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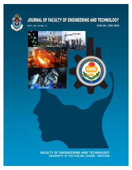

HYDRODYNAMIC STUDY OF INDIGENOUS BIOMASS-SAND MIXTURES IN A COLD FLUIDIZATION COLUMN

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Abstract

Biomass and sand mixtures are used in a circulating fluidized bed reactor/fast fluidized bed reactor. Hydrodynamics of the system is important in the operation and design of fluidized bed reactor. In this study, hydrodynamics of biomass (cotton stalk, maize stalk and saw dust) and sand mixture was investigated in a bench scale cold test rig. The particle size of sand and biomasses were -30, +60 mesh. Superficial velocity was plotted against the pressure drop per unit bed height to determine the minimum fluidization velocity. The pressure drop per unit bed height increased sharply to a maximum value and then eventually dropped as the bed became fully fluidized. Velocities were calculated for various biomass compositions of 0.50, 0.75, 1.0 and 1.25 % and compared with the predicted values by published correlations. The experimental and estimated values were in close agreement.

Keywords: Biomass-Sand Mixture, Hydrodynamics, Cold fluidized bed reactor, Minimum Fluidization Velocity, Superficial Velocity, Pressure Drop

1. Introduction

Fluidized bed reactors have numerous benefits over the other reactors such as they give good solids mixing, high heat and mass transfer rates, high surface area and find wide applications in industry. The behavior of fluidized bed reactor depends on the characteristics of the material being used. One of the most important parameter dealing with the optimum performance of fluidized bed reactor is the minimum fluidization velocity. The minimum fluidization velocity is defined as the minimum value of superficial velocity at which pressure drop across the bed becomes equal to the weight of the bed per unit cross sectional area [1, 2]. In fluidized bed reactors, a fluid is passed through a granular solid at high enough velocities so that the bed of solids is suspended and behaves like a fluid. This process is known as fluidization. The basic working principle underlying the process of fluidization is that the solid substrate is supported on a perforated porous plate known as the distributor; the fluid is then forced up the solid through the distributor plate. At low fluid velocities, the bed remains in contact and the fluidizing medium passes through the bed from voids in the solid and this is called as packed bed. As the velocity is increased, the situation is reached when the force acting on the solid due to the fluidizing medium is just able to balance the weight of the solid particles, this stage is known as incipient fluidization and the velocity is called as the

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minimum fluidizing velocity [3, 4]. Once this minimum fluidization velocity is achieved, the bed behaves as a boiling liquid and this state is called as fluidized bed.

The fluidization state occurs between a filtration of the bed and pneumatic conveying and includes various regimes like; stationary bubbling fluidized bed, turbulent fluidized bed and fast fluidized bed. The bubbling regime corresponds to the situation of the bed when small bubbles arise in the bed and the bed expands to a certain extent. As the fluidization velocity is increased the large bubbles break up into smaller ones and the pressure drop decreases. This is the moment when turbulent regime occurs with no big bubbles in the bed [3, 5]. In the particulate phase of the bed, the bed is becoming more homogenous, smaller voids exist in the form of the channels and jets, and particles form clusters [3, 4, 6-8]. The parameters responsible for the transition between the regimes are the fluidization velocity, pressure drop across the bed, the bed height and nature of the particles [9, 10]. The minimum fluidization velocity is important as it helps in understanding the kinetics of the reaction and in the design, scale up and modeling of fluidized reactors [7, 10].

The particles of different size, shape, density and composition are used to characterize the fluidization behavior of the mixtures of biomass and sand [11-13]. Beeckmans et al.[14] studied that particles with different densities and sizes result in vertical segregation in gas-solid fluidized beds. However, this action is not required as it threatens the particle circulation resulting in the uneven fluidization shapes, reducing the heat and mass transfer rates [15, 16].

Pilar Aznar et al. [17] investigated the fluidization of mixtures of solids with different particle sizes and mixtures of particles of different sizes and densities, together with mixtures of sands and biomass materials. The study established that there are no satisfactory equations to determine the minimum fluidization velocities, mainly for mixtures of sand-biomass materials. Thus, these studies established empirical equations to predict the minimum fluidization velocities and confirmed the model for the mixtures of sand-biomass materials in the gas solid fluidized beds.

