

Fluidization

Introduction

During the flow of fluid (gas or liquid), called a *continuous phase*, through a layer of solid material (bed), called a *dispersed phase*, a few stages of different bed behavior can be distinguished for various continuous phase velocities. These include [1]:

- ⤴ stationary layer – occurs at the lowest velocities. The loose material layer remains stationary with respect to itself and to appliance walls. Pressure drop in the bed increases as the velocity rises.
- ⤴ fluidized bed (boiling, pseudo-liquid) as the fluid velocity increases to a certain critical value, called *lower critical fluidization velocity, or minimum fluidization velocity* (w_{k1}) the bed undergoes a small expansion. With further velocity increase, the bed passes to the fluid state, which is characterized by the changes of particles' positions relative to each other and to appliance walls. As the fluid velocity rises, the pressure drop remains virtually constant.
- ⤴ pneumatic transport – occurs when fluid velocity increases to values higher than the so called *higher critical fluidization velocity* (w_{k2}). Particles forming the bed are carried away from the appliance.

Fluidization is therefore a process, in which the bed of solid material is maintained in a pseudo-fluid state. A characteristic feature of this state is the intense circulation and mixing caused by the flow of gas (gas fluidization) or liquid (liquid fluidization) through the bed. The liquid-like nature of the fluidized bed enables high heat and mass transfer rates between the gas phase and the solid phase. As a result many applications for fluidization are utilized. The three-phase fluidization, in which the gas, solid and liquid phases are present is also possible. Fluidization begins, when the fluid velocity increases above the lower critical fluidization velocity, in which the overpressure of the fluid exceeds the static pressure (weight) of the bed. In the inhomogeneous fluidization range, which is characterized by high irregularity in location of the solid phase particles in bed and large pressure and porosity fluctuations, we can distinguish bubble fluidization, plug fluidization (pulsating bed), tubular fluidization or fountain-like fluidization [2]. Examples of the non-homogeneous beds are shown in Fig. 1.

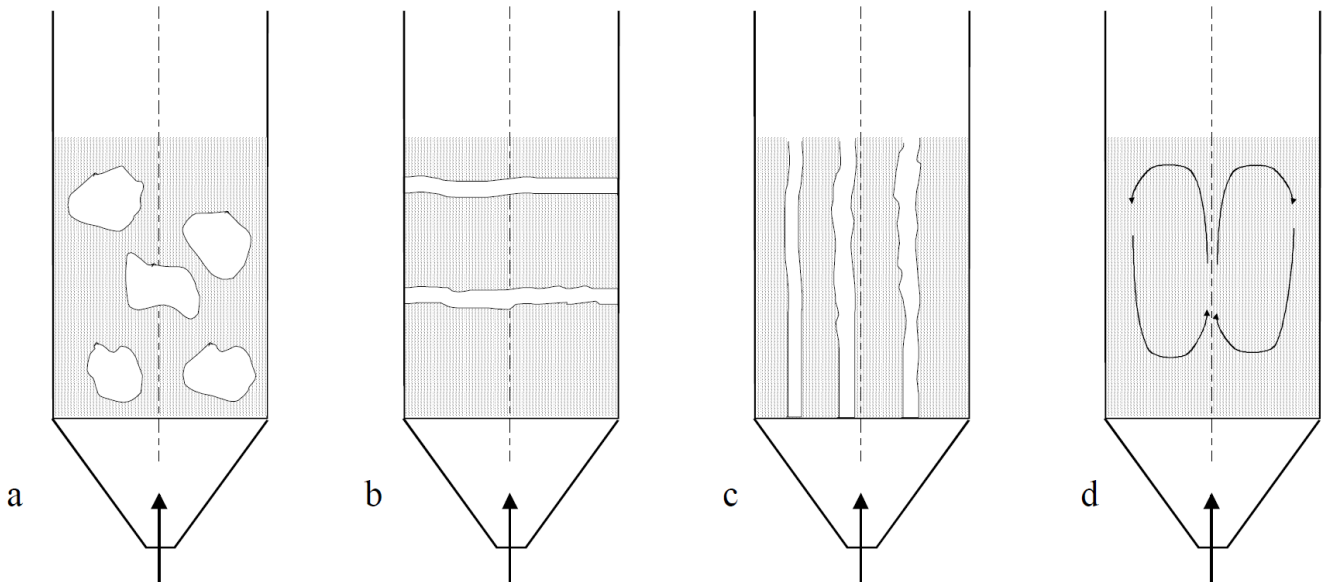


Fig. 1. Examples of inhomogeneous fluidized beds; a, bubbling bed, b. slugging fluidization; c, channelling fluidization; d, fountain fluidization

The parameters deciding about the layer movement (and also of the w_{k1} and w_{k2} values) are: average gas flow velocity, diameter of bed material grain particles (usually that is the representative diameter which is frequently given as Sauter mean diameter), density of material particles, physical properties (kinematic viscosity, density, temperature, pressure), porosity of the bed (volume fraction of fluid phase) [3].

