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EXPERIMENTAL STUDY OF A BINARY MIXTURE OF RICE HUSK AND SAND IN A FLUIDIZED BED

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Abstract. *Large quantities of rice husk are produced annually as a result from agricultural waste, which, if not treated or discarded correctly, may increase the greenhouse effect and more negatively impact the environment than a controlled process of combustion or gasification. One of the ways of avoiding this problem is using the rice husk as a source of energy. Although that there are many systems that can do that, the fluidized bed presents a good fuel flexibility and high conversion efficiency. In order to design the fluidized bed, the minimum fluidization velocity is one of the main parameters to be accounted. This parameter, however, is dependent on other factors such as granulometric distribution and density of the particulates composing the bed. Therefore, one way which may help reduce the resources and the amount of time spent in the development cycle is creating prediction models for this variable, making it possible to design the system without having to build several prototypes. Even though that have been studies involving prediction models of minimum fluidization velocity for biomass, not many have focused on the mixture between rice and sand. Consequently, the aim of this work is to test some of these models available in the literature and compare them to experimental results.*

Keywords: *Fluidized bed, Binary mixture, Rice husk, Minimum fluidization velocity*

1. INTRODUCTION

The fluidized bed is a system that has many types of applications in the industry, ranging from obtention of polymers and other types of chemical products to the processes of drying and heating. Considering all the possibilities for fluidized beds, one application that has a lot of potential is in thermochemical processes involving biomass. The fluidized bed can be used not only for pyrolysis and gasification, but also for combustion, having advantages such as fuel flexibility and high efficiency. However, in many cases, an inert such as sand is mixed with the biomass to improve the quality of fluidization and homogeneity of the thermal profile along the bed.

Biomass can be considered a good source of energy because it is renewable and it can be obtained from crop field residues. If these residues are discarded without any treatment, it will increase the greenhouse effect and it will more negatively impact the environment than if it were used in a controlled process of combustion or gasification. Therefore, if this biomass were used to produce energy, it could not only help mitigate the problem of the rising demand of energy predicted for the next years but also reduce the negative environmental impact caused by these residues. This is further supported if the calorific power of the rice husk is considered (12 to 18 MJ/kg) (KARMAKAR et al., 2013), which is not one of the biggest but can generate a considerable amount of heat.

Considering all that has been stated, it becomes important to better understand how this mixture between sand and rice husk behaves inside the fluidized bed. Among the many variables involved in this process, the minimum fluidization velocity is one of the most important design parameters (Rezaei, Sokhansanj and Lim 2018) Consequently, equations and empirical models that may help predict it will probably shorten the design process and decrease the resources spent to develop or build a new fluidized bed.

Even though that there have been studies concerning prediction models of the minimum fluidization velocity (U_{mf}) for biomass (Agu, Pfeifer and Moldestad 2019; Paudel and Feng 2013; Pecora et al. 2013; Rasteh, Farhadi and Ahmadi 2018; Rezaei, Sokhansanj and Lim 2018), not many works focus on models related to rice husk fluidization. Therefore, the objective of this work is to test some of these prediction models available in the literature and compare them to experimental results.

2. MATERIAL AND METHODS

2.1 Binary mixture

The particulates that compose the bed of the fluidization system are sand and rice rusk *in natura*. The characteristics of both are described in Tab. 1. This information is important not only to evaluate the results obtained from the experiment but also to be able to calculate the theoretical minimum fluidization velocity. The diameter of the particles is only a standard average of the granulometric distribution.

Table 1. Characteristics of sand and rice husk

Material	**dp (μm)**	**ρ (kg/m^3)**
Rice husk	1400	500
Sand	325	2550

2.2 Experimental determination of the minimum fluidization velocity

The experiment was conducted in a cold fluidized bed as shown in Fig. 1. The acrylic part of the bed has a height of approximately 0.7 m and a diameter of 0.156 m. The distributor used was a perforated plate. The gas velocity was measured using an orifice plate and the pressure was measured with pressure sensors fabricated by BOSCH from the model BMP280. The mass of the sand used in the experiment was of 2 kg and the mass of the rice husk was of 0.02 kg and 0.1 kg, 1% and 5% of the sand, respectively. These values were chosen due to experimental limitations, especially because, for higher values of rice husk, the quality of the fluidization begins to decrease, making the experimental determination of the minimum fluidization velocity much more complex and difficult.

