FLUIDIZATION CHARACTERISTICS OF BIOMASS IN A BUBBLING FLUIDIZED BED

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ABSTRACT

Fluidization is a favorable technology for thermochemical processing of biomass materials due to its inherent advantages such as flexibility to process fuels having a wide range of physical and chemical properties. In this study, fluidization characteristics are investigated and minimum fluidization velocities are determined for four different types of biomass (rice husk, sawdust, olive cake and hazelnut shell) - silica sand mixtures in a laboratory scale fluidized bed. Generally, except olive cake, pure sawdust, hazelnut shell, rice husk show poor fluidization characteristics with large gas voids. Mixing the biomass with silica sand result in an improvement in fluidization behavior with significant decrease in minimum fluidization velocity compared to pure biomass case. No single available empirical correlation in the literature is able to predict the minimum fluidization velocities of all types of biomass-silica sand mixtures investigated.

1. INTRODUCTION

Energy demand has been growing steadily in parallel to the technological development and industrialization. Global environmental problems together with limited amount of fossil fuels place pressure on governments to take steps for widespread use of renewable energy that will decrease the dependency on fossil fuels and lead to more sustainable and environmentally friendly energy supply technologies. Biomass is the name used to describe all organic yields obtained from plants and waste from animals. Usage of biomass as a fuel in an energy conversion system is carbon neutral and does not affect the carbon balance between earth and atmosphere.

Biomass-agricultural and forest residues and sometimes certain urban and industrial wastes can be processed thermochemically in order to yield gases, tars and a carbonaceous residue (char) which can be employed for energy production purposes. Among the well-known thermochemical processes are gasification, pyrolysis, combustion or incineration in fluidized beds (bubbling, fast, circulating and circulating-multisolid beds) [1,2]. Fluidization is a favorable technology for thermochemical processing of biomass materials due to its inherent advantages such as flexibility to process fuels having a wide range of physical and chemical properties. However, uniform fluidization of most biomass such as sawdust, rice husk, straw and bagasse is difficult because of their characteristic shapes, sizes, densities, and moisture contents. For successful design of a fluidized bed gasifier or combustor, the fluidization characteristics of the feedstock should be well understood [2].

2. EARLY WORKS

It has been suggested that the mixing of biomass with an easily fluidizable solid can improve the fluidization quality and the resulting binary mixture can be handled more easily compared to pure biomass. In this respect, determination of the minimum fluidization velocity characteristics of the binary mixture is very crucial and has been the subject recent investigations [2]. Bilbao et al. [3] determined the minimum fluidization velocities for sand-wheat straw binary mixtures for different experimental conditions. The velocity values obtained have been correlated with the straw and sand sizes and the proportions of both solids in the bed. Pilar et al. [1] investigated the fluidization of binary mixtures of biomass and a second solid. They argued that no proposed correlation was able to predict all the results in their study. Rao et al. [4] studied the fluidization of mixtures of various types of biomass and sand. Equations were developed for predicting the minimum fluidization velocity. Abdullah et al. [5] conducted an experimental study to determine the minimum fluidizing velocities for locally available biomass residue fuels in Malaysia such as rise husk, sawdust, peanut shell, coconut shell, palm fiber as well as coal and bottom ash. Bulk density and voidage were found to be the main factors affecting the fluidizing quality of the bed. Patil et al. [6] conducted experiments to study the fluidization behaviors of sand-switchgrass mixtures with different particle sizes and bulk densities. They found that minimum and complete fluidization velocity values were more sensitive to the sand particle size compared to the amount of switchgrass in the switchgrass-sand mixture. Clarke et al. [7] investigated the fluidization behavior of binary mixtures of moist sawdust and glass spheres. Since the sawdust alone was observed to fluidize poorly, with extensive channeling occurring, glass spheres were added to the bed of sawdust to improve the fluidization characteristics.

In this paper results on minimum fluidization velocities of biomass-silica sand mixtures for four types of locally available biomass (rice husk, sawdust, olive cake and hazelnut shell) are presented. Especially, there is no study in the literature on the hydrodynamic behavior of olive cake and hazelnut shell in a bubbling fluidized bed. These two types of biomass constitute an important share of Turkey's biomass sources. Furthermore, the determination of the minimum fluidization velocity is critical in terms of setting the operating velocities for biomass combustors and gasifiers since the operating velocity is known to affect the CO emisssions and combustion efficiency [8].

