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STUDIES ON FLUIDIZATION BEHAVIOUR OF SAND AND BIOMASS MIXTURES

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ABSTRACT

The present work is focused on the study of fluidization behaviour of biomass and sand mixtures in a laboratory scale test set up. The biomass materials used during the experimentation were rice husk, bagasse and sawdust. Two different particle sizes of silica sands were used in forming the mixture. The percentages of biomass in the mixtures were 2%, 5%, 10% and 15% by weight. The minimum fluidization velocities of the binary samples were experimentally found out in a transparent fluidized bed column. The experimental values of the minimum fluidization velocities were compared with the correlations available in literature. The pressure drops across the fluidized beds were also measured at different operating conditions and such data have been analyzed to explain the hydrodynamic behaviour.

Keywords: Fluidized bed, Biomass and sand mixtures, Fluidization velocities, Pressure drop.

1. INTRODUCTION

The fluidized bed reactors have many advantages that provide good solids mixing, high heat transfer and large contact surface area. So the fluidized beds have been employed in many industrial processes. However, important parameters like the minimum fluidization velocity and particle size distribution, which play a critical role in the design and operation of fluidized beds, are difficult to be predicted [1]. The knowledge of the minimum fluidization velocity facilitates the study of reaction kinetics because it allows a rational use of the gas in the gas phase as an excess over that required for minimum fluidization [2].

The fluidization characteristics of biomass materials are very important for modeling and design of the reactors because these materials cannot be easily fluidized. A second solid, usually an inert material like silica sand, alumina, calcite, etc., is mixed with biomass to facilitate its fluidization and to maintain the desired hydrodynamics of the bed. It also acts as a heat transfer medium in the reactor. The fluidization behavior of sand and biomass mixtures is characterized by the particles of different shapes, sizes, densities and compositions [3]. Beeckmans et al. [4] stated that the presence of particles with different densities and/or sizes may cause vertical segregation in gas-solid fluidized beds. In most fluidized beds this is not desired, since it may jeopardize particle circulation, thus causing unstable fluidization patterns and reducing the heat and mass transfer rates [5].

Pilar Aznar et al. [6] reviewed several investigations on the fluidization of mixtures of solids with different particle sizes as well as mixtures of particles of different sizes and densities, including that of mixtures of sands and biomass materials. They concluded that no satisfactory equations for predicting the minimum fluidization velocities, particularly for mixtures of sands and biomass materials, are available. Subsequently, Rao and Bheemarasetti [3] made an attempt to develop an empirical equation for predicting the values of minimum fluidization velocities and they validated the model for the mixtures of sands and biomass materials in a fluidized bed system.

In the present research work, the experimental studies have been performed using mixtures of two different sizes of sand and widely used biomass like rice husk, bagasse and saw dust in a fluidized bed column. These practical data have been compared with the empirical correlations available in literature.

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2. EXPERIMENTAL SET UP AND METHODOLOGY

2.1. EXPERIMENTAL SET UP

The tests were conducted in a transparent plexiglass cylindrical fluidizer with an internal diameter of 0.1 m and a height of 1.2 m fitted with a perforated distributor plate. The fluidizer outlet is fitted with a cyclone separator. Air was supplied from a blower and the air flow was controlled by a regulating valve. An orifice flow meter has been used to measure the air flow rate. The pressure drops across the distributor plate and the bed were measured by U-tube water manometers. The biomass and sand mixture were put inside the vessel through a screw feeding system. The schematic diagram is presented in Fig. I.

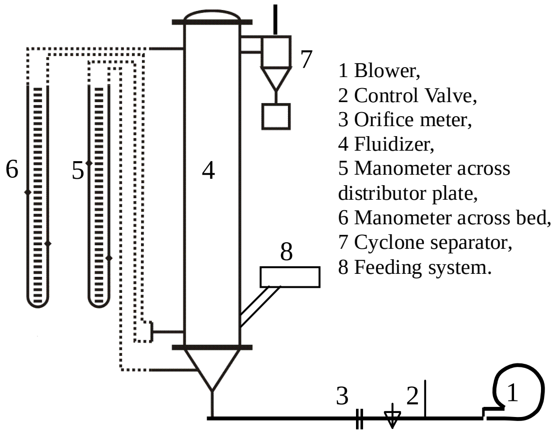

Fig. I. Schematic diagram of experimental set-up.

