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# Experimental Study on the Bed Voidage and Minimum Fluidization Velocity of Gas-Solid Fluidization under Different Conditions

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## ABSTRACT

***The objective of this research is to study the effect of particle size on minimum fluidization velocity ($U_{mf}$) and the gas superficial velocity on bed voidage. Three particles sizes of sand were fluidized in air at atmospheric pressure and temperature. The experiments were conducted in a 0.1 m ID and 1 m height fluidization column made from acrylic. Local sand of three different sizes 301µm, 454µm, and 560µm were used as the bed material. Four superficial air velocities of 1.0 m/s, 1.25 m/s, 1.5 m/s, 1.75 m/s were used.The suitability of several minimum fluidization velocity correlations has been investigated for sand particles. Prediction due to Todes et al. (1958) agree reasonably with experimental data. The bed voidage calculation showed two different region, dense phase section 1 and the lean phase sections 2, 3, 4, and 5. The bed voidage found to be increasing in the section 1 and is decreasing in the other sections with increasing the gas superficial velocity.***

**Keywords:** Fluidization, Hydrodynamics, Minimum Fluidization Velocity, Bed Voidage.

## 1. INTRODUCTION

Fluidized beds find extensive applications in chemical process industries as they provide large interfacial area, high degree of mixing, and temperature uniformity[1], [2]. Gas –solid systems generally behave in a quite different manner. With an increase in flow rate beyond minimum fluidization, large instability with bubbling and channeling of gas is observed. At higher flow rates agitation becomes more violent and the movement of solids becomes vigorous. In addition, the bed does not expand much beyond its volume at minimum fluidization called an aggregative fluidized bed. Therefore proper characterization of the bed dynamics for the binary and the multi-component mixtures in gas solid systems is an important prerequisite for their effective utilization, where the combination of particle size ,density and shape factor influence fluidization behavior by Sau. et al[3]. The hydrodynamic behavior of fluidized beds depends upon the properties of the solids, gas properties, factors affecting inter-particle forces (Van der Waals force, fine particles content, liquid bridges and sintering) and distributor properties, such as aspect ratio. It is further complicated by air bubble growth, intermittent coalescence/splitting, rising velocity, size, and the existence of non-uniformity of distributed particle clusters in addition. The instability arising due to density waves, propagation of pressure waves and transition of flow regimes further intensifies the problem of characterizing the constitutive bed behavior and designing a precise system relying on fluidized bed dynamics [4], [5]. The study of hydrodynamics plays an important role in the economical design and operation of a fluidized bed. A.Sivalingam, and T.Kannadasan (2009) investigated the hydrodynamic behavior of a co-current three phase fluidized bed with liquid as a continuous phase in a 54 mm id Perspex (Acrylic column) with particle size of 4.38 and 1.854 mm glass beads. Based on the experimental work, theeffect of fluid rates on the various parameters such as pressure drop, porosity, gas and liquid holdups were studied and the observed data was reported. They found that the gas hold up and bed porosity increases with increasing gas flow rate. From the comparison of the effect of gas flow rates and liquid flow rates on the hydrodynamic characteristics they could infer that the influence of the gas flow rate on the various parameters is more when compared to that of the liquid flow rates [6]. The superficial gas velocity is one of the key parameters used to determine the flow hydrodynamics in gas–solids fluidized beds. However, the superficial velocity varies with height in practice, and there is no consistent basis for its specification. Different approaches to determine the superficial gas velocity in a deep gas–solids system are shown to cause difficulties in developing models and in comparing predictions with experimental results. In addition, the reference conditions for superficial gas velocity are important in modeling of deep gas–solids systems where there is a considerable pressure drop [7]. Many studies have discussed the effect of the binary bed material on minimum fluidization velocity ($U_{mf}$), elutriation and mixing, etc. Most studies indicated that fluidized behaviors will be changed due to complex bed materials. But these results did not use enough material in incineration process to provide insight information.The results indicated that the fluidized behavior of a binary bed material was affected by weight fraction, particle size and density of the added material. Among these parameters, the weight fraction of added particle played an important role in influencing the fluidized behavior of the binary system [8]. Many researchers studied the effect of high temperature and particle size distribution (PSD) on minimum fluidization velocity ($U_{mf}$) [9]-[13].Guadalupe Ramos Caicedo et. al. presented some new data to estimate minimum fluidization velocity ($U_{mf}$) in a two-dimensional bed. Fluidization experiments with different height and weight bed and for different particle sizes were carried out in a two-dimensional fluidized bed. They found that the minimum fluidization velocity was a function of bed weight, particle diameter and column width[14]. Sau et al. concluded that variables such as the tapered angle affect the magnitude of the minimum fluidization velocity. Meanwhile, the bed height for this type of bed does not have a significant effect on the minimum fluidization velocity[15]. The minimum fluidization velocity, $U_{mf}$may be found by measuring the pressure drop through a bed of particles as a function of the gas velocity. At $U_{mf}$the weight of the bed is fully supported by the flow and the pressure drop becomes constant[16].The bed voidage, deduced from the mean pressure drop, is used to characterize the bed expansion. Avidan and Yerushalmi (1982) related changes in slope of the expansion curve, for a 0.15 m diameter column, to regime transitions. However, Geldart and Rhodes (1985), employing a similar Group A powder in their 0.29 m column, observed gradual changes as the transition occurred with no indication of any discernible abrupt variation as a result of entry to the turbulent regime[17]. This paper addresses the experimental determination of bed voidage and minimum fluidization velocity for the air-sand fluidization system.

