AN EXPERIMENTAL INVESTIGATION ON FLUIDIZATION OF TERNARY MIXTURES OF COAL, BIOMASS AND INERT

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Abstract. *The co-firing or combined use of coal and biomass is shown as a short-term alternative to the problem of energy and environment. The co-firing can be performed in fluidized bed systems, however, due to their different physical properties, the fluidization of this materials is very difficult. The fluidization of coal blended with biomass particles is an important issue in the co-firing process since an improper fluidization leads to inefficient conversion. In this work is reported a study of fluidization behavior of ternary mixtures in a fluidized bed laboratory scale tests cold conditions. The objective was to investigate the effects of bed materials (coal, biomass and inert) on fluidization characteristics that are critical for optimizing reaction conditions in a fluidized bed combustor. The hydrodynamics characteristics determined include the pressure drop, minimum fluidization velocity, bed fluctuation and bed expansion ratios. The experiments were performed in a 0.17 m internal diameter and 1.5 m height fluidized bed. A perforated plate gas distributor was used. The materials used were coal, biomass (sugarcane bagasse) and inert (sand). It was considered a proportion L/D near to 1 for bed materials in order to allow a bubbling condition regime. The results show a stability of fluidization depend on inert mass fraction and materials segregation is caused when biomass mass fraction was increased. The experimental values of minimum fluidization velocities were compared with the correlation for ternary mixture available in the literature.*

Keywords: *Fluidized bed, ternary mixture, coal, biomass, inert.*

1. INTRODUCTION

The co-firing or co-combustion of coal and biomass is shown as a short-term alternative to the problem of energy and environment. According to Sahu et al. (2014) co-firing is one of the most advantageous ways of utilizing biomass and waste for replacement of fossil fuels for stationary energy conversion. Moreover, use of coal with biomass as a supplementary fuel in the combustion is a viable technological option for reducing the harmful emissions.

Co-firing can be performed in fluidized bed systems. Fluidized bed has many advantages over fixed bed, including good gas-solid contact, better temperature control, and excellent heat transfer characteristics (Patil et al. 2005).

Fluidized bed combustion is characterized by being very flexible, allowing a great variability combustion of fuels, such as coal, biomass, and different types of waste fuels and also of mixtures of different fuels. However, due to differences in physical properties of these materials, the fluidization is very difficult. In order to facilitate the fluidization, an inert material is used, generally silica sand, dolomite, olivine or artificial catalysts (Zhang et al. 2012).

The fluidization of coal blended with biomass and inert material is an important issue in co-firing process, since an improper fluidization of bed materials can result in low heat and mass transfer, ineffective gas-solid phase reactions, inability to maintain a uniform reactor temperature and inefficient conversion (Freire et al. 2008; Sharma et al. 2013).

Coal combustion in bubbling fluidized bed or circulating fluidized bed has been well-established from small to large scale, however, co-firing of coal and biomass is still underdeveloped (Zhang et al. 2012). Actually, there is interest in the use of fluidized beds for waste utilization, potential applications of multi-component fluidized beds are on the rise (Dora et al. 2013). As appointed by Valaszek et al. (2013) a major attention is given for combustion, and more recently for the co-firing process involving ternary mixtures of fossil fuel, biomass, and inert material.

The literature shows several studies about the hydrodynamic of binary mixtures of solids. However, there are limited studies on the hydrodynamics of ternary or multicomponent mixtures of solids in bubbling fluidized beds. Jena et al. (2008) investigated the fluidization behavior of ternary mixtures in unpromoted and promoted square fluidized bed. They used dolomite regarding three different particles sizes at varying composition. Parameters such as pressure drop and minimum fluidization velocity were studied. Asif, (2013) developed a correlation in order to determine the minimum fluidization velocity of multi-component solid mixtures. Dora et al. (2013) examined the hydrodynamic behavior of homogeneous ternary mixtures in conical fluidized beds. They used dolomite regarding three different particles sizes at varying composition. The hydrodynamic characteristics determined include the minimum fluidization velocity, bed fluctuation, and bed expansion ratios. Recently, Sharma et al. (2013) investigated the effect of a ternary mixture composed of switchgrass, gasifier solid residues (GSR), and silica sand on fluidization. To the best of our knowledge, no study has been reported on fluidization characteristics of ternary mixtures composed of coal, biomass, and inert material. In this paper is investigated the fluidization characteristics of a mixture of coal, sugarcane bagasse, and silica sand. The hydrodynamics characteristics determined include pressure drop, minimum fluidization velocity, bed expansion, bed fluctuation, and segregation phenomena.