2.2. METHODOLOGY

Each sample of rice husk, bagasse and sawdust material was mixed with silica sands of two different particle sizes. For the first sand sample, the mean diameter was 230 μm and for the second, it was 300 μm. The measured density of sands was found to be 2650 kg/m^3. For rice husk, the average particle size was 1100 μm with a density of 390 kg/m^3. The similar parameter for bagasse was 1250 μm with a density of 694 kg/m^3 and also, the mean size of sawdust was 530 microns with a density of 396 kg/m^3. The silica sands and biomass samples were prepared by sieving through British Standard BS-410. The proportion of biomass and sand were taken on weight basis as it was easier to measure more accurately than on the basis of bulk volume. The weight percentages of biomass in the mixtures were taken to be 2%, 5%, 10% and 15%. During experimentation, the total weight of binary mixture was taken as 1.2 kg for each run.

Initially the sand and biomass samples were thoroughly mixed and were put inside the fluidizing chamber. When air was gradually passed through the bed, the initial pressure drops across the bed were nearly proportional to gas velocities. But after sometime, with further increase of air velocities, the pressure drops did not change and were remain nearly constant. The pressure drops were measured using the U-tube water manometer and have been plotted against the air velocities. The intersection of the sloping curve corresponding to initial air velocities under packed bed condition with the horizontal line indicating constant pressure drop represents the minimum fluidization velocity of the bed particles. The pressure drops were also measured with decreasing flow rates and the similar method was applied to obtain the minimum fluidization velocity for decreasing air flow rates.

3. THEORETICAL ANALYSIS

The pressure drop through a packed bed of height L using non-spherical particles with a mean diameter d_p is given by Ergun [7]

$$\frac{\Delta P}{L}=150\,\frac{(1-\varepsilon)^2}{\varepsilon^3}\,\frac{\mu_g U}{(\varphi d_p)^2}+1.75\,\frac{1-\varepsilon}{\varepsilon^3}\,\frac{\rho_g U^2}{\varphi d_p} \quad (1)$$

When the pressure drop becomes equal to weight of the bed per unit cross-sectional, the bed begins to expand and for such conditions, it is written as

$$\Delta P=\left(1-\varepsilon_{mf}\right)\left(\rho_s-\rho_g\right) g\, L \quad (2)$$

After re-arrangement of eqns.(1) and (2), one gets

$$\left(1-\varepsilon_{mf}\right)\left(\rho_s-\rho_g\right) g=150\,\frac{(1-\varepsilon_{mf})^2}{\varepsilon_{mf}^3}\,\frac{\mu_g U_{mf}}{(\varphi d_p)^2}+1.75\,\frac{1-\varepsilon_{mf}}{\varepsilon_{mf}^3}\,\frac{\rho_g U_{mf}^2}{\varphi d_p} \quad (3)$$

Again, multiplying each side by $\frac{d_p^3\rho_g}{\mu_g^2(1-\varepsilon_{mf})}$, one would get the following correlation.

$$\frac{d_p^3\rho_g\left(\rho_s-\rho_g\right)g}{\mu_g^2}=\frac{150\left(1-\varepsilon_{mf}\right)}{\varphi^2\varepsilon_{mf}^3}\left(\frac{d_p U_{mf}\rho_g}{\mu_g}\right)+\frac{1.75}{\varphi\varepsilon_{mf}^3}\left(\frac{d_p U_{mf}\rho_g}{\mu_g}\right)^2 \quad (4)$$

