Visualization of Fluidization and Solid-Gas (Iron Sand-Air) Flow Regimes in A Vertical Straight Tube

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Abstract

The aim of this research is to obtain fluidization and solid – gas flow regimes in a vertical straight tube of 24 mm in diameter. Iron-sand particles and air are utilized as the solid and gas phase respectively. The regimes of fluidization and solid-gas flow are recorded using digital camera. In general, results show that there are six regimes of fluidization process i.e. fixed bed, particulate bed, bubble, slugging, turbulent bed, and fast fluidization. In addition, the solid-gas flow in a vertikal tube yields the dilute and dense phase..

Keywords: *Fluidization, solid-gas flow, flow regimes.*

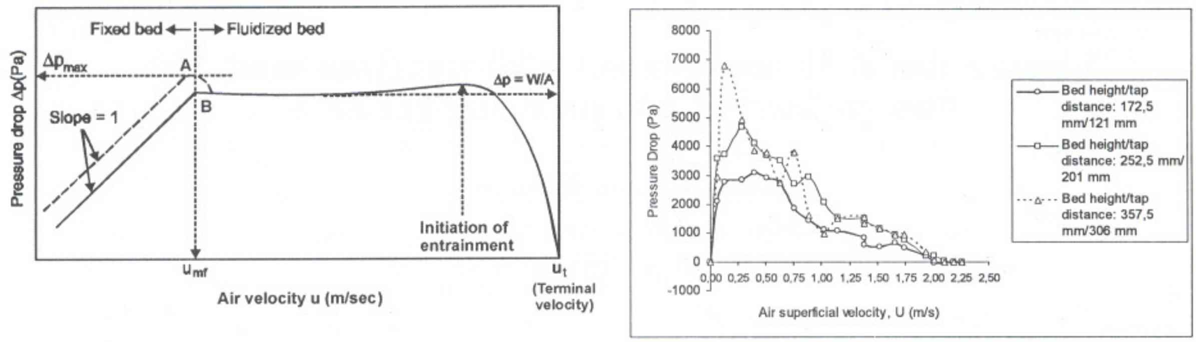
1. Introduction

Fluidization and solid - gas flow have been used in many industrial devices, e.g. as fluidized bed combustor, cyclone pre-heater in cement manufacturing, and pneumatic transport. They are applied in fluidized bed combustor in order to achieve a good mixing between solid fuel and gas to assist the combustion process. The chemical process of limestone calcinations in cement manufacturing is also conducted using this method. In this process, a contact between heated gas coming from the bottom side of cyclone pre-heater and the raw material (limestone) from the upper side results the decomposition of limestone ($CaCO_3$) into CaO and CO_2. Another application is found in the pneumatic transport devices in which the particles are blown and transported by gas flow along the pipelines. There are some advantages of this method in comparison with the conventional transport method, e.g. lower cost operation and low environmental impact.

As in common multiphase flow system, there are some flow regimes occur in fluidization and solid - gas flow. These regimes significantly influence in the operational characteristics of the device, such as the gas flow rate requirement, fluid pressure drop and pressure fluctuation. Therefore, it is important to understand those regimes and their properties in order to optimize the device utilization. The fluidization and solid-gas flow regimes of iron sand particles and air is visualized and studied in this paper. Research is done in constant tube diameter with an adiabatic condition..

2. Fundamental

Fluidization process could be recognized theoretically by using the curve in Figure 1. Figure 1b is taken from results of the previous research (Arifvianto and Indarto, 2006).



(a)

(b)

Figure 1. Fluidization curve (a) Kunni-Levenspiel (1969); (b) Arifvianto-Indarto (2006)

The curve of Figure lb consists of three parts. The first one is in the range of 0 to 0.13 m/sec where the gas velocity is proportional to the pressure drop. This means that increasing of gas flow rate results greater pressure drop as the requirement of larger pressure to exert and fluidize the stationary particles. The second part occurs in the range of 0.2 to 0.75 m/sec where the curve moves horizontally or has a constant pressure drop. Although the curve of Figure 1 a performs this character, actually it is difficult to approach constant pressure drop as the consequence of pressure fluctuation in slugging and turbulent regime. The last one is the third part which occurs in gas velocity up to 0.75 m/sec. The curve begins to move down and cuts off the horizontal axis. The terminal velocity is defined as the gas velocity at which the fluidization curve and horizontal axis intersect. The particles begin to fly upward within the gas flow, no longer to be stationary in the bed section.