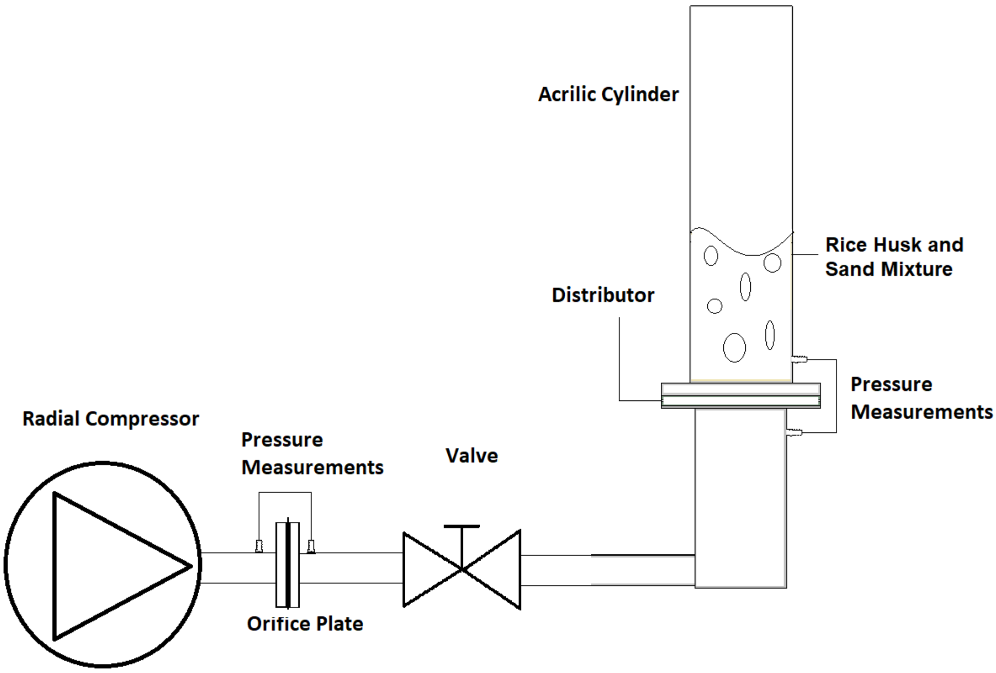

Figure 1. Fluidization system used in the experiments

In order to determine the minimum fluidization velocity, the velocity of the air being injected in the fluidized bed was steadily increased while the pressure at the bottom of the fluidized bed was measured. When the pressure at the bed stabilizes and stops increasing with the increase in the air flow, the bed has reached a state of fluidization. The velocity in which this change and stabilization occurs is considered the minimum fluidization velocity. This velocity is determined in the curve obtained from this process of increasing the velocity of the air, the same procedure realized by Rao and Bheemarasetti (2001) and Qiaoqun et al. (2005). However, in these experiments, the U_{mf} is obtained from the defluidization curve, in which the velocity of the air is decreased from its maximum value to zero. This is done to avoid the possible instabilities created by the heterogeneous mixture in the fluidization curve. Therefore, the same process will be used in this work and the minimum fluidization velocity will be determined using the defluidization curve.

2.3 Determination of theoretical minimum fluidization velocity

In Tab. 2 is shown the correlations used to compare to the values obtained from the experimental results. It was used an older prediction model from Rao and Bheemarasetti (2001) and a relatively recent correlation from Paudel and Feng (2013). U_{mf} is the minimum fluidization velocity, d is the diameter of the particle, ρ is the density, x is the mass proportion of the mixture, μ is the viscosity, Re is the Reynolds Number, Ar is the Archimedes Number, w is the weight, k is a correction factor and g is the gravity. The subscripts determine the material that is being considered, in which $_b$ is for biomass, $_s$ is sand, $_{eff}$ is the effective value of the mixture and $_{mf}$ is the minimum fluidization state.

Table 2. Correlations used to determine the minimum fluidization velocity (U_{mf})

Correlation	Equations	
Rao and Bheemarasetti (2001)	$U_{mf} = \frac{d_{eff}^2(\rho_{eff} - \rho_{air})\, g}{1650\, \mu_{air}}$	(1)
	$\rho_{eff} = x_b\rho_b + x_s\rho_s$	(2)
	$d_{eff} = k\left\{d_s\left[\left(\frac{\rho_s}{\rho_b}\right)\left(\frac{d_b}{d_s}\right)\right]^{w_b/w_s}\right\}$	(3)
	$k = 2000d_s + 0.36$	(4)
Paudel and Feng (2013)	$U_{mf} = \frac{Re_{mf}\mu}{d_{eff}\rho_{air}}$	(5)
	$Re_{mf} = \{30.28^2 + [0.046(1 - x_b) + 0.108x_b^{0.5}]Ar\}^{0.5} - 30.28$	(6)
	$Ar = \frac{d_{eff}^3\, \rho_{air}(\rho_{eff} - \rho_{air})g}{\mu_{air}^2}$	(7)
	$\frac{1}{\rho_{eff}} = \frac{x_b}{\rho_b} + \frac{x_s}{\rho_s}$	(8)
	$d_{eff} = d_b d_s\left[\frac{x_b\rho_s + x_s\rho_b}{x_b\rho_s d_s + x_s\rho_b d_b}\right]$	(9)

