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Research paper

Prediction of the minimum fluidization velocity of particles of sugarcane bagasse

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ABSTRACT

This study refers to an experimental analysis of the fluid-dynamics of particles of sugarcane bagasse in a fluidization column with an internal diameter of 190 mm, which determined the minimum fluidization velocity of the particles with different characteristic diameters ($0 < dp < 9.5$ mm), using air as fluidization means. The results have shown that the minimum fluidization velocity has a tendency to increase as the diameter of the particle increases. However, in a certain range of diameter ($0.88 \text{ mm} < dp < 9.5 \text{ mm}$), where the particles have a high aspect ratio (length/diameter), it has not been possible to fluidize them. High superficial air velocities have been used, mainly due to the strong trend to interlace and to develop high adhesion forces in this type of particles, as well as the high porosity that is displayed. Based on the experimental results, two new models have been developed in order to determine the minimum fluidization velocity and the complete fluidization velocity of the sugarcane bagasse with diameters that range from 0.075 to 0.445 mm. The comparisons have been made by using correlations from the literature for the determination of the minimum fluidization velocity, and the experimental results have shown that the new suggested correlations finely predict this parameter, with a maximum error range of 6%, respecting the experimental values.

1. Introduction

The minimum fluidization velocity is one of the most important parameters that define the fluid-dynamic characteristics of a fluidized bed [1]. Not only does this parameter quantitatively indicate the drag force that is required for the suspension of a solid in the gaseous phase, it also constitutes a reference for evaluating the intensity of the fluidization regime when using high velocities [2].

Therefore, a precise determination of this parameter has vital importance for the fluidization behavior, which is one of the most important factors that influence the combustion and gasification efficiencies [3], and the correct design and operation of fluid-bed equipment [4] [5].

So far, many equations have been obtained in order to calculate this variable for different materials, including steel balls [6], dolomite [7], coal, limestone, iron ore [8], glass beads [9], and others [10], each one with a different particle size distribution and a well-known manner.

A study to determine the minimum fluidization velocity involving wood particles, corresponding to Group C from Geldart classification, has been reported by Reina et al. [1]. By comparing experimental results with correlations reported in the literature by Refs. [6] and [11], these authors conclude that there is not much coincidence between the calculated values in regards to the experimental results, especially in the second correlation., coinciding with the study by Lippens and Mulder [12], where it is suggested that this equation provides poor results when it is used for particles with an sphericity between 0.1 and 0.5. Abdullah et al. [13] report a theoretical and experimental study using biomass residues, such as rice husk, peanut shells, sawdust, coconut shells, and palm fibers, as well as coal and bottom ash, by using the small cold-flow chamber and the pressure drop method for determining the minimum fluidization velocity. Particles from Group B from Geldart classification (coconut shells, sawdust, peanut shells, coal, and bottom ash) have shown a good fluidization, while particles from Group D (rice husks) and A (palm fibers) have had a poor fluidization. The results obtained have been compared to the empirical equation by Leva [14], which has shown significant differences, except for the

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Nomenclature

A_c	cross-sectional area (m^2)
A_{pe}	sphere area (m^2)
A_r	Archimedes number (−)
d_p	characteristic particle diameter (m)
$\bar{d}_p$	Sauter mean diameter (m)
d_{tp}	Feret's diameter (m)
g	gravity (m/s^2)
H	height (m)
ΔP	drop pressure (Pa)
R_e	Reynolds number (−)
V	superficial velocity (m/s)
W	weigh of bed material (kg)
X	mass fraction of particles (%)

Greek symbols

E	voidage (−)
P	density (kg/m^3)
Φ	roundness (−)
μ	viscosity (Pa.s)

Subscript

bulk	bulk
cf	complete fluidization
e	experimental
f	fixed bed
g	gas
i	each parameter
mf	minimum fluidization
p	particle
r	real or skeletal
s	solid
t	theoretical

prediction made from rice hulls, which has shown similar values to those from the experimentation stage.