There are some fluidization regimes that are known among the researchers.

Fixed bed regime (Figure 2a) occurs when the gas velocity is in the range of $0 < U \leq U_{mf}$. Particles are still quiescent settling over the grid and the gas flows through interstices. Particulate regime (Figure 2b) occurs at the velocity of $U_{mf} < U \leq U_{mb}$. Physically, the bed begins to expand smoothly. Bubble regime (Figure 2c) occurs when the gas velocity is $U_{mb} < U \leq U_{ms}$. This regime can be recognized by bubbles formation inside the bed, although it might be observed only by bubbles' breaking off at the top of bed surface. Bubbles rise from distributor plate and expanding its volume. As the gas flow rate increases, the volume of bubbles fills almost entire column cross section. This regime is defined as slugging regime (Figure 2d). It commonly appears in three different shapes (see Figure 3.), i.e. bullet shape slug (Figure 3a), wall slug (Figure 3b), and square-nosed slug (Figure 3c). Figure 2e shows a turbulent bed regime that occurs at $U_k < U \leq U_{tr}$. This regime is marked by a chaotic condition in the bed that creates difficulties in defining the bed surface. But, a good mixing of two or more substances will be obtained by setting the gas flow rate at this regime. Greater gas flow rate, i.e. $U > U_{tr}$, more particles begin to be transported upward. This regime is defined as fast fluidization regime. There are some particles moving downward near the wall.

3. Methodology

This study was conducted in Heat and Mass Transfer Laboratory of Engineering Science Study Center (PSIT) Gadjah Mada University. Experiment was carried out in a transparent column of 24 mm ID and could be equipped with multi-orifice or single-orifice as option of distributor plate. The design of apparatus used in this research is performed schematically in Figure 4.

The iron-sand particles are utilized as the solid phase. They are placed in bed section column and supported by multi-orifice or single-orifice grid. The fluidizing gas is compressed air of 1.0 to

1.1 kglcm^2 and blown until each regime is appeared. The monitoring of air flow rate is done by using a rotameter. The visualization of fluidization and solid-gas flow regimes is done by recording them with Canon Power Shot G2 digital camera.

4. Results and Discussion

The experiment yields these following results. It is necessary to make a note that either multi-orifice or single-orifice grid resulted similar flow pattern. A distinct character as a result of the use of single-orifice and multi-orifice grid is only associated with the air flow rate capability to approach terminal velocity. The fluidization process of bed with single-orifice grid has insufficient pressure near the grid so that the particles entrainment and terminal velocity can not be performed. This condition may be caused by a larger pressure loss as the air passes over a single-orifice grid than that in multi-orifice grid (Arifvianto and Indarto, 2006).