3. RESULTS AND DISCUSSION

3.1 Experimental determination of the minimum fluidization velocity

The experiments were executed and the curves obtained, which can be visualized in Fig.2 and Fig.3, showing the fluidization and defluidization process as well as the duplicate of 1% and 5% of rice husk, respectively.

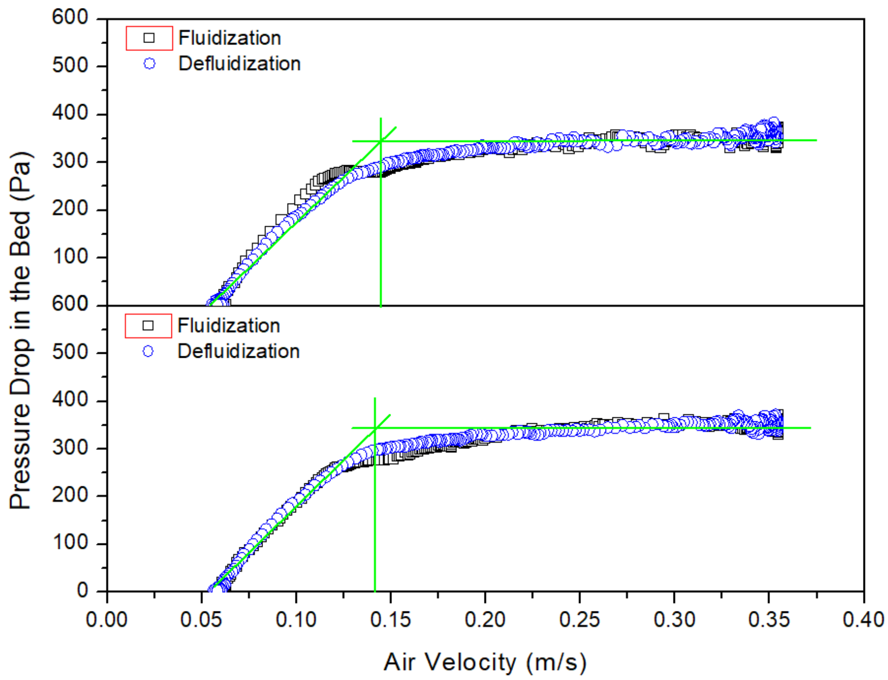

Figure 2. Fluidization and Defluidization curves (with duplicate) of 1% of rice husk and 2 kg of sand

It is possible to notice that the values of the minimum fluidization velocity are very close to their duplicate, for both proportions of rice husk. The effect of the heterogeneous mixture in the fluidization curve can be clearly visualized, especially in the 5% rice husk mixture. In this biomass proportion, the behavior of the curve starts to differ from the defluidization curve.