The eqn. (4) can be expressed in terms of dimensionless quantities namely Archimedes no.(A_r) and Reynolds no. (R_e) as follows

$$A_r=\frac{150\left(1-\varepsilon_{mf}\right)}{\varphi^2\varepsilon_{mf}^3}Re_{mf}+\frac{1.75}{\varphi\varepsilon_{mf}^3}Re_{mf}^2 \quad (5)$$

where

$$A_r=\frac{d_p^3\rho_g\left(\rho_s-\rho_g\right)g}{\mu_g^2} \quad (6)$$

and

$$Re_{mf}=\frac{d_p U_{mf}\rho_g}{\mu_g} \quad (7)$$

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The superficial air velocity at minimum fluidization condition, U_{mf}, demonstrated by Kunii and Levenspiel [8] is written as

$$U_{mf} = \frac{\mu_g}{d_p \rho_g}\left[(33.7)^2 + 0.0408 \frac{d_p^3 \rho_g (\rho_s - \rho_g) g}{\mu_g^2}\right]^{\frac{1}{2}} - 33.7 \qquad (8)$$

Rao and Bheemarasetti [3] conducted a similar study and they used the biomass samples of sizes 10 × 2 × 1mm for rice husk, +800–1000 µm for sawdust and +800–1200 µm for groundnut shell powder, with sand samples of +355–600 µm and +250–355 µm in diameter. The correlations developed by them were based on an average effective mixture density and an effective particle diameter, which are explained below

$$U_{mf} = \frac{dp_{eff}^{\ 2} (\rho_{eff} - \rho_g) g}{1650\ \mu_g} \qquad (9)$$

where

$$\rho_{eff} = \frac{w_1 \rho_{s1} + w_2 \rho_{s2}}{w_1 + w_2} \qquad (10)$$

and

$$dp_{eff}^{\ 2} = k' \left[dp_1 \left\{ \left(\frac{\rho_1}{\rho_2}\right) \left(\frac{dp_2}{dp_1}\right) \right\}^{w_2/w_1} \right]^2 \qquad (11)$$

The constant k´ depends on the sand diameter. The relation of k´ with sand diameter d_{p1} was given by Rao and Bheemarasetti [3] as

$$k' = 20\ dp_1 + 0.36 \qquad (12)$$

In order to predict the minimum fluidization velocity, many researchers have developed empirical correlations in different operating conditions based on the experimental data which is listed in Table 1.

Table 1: Correlation equations by researchers

References	Equation
Leva, 1959	$U_{mf} = \frac{0.0093\ d_p^{1.82} (\rho_p - \rho_g)^{0.94}}{\mu_f^{0.88}\ \rho_g^{0.06}}$
Barbosa et al., 1995	$Re_{mf} = 1.9 \times 10^{-3}\ A_r^{\ 0.87}$
Bourgeois and Grenier, 1968	$Re_{mf} = \left(\sqrt{25.46^2 + 0.0382\ A_r} - 25.46\right)$
Richardson and St. Jeronimo, 1979	$Re_{mf} = \left(\sqrt{25.7^2 + 0.0365\ A_r} - 25.7\right)$
Thonglimp et al., 1984	$Re_{mf} = 7.54 \times 10^{-4}\ A_r^{0.98}$ for Re<30 $Re_{mf} = 1.95 \times 10^{-2}\ A_r^{0.66}$ for 30< Re<180
Lucas et al., 1986	$Re_{mf} = \left(\sqrt{29.5^2 + 0.0357\ A_r} - 29.5\right)$
Pillai and Raja Rao, 1971	$U_{mf} = \frac{7.01 \times 10^{-4}\ d_p^2\ g (\rho_p - \rho_g)}{\mu_g}$
Adánez, 1991	$Re_{mf} = \left(\sqrt{25.18^2 + 0.0373\ A_r} - 25.18\right)$
Grace, 1986	$Re_{mf} = \left(\sqrt{27.2^2 + 0.0408\ A_r} - 27.2\right)$

4.0 RESULTS AND DISCUSSION

All the experiments were performed to measure the characteristic of minimum fluidizing velocities of binary mixtures using the procedure with increasing and decreasing air velocities. It was observed that the pressure profiles in two cases differ to an extent. The profile for decreasing velocity was the smooth one due to insignificant effect of inertial phenomenon. It was also observed that the defluidization curve (in case of decreasing air velocities) was above the fluidization curve (in case of increasing air velocities). Rao and Bheemarasetti [3] and Pilar Aznar et al. [6] also reported similar behaviour.