2. MATERIALS AND METHODS

2.1 Materials

Figure 1 shows the materials used in this study. Coal from Criciúma-SC called CE4500 (i.e. gross calorific value of 4500 kcal/ kg). The sugarcane bagasse analyzed was provided by Equipalcool company, located in Sertaozinho, Sao Paulo. In this study was used a sand of the Institute for Technological Research (IPT). According to this information, IPT sand is characterized by a smaller size distribution.

The co-firing processes operate with a polydisperse particle systems, as well for study the fluidization of ternary mixtures, it was considered a particle size range for coal, in the case of biomass, due to their irregular particle size and shape, it was considered an average particle size being twice the diameter of the bed material (sand).

Figure 1. (a) Coal, (b) sugarcane bagasse and (c) sand.

Table 1 shows the physical properties of materials used in this study. The density of coal CE4500, sugarcane bagasse, and sand, were obtained using a Pycnometer Helium UltraPyc1200e (Figure 2). From the results, It can be seen that sugarcane bagasse and coal CE4500 have relatively close density. However, this condition does not rule out the development of segregation of the materials in a given gas velocity fluidization.

Table 1. Physical properties of particles.

Property	Coal	Sugarcane	inert
particle size (µm)	250-1190	300	150
density (kg/m^3)	1659	1311	2500

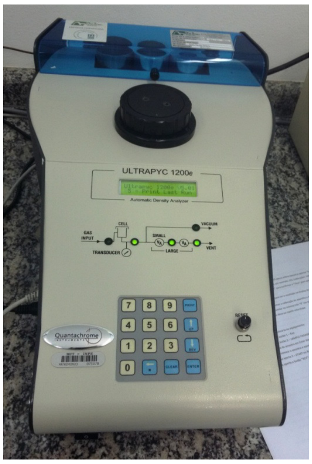

Figure 2. Pycnometer Helium UltraPyc1200e.

2.2 Cold fluidized bed

Figure 2 shows the cold fluidized bed. The experiments were performed in a 0.17 m internal diameter and 1.5 m height fluidized bed. A perforated plate gas distributor was used. Differential pressure transducers were used (DP) and static (SP) were used. LabView software was used to acquire the pressure signal. For the supply of the fluidizing air was used Artek one blower ACR - 7.5 (7.5 HP, 6.3m3 / min, 5150mmH_2O).

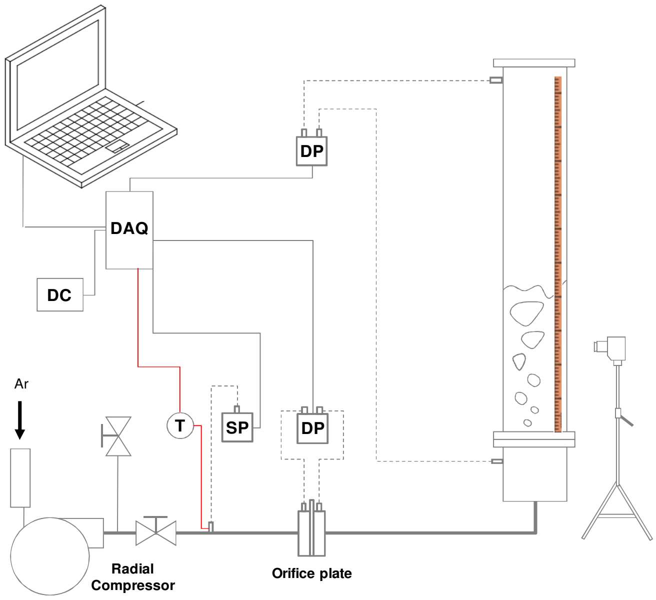

Figure 2. Cold fluidized bed.

2.3 Minimum fluidization velocity of ternary mixtures

The minimum fluidization velocity (Umf) is an important parameter in the determination of the minimum flow rate of the blower or compressor gas to reach a fluidization regime. The literature shows many correlations for determination of Umf for systems consisting of a single material or binary mixtures such as biomass and sand, however, there is little information on the determination of Umf ternary mixtures. For the determination of Umf for ternary mixtures will use the correlation proposed by Sharma et al. (2013), which is an adaptation of the equation proposed by Rao and Bheemarasetti (2001).

$$\rho_{eff} = \frac{w_1\rho_1 + w_2\rho_2 + w_3\rho_3}{w_1 + w_2 + w_3} \tag{1}$$

$$dp_{eff} = k_1 dp_1 \left\{ k_2 \left[\frac{(\rho_1 dp_2 w_2 + \rho_1 dp_2 w_3)}{(\rho_2 dp_1 w_2 + \rho_3 dp_1 w_3)} \right] \left(\frac{\rho_2 dp_3}{\rho_3 dp_2} \right)^{(w_3 / w_2)} \right\}^{(w_2 + w_3)/w_1} \tag{2}$$

$$k_1 = (20dp_1 + 0{,}36)^{0{,}5} \tag{3}$$

$$k_2 = (20dp_2 + 0{,}36)^{0{,}5} \tag{4}$$

where w1, ρ1 e dp1, corresponding to mass fraction, density and particle diameter of sand in the ternary mixture.