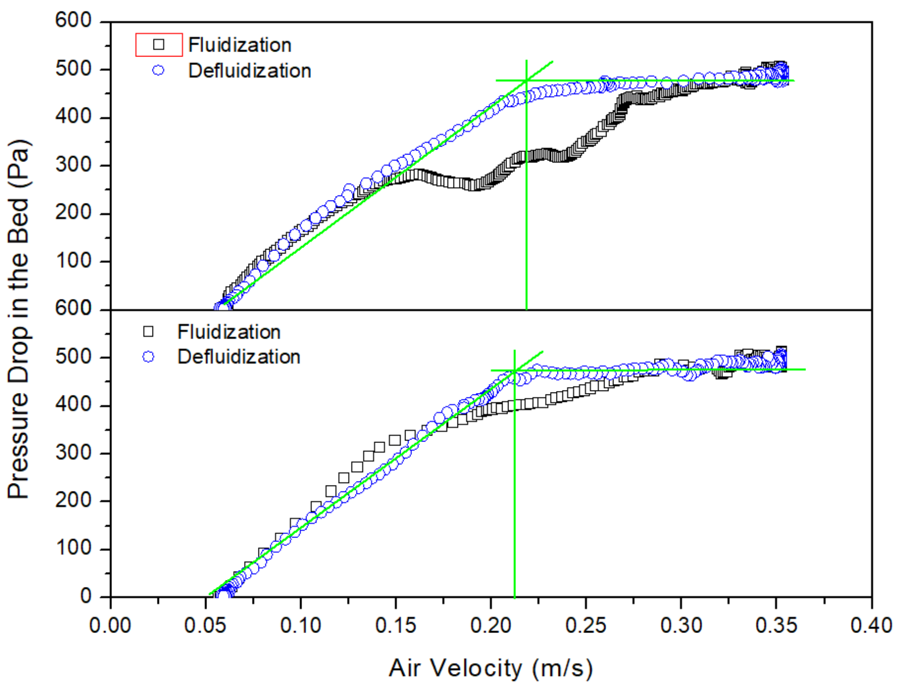

Figure 3. Fluidization and Defluidization curves (with duplicate) of 5% of rice husk and 2 kg of sand

The minimum fluidization velocity is an average from the values obtained from both curves in each rice husk proportion, resulting in velocities of $U_{mf\ 1\%}$= 0.145 m/s for 1% and $U_{mf\ 5\%}$=0.216 m/s for 5% of rice husk.

3.2 Determination of theoretical minimum fluidization velocity

The correlations given by Rao and Bheemarasetti (2001) and Paudel and Feng (2013) were used to generate two different curves, using the same proportions of rice husk (1% and 5%) used in the experimental procedure. The third curve was constructed using the data obtained from the experiments. The results are shown in Fig.4.

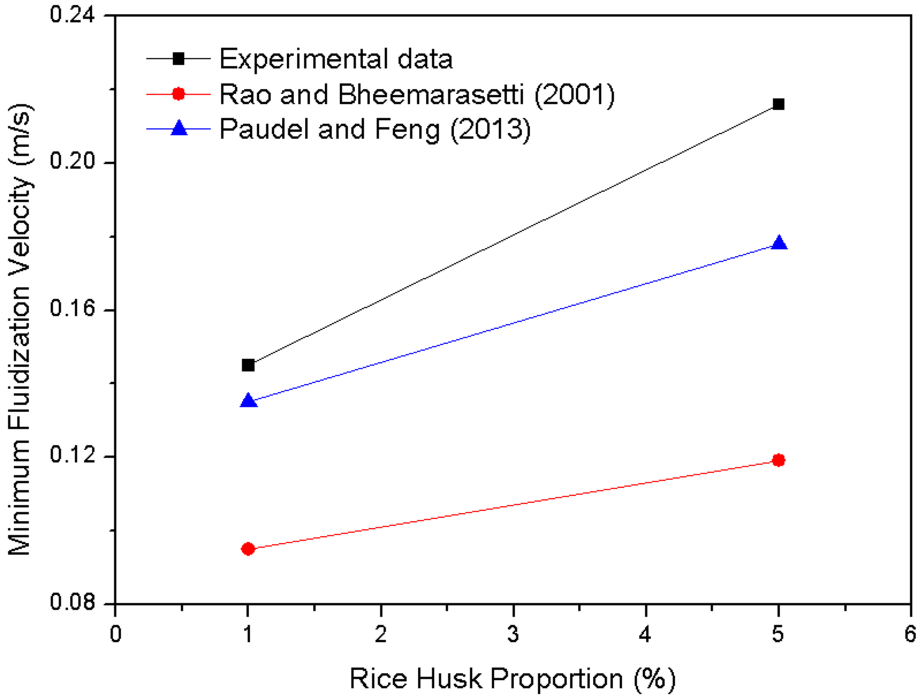

Figure 4. Minimum fluidization velocities obtained from the correlations and the experiments for 1% and 5% rice husk

Both correlations underestimate the minimum fluidization velocity of the mixture, although the one proposed by Rao and Bheemarasetti (2001) is more imprecise if compared to the correlation of Paudel and Feng (2013). It is also possible to see that for a small amount of rice husk (1%), the most recent prediction model (2013) is considerably accurate. However, for a higher proportion of rice husk, the prediction model begins to show a possible reduction of precision.

4. CONCLUSION

The minimum fluidization velocity is one of the main variables in a fluidized bed, important not only to better understand the fluidization behavior of different mixtures but also to aid in the design of future fluidized beds used for thermochemical conversion of biomass, including rice husk. Therefore, in this work, the minimum fluidization velocity obtained experimentally for mixtures of 2 kg of sand and 1% and 5% of rice husk, respectively, are compared to two empirical correlations available in the literature, suggested by Rao and Bheemarasetti (2001) and Paudel and Feng (2013). The results show that both models underestimate the values for both proportions, but this effect is increased for higher proportions of rice husk. Considering the data collected, the most precise model for rice husk in the proportions tested seems to be the one proposed by Paudel and Feng (2013).

5. ACKNOWLEDGEMENTS

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