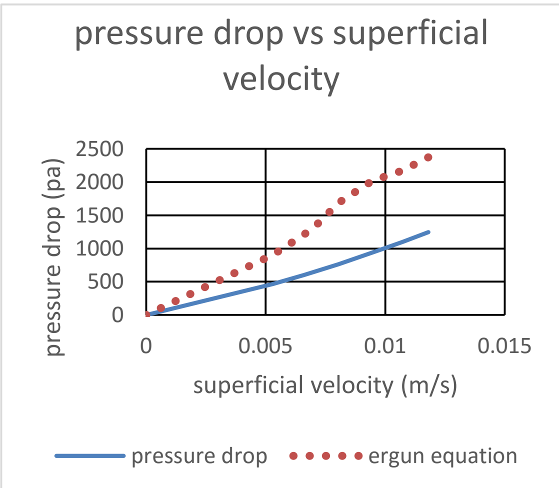


Fig 9: pressure drop vs superficial velocity (3mm)

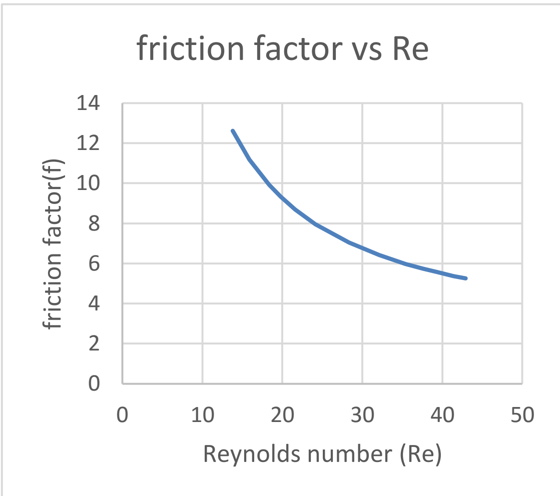


Fig 10: friction factor vs Reynolds number

Table 01: comparison of data obtained from two different experimental procedure

observation	Diameter	Fluidized bed Test	Settled bed Test
1	1mm	0.52	0.51
2	2mm	0.57	0.55
3	3mm	0.61	0.61

In the figure 5,7,9 we have plotted pressure drop vs superficial velocity for three different types (1mm, 2mm, 3mm) of bed particles. In figure 6,8,10 we have plotted friction factor vs Reynolds number. Pressure drop increases with respect to superficial velocity up to a certain point of velocity. After which the bed became fluidized. While Reynold's number is increasing friction factor shows an increasing nature. The superficial velocity U0 has been calculated from the water flow being divided by the cross sectional area of the bed (A= πD2/4). It is found that the higher flow imparts higher drag to the water flow and that system exhibits hysteresis at the higher flows. Drag in the present study deviates significantly from those predicted by Ergun Equation at higher velocities. It is to be admitted that at the higher velocities a creek was observed near the onset of fluidization. This is what is called wall effect. In this study, the ratio of bed to particle diameters (D/d_p) is 25, which negligibly influence the voidage in this study. Therefore, the wall effect [4]is not solely responsible for this deviation. The wall effects are believed to be absent in this situation. The deviation can be explained as the inability of Ergun prediction in this regard. More studies are necessary to look for appropriate model in predicting flow resistance in this situation, which will be useful in predicting the size, shape and concentration of solids in packed bed. Table 01 shows the summary of this experiment showing the comparison of two methods for three different size particles.

5. Conclusion

The obtained result variation for the fluidized bed to the conventional method has been found to be 3.5% in the case of maximum solid concentration. Variation of void fraction is seen 10.42% for mean particle diameter from 1mm to 2mm and 9.3% for mean particle diameter from 2mm to 3mm.

6. References

[1] Gillies, D.P., 2013. Particle contributions to kinematic friction in slurry pipeline flow.

[2] Ergun, S., 1952. Fluid flow through packed columns. *Chem. Eng. Prog.*, *48*, pp.89-94.

[3] Bunte, K. and Abt, S.R., 2001. Sampling surface and subsurface particle-size distributions in wadable gravel-and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. *Gen. Tech. Rep. RMRS-GTR-74. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 p.*, *74*.

[4] Harrison, L.D., Brunner, K.M. and Hecker, W.C., 2013. A Combined Packed‐ Bed Friction Factor Equation: Extension to Higher Reynolds Number with Wall Effects. *AIChE Journal*, *3*(59), pp.703-706.