3. RESULTS AND DISCUSSIONS

In the co-combustion, the substitution of coal by biomass was limited to a maximum of 25% of mass fraction, in order to simulate a realistic condition. In the study of fluidization of ternary mixtures, it was considered approximately a ratio between bed height and bed diameter equal to 1 (L/D = 1). This ratio is the ratio between the height occupied by the bed material and the inner diameter. This in order to avoid the premature formation of sluggings which hinder the measurement of the bed expansion increases as the gas velocity fluidization. Furthermore, this phenomenon causes fluctuation of the static pressure measurement in the bed.

The proportion between coal and sugarcane bagasse is 75% and 25% respectively. The mass proportions considering the total mass of material in the bed were 11% carbon, 3% biomass and 86% biomass and sand. However, the L/D ratio is 0.10, 0.38 and 0.50 for coal, sugarcane bagasse, and sand respectively. Figure 3 shows the proportions considered for the ternary mixture. The inert material is considered to a greater extent in order to ensure the fluidization of the material (L/D = 0.5). In the tests, the materials were premixed.

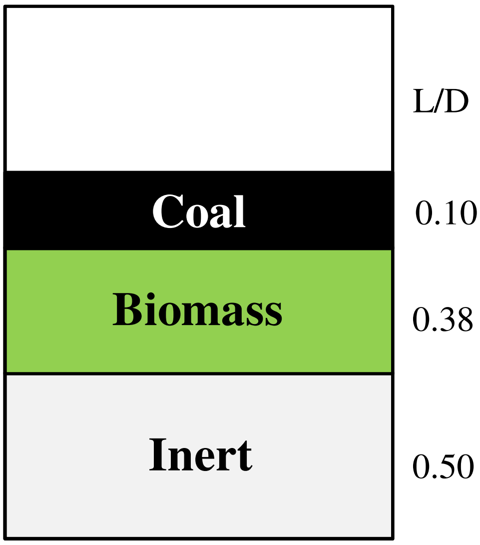

Figure 3. Proportions of materials into fluidized bed

Fig. 4 (a) shows the dynamic behavior of the materials in bubbling regime (Ug> 0.1 m/s). Figure 4 (b) shows the particle distribution of coal , sugarcane bagasse and sand in the bed. It can be observed that coal particles are distributed across the bed height, that is because its density is close to the sand, moreover the regular shape of coal particles. In the case of sugarcane bagasse, it is partially segregated on top, even considering a constant diameter. From visual analysis (white circles) can be observed that the biomass can mix up to approximately 1/4 of the height of the bed above the gas distributor.

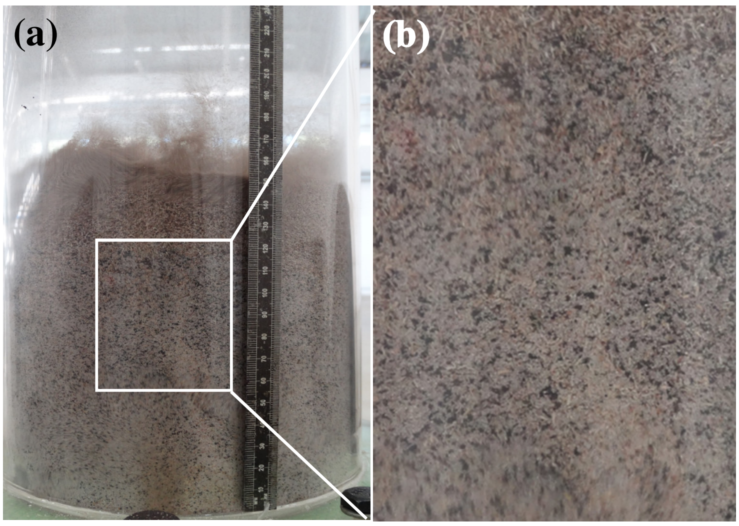

Figure 4. Ternary mixture fluidization behavior.

3.1 Pressure drop profiles

The pressure drop is steadily increased in a specific gas velocity fluidization. According to Kunii - Levenspiel (1991) this developed the profile is characteristic of the polydispersed systems, this gas velocity fluidization is called the initial fluidization (Uif), with the partial movement of the materials in the bed. With increasing gas velocity can cause a bubbling fluidization regime and achieves a complete fluidization regime (U_{CF}), where particles move up completely.