2. EXPERIMENTAL SET-UP AND METHODOLOGY

Experiments were carried out in a column of cylindrical plexiglass bed with 14.6 cm internal diameter. The schematic of the experimental set-up is shown in Fig. 1. The bed height was 2 m to provide visual observations for freeboard region. Top of the bed was covered with a wire mesh to prevent elutriation of the particles. The distributor plate is a perforated plate having 256 holes of 1.5 mm in diameter to ensure uniform air distribution. A 63 micron wire mesh wire was placed over the distributor plate to prevent falling of fine particles through the holes. 15 cm long wind box that has the same diameter as the bed was installed under the distributor plate. The fluidizing medium was room air supplied by a compressor. Pressure of the air exiting the compressor was adjusted by a pressure regulator and then was passed through a rotameter to measure its flow rate. Air flow rate was adjusted by a valve inserted before the rotameter. To measure the pressure drop along the bed height a U-type water manometer was used. For all experiments the static bed height was kept at 15 cm. Prior to the each experiment, the corresponding binary mixture was fluidized for a long time and the gas flow suddenly was cut off to obtain a well mixed bed before the beginning of the experiments.

3. MATERIALS

Binary mixtures used this study are formed by mixing biomass and silica sand. Four different biomass materials and silica sand with three different particle sizes were employed as materials. Silica sand is widely utilized in fluidized beds as an inert material. Silica sand was obtained from a casting factory. It falls in Group B according to Geldart's classification. It was sieved and three different particle sizes within the ranges of 150–425 μm, 425–595 μm and 595–850 μm, were obtained to be used in the experiments to investigate the effects of sand particle size on the fluidization characteristics. Bulk densities of silica sand and biomass materials are given in Table 1.

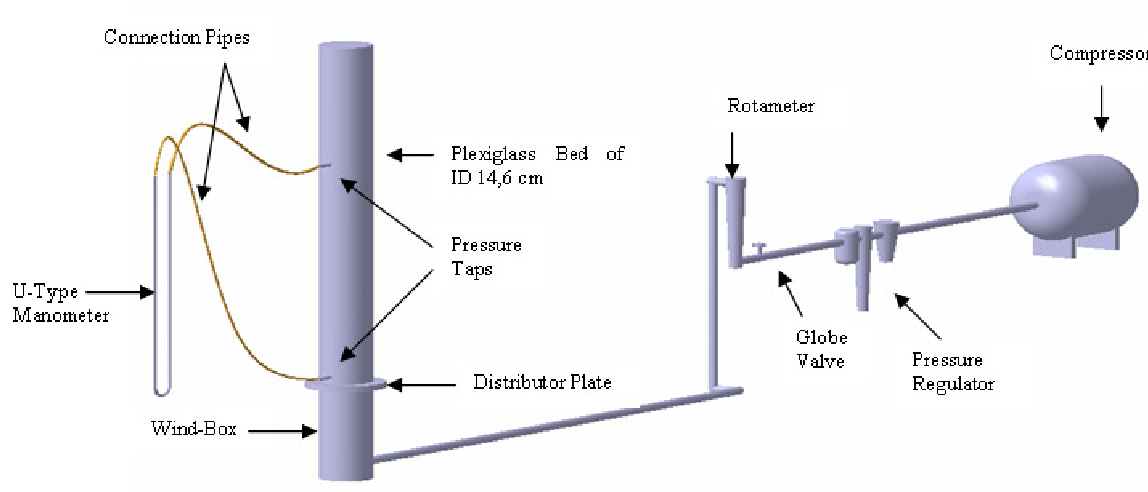

Fig. 1. The experimental set-up to determine the minimum fluidization velocity of biomass-silica sand binary mixtures

Table 1. Bulk densities of silica sand and biomass materials

	Silica Sand	Olive Cake	Hazelnut Shell	Rice Husk	Sawdust
Bulk Density (kg/m^3)	1580	527	477	97	211

Rice husk used in this study was obtained from Beypazarı Rice Factory and particles had average dimensions of 7.7x2.7x1.3 mm. Sawdust used in this study was obtained from a wood processing plant. Its particle size distribution is given in the Fig. 2. Particle size distribution of olive cake used in this study is given in Fig. 3. Hazelnut shell used in this study is crunched after separated from edible part. Crunched particles were sieved and particles accumulated between mesh openings 4 and 2 mm were employed in the experiments.