During the experiment using rice husk and sand mixtures, some voids in the bed were noticed when the fluidizing air was passed through the bed. The inter particle friction forces for rice husk are high and impact of gravitational forces on particles is weak due to light weight. Addition of sand particles, however, reduced this friction and, the behaviour of bed was found to be improved. Fig. II shows the pressure drops across the chamber against superficial air velocities using 10% rice husk samples in the mixture. The minimum fluidization velocity, U_{mf} was obtained as 0.155 m/s with the pressure drop of 140 mmWC. The measured pressure drop across this bed was slightly lower than that required to support the weight of the bed solids. This may be explained for the fact that the entire air was not percolated through the bed and some channels could have been formed inside the bed to allow a portion of gas to by-pass the husk particles.

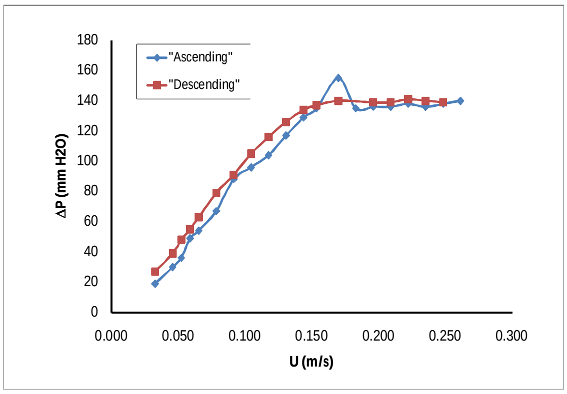

Fig. II Pressure drop versus gas velocity for sand and rich husk mixtures (10%).

Fig. III shows the experimental results using bagasse (10% by weight) and sand mixture where the pressure drops across the bed are plotted against the corresponding superficial air velocities. The experimental value of U_{mf} is obtained as 0.153 m/s with the corresponding pressure drop of 167 mmWC. The static bed height was initially 165 mm. In this case it is found that the experimental value of pressure drop at minimum fluidization velocity was nearly equal to the pressure due to the weight of bed materials.

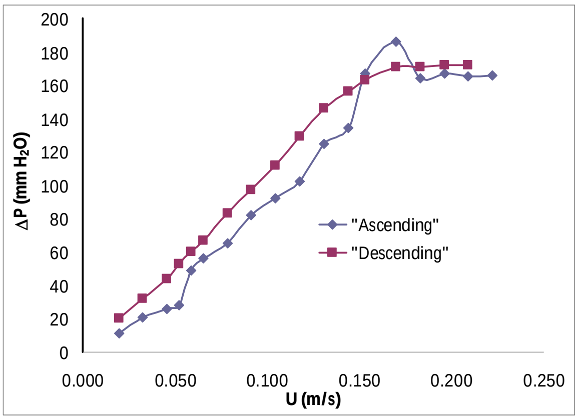

Fig. III. Pressure drop versus gas velocity for sand and bagasse mixtures (10%).

Similarly, for sawdust and sand mistures, the variation of pressure drop across the bed against superficial air velocity is shown in Fig. IV. The value of U_{mf} for the mixture as obtained from the graph was found to be 0.145 m/s with the corresponding pressure drop of 160 mmWC.

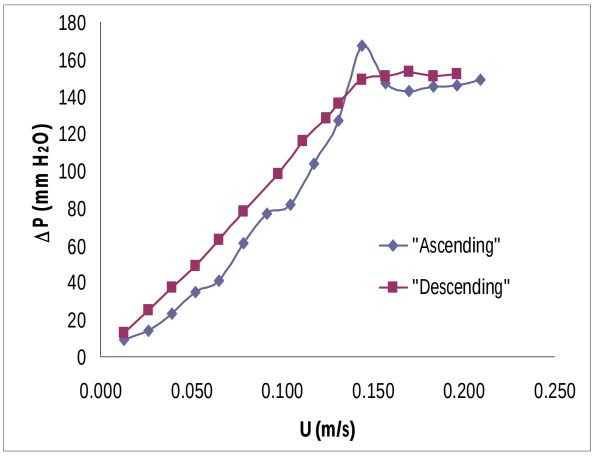

Fig. IV. Pressure drop versus gas velocity for sand and saw dust mixtures (10%).