In this study, the hydrodynamic behavior of biomass mixtures with sand was investigated at ambient conditions in a cold test rig. The minimum fluidization velocity was established in the present work to facilitate the optimization of the fluidized bed pyrolysis reactor using different biomasses with the same particle size. The velocity was also computed from standard correlations [5] and compared with the experimental data.

2. Methodology

Biomass and sand were mixed in different proportions to prepare the samples. The samples were led from the top of the fluidized bed tube. The flow rate of air was controlled by throttle valve and measured from the rotameter fitted on the fluidized bed tube. The flow rate of air was increased slowly and pressure drop was measured from the manometer. A point is achieved where the bed turned out to be fully fluidized and pressure drops becomes constant[4].The initial increase of velocity is represented by the slope of the curve and horizontal line indicates the constant pressure drop and minimum fluidization velocity is determined.

The published correlation by Kunni and Levenspiel [5] is used to determine the minimum fluidization velocity. Equations (1) & (2) are used to calculate the minimum fluidization velocity and Reynolds number as:

$$U_{mf} = \frac{D_p^2(\rho_s - \rho_g) g E_{mf}^3 (\varnothing_s^2)}{150\mu\,(1 - E_{mf})} \qquad \text{at Reynolds number <20} \qquad (1)$$

$$\text{Reynold No.} = \frac{D_p U_{mf} \rho_s}{\mu_g} \qquad (2)$$

Where

D_p is the particle diameter (cm)

ρ_s is density of the sand or sand and biomass mixture (gm/cm^3)

ρ_g is the density of air (gm/cm^3)

E_{mf} is the bed voidage (from literature)

$\acute{\varnothing}_s$ is the sphericity factor for sand or sand biomass mixture taken from literature

μ is the viscosity of air (gm/cm-s)

U_{mf} is the minimum fluidization velocity in cm/s

This expression [A] is used for evaluation of minimum fluidization velocity for fine particles provided that the Reynolds number at the computed minimum fluidization velocity is less than 20. The spherecity and bed voidage are taken from literature[5].

Table 1: Values of Spherecity for Different Types of Particles [5]

Type of particle	**Sphericity (Ǿs)**
Sphere	1.00
Cube	0.81
Activated carbon and silica gel	0.47
Coal anthracite, bituminous , natural dust, pulverized	0.63,0.63,0.65,0.73
Sand round, sharp, old beach, young river	0.86,0.66, as high as 0.86 & as low as 0.53
Tungsten powder	0.89
Wheat	0.85

2.1 Experimental Setup

The experimental setup shown in Figure 1 consists of an air blower (1), throttle valve (2), a rotameter (3), a cylindrical fluidization column (4) and a u-tube manometer across the column (5). The glass tube has an internal diameter of 100 mm and length of 760 mm. A perforated plate of about 200 mesh size is fitted at the bottom of the tube in order to retain the sand bed. The air is supplied through the blower and the air flow rate is regulated by throttle valve and measured by using the rota-meter with a maximum measuring capacity of 10 cubic meters per hour. The different biomass and sand mixtures are introduced into the fluidized bed tube from the top and subjected to fluidization at different flow rates of air for the analysis of the bed behavior. The expansion of the bed (bed height) is noted along with the pressure drop across the bed.

