Biomass and Bioenergy 107 (2017) 135–149

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Fluid dynamic study of mixtures of sugarcane bagasse and sand particles: Minimum fluidization velocity

Nestor Proenza Pérez [a, *], Daniel Travieso Pedroso [b, c], Einara Blanco Machin [c], Julio Santana Antunes [c], Ricardo Alan Verdú Ramos [d], Jose Luz Silveira [c]

[a] Federal Center of Technological Education Celso Suckow da Fonseca (CEFET/RJ), Angra dos Reis Campus, Brazil
[b] Technological Development Unit-UDT, University of Concepcion, Coronel, Chile
[c] São Paulo State University, Faculty of Engineering at Guaratinguetá, Department of Energy, Laboratory of Optimization Energetic Systems (LOSE), Brazil
[d] São Paulo State University, Faculty of Engineering at Ilha Solteira, Institute of Bioenergy Research (IPBEN-UNESP), Brazil

ARTICLE INFO

Article history:
Received 11 February 2017
Received in revised form
31 July 2017
Accepted 9 August 2017

Keywords:
Biomass sand mixture
Minimum fluidization velocity
Fluidized bed
Segregation

ABSTRACT

This paper is focused on the study of fluid-dynamic behavior of mixtures of the sugarcane bagasse particles and quartz sand in a transparent fluidized bed column. The minimum fluidization velocity (V_{mf}) was determined by different mean particle diameters and different mass fractions in the mixture compositions. The values of V_{mf} increased with amount of biomass in the mixture increased as well as with the size of the biomass particles in the range of $9.5 \geq d_{pb} > 0.225$ mm. Binary mixtures with diameter ratios biomass/sand ≤ 1 had a (V_{mf}) almost constant as a function of mass fraction of biomass. It is suggested a practical upper limit of biomass fraction in the mixtures less than 5% of the overall bed mass to obtain a good mixing and uniform distribution in the bed. New correlations were developed to predict the values of (V_{mf}). It was found that the present proposed correlation predicted the (V_{mf}) for binary mixtures of sugarcane bagasse and sand particles more accurately than other correlations reported in the literature available.

1. Introduction

The use for energy purposes of biomass materials using fluidized bed technology has reached grounds recently due to the advantages of this type of process [1,2]. The use of fluidized bed has been widely used in processes involving gasification, pyrolysis and combustion of a wide range of particular materials including biomass, [3–6].

Many of these processes are based on fluidization, but the particles of biomass, especially those with very irregular shapes, such as sugarcane bagasse, are very difficult to fluidize alone as it is already known, due to their peculiar shapes, variety of sizes and density (e.g. long thin particles, low density and very irregular shape) [7,8], which is generally added to an inert material to facilitate and improve fluidization (e.g. sand, alumina, etc.) [9]. This inert material, at the same time, brings about an increase in the heat transfer coefficient, increasing the rate of heat exchange [10], improving the yield of gasification, pyrolysis and combustion processes.

The fluid-dynamic behavior of binary mixtures of sand and biomass is strongly influenced by the differences of the distributions of shape, size and density of particles [11], often it propitiates a segregation, which is characterized by a downward motion towards the base of the bed particles of higher density, such as sand, while the solid of lower density, usually biomass particles, float on the top of the bed [11], being called the *jetsam* and *flotsam* respectively [12].

Accordingly, the fluid-dynamic characteristics, including the minimum fluidization velocity, mixing, segregation and residence time, are of great interest to the design and optimization of processes in the fluidized bed equipment [7]. The minimum fluidization velocity is definitely the most important parameter in fluidization processes [13], the knowledge of this parameter is of vital importance to a proper design and operation of fluid bed equipment [14–16].

Several studies have been developed to investigate the fluid-dynamic characteristics of mixtures of inert and biomass materials. Rao and Bheemarasetti [17] reported a study evaluating the influence of the weight ratio biomass/inert and the size of inert material, using different types of biomasses. An increase of the

* Corresponding author.
E-mail address: nestor.perez@cefet-rj.br (N.P. Pérez).

https://doi.org/10.1016/j.biombioe.2017.08.015
0961-9534/

Nomenclature

A_{pe}	sphere area (m^2)
A_r	Archimedes number (-)
A_c	cross-sectional area (m^2)
a	width (m)
d_{pm}	effective particle diameter of mixture (m)
$\overline{d}_p$	Sauter mean diameter (m)
d_p	particle diameter (m)
d_{pin}	inert particle diameter (m)
d_{pb}	biomass particle diameter (m)
d_{tp}	Feret's diameter (m)
g	gravity (m/s^2)
H	height (m)
L	length (m)
ΔP	drop pressure (Pa)
R_e	Reynolds number (-)
V_{sg}	superficial air velocity (m/s)
V_{if}	incipient fluidization velocity (m/s)
V_{cf}	complete fluidization velocity (m/s)
V_{mf}	minimum fluidization velocity (m/s)
W	weigh of bed material (kg)
X	mass fraction of particles (%)
X_b	weight percentage of biomass (−)
X_{in}	weight percentage of inert (−)
D_c	column diameter

