# CHAPTER I
# INTRODUCTION

## 1.1 Background

Fluidization is one method of contacting solid particles with a fluid (gas or liquid). An illustration of fluidization can be observed in a vessel where a solid particle in the form of a sphere is placed in a bed, and then gas is flowed through it in an upward direction. At sufficiently low flow rates, the particles remain stationary. This phenomenon is referred to as a stationary bed or fixed bed. As the flow rate is increased, the solids in the bed gradually become suspended. In this suspended state, the bed exhibits properties similar to those of a high-viscosity fluid, exhibiting a tendency to flow and possessing hydrostatic properties. This phenomenon is referred to as a fluidized bed.

## 1.2 Problem Statement

This experiment will investigate the effect of changes in fluid superficial velocity on pressure changes and on changes in stack height.

## 1.3 Practicum Objectives

1. To determine and measure parameters in fluidization events, namely particle density, porosity, and fluid bed height.
2. To determine fluidization characteristic curves and the relationship between pressure drop and flow rate.
3. To explain the phenomena that occur during fluidization operations.
4. To understand how fluidization experimental equipment works.
5. To prepare a fluidization laboratory report.

## 1.4 Practicum Benefits

1. Students are able to determine and measure parameters in fluidization events, namely particle density, porosity, and fluid bed height.
2. Students are able to determine fluidization characteristic curves and the relationship between pressure drop and flow rate.
3. Students are able to explain the phenomena that occur during fluidization operations.
4. Students are able to understand how fluidization experimental equipment works.
5. Students are able to prepare a fluidization laboratory report.

# CHAPTER II
# LITERATURE REVIEW

## 2.1 Definition of Fluidization

Fluidization is used to explain or describe one way of contacting solid particles with a fluid (gas or liquid). As an illustration of what is called fluidization, let us consider a vessel in which a number of spherical solid particles are placed to form a bed that will be flowed through by gas in an upward direction. At sufficiently low flow rates, the solid particles remain stationary. This condition is referred to as a stationary bed or fixed bed. If the gas flow rate is increased, a state is reached where the solid bed becomes suspended within the gas flow passing through it. In this suspended state, the bed exhibits properties similar to those of a high-viscosity fluid. For example, there is a tendency to flow and exhibit hydrostatic properties. This state is referred to as a fluidized bed.

The fluidization phenomenon occurs when a fluid flow passes through the bed particles in a tube, causing the flow to exert a drag force on the particles. When this force exceeds the gravitational force and interparticle forces, the particles are lifted, reducing airflow resistance and causing a pressure drop along the bed particles.

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## 2.2 Pressure Drop

The main aspect to be examined in this experiment is to determine the magnitude of pressure drop in the bed, which is quite important because it is closely related to the amount of energy required and can also provide an indication of the behavior of the bed during operation. The mathematical correlation describing the relationship between pressure drop and fluid flow rate within a bed system is obtained through several semi-empirical methods using dimensionless numbers.

For laminar flow, where energy loss is primarily caused by viscous losses, Blake provides the following relationship:

$$\frac{\Delta P}{L} \times gc = \frac{k.\mu.s^2}{\varepsilon^3} \times V \tag{2.1}$$

dP/L : Pressure loss per unit height or length of the bed

gc : Conversion factor

$\mu$ : Fluid viscosity

$\varepsilon$ : Bed porosity defined as the ratio of the volume of empty space within the bed to the volume of the bed

V : Superficial fluid flow velocity

s : Specific surface area of the particle

The specific surface area of particles (surface area per unit volume of the bed) is calculated based on the following correlation:

$$s = \frac{6(1-\varepsilon)}{d_p} \tag{2.2}$$

So equation (2.1) becomes:

$$\frac{\Delta P}{L} \times gc = \frac{36\ k.\mu.(1-\varepsilon)^2}{{d_p}^2.\varepsilon^3} \times u \tag{2.3}$$

or:

$$\frac{\Delta P}{L} \times gc = \frac{k'.\mu.(1-\varepsilon)^2}{{d_p}^2.\varepsilon^3} \times u \tag{2.4}$$

Equation (2.4) was then further derived by Kozeny (1927) by assuming that the solid mass is equivalent to a set of straight channels whose particles have a total internal surface area and total volume equal to the external surface area and volume of empty space of the particles. The value of the constant $k'$ obtained by several researchers differs slightly, for example:

Kozeny (1927) $k' = 150$

Carman (1937) $k' = 180$

US Bureau of Munes (1951) $k' = 200$

For turbulent flow, equation (2.4) can no longer be used, so Ergun (1952) then derived another formula in which pressure loss is described as a relationship between viscous losses and kinetic energy losses.