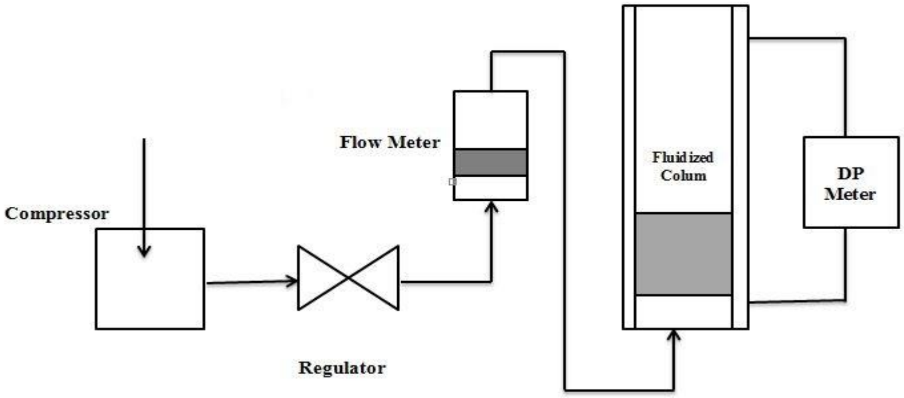

Figure 1. Schematic of experimental setup consist of a compressor, regulator, flow meter, fluidized column and dp meter (5)

3. Results and Discussion

The pressure drop across the column versus superficial velocity is depicted in Figures 2-4 for cotton stalk, maize stalk and saw dust mixtures with sand for different percentages of biomass in the bed respectively.

It is obvious from Figure 2 that the pressure drop becomes steady at the fluidization of the solid bed. The minimum velocity corresponding to this point is 0.23 m/s approximately. It is further notable that the fluidization starts at the same velocity for all mixtures although pressure drop is slightly different for the mixtures at the point of minimum fluidization. This difference of pressure drop is due to the difference in initial bed heights measured against various biomass contents in the overall sand and biomass mixture. The initial pressure drop is low for less content of biomass and higher for higher content of biomass. There is a sharp rise in pressure drop for high biomass as compared to the rise in pressure drop for lesser biomass content. Another observations was the geometry difference of cotton stalk, the cotton stalk intimately mix with sand and low initial bed heights was observed (0.155 m).

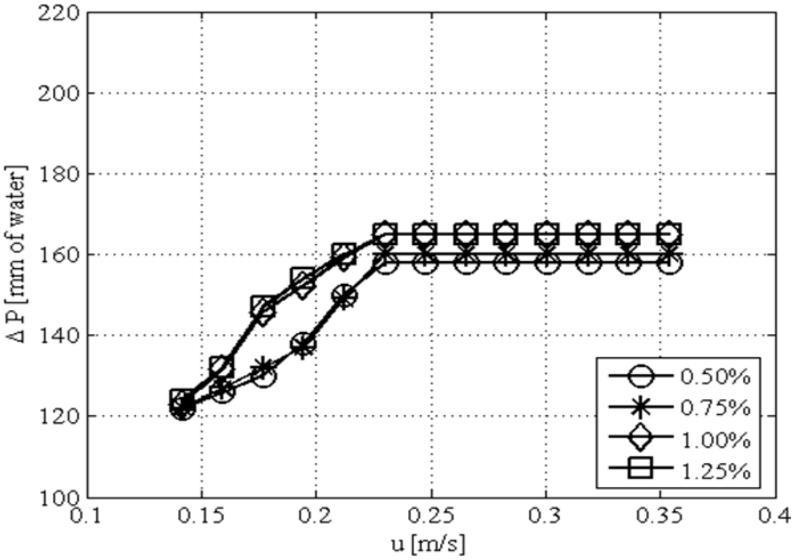

Figure 2. Column pressure drop (ΔP) versus superficial velocity (U) for cotton stalk (CS) and sand mixture

The data for maize stalk is presented in Figure 3 which reveals a relatively higher pressure drop across the column and the fluidization commences at slightly lower superficial velocity (2.23 versus 2.25 m/s) for the samples with higher biomass content. The reasons for such behavior are the less tendency of maize stalk mixing with sand due to geometrical difference b/w cotton stalk and maize stalk. The maize stalk was observed to be dispersed on the top of the bed which resulted in higher initial bed height for different proportion of biomass and eventually resulted in higher pressure drop due to greater static head.

