Study and Experimental Setup of Liquid-Solid Fluidization in Rangsit University

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Abstract. This article explains the basics of fluidization theory and how to construct of liquid-solid fluidization apparatus for the laboratory of the chemical engineering department at Rangsit University. The minimum fluidization velocity of solid particles (calculate from the Ergun equation) is essential for the effective operation and design of fluidized beds. All Chemical engineers need to learn about this technique to apply to the mixing processes, drying process, leaching, and washing processes. In this paper, the apparatus of a fluidized bed constructed with three different diameters of the column; that was 2.7, 5.4, and 10 cm, respectively. The three different diameters of round glass bead were a solid phase; that was 2, 3, and 4 mm, respectively. The parameter in the fluidized bed was the minimum fluidization velocity ($U_{mf}$). This paper describes the experimental investigation of the liquid-solid fluidized bed. The pressure drops across the fluidized bed measured at a different liquid flow rate. The data analyzed by the graphical method. It found that the minimum fluidization velocity increases with increasing particle size, the height of the bed, and decreasing particle sphericity.

Keywords: liquid-solid fluidization; fluidization; minimum fluidization velocity

Introduction
Fluidization is a process in which solids are caused to behave like a fluid by blowing gas or liquid upwards through the solid-filled reactor. (Dechsiri, C. 2004). There are widely used in the processing industries, for example, in fluidized catalytic cracking units for the production of high-octane gasoline, (A.W. Peters, et al. 2009), heating units for continuous-flow paddy dryer, and fluidized bed drying on quality of waxy rice (Jaiboon, P. 2009), liquid-solid circulating fluidized bed for continuous protein recovery protein recovery (Jahirul Mazumder, et al. 2010). The best advantages are that the particles are mixed well, continuous flow processing, the best heat transfer and suitable for small and large scale operations. Then it is necessary for Chemical engineering to learn and step up technologies. The objective of a paper was to construct of liquid-solid fluidization apparatus for the laboratory of the chemical engineering department at Rangsit University.

There are many steps of regimes of fluidization, as shown in Figure 1. When the velocity of liquid passed through a bed of particles is slowly continually, the particles are still not moving as the bed at rest. This step is called a fixed bed (Figure 1a). With increasing the velocity of the liquid, the particles start moving where the drag force equals the weight of particles. This step is called the minimum fluidization (Figure 1b). At this point, the velocity is called a minimum fluidization velocity; $U_{mf}$. After this time, where the speed of the liquid increased, the formation of fluidization bubbles sets. (Figure 1c). At this step, a bubbling fluidized bed occurs. The fluid velocity still increased; the size of bubbles may become almost as big the same as the diameter of the bed. This step is called slugging. (Figure 1d). If the liquid velocity increased exceeds the terminal velocity, the particle bed under this
condition called a turbulent bed, as shown in Figure 1e. With further increases in gas velocity, eventually, the fluidized bed becomes an entrained bed in which we have to disperse, dilute, or lean phase fluidized bed, which amounts to pneumatic transport of solids. (Figure 1f)

In the case of design and construction of Fluidization, the fluidized bed depended on minimum fluidization velocity, particle size, and particle shape and particle density. If there are irregular particle size and shape, so the shape factor or sphericity be able to find from the equation below. (Olajide and Ade-Omowaye, 1999)

\[
\phi = \left[ \frac{\pi}{6} abc \right]^{1/3}
\]

Where \( \phi \) is a shape factor, \( a, b, \) and \( c \) are a side of a particle.

When the particles packed into the fluidized bed column, the void or particle porosity effect for fluidization, the equation was shown below.

\[
\varepsilon = 1 - \frac{m_p}{\rho_p LA}
\]

Where \( \varepsilon \) is the void or particle porosity of particles in the fixed bed (dimensionless), \( m_p \) is the particle mass (kg), \( \rho_p \) is the particle density (lb/ft\(^3\)), \( L \) is the height of particle in the fixed bed (ft), and \( A \) is the cross-section area of particle bed in the fixed bed (ft\(^2\)).

When the liquid slowly passed through the fixed bed particles at a constant flow rate, the height of the particle bed in all cross-section areas was not changed. The void of particles called minimum fluidization void; \( \varepsilon_{mf} \).

\[
\varepsilon_{mf} = \frac{(L - L_0)}{L} = 1 - \frac{L_0}{L}
\]

From the relationship between the fixed bed and fluidized bed, the minimum fluidized bed height could find from the equation below.
\[ L_{mf} = L_0 \frac{(1 - \varepsilon)}{(1 - \varepsilon_{mf})} \]

Where \( \varepsilon_{mf} \) is the void of the minimum fluidization (dimensionless), \( L_{mf} \) is the particle height of the minimum fluidization (ft), \( L \) is the particle height of the fluidized bed (ft), \( L_0 \) is the particle height of the fixed bed (ft).