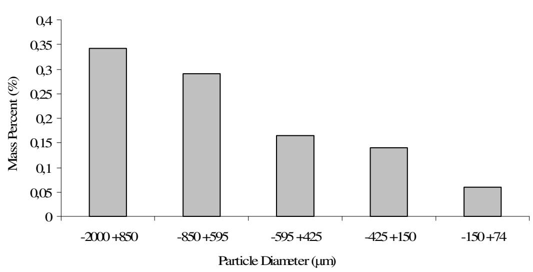

Fig. 2. Particle size distribution of sawdust

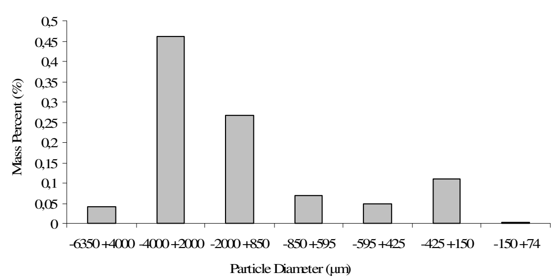

Fig. 3 Particle size distribution of olive cake

4. RESULTS AND DISCUSSION

Pure rice husk, sawdust, wheat straw and hazelnut shell were all observed to have poor fluidization quality due to their physical shapes. Fig.4 shows the variation of the bed pressure drop with respect to superficial gas velocity (U_o, defined as volumetric flow rate of the air divided by the bed cross-sectional area) for pure rice husk. A typical bed pressure drop vs superficial gas velocity curve for an easily fluidizable solid would have an increasing trend in the packed bed region and then level off to a constant value when the bed is fluidized. The minimum velocity at which the curve levels off is known as minimum fluidization velocity, U_{mf}. As shown in Fig. 4, the fluidization of pure rice husk does not show a typical behavior for both types of experiments carried out by increasing and decreasing the superficial gas velocity. Before minimum fluidization, pressure fluctuations are observed due to formation of channels. Fluidization is attained at about 1m/s for rice husk. However, visual observations suggest that the bed shows the characteristics of a turbulent-like fluidization marked by large gas voids rather than well defined bubbles.

As rice husk is mixed with silica sand, the minimum fluidization velocity decreases with increasing mass fraction of biomass as seen in Fig. 5. It is interesting to note that pure silica sand (case 0%) has a lower minimum fluidization velocity than that of the mixture. This may be attributed to the fact that the amount rice husk increase in the mixture creates resistance to fluidization due to peculiar shape and density of the rice husk. Fig. 6 compares the minimum fluidization velocities for two different sizes of silica sand. As expected, as the size of the silica sand increases, minimum fluidization velocity also increases.

Fig. 7 shows the snapshots of the fluidization of pure sawdust at different superficial gas velocity obtained from a 2-D fluidized bed. The details of the 2-D bed can be found elsewhere [9]. The large gas voids observed in pure rice fluidization is also seen here. Fig. 8 shows the variation of the minimum fluidization velocity for sawdust-silica sand mixtures. Compared to rice husk case, the minimum fluidization velocity of sawdust-silica sand mixture does not show a significant sensitivity to sawdust mass fraction.

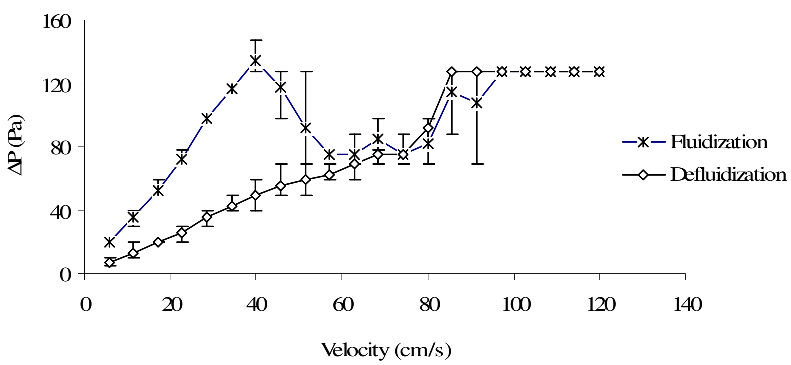

Fig. 4. Bed pressure drop vs superficial gas velocity for pure rice husk (fluidization: increasing velocity, defluidization: decreasing velocity)