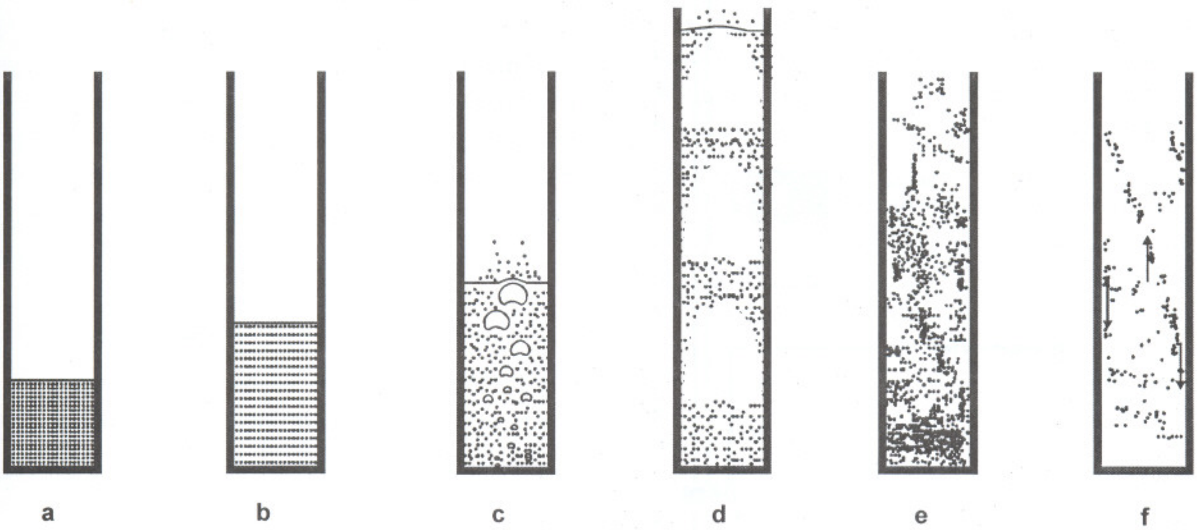


Figure 2. Fluidization regimes

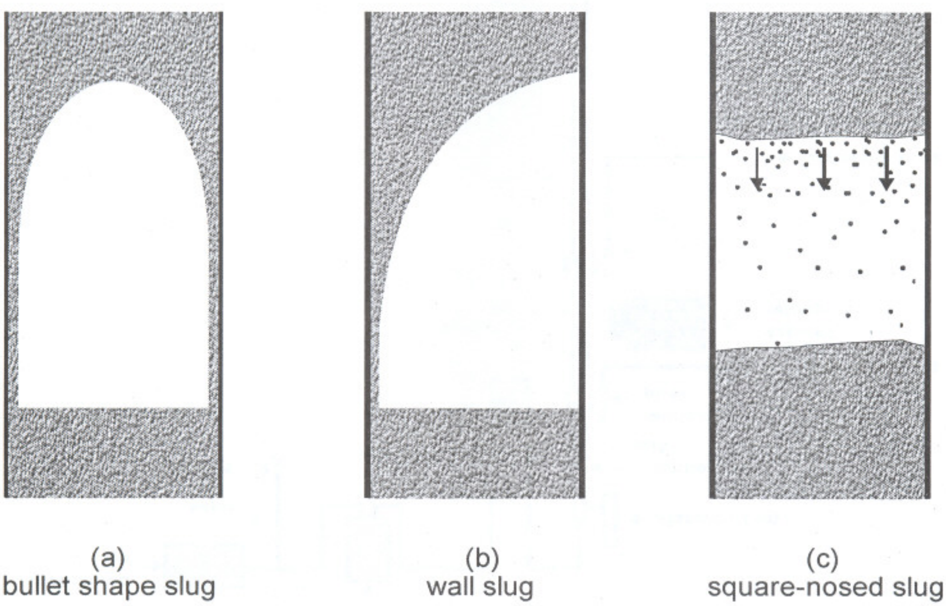


Figure 3. Slugging regime

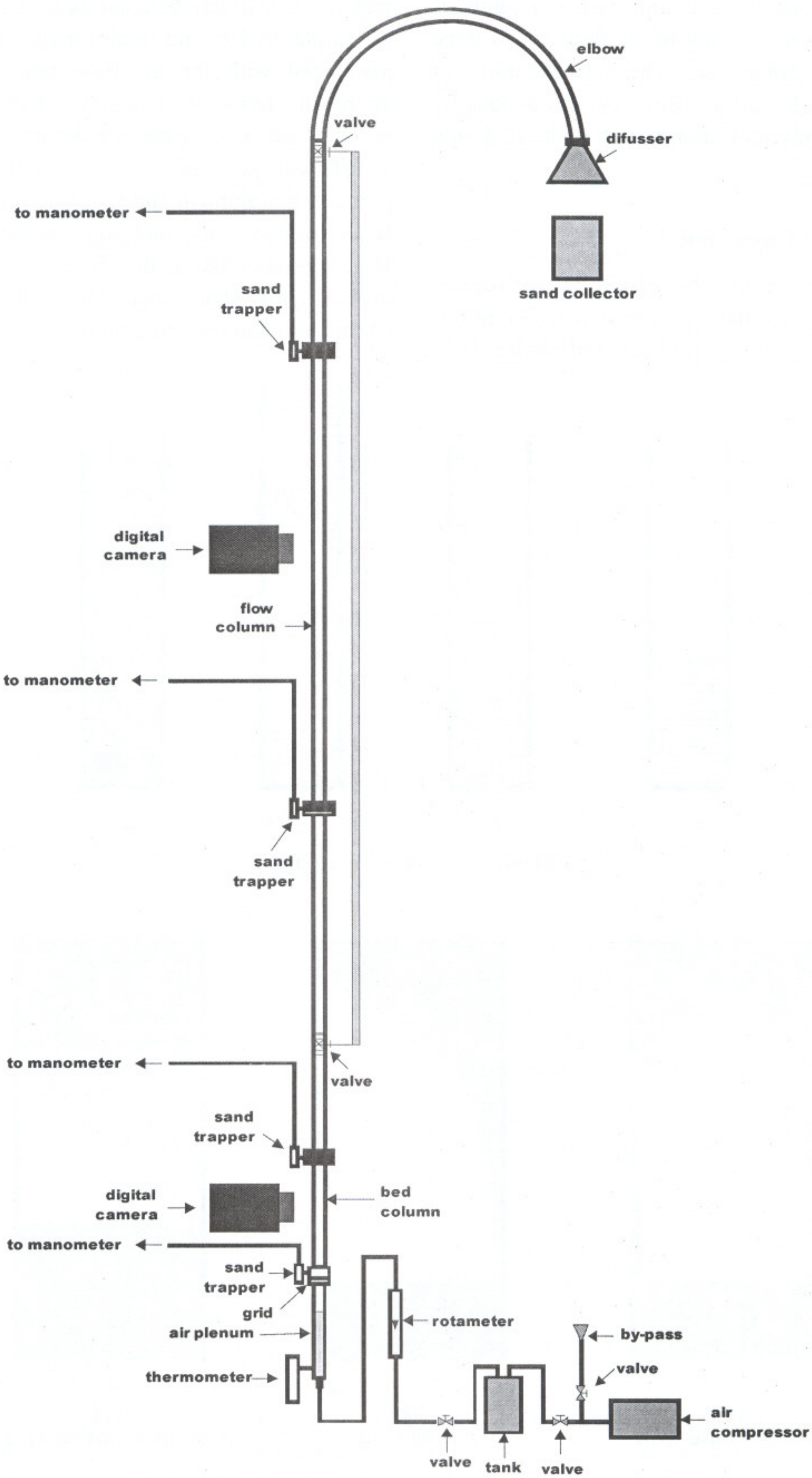


Figure 4. Schematic diagram of the apparatus

A. Fluidization regimes

1. Fixed bed regime, paeticulate bed regime and bubble regime

Particles are quiescent since the air flow is still incapable to produce sufficient force by which particles are supported and fluidized. Figure 5 shows a fixed bed regime with approximately 0.068 m/sec of air velocity. Above this value, there is a particulate bed regime over the bed in which the bed surface expanded smoothly. The bed height ascends in a few millimeters. The bubble regime occurs as the air velocity slightly greater than that in particulate regime. This regime is marked by the appearance of bubbles breaking off on bed surface. Both of these two last regimes are not presented here since they have much similarities of physical appearance with the fixed bed regime.

2. Slugging regime

Slug is recognized by the appearance of gas pockets filling almost entire column cross-section. Mostly, slugging regime that occurs in this research was found in the form of square-nosed slug i.e. flat on both its top and bottom side (Figure 6).