During experimentation, it was observed that at a higher weight fraction of biomass, the minimum fluidization velocity rises. In Fig. V, the experimental minimum fluidization velocities for sand and biomass mixtures using rice husk, bagasse and saw dust are shown. This is due to the fact that the biomass particles negatively influence the fluidization behaviour.

The experimental values of the minimum fluidization velocity, U_{mf}, determined in this work were compared to the values calculated from the correlations as suggested by Rao and Bheemarasetti [3] and also with other equations listed in Table 1. These comparisons are given in Table 2 and it is observed that in most cases there is a slightly over or under prediction of U_{mf}.

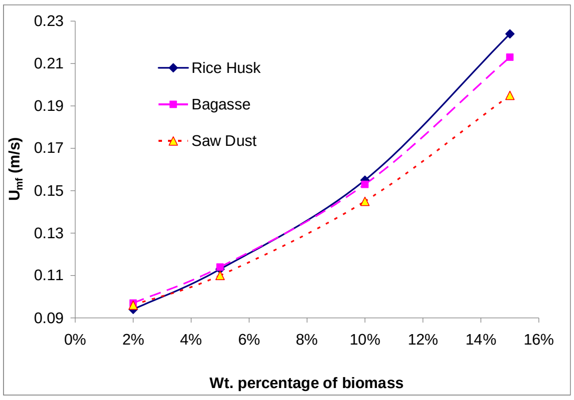

Fig. V. Effect of weight percent of biomass in mixture on minimum fluidization velocities.

During this study, the k´ values have been calculated using eqns. (9-12) based on the experimental values of minimum fluidization velocities of the binary mixtures using silica sands of two mean diameters. The calculated values of k´ for the present study have been plotted against the sand diameters dp_1 as shown in Fig. VI and these values have also been compared with the literature values [3, 6].

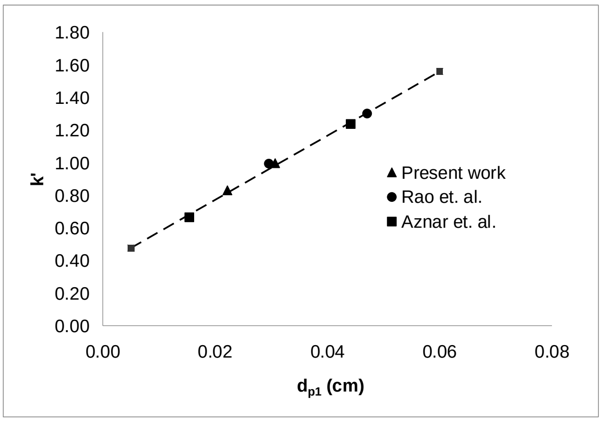

Fig. VI. Variation of constant k´ with sand particle size (dp_1)

5.0 CONCLUSIONS

The minimum fluidization velocities for mixtures of sands and different biomass materials like rice husk, bagasse and sawdust were experimentally determined in a cold model set up. The correlations in literature have been used for predicting the minimum fluidization velocities for these mixtures and it was found that these equations in general closely predict the minimum fluidization velocities, although there are some differences between the theoretical values and the experimentally observed data. The equations also satisfactorily predict the pressure drops across the fluidized bed in flow conditions using different sand biomass mixtures as well.

Table 2: Experimental and theoretical data of minimum fluidization velocities, U_{mf} (m/s)