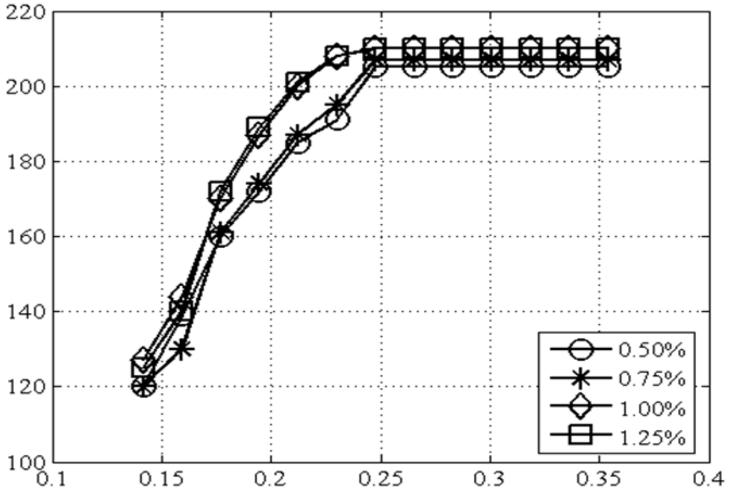

Figure 3. Column pressure drop (ΔP) versus superficial velocity (U) for maize stalk (MS) and sand mixture

The behavior of Saw dust samples (Figure 4) is similar as well except an intermediate pressure drop at fluidization. The fluidization commences at superficial velocity of 0.23 m/s for all samples. The particles of saw dust have uniform appearance in contrast to maize stalk. They intimately mix with sand during the commencement of fluidization. And the initial bed height observed was close to cotton stalk. The pressure drop increases quite sharply with the increase in superficial velocity.

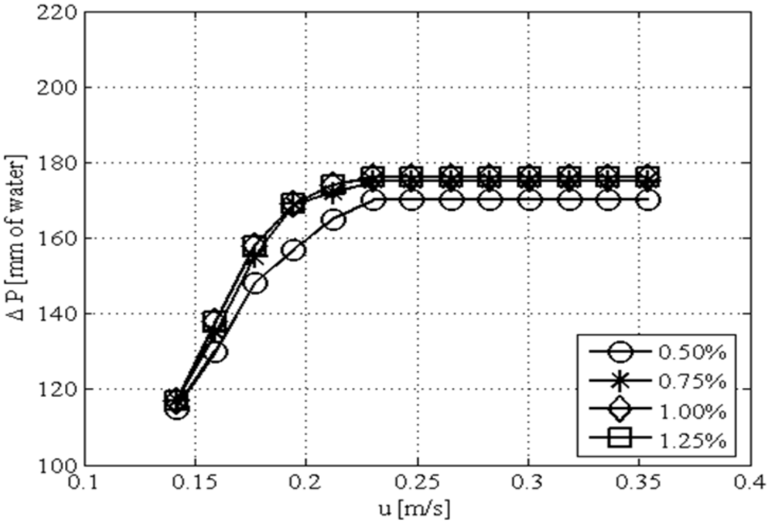

Figure 4. Column pressure drop (ΔP) versus superficial velocity (U) for saw dust (SD) and sand mixture

The column pressure drop per unit bed height (Figure 5) is higher at low bio-mass content and lower at higher biomass content. This is due to the fact that the bed height at lower biomass content was less and pressure drop was higher which resulted in higher pressure drop per unit bed height. While at higher biomass content the initial bed height as well as the pressure drop was high which resulted in a lower ratio and thus a lower value of column pressure drop per unit bed height.