The minimum fluidization velocity \( (u_{mf}) \) defined as the superficial fluid velocity at which the weight of the particles in the bed becomes equal to the buoyancy force of the upward moving fluid. The minimum fluidization velocity calculated from Ergun’s equation:

\[ \frac{\Delta P}{L} = \frac{150(1 - \varepsilon_{mf})\mu_f U_{mf}^2}{\varepsilon_{mf}^3 \phi^2 d_p^2} + \frac{1.75(1 - \varepsilon_{mf})\rho_f U_{mf}^2}{\varepsilon_{mf}^3 \phi d_p 2} \]

Where \( \Delta P \) is the pressure drop between the fluidized bed columns (lbf/ft^2), \( \rho_f \) is the density of the fluid (lb/ft^3), \( d_p \) is the diameter of the particle, \( \mu \) is the viscosity of the fluid.

**Experimental and Procedure**

Refer to the purpose of this paper; the liquid-solid fluidization apparatus was designed, fabricated, as shown in Figure 2. The liquid-solid fluidization apparatus consists of four fluidized bed columns with 2.7 cm, 5.4 cm, and 10 cm (for 2 columns) of acrylic diameter columns respectively, all 100 cm height. The water acts as a liquid phase, and the 2 mm, 3 mm, and 4 mm of glass beads are act as a solid phase in the fluidization apparatus.

The lab-scale fluidized bed was used to measure the minimum fluidization of three size diameter of the glass beads under a different water flow rate. The variables are the particle sizes, the height of the bed, and the liquid flow rate. The manometer was used to measure the pressure drop. The Rotameter was used to measure the water flow rate.

A summary of parameters related to the experiment shown in Table 1.

**Fig. 2 Drawing of Fluidization apparatus**

| Table 1. Property of solid particle |
|-----------------------------------|

| Solid particle |     |     |     |     |     |     |     |     |     |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|

3
| Gas bead diameter (mm) | 2  | 3  | 4  |
|------------------------|----|----|----|
| Gas bead density (g/cm³) | 2.37 | 3.44 | 2.58 |
| Shape factor           | 1  | 1  | 1  |

After putting glass bead particles into the fluidized bed apparatus, the water flow rate was increased slowly until the turbulent bed regime was reached. The pressure drop and water flow rate were measured. The different particle sizes were following by this procedure.

**Result and Discussion**

The lab-scale fluidization was built for the laboratory of the chemical engineering department at Rangsit University, as shown in Figures 3 and 4. All four fluidized bed columns made with 2.7 cm, 5.4 cm, and 10 cm (for 2 columns) of acrylic diameter cylinders respectively, and 100 cm height. (1). The two Rotameters for measuring the water flow rate. (2). A carbon tetrachloride manometer was for measuring the pressure drop between beds. (3). The 200 L of the cylindrical tank was for water reserve. (4).

![Fig. 3 The lab-scale fluidization](image1)

For the different glass beads, the 10 cm, 5.4 cm, and 2.7 cm of the diameter of the column, respectively, as shown in Fig 5, 6, and 7. It found that the minimum fluidization velocity increases with increasing particle size. If the particle size increases, that means the weight and the density...
increases too. That means the buoyancy force or drag force increased too. For this reason, the minimum velocity increase.

Fig 7. The relationship between water flow rate and pressure drop for the different glass beads at 2.7 cm diameter of the column, the 2 mm of glass beads at the 2.7 cm of the diameter of the column could not get the minimum fluidization velocity due to the high velocity of the water. The glass bead particles were in pneumatic transport regimes. The minimum fluidization velocity of the different glass bead particles and the green bean have shown in Table 2.

![Graph](image1)

**Fig 5.** The relationship between water flow rate and pressure drop for the different glass beads at 10 cm diameter of the column

![Graph](image2)

**Fig 6.** The relationship between water flow rate and pressure drop for the different glass beads at 5.4 cm diameter of the column
Fig 7. The relationship between water flow rate and pressure drop for the different glass beads at 2.7 cm diameter of the column

Table 2. The minimum fluidization velocity of the different diameter of glass beads

| The diameter of column (cm) | The minimum fluidization velocity (ft/s) |
|-----------------------------|------------------------------------------|
| Glass bead size (mm)        | 2     | 3     | 4     |
| 10                          | 0.0593| 0.0912| 0.1209|
| 5.4                         | 0.0376| 0.0904| 0.1054|
| 2.7                         | 0.0191| 0.0484| 0.1345|

Fig 8. The relationship between water flow rate and pressure drop for the 3 mm of glass beads at 10 cm diameter of the column with the different height. It found that the minimum fluidization velocity increases with increasing the height of the bed. Because of the height of the bed increases, the volume, and the weight increased. So that a drag force increase to make it equal to the weight. The minimum fluidization velocity increased too.

Fig 8. The relationship between water flow rate and pressure drop for the 3 mm of glass beads at 10 cm diameter of the column with the different height

Conclusion
This paper was constructed the lab-scale liquid-solid fluidization apparatus for the laboratory of the chemical engineering department at Rangsit University. Also, determined the minimum fluidization velocity for the 2 mm, 3 mm, 4 mm of glass bead particles respectively at the different diameter of the fluidization column and tested the experiment; It found that the minimum fluidization velocity increases with increasing particle size, the height of the bed.

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