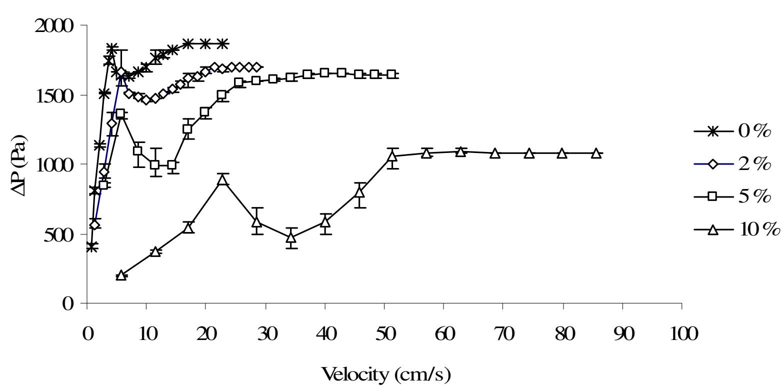

Fig. 5. Bed pressure drop vs superficial gas velocity for pure rice husk-silica sand (150-425 μm) mixtures with 2%, 5% and 10% mass percent of rice husk.

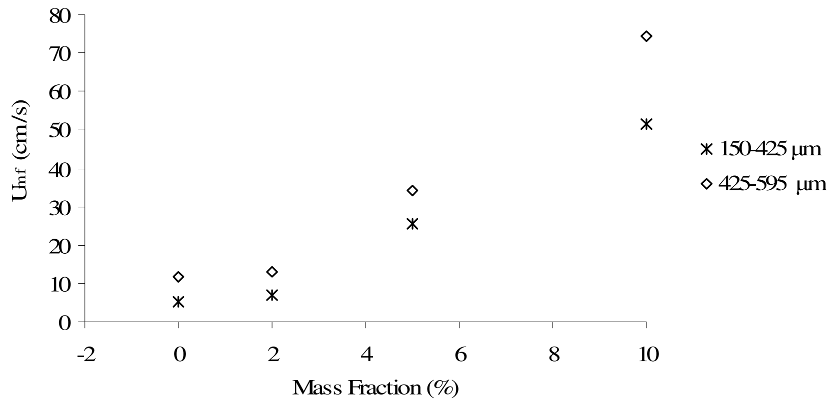

Fig. 6. Effect of mass fraction of rice husk in the mixture on the minimum fluidization velocity

(a) (b) (c)

Fig. 7. Bubbling behavior of pure sawdust in a 2-D bed, (a) U_0/U_{mf}=1.5 (b) U_0/U_{mf}=2.0 (c) U_0/U_{mf}=2.5

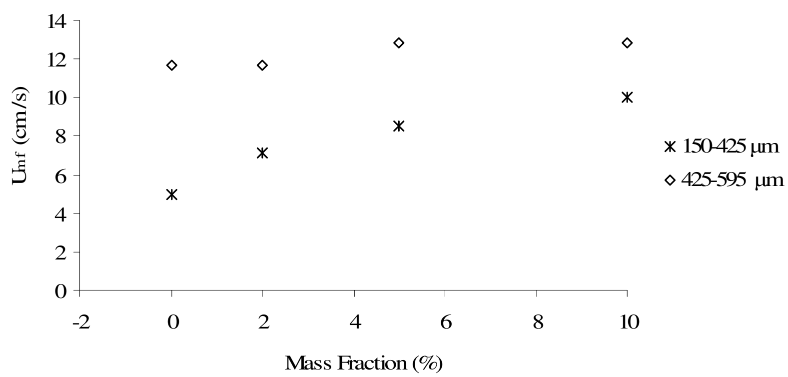

Fig. 8. Effect of mass fraction of sawdust in the mixture on the minimum fluidization velocity

Olive cake is composed of particles that vary in size and during its fluidization, small particles get fluidized first at lower gas velocities and the whole bed fluidizes after the superficial gas velocity exceeds the minimum fluidization velocity of the large particles. This can be seen from Fig. 9. The whole bed fluidizes at a velocity about 60 cm/s. Composing mixtures of olive cake and silica sand provide better fluidization at smaller superficial gas velocities as seen in Fig. 10. Minimum fluidization velocities of the mixtures are very close to the minimum fluidization velocity of silica sand regardless of the size of the silica sand. This may be attributed to the density, size and shape of the olive cake. Density of the olive cake is relatively much higher than the rice husk and sawdust and the shape of the olive cake particles are more spherical resulting in better fluidization quality. The hazelnut-silica sand mixture also shows a similar behavior as olive cake-silica sand mixture (Fig. 11).