Lower and upper critical fluidization velocities can be calculated from empirical formulae, but due to a number of simplifications, it is advisable to determine them experimentally. The constant pressure drop in the bed, which is characteristic for fluidized bed hydrodynamics, is used to determine the lower critical velocity w_{k1} . Figure 2 shows changes in the pressure drop Δp resulting from flow resistance in the bed as fluid velocity through the bed increases. As can be seen, increasing the flow rate of the fluid through the stationary bed increases the flow resistance and by this, increases the pressure drop. Once the overpressure exceeds the bed's static pressure ($w = w_{k1}$), small layer expansion occurs. As the fluid velocity keeps rising, the layer turns into a fluid state.

In the transition area from the stationary layer state to the fluidized bed a hysteresis occurs, due to the segregation and grain reorientation. As the fluid flow rate decreases, the characteristic hump is not observed, as shown by the dashed line. The lower critical fluid velocity w_{k1} shall be read at the intersection of line 1 and 2.

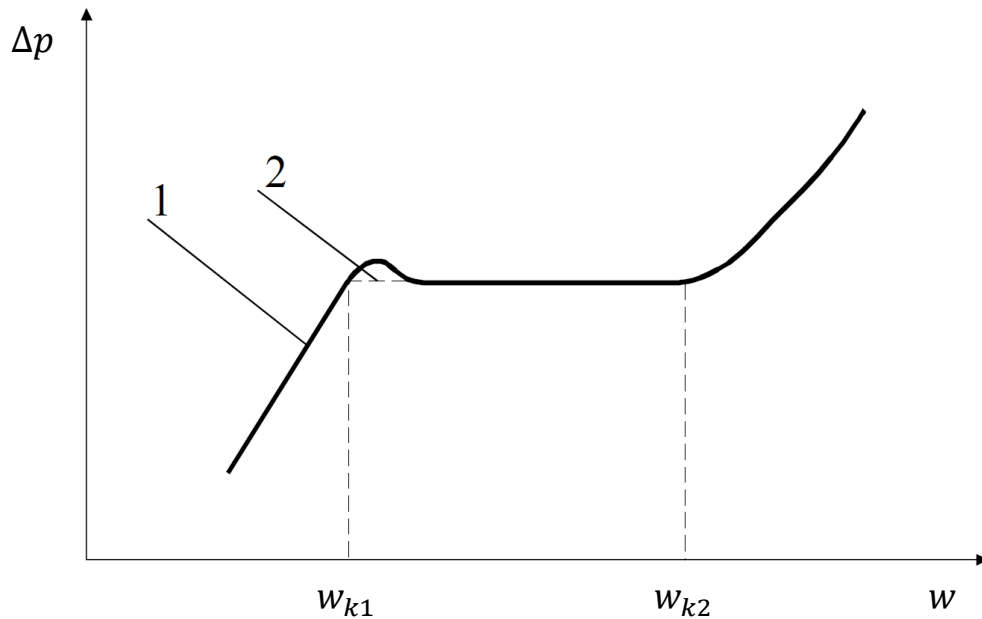


Fig. 2. Changes in the pressure drop with the velocity of fluidization. Crossing of lines 1 and 2 determines the lower critical velocity (minimum fluidization velocity)

The aim of the exercise

The aim of the exercise is to determine the lower critical air flow velocity by measurements of the pressure drop and air velocity, and to become acquainted with the fluidization process.

Description of the test rig

The scheme of the test rig is shown in Fig. 3. The main element of the test rig is the fluidized bed appliance with a circular cross-section and a perforated plate made out of a transparent material in order to facilitate the observations. The air flows inside from the bottom through the perforated plate. Flow rate of the air is regulated by a valve. Flow and overpressure of the air are measured by a rotameter and a manometer, respectively. Increasing the flow velocity of the fluidized medium (air) above the lower critical velocity causes conversion of the bed behavior to the fluid state. The pressure drop in the bed results from flow resistances occurring between fluid and solid particles. The resistance to flow appears as the drop of air pressure through the bed. The pressure drop changes are measured using a U-tube manometer.