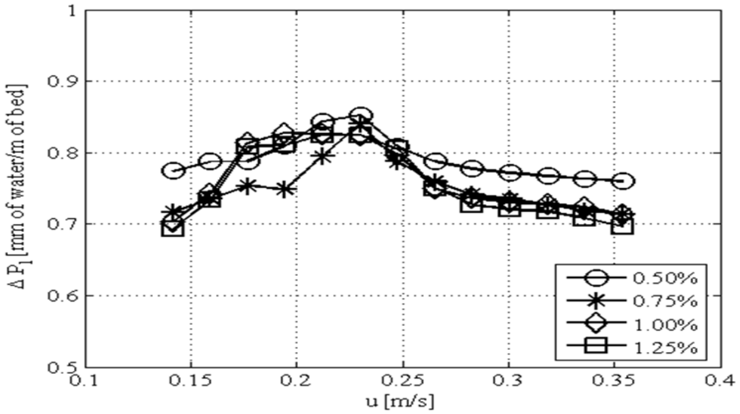

Figure 5. Column pressure drop per unit bed height (ΔP_1) versus superficial velocity (U) for the mixture of cotton stalk (CS) and sand

The column pressure drop per unit bed height (Figure 6) increased more uniformly for maize stalk in comparison to cotton stalk. Higher pressure drop are recorded for maize stalk along with high initial bed height. The pressure drop rise for maize stalk is much steeper than that for the cotton stalk. So, the overall ratio b/w pressure drop and bed height is higher than that observed for the cotton stalk.

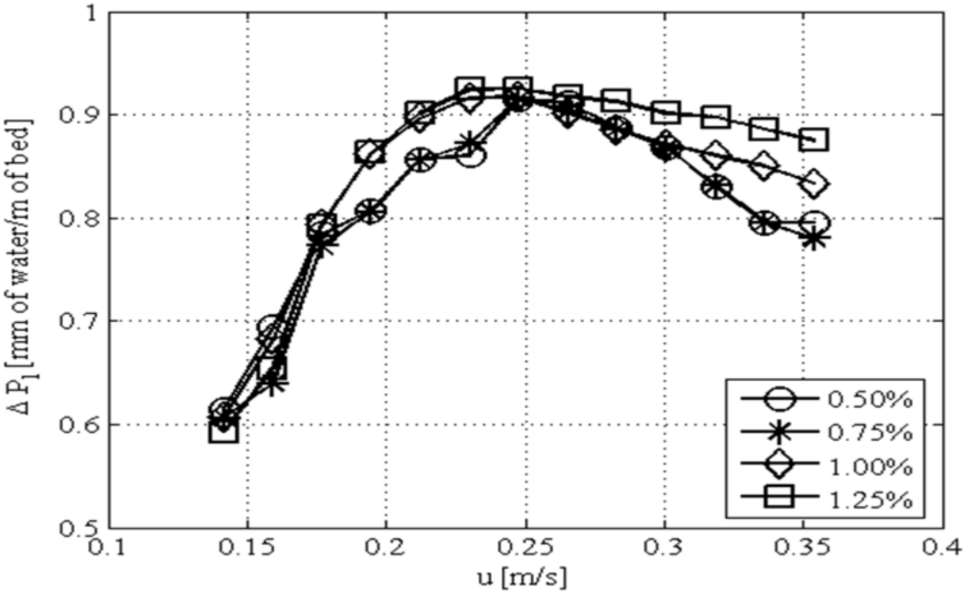

Figure 6. Column pressure drop per unit bed height (ΔP1) versus superficial velocity (U) for maize stalk (MS) and sand mixture

The trend for the saw dust (Figure 7) is similar to the trend for the cotton stalk. The major reasons attributable are the geometry and bed height as discussed above.