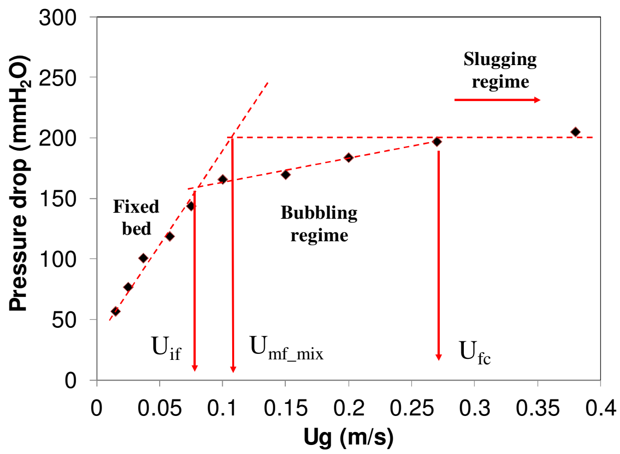

Figure 5. Pressure drop of ternary mixture.

Through the pressure drop profile study is achieved by determining the minimum fluidization velocity (Umf), which is the intersection of two straight lines, one following the pressure drop caused by the material in the packed bed regime and other when the pressure drop is stabilized. Thus, the minimum fluidization velocity of the sand was determined in preliminary tests being equal to 0.035 m/s.

Figure 5, the intersection of the straight line, minimum fluidization velocity of the ternary mixture is approximately 0.07 m/s. Due to the higher mass fraction of sand in the bed, Umf value of the ternary mixture was close to the sand value. However, by observation during the tests, the material exhibit an incipient fluidization as gas fluidization velocity increases, it reaches a bubbling regime approximately 0.10 m/s, and the intersection of the straight lines exhibit a value of 0.11 m/s. At this point, the intensity of the movement of the particles in the fluidization was increased in proportion to the fluidizing gas velocity, and gas velocity above 0.2 m/s develops a slugging regime.

The value of Umf for ternary mixtures proposed by Sharma et al. (2013) gave a value of 0.15 m/s. Therefore, there is an overestimation. The pressure drop to this mixture developed a regular pattern, this is due to the maximum sand fraction, which is greater than the other materials. Moreover, other factors may influence the pressure drop behavior such as the uniformity of sand particles and the particle size used by the biomass. This behavior was also observed by Shao et al. (2013), which studied the behavior of multi-component mixtures fluidization.

3.2 Bed expansion

Figure 6 shows the bed expansion profile. The bed expansion is an important parameter in the design of fluidized bed reactors because it allows approaching what would be the height of the reactor depends on the operating system. It should be noted that the expansion of the bed is applied specifically to the flow from the bubbling regime to turbulent respectively, in the latter difficult to determine. In Fig. 5 it can be observed that the bed expansion begins in the next minimum fluidization velocity of sand 0.06 since on ternary mixture have a greater proportion. The bed expansion was determined up to a gas velocity approximately 0.2 m/s. However, above this value, the determination is compromised due to the formation of sluggings (big bubbles) which deformed the surface of the bed greatly hindering its measurement of the expanded bed.

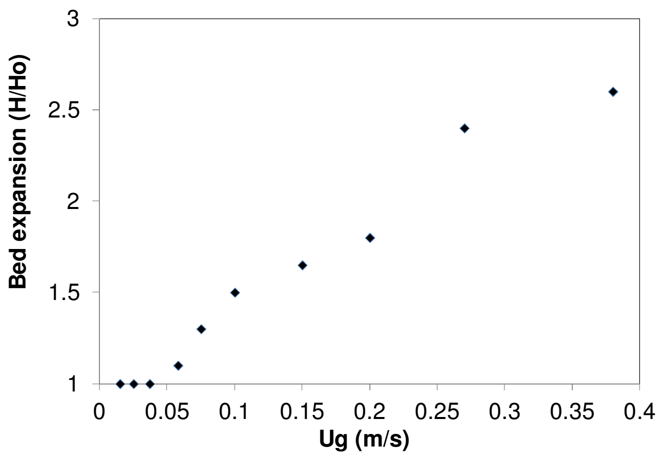

Figure 6. Bed expansion (75% coal - 25% sugarcane).

4. CONCLUSIONS

In this study was verified the ternary fluidization of coal, sugarcane bagasse and inert. The experimental correlation used in this study presents an overestimation of the Umf value for ternary mixtures. More studies are needed to evaluate other conditions. The value of the minimum fluidization velocity of the ternary mixture will be very close to the bed material which is in the greater proportion. In order to improve mixing biomass, alternatives such as the use of pellets or torrefaction of biomass must be evaluated. In order to improve the mixing of materials in the bed, another type of gas distributor must be evaluated.

5. ACKNOWLEDGEMENTS

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