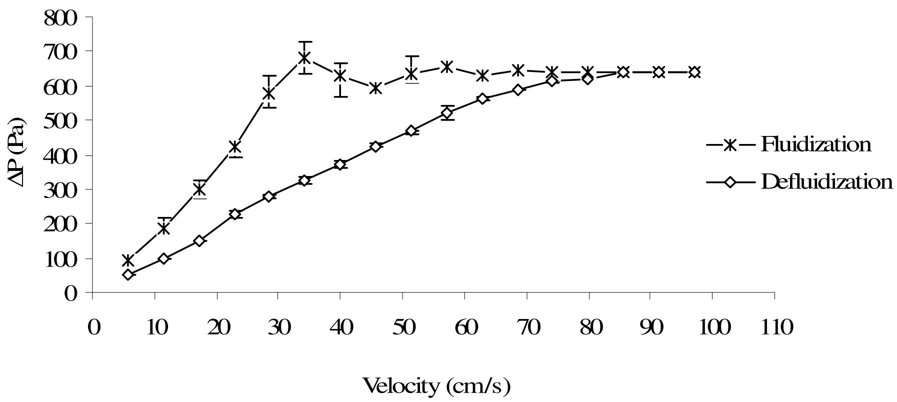

Fig. 9. Bed pressure drop vs superficial gas velocity for pure olive cake (fluidization: increasing velocity, defluidization: decreasing velocity)

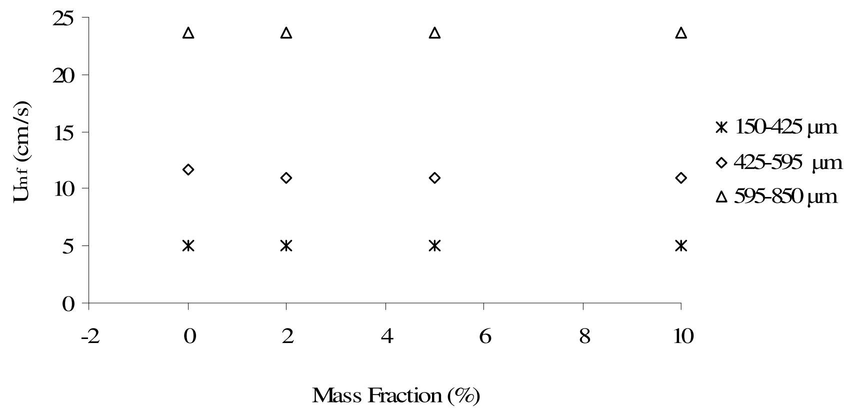

Fig. 10. Effect of mass fraction of olive cake in the mixture on the minimum fluidization velocity

Empirical correlations for minimum fluidization velocity of binary mixtures are mostly based on the size, density, shape and fraction of components in the mixture. Comparisons of the experimental results obtained in this study with the predictions of the available correlations in the literature are given in Fig. 12. For rice husk all correlations fail to predict the U_{mf} except the case with 2% rice husk. For sawdust, predictions of Cheung et al. are quite satisfactory for all mass fractions. For olive cake predictions of both Cheung et al. and Chiba et al. are very successful. For hazelnut shell, it is advisable to use Chiba et al. for predicting the $U_{mf.}$

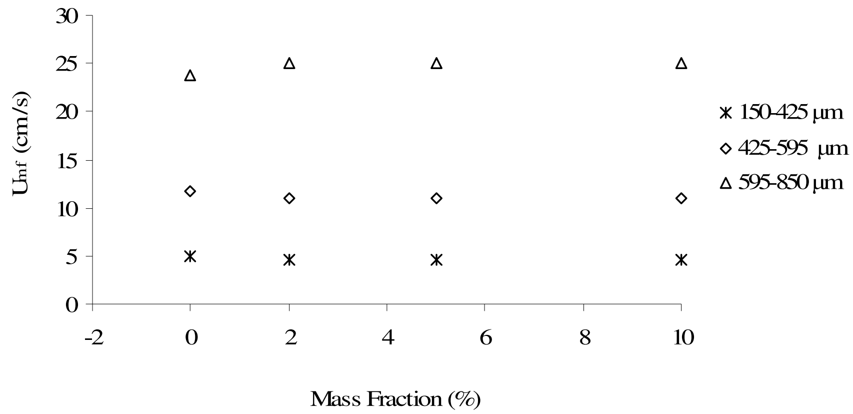

Fig. 11. Effect of mass fraction of hazelnut shell in the mixture on the minimum fluidization velocity.