Meanwhile, a solid slug is defined as a pocket of particles flows regularly following the gas pocket. Slug behaves like a piston movement. Higher air velocity larger size of slug and greater pressure fluctuation are obtained..

3. Turbulent regime

Turbulent regime is characterized by a chaotic condition and larger pressure fluctuation than that of slugging regime. Bed surface is difficult to be defined clearly. Particles are moving up and down irregularly as the gas flows through the bed. This condition is promoted by an insufficient drag force to transport all particles upward. On the other hand, gravitation force still significantly affects in pulling down particles back into the bed.

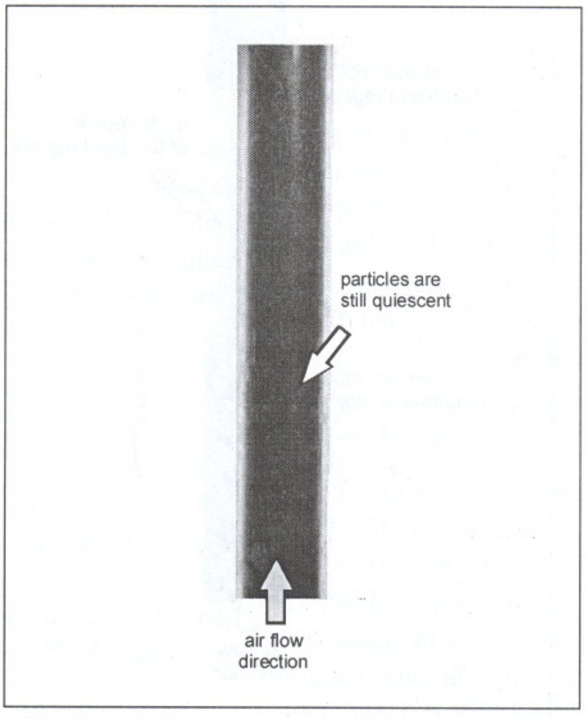


Figure 5. Fixed Bed, U = 0.068 m/sec

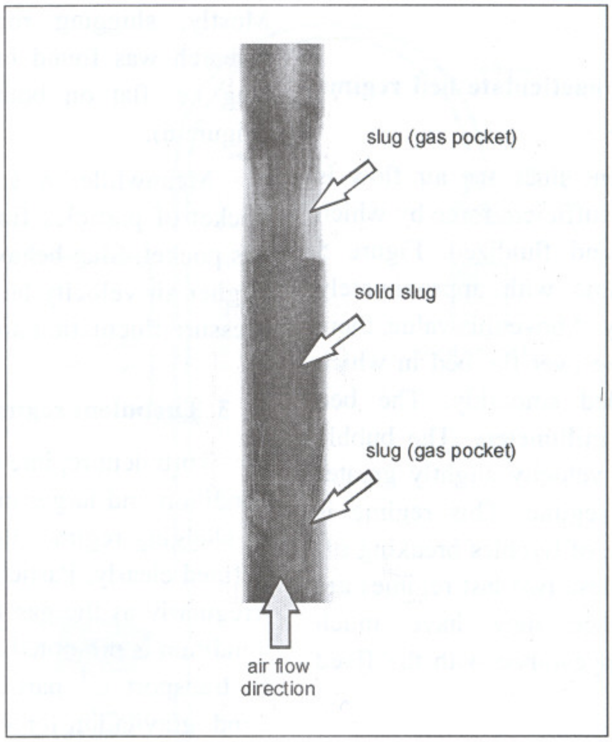


Figure 6. Slugging regime, $U = 0.28$ m/sec

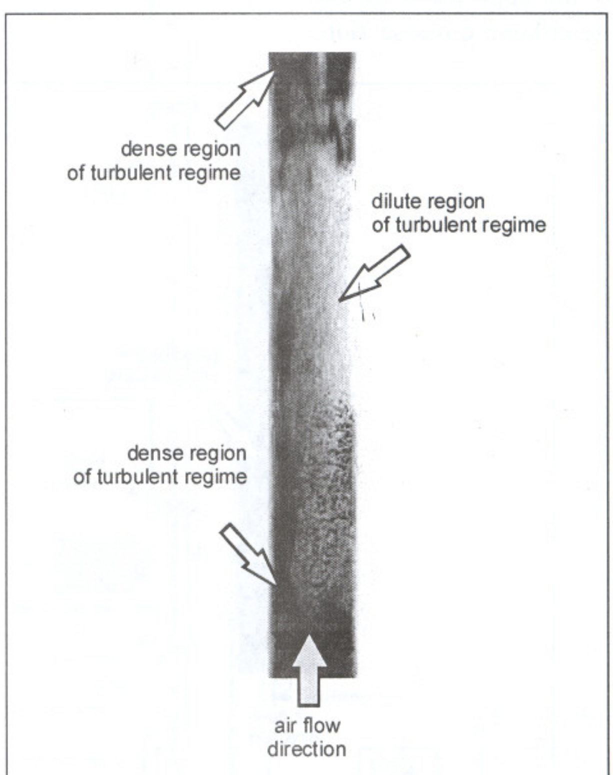


Figure 7. Turbulent regime, $U = 0.51$ m/sec

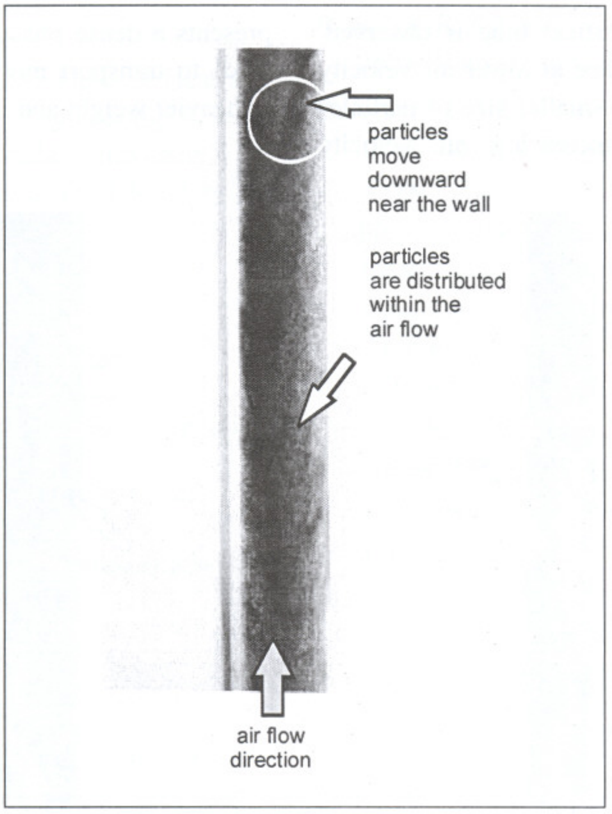


Figure 8. Fast fluidization regime, $U = 2.0$ m/sec

4. Fast fluidization regime

Transition between turbulent regime and fast fluidization regime occurs when air velocity was in range of 1.38 - 1.53 m/sec. Up to this, the fast fluidization regime occurs as the particles begin to be fully dispersed within the air flow, although a few of them are still falling back to the bed with a passage near the wall.

B. Particles – air flow regimes

Some regimes of particles - air flow in a vertical straight tube are performed in this section. The visualization is carried out at the air velocity of 0.75 m/sec and up at which more particles are transported to the observation tube located approximately 1 m above the fluidization bed section.

Figure 9 shows that a good mixing between particles and air is not obtained at the air velocity of 0.75 m/sec. The mixed flow begins to be homogenous as the increasing of air velocity although some particles appears to move down near the wall (Figure 10). This regime is defined as a dilute phase because of its lower particle fraction than the air flow. A dense phase occurs as a result of more particles that are transported upward at the air velocity of 1.53 m/sec (Figure 11). In addition, as shown in the previous study (Arifvianto and Indarto, 2006), a denser flow creates a greater pressure drop.