A proposal of a new correlation to determine the minimum fluidization velocity of particles of walnut shell and corn cob is reported by Paudel and Feng [15]. The results have been compared to reported studies by other authors [13], showing that the model has a good behavior when it is used in these types of biomass.

The disagreements between the values predicted by existing correlations applied to biomass particles show the necessity of further information and studies in order to reveal the fluid-dynamic behavior of these types of particles. Several studies have been made by using different types of biomass, but no work has been reported on the fluidization characteristics using sugarcane bagasse. Thus, the aim of this study is to determine the minimum and complete fluidization velocity of particles of sugarcane bagasse, aimed at examining the effect of the particle diameter, density, and form in this parameter.

2. Materials and methods

2.1. Material preparation and properties

A sample of approximately 150 kg of sugarcane bagasse from the mills in the central region of São Paulo and from the Brazilian Northeast has been collected. The collected bagasse was composed by mixtures of different varieties of sugarcane, such as RB867515, SP81-3250, RB855453, SP79-1049, SP 91–1049, which are the most used varieties in Brazil and, mainly, in those regions [16]. This bagasse comes from different geographic locations, soil types, harvest time, weather conditions, and harvesting procedures (manual or mechanized ones).

The juice extraction and the bagasse production process is similar to the one reported by Lobo et al. [17]. The process consists of a washing system in which the excessive amounts of soil particles are extracted; then, the sugarcane is inserted in a series of systems, using knives, to reduce the size of the stems, and shredders. These systems, then, promote the fiber opening and the formation of a uniform layer of sugarcane, improving the juice extraction. The extraction process is called tandem mill, and it is typically constituted by 4–7 mills. In each one of them, there are 3–5 rollers and radial grooves in the form of "V", which serve to crush and remove the cane juice. Generally, the rollers are arranged in a triangle way, so that the fiber fraction of the sugar cane stalks is compressed twice: once by the upper mobile roller and the input fixed roller, and once between the upper roller and the output roller, in order to separate the juice from the pulp. The bagasse is collected at the end of the belt, and is, from this moment on, called bagasse "*in natura*". In the previously selected material samples, a subsample has been taken. This sub-sample has been divided, and one of its quarters has been dried in an oven, in order to accelerate this process, due to the high humidity the bagasse has (between 48 and 52% [18] [19]) at the end of the process. The temperature used in the drying was 103 ± 1 °C with a natural air circulation, according to ASTM E871 norm [20]. This dried sample has been divided again in four parts and left in an open bag under atmosphere conditions for several days, until there was an equilibrium moisture content, at an environmental temperature of 27 °C, and atmosphere pressure, simulating the natural drying process that takes place in sugar mills or when different drying techniques are used to diminish humidity to a 10–20% [19]. In this case, the equilibrium humidity experimentally determined for this bagasse sample has been 8.71 ± 0.4%.

2.2. Classification of particle size

The classification of the particles has been performed according to Geldart's criterion [21], based on the density and particle size and using air as a fluidizing agent under environmental conditions.

In order to determine the distribution of particle sizes, a representative sample of 80 g of bagasse has been fractionated using sieving techniques. The equipment used was a Produtest vibrating machine, model T, with a sieving time of 20min. A standardized ASTM E828 has been used [22], with eight screens and wholes of 9.5, 4.75, 2.36, 1.18, 0.59, 0.3 and 0.15 mm respectively in the bottom. The weight retained on each sieve has been quantified in a DIGIPESO digital electronic balance, model DP-3000, with an accuracy of 0.01 g. The experiment for the determination of the distribution particle sizes has been repeated 270 times so as to obtain a reliable distribution and an adequate amount of bagasse particles from each diameter of screens used, which would later be used in the fluidization experiments. The average value from all experiments has been adopted as the final result.

The Sauter mean diameter is calculated as [23] [24]:

$$\bar{d}_p = \left[\frac{1}{\sum_{i=1}^{n}\left(\frac{x_i}{d_{p,i}}\right)}\right] \tag{1}$$

Where:

$$d_{p,i} = \left[\frac{(x_i^2 + x_{i+1}^2)\cdot(x_i + x_{i+1})}{4}\right]^{0,33} \tag{2}$$