$$\frac{\Delta P}{L}.gc = \frac{k_1.\mu.(1-\varepsilon)^2}{{d_p}^2.\varepsilon^3}.u + \frac{k_2(1-\varepsilon)}{\varepsilon^3}.\frac{\rho g}{d_p}.u^2 \tag{2.5}$$

Where:

$k_1 = 150$

$k_2 = 1{,}75$

At extreme pressures, namely:

1. Laminar flow (Re = 20), so term II can be ignored
2. Turbulent flow (Re = 1000), so term I can be ignored

## 2.3 Fluidized Bed

For fluidized beds, the equation describing pressure drop is Ergun's equation, namely:

$$\frac{\Delta P}{L}.gc = \frac{150.(1-\varepsilon_f)^2}{{d_p}^2.{\varepsilon_f}^3}.u + \frac{1{,}75(1-\varepsilon_f)}{\varepsilon_f}.\frac{\rho g}{d_p}.u^2 \tag{2.6}$$

Where $\varepsilon_f$ is the porosity of the bed in a fluidized state. In this state, the solid particles appear to float in the fluid because there is an equilibrium between the weight of the particles and the gravitational force and buoyancy force of the surrounding fluid.

The gravitational force acting on a particle in an ascending fluid is the difference between the particle's weight and the buoyant force it receives. Mathematically, this can be expressed as follows:

$$\begin{bmatrix}\text{pressure}\\ \text{loss in the}\\ \text{bed}\end{bmatrix}\begin{bmatrix}\text{cross} - \text{sectional}\\ \text{area}\end{bmatrix} = \begin{bmatrix}\text{bed}\\ \text{volume}\end{bmatrix}\begin{bmatrix}\text{solid}\\ \text{density}\end{bmatrix} - \begin{bmatrix}\text{fluid}\\ \text{density}\end{bmatrix}$$

$$[\Delta P][A] = (A.L)(1-\varepsilon_f)(\rho_p - \rho_f)\frac{g}{gc} \quad (2.7)$$

$$\frac{\Delta P}{L} = (1-\varepsilon_f)(\rho_p - \rho_f)\frac{g}{gc} \quad (2.8)$$

## 2.4 Minimum Fluidization Velocity

Superficial velocity is one of the important factors in fluidization. Particles will remain stationary if the superficial velocity is low. The minimum fluidization velocity (Umf) is the minimum superficial velocity of the fluid at which the fluid begins to move upward. The value of Um can be obtained by combining Equation (2.6) with Equation (2.8).

$$\frac{150(1-\varepsilon mf).\rho_g}{\varepsilon mf.\mu}.umf + \frac{1{,}75 d_p{}^2}{\varepsilon mf^3 \mu^2}.\varepsilon mf^2 = \frac{d_p{}^3.\rho_g(\rho_s - \rho_g)g}{\mu^2} \quad (2.9)$$

For extreme conditions, namely:

1. Laminar flow (Re = 20) minimum fluidization velocity is:

$$umf = \frac{d_p(\rho_s - \rho_g)}{150.\mu}.g.\varepsilon mf \quad (2.10)$$

2. Turbulent flow (Re = 1000) minimum fluidization velocity is:

$$umf = \frac{d_p(\rho_s - \rho_g)}{1{,}75.\mu}.g.\varepsilon mf \quad (2.11)$$

## 2.5 Characteristics of Fluidized Beds

The characteristics of fluidized beds are usually expressed in a graph showing the relationship between pressure drop (ΔP) and fluid superficial velocity (U). Under ideal conditions, this relationship curve is as shown in Figure 2.1.

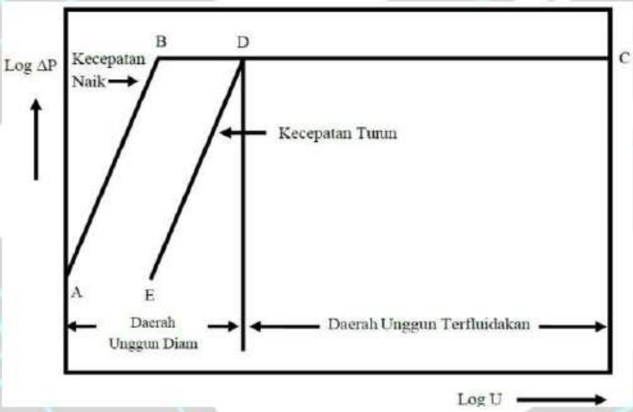


Figure 2.1 Relationship between pressure drop and superficial fluid velocity

Explanation:

Line AB : Shows pressure loss in the stationary bed area.

Line BC : Shows the condition where the bed has been fluidized.

Line DE : Shows the pressure loss in the stationary bed region when we reduce the fluid flow velocity. The pressure drop value for a specific fluid flow velocity is slightly lower than the pressure drop value at the start of operation.