## 2. EXPERIMENTAL SET-UP

Laboratory scale fluidized bed setup can be shown in figure 1, the experiments were conducted in a 0.1 m ID and 1 m height fluidization column made from acrylic. Air was supplied by a compressor. The air flow was measured by a rotameter. The air was passing through the plenum chamber filled by glass beads to maintain uniform distribution of air through bed, with a height of 0.1m and upper diameter of 0.1m and bottom diameter of 0.015m. The air was distributed by a perforated plate of mild steel with a diameter of 0.1m and a thickness of 0.003 m will consists of 256 holes of 2.7 mm diameter drilled on a 7.5 mm square pitch. An ultrafine mesh was fixed on the distributor plate to prevent bed particles leakage. Another ultrafine mesh was fixed on the top end of the column to avoid escaping the particles from the top. There were 10 pressure ports in the fluidized column for pressure drop measurements.Local sand of three different sizes 301µm, 454µm, and 560µm were used as the bed material. Four superficial air velocities of 1.0 m/s, 1.25 m/s, 1.5 m/s, 1.75 m/s were used. The local cross-sectional voidage of the bed in the *ith* location is estimated from the measured pressure drop across the test section:

$$\varepsilon_i = 1 - \frac{\Delta P}{\rho_s L_i g} \tag{1}$$

Where ¸ $L_i$ is the distance between two pressure tappings
The cross-sectional bed average suspension density is determined from the relation

$$\rho_{sus} = \rho_s(1-\varepsilon) + \rho_g \varepsilon \tag{2}$$

Where $\rho_s$ and $\rho_g$ are the densities of the sand particles and the gas, respectively
Four correlations were employed to predict the minimum fluidization velocity [4]

Todes et al. (1958) $$Re_{mf} = \frac{Ar}{(1400 + 5.22 Ar^{0.5})} \tag{3}$$

Leva (1959) $$U_{mf} = \frac{7.169 \times 10^{-4} d_p^2 (\rho_p - \rho_g)^{0.94} g}{\rho_g^{0.006} \mu_g^{0.88}} \tag{4}$$

Havsky and Bena (1967) $$Re_{mf} = \frac{0.00138 Ar}{(Ar+19)^{0.11}} \tag{5}$$

Gauthier et al (1999) $$Re_{mf} = 0.0022 Ar^{0.818} \tag{6}$$

Reina & Velo (2000) $$Re_{mf} = (48^2 + 0.045 Ar)^{1/2} - 48 \tag{7}$$

The percentage error equation used is as follow:

$$\%error = \frac{U_{mf\,exp} - U_{mf\,pred}}{U_{mf\,exp}} * 100 \qquad (8)$$

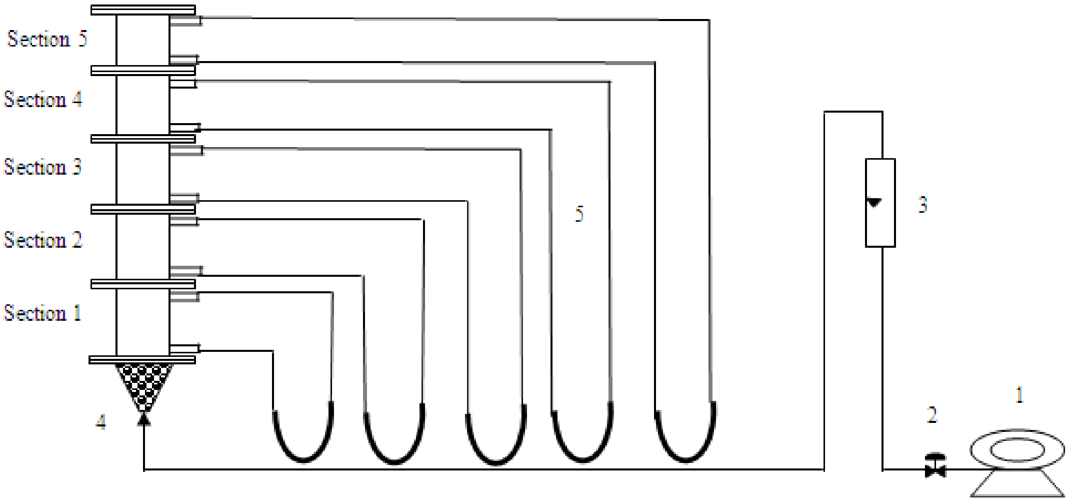


**Figure1:** Experimental setup of fluidized bed column

1-compressoe, 2-Valve, 3-air rotameter, 4-plenum chamber, 5-five U manometers

## 3. RESULTS AND DISCUSSION

### 3.1. Effect of Superficial Gas Velocity on Bed Voidage

The variation of bed voidage in five section in the fluidized column of the sand of particles size of 301µm can be shown in figures 2 and 3. In section 1, bed voidage increased as the gas velocity increased. While in the other sections 2, 3, 4, and 5 the bed voidage decreased. This may be because of more amount of bed rise up from section 1 to the upper sections as the velocity increased.

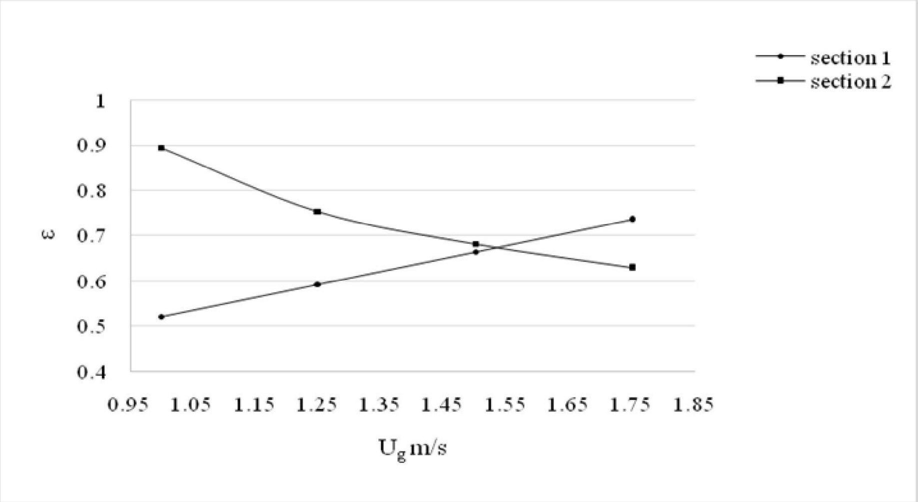


**Figure 2:** Effect of gas superficial velocity on bed voidage in sections 1 and 2 at $d_p$=301µm

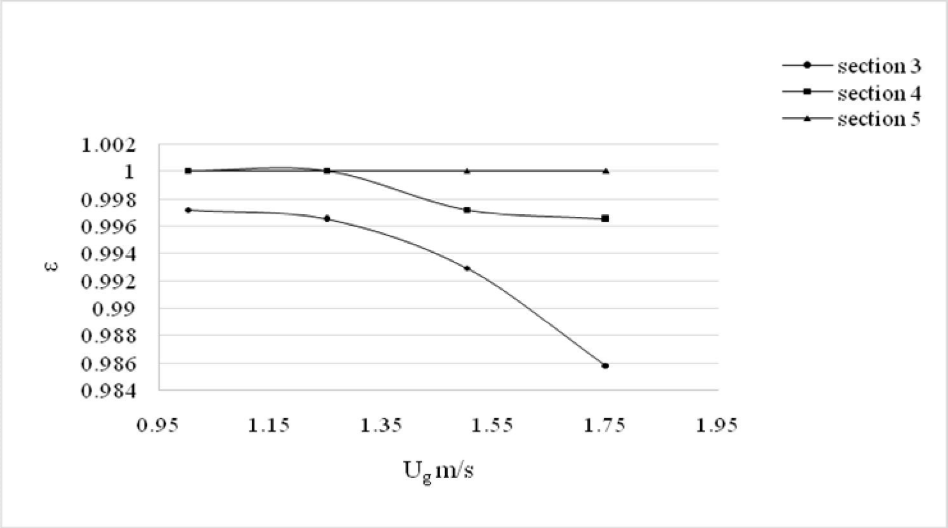
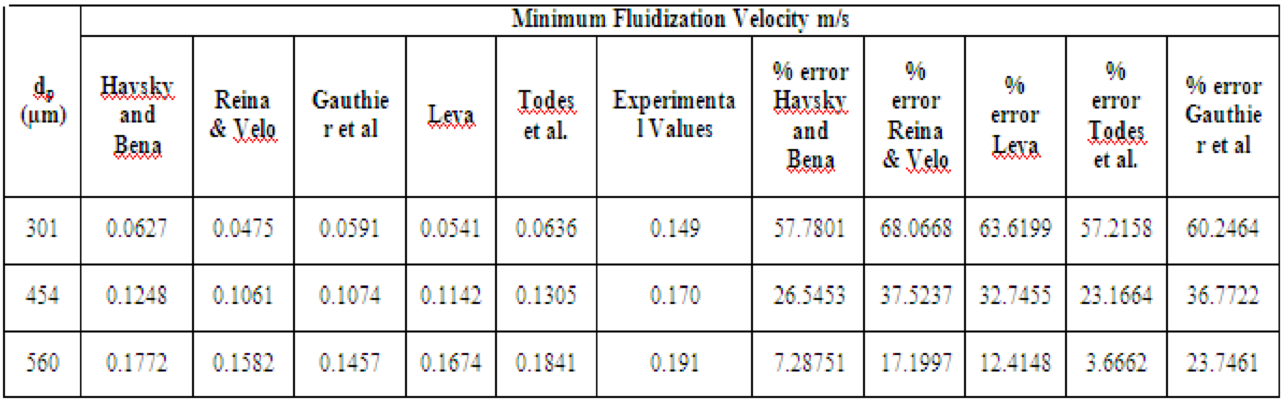