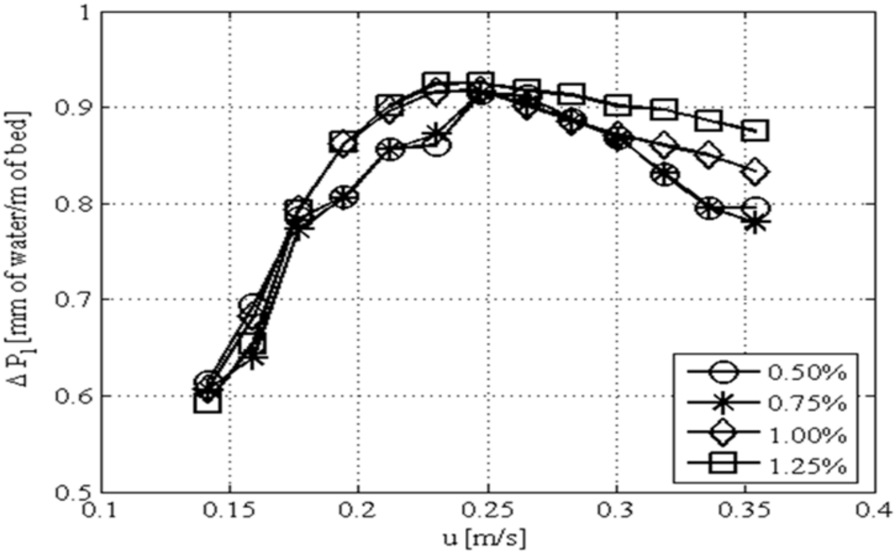

Figure 7. Column pressure drop per unit bed height (∆P1) versus superficial velocity (U) for saw dust (SD) and sand mixture

Predicted values of minimum fluidization velocities are closely similar, independent of BMC, and higher than experimentally determined values. The experimental values (Figure 8) show a slight increase with increasing the biomass percentage (BMC). The minimum fluidization velocity (MFV) for the maize stalk samples are 4-6% higher than the MFV's for other biomasses at the corresponding experimental conditions. The theoretical value is higher than the experimental value due to the reason that spherecity factor and the bed voidage are assumed constant while using the correlation but in actual practice they are different for different biomasses and their different mixtures with sand.

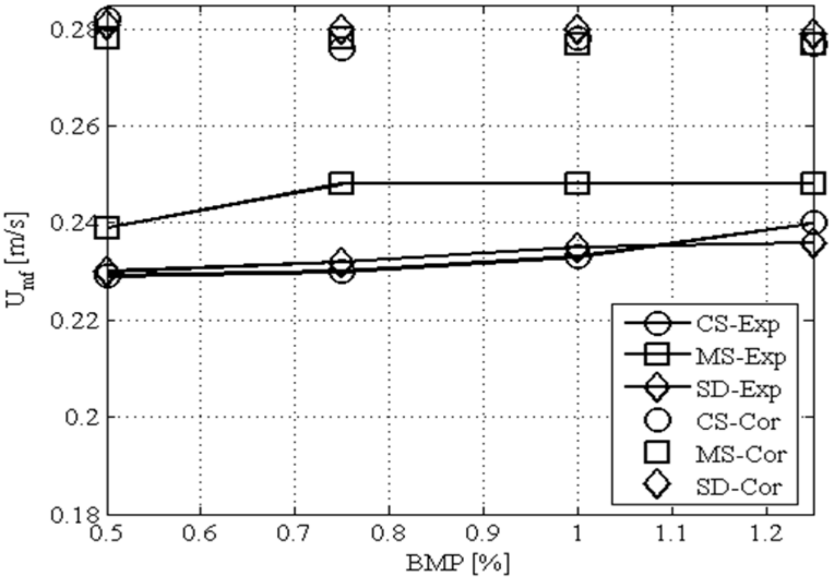

Figure 8. Comparison of minimum fluidization velocities (U_{mf}) determined from experiments and those predicted from published correlation for mixtures of cotton stalk (CS), maize stalk (MS), and saw dust (SD) with sand versus biomass percentage (BMP)

4. Conclusions

The minimum fluidization velocities were determined experimentally for biomass–sand mixtures of different compositions for cotton stalk, maize stalk and saw dust using cold fluidized test rig. Kunni and Levenspeil correlations were used to predict the minimum fluidization velocities for the mixtures of the same compositions. It is observed that the values of minimum fluidization velocities calculated from the correlation are higher than those determined from experiments by 12-21%. This difference may be due to the presence of Inter-particle forces which have not been accounted for yet in the correlations. It is also observed that the biomass percentage (BMC) has a slight positive impact on minimum fluidization velocity (MFV). The effect of biomass itself also showed an influence on the MFV. Therefore, experimental investigation of hydrodynamics of new systems should be carried out to obtain more reliable data on plant performance.

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