## 2.6 Types of Fluidized Bed

### 2.6.1 Gas–Solid Fluidized Bed

A gas–solid fluidized bed is a phenomenon in which solid particles are suspended in a gas flow and behave like a fluid. This process occurs when the gas velocity exceeds the minimum fluidization velocity (Umf), so that the drag force of the gas is able to counterbalance the effective weight of the particles. Under these conditions, the solid bed expands, porosity increases, and particles undergo random motion due to collisions between particles and interactions with gas bubbles. This system is widely used in particle separation based on density.

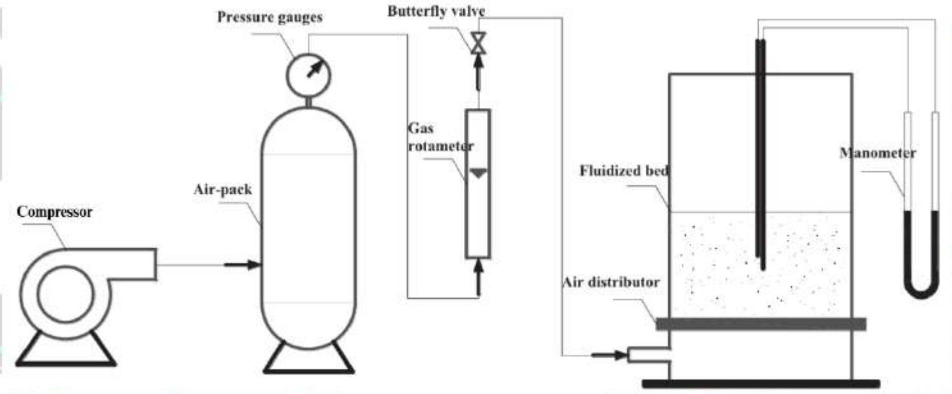


Figure 2.2 Schematic diagram of the gas-solid process system in a fluidized bed reactor

In this gas fluidization process, pressurized air is generated by a compressor and then fed into an air pack, which stores and stabilizes the air supply before it enters the column. Next, the gas flow rate is regulated using a butterfly valve and measured with a gas rotameter to ensure that operating conditions are within the target range. This controlled air is then directed to the air distributor at the bottom of the column, which evenly distributes the flow to prevent channeling. Within the fluidized bed, solid particles such as powder are fluidized by the air flow, forming a fluid-like mixture that enables separation based on density. Throughout the process, pressure gauges monitor the air pressure, while manometers measure the pressure difference at various points in the bed.

### 2.6.2 Liquid–Solid Fluidized Bed

A liquid–solid fluidized bed is a condition in which solid particles are suspended and move freely within a liquid fluid flow due to the buoyancy force generated by the fluid exceeding the effective weight force of the particles, causing the bed to behave like a viscous fluid. In a Liquid–Solid Fluidized Bed (LSFB) system, the liquid fluid used is typically water or a specific solution, while the solid phase can consist of single particles or a mixture of two types of particles (binary particles) with differences in size, density, or shape.

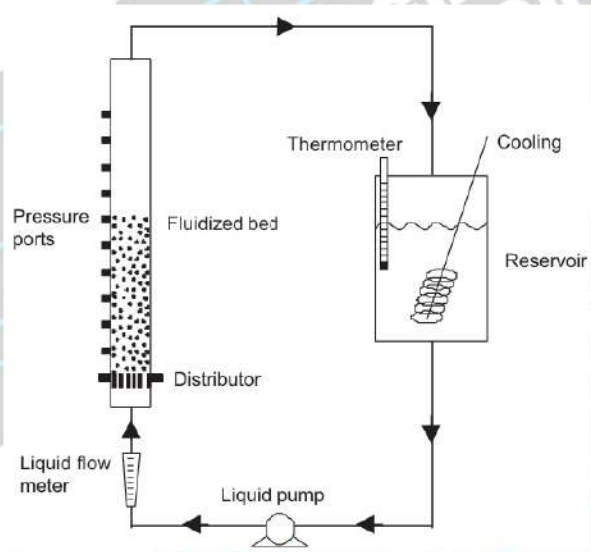


Figure 2.3 Schematic diagram of the liquid-solid process system in a fluidized bed reactor

In this liquid fluidization process, water is stored in a reservoir equipped with cooling coils to maintain a constant temperature and a thermometer to monitor the temperature. From the reservoir, the liquid is pumped to the fluidization column through a flow meter that measures the flow rate of the incoming fluid. At the bottom of the column, there is a distributor in the form of a perforated plate that distributes the fluid flow evenly to prevent the formation of jet flow zones. When the flow rate exceeds the minimum fluidization velocity (Umf), the particles become suspended and the bed expands. Along the column, there are several pressure ports used to measure pressure drop and calculate the bed voidage value. After passing through the column, the fluid flows back to the reservoir, forming a closed-loop circulation system.