Subscript

b	biomass
i	each parameter
in	inert
g	gas
t	theoretical
f	fixed bed
m	mixture
fl	*flotsam*
j	*jetsam*
mf	minimum fluidization

Greek symbols

ε	voidage (-)
ρ_p	particle density (kg/m^3)
ρ_r	real or skeletal density (kg/m^3)
ρ_{bulk}	bulk density (kg/m^3)
ρ_b	particle density of biomass (kg/m^3)
ρ_{in}	particle density of inert (kg/m^3)
ρ_{pm}	effective particle density of mixture (kg/m^3)
ϕ	sphericity (-)
μ	viscosity (Pa.s)

fraction by mass of biomass causes an increase in the minimum fluidization velocity, and an increase in the diameter of the sand almost doubles the value of the (V_{mf}) for fractions up to 10% of biomass in the binary mixture. The authors propose a new correlation for determining the (V_{mf}) of mixtures biomass/sand, based on density properties and effective diameter of the mixture, showing good correlation with experimental results.

Similar studies have been reported by Aznar et al. [18] using different biomasses like thinning pine, cereal straw and wood chips of various sizes, sawdust, and ground thistle, mixed with beach and silica sands, dolomite and commercial catalytic cracking catalyst. These authors determined an increase of (V_{mf}) when the volume fraction of biomass in the mixture was increased. They also determined that the existing conventional correlations for binary mixtures do not predict satisfactorily this parameter due to its limitations, especially for binary mixtures biomass/sand.

Cook et al. [19] studied binary mixtures of palm shell particles with different size and of different types and sizes of sand, showing that the (V_{mf}) remains practically constant for different fractions of biomass/sand when the particle diameters are too small (particles of palm shell between 1.18 and 2.36 mm with 2–10% of biomass in the mixture and sand of 0.196 mm of diameter). Rao and Reddy [13] also studied the fluid-dynamic characteristics of mixtures of rice husk, sawdust, and groundnut shells and sand with different sizes, making comparisons between experimental and theoretical values obtained from different correlations. Concluding that the correlation proposed by Todes [20] was the most suitable to predict the (V_{mf}) of the studied biomasses.

Remake et al. [21] analyzed the fluidization behavior for wood/sand mixtures. Experimental results of minimum fluidization velocity were compared with many correlations found in the literature, showing in all cases, that correlations underestimate or overestimate around 50% the experimental value. Further experiments are recommended to get a correlation to predict this parameter correctly. Paudel and Feng [8] developed a new correlation for mixtures of walnut shell and corn cob with sand, glass bead and alumina, based on forty-five sets of experimental data found in the literature. This correlation takes into account the biomass weight percentage, the predicted results showed good agreement with the experimental results.

Woh et al. [22] studied the effects of the size of the palm kernel cake particle, they assumed the (V_{mf}) increases as diameter increases. Si and Guo [23] proposed a new correlation for mixtures of biomass/sand, taking into account the sphericity of the particles. Another study using mixtures of wood chip, mung beans, millet, corn stalk, cotton stalk and with different bed materials (silica sand, continental flood basalt (CFB) cinder, and alumina) was reported by Zhong et al. [7]. They determined that the minimum fluidization velocity of long thin biomass, increases, with an increase of diameter and aspect ratio (length/diameter) of biomass particles, and for binary mixtures, the (V_{mf}) increases as increasing weight percentage of biomass particles, as well as with an increase of diameter and density of inert particles. Two new correlations were proposed which take into account the effective density and diameter of the mixture.

Although many studies of mixtures of biomass and inert material has been developed in recent years, most of them have focused on the influence of the diameter of the inert material and the mass fraction of biomass on (V_{mf}), but very few studies have evaluated the influence of the physical and geometrical properties of biomass particles with extreme forms (e.g. long thin particles with low density) such as sugarcane bagasse.

The results have shown that the predicted values for the (V_{mf}) are far from experimental values, due to the phenomena of segregation, poor quality of fluidization and emergence of preferential channels, so that more experimental studies on fluid-dynamic behavior of binary mixtures of extreme biomasses (e.g. sugarcane bagasse) and inert particles like quartz sand are still needed, in order to understand the influence of important properties of the particles as size distribution, extreme forms and low densities.