5. Conclusions

Fluidization and solid-gas flow of iron sand-air yields some regimes that correspond with the air flow velocities. There are six regimes of fluidization process that orderly take place as the increasing of air velocity, i.e. fixed bed, particulate regime, bubble regime, slugging regime, turbulent bed, and fast fluidization. Bubble regime can not be obviously observed but it could be predicted as the bubbles' break off over the bed surface. A dilute and dense phase as the mixed flow of iron sand particles-air in a vertical tube is observed. The dilute phase takes place at lower air velocity in which only lighter and smaller size of particles are blown first. The increasing air velocity presents a dense phase as a result of greater drag force to transport more particles, including those of heavier weight and larger size.

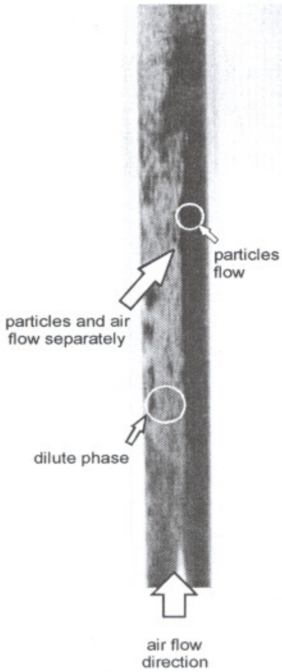


Figure 9. Mixed flow, $U = 0.75$ m/sec

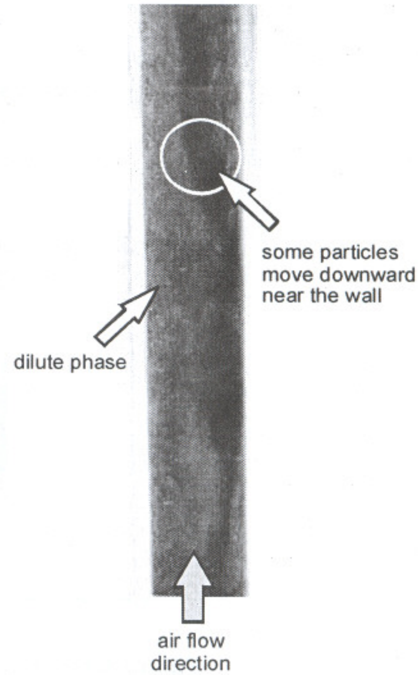


Figure 10. Mixed flow, $U = 1.53$ m/sec

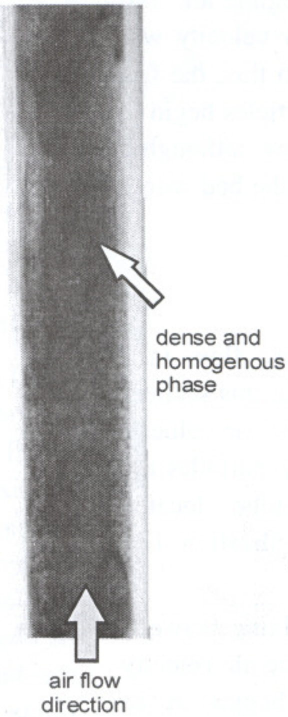


Figure 11. Mixed flow, $U = 2.0$ m/sec

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Nomenclature

U = superficial air velocity (m/sec)
dp/dz = pressure drop gradient (kPa/m)
U_b = superficial air velocitiy of bubble regime (m/sec)
U_{mb} = minimum superficial air velocitiy of bubble regime (m/sec)
U_{mf} = minimum superficial air velocitiy of onset fluidization (m/sec)
U_{ms} = minimum superficial air velocitiy of slugging regime (m/sec)
U_k = minimum superficial air velocitiy of turbulent regime (m/sec)
U_{tr} = minimum superficial air velocitiy of fast fluidization regime (m/sec)

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