## 2.7 Heterogeneous Fluidization (Aggregative Fluidization)

When solid particles are completely separated but grouped together to form an aggregate, this condition is called heterogeneous fluidization (aggregative fluidization). Three types of fluidization commonly occur due to the occurrence of:

a. Bubbling
b. Slugging
c. Separate fluid channels (channeling)

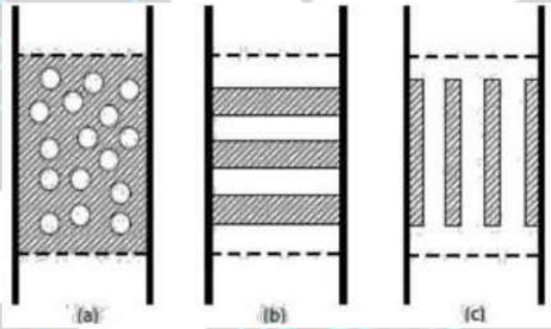

Figure 2.4 Three types of heterogeneous fluidization

# CHAPTER III
# METHODOLOGY

## 3.1 Experimental Design

### 3.1.1 Practicum Framework

Measuring particle height in a column

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Measuring P and pile height in a column containing solids

↓

Varying the fluid flow rate using a flowmeter

Figure 3.1 Practical design scheme

### 3.1.2 Variable Determination

A. Constant Variable

| | |
|---|---|
| Particle Type | : Resin |
| Initial Bed Height | : |

B. Independent Variable

| | |
|---|---|
| Fluid Flow Rate | : |

## 3.2 Materials and Equipment Used

A. Materials Used

Solid particles: Resin

B. Equipment Used

1. Fluidization column
2. compressor
3. flowmeter
4. Pressure gauge
5. Ruler
6. Vernier caliper

### 3.3 Equipment Setup

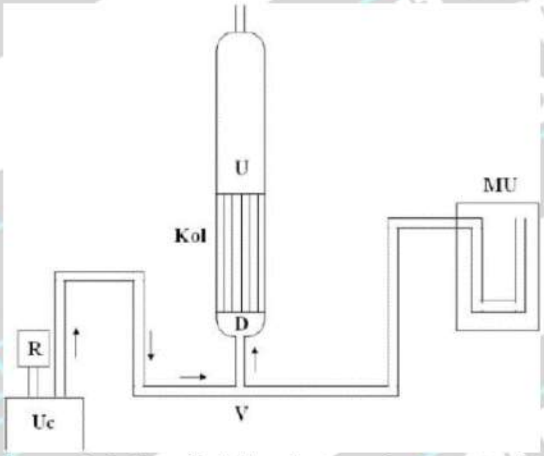


Figure 3.2 Gas fluidization equipment series

Description:

D = Distributor (grid)

U = Solid particle bed

Kol = Fluidization column

Uc = Compressed air

R = Flowmeter

MU = Pressure gauge

V = Valve


Figure 3.3 Liquid fluidization equipment series

Description:

1 = Reservoir

2 = Liquid pump

3 = Flowmeter

4 = Distributor

5 = Fluidization column

### 3.4 Response

Pressure drop ($\Delta P$) of air passing through the column is measured at each different flow rate.

## 3.5 Required Data

1. Pressure on the pressure gauge
2. Height of the pile (bed)

## 3.6 Practicum Procedure

### 3.6.1 Gas Fluidization

1. Plug the compressor cable into the power outlet and wait until the compressor is full.
2. Measure the diameter of the fluidization tube with a vernier caliper.
3. Measure the height of the stationary bed with a ruler.
4. Turn on the compressor and adjust the flow rate according to the variable.
5. Measure ΔP and the height of the bed in the column containing solids for different fluid flow rates.
6. The fluid flow rate is varied using a flowmeter from low speed until no further difference in height is observed on the pressure gauge. The fluid flow rate is then slowly reduced until the bed becomes stationary again.

### 3.6.2 Liquid Fluidization

1. Insert the liquid fluid into the reservoir tank.
2. Measure the diameter of the fluidization tube using a vernier caliper.
3. Turn on the liquid fluidization device and adjust the flow rate according to the variables.
4. Measure ΔP and the height of the bed in the column containing solids for different fluid flow rates.
5. The fluid flow rate is varied using a flowmeter from low speed until no further difference in height is observed on the pressure gauge. The fluid flow rate is then slowly reduced until the bed becomes stationary again.

## 3.7 Experiment Result Matrix

Table 3.1 Experiment result matrix

| Q | Height of Bed (cm) | | ΔP | |
|---|---|---|---|---|
| | Up | Down | Up | Down |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

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