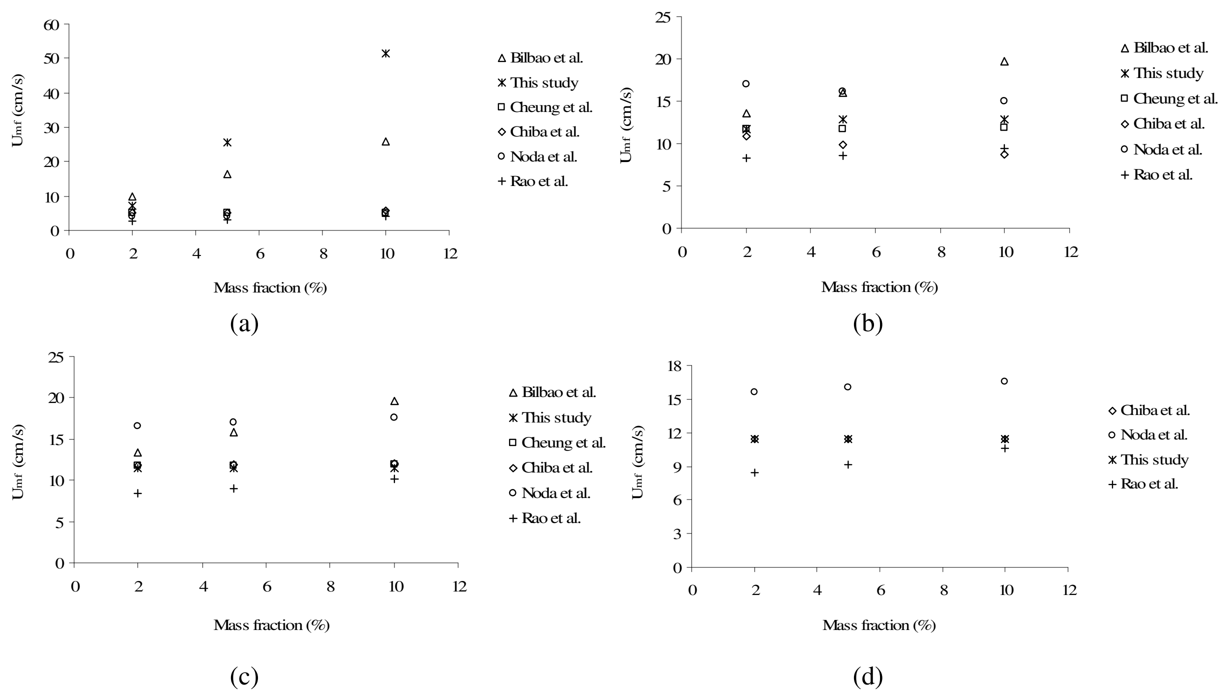

Fig 12. Comparison of the experimental minimum fluidization velocities obtained in this study with the available correlations in the literature.

5. CONCLUSIONS

In this study, fluidization characteristics are investigated and minimum fluidization velocities are determined for four different types of biomass-silica sand mixtures in a laboratory scale fluidized bed at cold room conditions. The types of biomass studied are rice husk, sawdust, olive cake and hazelnut shell. Generally, except olive cake, pure sawdust, hazelnut shell and rice husk show poor fluidization characteristics with large gas voids and channels and quite high minimum fluidization velocities. Mixing the biomass with silica sand result in an improvement in fluidization behavior with significant decrease in minimum fluidization velocity compared to pure biomass case. The increasing mass percentage of biomass in the mixture increases the minimum fluidization velocity for rice husk significantly, has only slight a slight effect for sawdust, and does affect the minimum fluidization velocity for olive cake and hazelnut shell at all within the ranges tested in this study. No single available correlation in the literature is able to predict the minimum fluidization velocities of all types of biomass-silica sand mixtures.

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