Biomass	Biomass mix (%)	Present experiment	Rao and Bheemarasetti [3]	Leva [9]	Barbosa et al. [10]	Bourgeois and Grenier, [11]	Richardson and Jeronimo, [12]	Thonglimp et al. [13]	Lucas et al. [14]	Pillai and Raja Rao, [15]	Adanez [16]	Grace [17]
Sand # I (Mean size: 230 μm, 2600-2650 kg/m^3) and Rice Husk	2	0.0470	0.0443	0.0518	0.0532	0.0507	0.0480	0.0450	0.0410	0.0480	0.0500	0.0507
	5	0.0580	0.0542	0.0622	0.0625	0.0618	0.0585	0.0548	0.0501	0.0588	0.0610	0.0618
	10	0.0850	0.0784	0.0871	0.0841	0.0882	0.0837	0.0785	0.0719	0.0852	0.0871	0.0884
	15	0.1310	0.1189	0.1272	0.1173	0.1302	0.1237	0.1176	0.1069	0.1294	0.1286	0.1307
Sand # I (Mean size: 230 μm, 2600-2650 kg/m^3) and Bagasse	2	0.0480	0.0461	0.0550	0.0534	0.0509	0.0482	0.0452	0.0412	0.0482	0.0502	0.0509
	5	0.0580	0.0547	0.0645	0.0614	0.0604	0.0572	0.0535	0.0490	0.0574	0.0596	0.0604
	10	0.0810	0.0746	0.0861	0.0792	0.0822	0.0779	0.0730	0.0668	0.0791	0.0811	0.0823
	15	0.1170	0.1058	0.1194	0.1056	0.1154	0.1095	0.1035	0.0944	0.1134	0.1139	0.1157
Sand # I (Mean size: 230 μm, 2600-2650 kg/m^3) and Saw Dust	2	0.0430	0.0403	0.0478	0.0481	0.0449	0.0425	0.0399	0.0363	0.0424	0.0443	0.0449
	5	0.0510	0.0472	0.0552	0.0546	0.0524	0.0497	0.0466	0.0425	0.0497	0.0518	0.0525
	10	0.0690	0.0631	0.0718	0.0689	0.0696	0.0660	0.0617	0.0565	0.0666	0.0687	0.0697
	15	0.0970	0.0875	0.0968	0.0895	0.0953	0.0904	0.0849	0.0777	0.0925	0.0941	0.0955
Sand # II (Mean size: 300 μm, 2600-2650 kg/m^3) and Rice Husk	2	0.0940	0.0926	0.1002	0.0997	0.1073	0.1018	0.0959	0.0876	0.1047	0.1059	0.1076
	5	0.1130	0.1100	0.1160	0.1133	0.1247	0.1184	0.1121	0.1022	0.1231	0.1231	0.1251
	10	0.1550	0.1505	0.1545	0.1458	0.1659	0.1578	0.1524	0.1370	0.1689	0.1638	0.1666
	15	0.2240	0.2144	0.2135	0.1937	0.2248	0.2143	0.2153	0.1881	0.2414	0.2220	0.2264
Sand # II (Mean size: 300 μm, 2600-2650 kg/m^3) and Bagasse	2	0.0970	0.0959	0.0992	0.0988	0.1063	0.1008	0.0949	0.0868	0.1036	0.1049	0.1065
	5	0.1140	0.1118	0.1132	0.1109	0.1216	0.1155	0.1092	0.0996	0.1198	0.1201	0.1220
	10	0.1530	0.1479	0.1467	0.1393	0.1577	0.1499	0.1442	0.1300	0.1595	0.1557	0.1584
	15	0.2130	0.2028	0.1966	0.1802	0.2085	0.1987	0.1971	0.1738	0.2204	0.2059	0.2099
Sand # II (Mean size: 300 μm, 2600-2650 kg/m^3) and Saw Dust	2	0.0960	0.0952	0.0982	0.0979	0.1052	0.0998	0.0939	0.0859	0.1025	0.1038	0.1054
	5	0.1100	0.1091	0.1103	0.1084	0.1185	0.1125	0.1063	0.0970	0.1165	0.1170	0.1188
	10	0.1450	0.1401	0.1389	0.1327	0.1495	0.1421	0.1361	0.1231	0.1503	0.1476	0.1501
	15	0.1950	0.1860	0.1804	0.1669	0.1923	0.1831	0.1799	0.1598	0.2006	0.1899	0.1934

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NOMENCLATURE

Symbol

Ar	Archimedes no.
ΔP	Pressure drop (mmWC)
L	Height of bed (m)
ε	Bed voidage
μ	Viscosity (kg/m-s)
U	velocity (m/s)
Φ	Sphericity of sand particle
d	Diameter (m)
ρ	Density (kg/m^3)
g	Acceleration due to gravity (m/s^2)
Re	Reynolds no.
w	Weight (kg)
k´	Constant

Subscripts

g	Air
mf	Minimum fluidization
p	Particle
eff	Effective
1	Sand
2	Biomass
s	solids

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