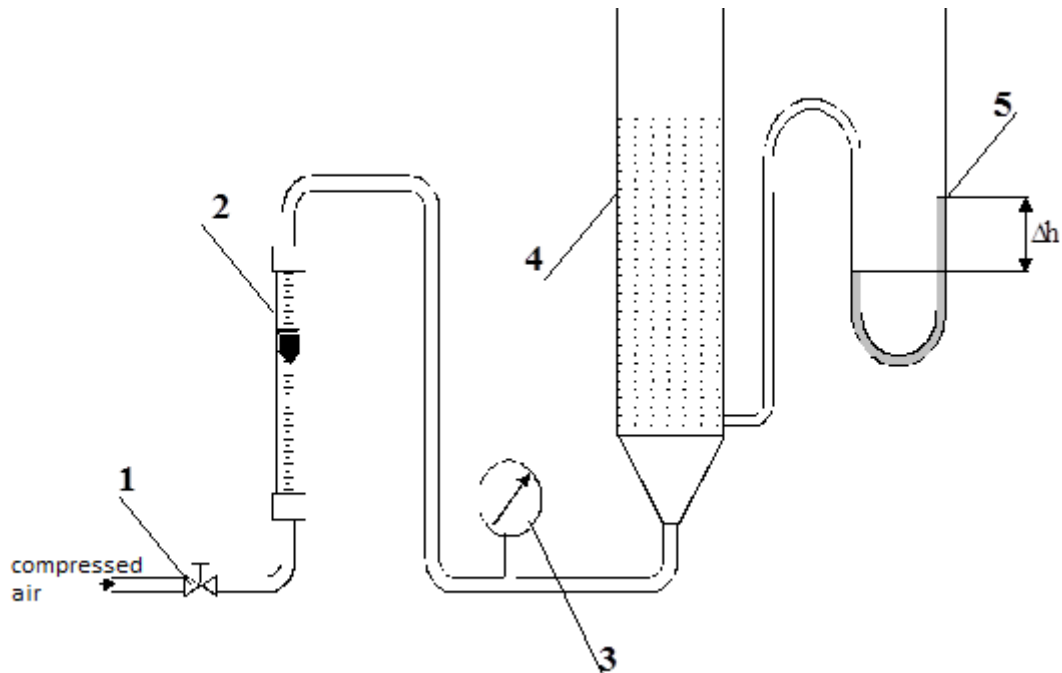


Fig. 3. Scheme of the minimum fluidization velocity measurements facility: 1, regulatory valve; 2, rotameter; 3, manometer; 4, the chamber filled with fluid; 5, differential manometer

Methodology of measurements

Check the general condition of the equipment and then:

- Fill the fluidized bed appliance with the particulate material of homogeneous fractional composition to the level specified by the instructor
- In order to determine approximately the lower critical fluid flow velocity, gradually increase the air flow rate and observe the behavior of the bed. When the bed will transform to the fluidized state note the rotameter indications. Stop the air flow by closing the regulatory valve.
- Re-open the air valve and increase the air flow rate gradually writing down the manometer's indications every time a change of 4 units in the manometer scale is observed. In the range of 10 units before and after observed approximately lower critical fluid velocity, increase the frequency of noting down the manometer indications to every 1 unit. Further readings should be made every 3 units.
- If increasing the flow rate through the bed will not result in changes of pressure drop anymore, (which is the characteristic for the fluidized state) make measurements for the same rotameter indications but decreasing the air flow velocity.
- Follow steps 1-4 for other bed heights, which will be specified by the teacher.
- Note the values of ambient temperatures and pressure.

Analysis of the results

Results of the measurements must be presented in form of a report by filling Table 1. Symbols used there stand for: \dot{V}_{air} - volumetric air flow rate read from the rotameter, p - air gauge pressure before rotameter, Δh - the differences in heights of the liquid column noted from the U-tube, k_z - correction factor for rotameter indications, \dot{V}_r - actual value of the volumetric air flow rate, after applying the rotameter correction k_z , w - the air velocity through the appliance (so called superficial gas velocity calculated per empty appliance).

Basing on the measurement results prepare a plot of pressure drop in relation to the velocity for different bed heights. Determine the lower critical fluid flow velocity for a given bed height by analyzing the plot and describe pressure drop changes in relation to the gas flow velocity through the appliance. Explain the presence of a characteristic hump and differences between values of pressure drop in the bed for increasing and decreasing air flow velocities. During the calculations remember to include rotameter correction, which corrects the differences in values of gas flow rates during the measurement and the calibration of rotameter. While converting the U-tube indications for pressure drop, assume that the manometer fluid density is $\rho_f = 1000 \text{ kg/m}^3$. Based on the volumetric flow rate and fluidized appliance cross-section area, calculate the gas flow velocity.

Tab. 1. Results of the measurements of lower critical fluid flow velocity

Bed material: Bed heights $h_1 =$ Appliance internal diameter $d =$ Manometer fluid density $\rho_f =$ Ambient air temperature $t_{amb} =$ Barometric pressure $p_{amb} =$						
No.	\dot{V}_{air} , dm ³ /h	p , kG/cm ²	Δh , mm	k_z	\dot{V}_r , dm ³ /h	w , m/s
1						
2						

Literature

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- 2) Radovanović M.: Fluidized Bed Combustion, Hemisphere Publishing Corporation, 1985
- 3) Szarawara J.: Podstawy technologii chemicznej. Część III: Projektowanie reaktorów chemicznych i modelowanie procesów chemicznych, Skrypt Politechniki Śląskiej Nr 610, Gliwice, 1975