**Figure 3:** Effect of gas superficial velocity on bed voidage in sections 3, 4 and 5 at $d_p$=301µm

### 3.2.MinimumFluidization Velocity

The minimum fluidization velocity ($U_{mf}$) serves as a critical parameter for design and operation of a fluidized bed. The determination of the minimum fluidization velocity is conventionally based on experimental. When the superficial velocity increases successively beyond ($U_{mf}$),the pressure drop remains almost constant as shown in figure 4. The minimum fluidization velocity $U_{mf}$ was calculated experimentally using three different particles sizes 301µm, 454µm, and 560µm. Figure shows the effect of particles size on $U_{mf}$ , it is observed that the minimum fluidization velocity directly proportional with particles size. The experiments showed that there was no influence of bed inventory on minimum fluidization velocity. Table 1 compares the calculated minimum fluidization velocity using different experimental correlations proposed by Todes et al. (1958), Leva (1959), Havsky and Bena (1967), Gauthier et al (1999), and Reina & Velo (2000), with the experimental data.A good agreement of the experimental value with prediction of Todes et al. can be seen.



| $d_p$ (µm) | Minimum Fluidization Velocity m/s | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Havsky and Bena | Reina & Velo | Gauthier et al | Leva | Todes et al. | Experimental Values | % error Havsky and Bena | % error Reina & Velo | % error Leva | % error Todes et al. | % error Gauthier et al |
| 301 | 0.0627 | 0.0475 | 0.0591 | 0.0541 | 0.0636 | 0.149 | 57.7801 | 68.0668 | 63.6199 | 57.2158 | 60.2464 |
| 454 | 0.1248 | 0.1061 | 0.1074 | 0.1142 | 0.1305 | 0.170 | 26.5453 | 37.5237 | 32.7455 | 23.1664 | 36.7722 |
| 560 | 0.1772 | 0.1582 | 0.1457 | 0.1674 | 0.1841 | 0.191 | 7.28751 | 17.1997 | 12.4148 | 3.6662 | 23.7461 |

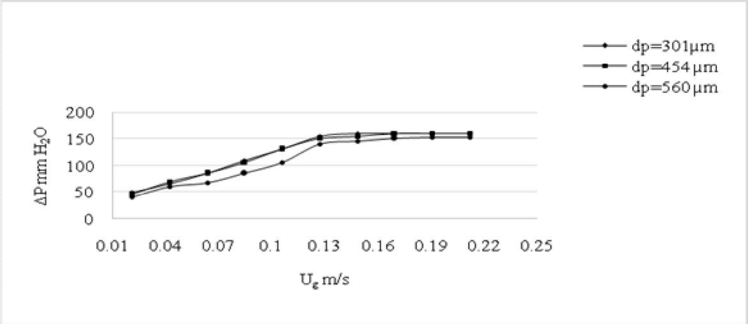


**Figure 4:** Effect of particle size on minimum fluidization velocity

## 4. CONCLUSIONS

Experiments showed that the minimum fluidization velocity increased as the particle size increased, at the same time there was no influence of bed inventory on minimum fluidization velocity. The values obtained from the prediction of Todes et al. showed good agreement with experimental data obtained from this work. The bed voidage calculation showed two different region, dense phase section 1 and the lean phase sections 2, 3, 4, and 5. The bed voidage found to be increasing in the section 1 and is decreasing in the other sections with increasing the gas superficial velocity.

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