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DESIGN OF A PERFORATED PLATE GAS DISTRIBUTOR FOR FLUIDIZATION OF SUGARCANE BAGASSE AND SAND MIXTURES

Carlos Manuel Romero Luna
Felipe Rigone Francischetti
Ivonete Ávila
UNESP - Univ Estadual Paulista, Faculty of Engineering at Guaratinguetá, Department of Energy, Av. Dr. Ariberto Pereira da Cunha, 333 - 12.516-410, Guaratinguetá-SP, Brazil
c_romeroluna@yahoo.com; felipe.francischetti@gmail.com; iavila@unesp.br.

Gretta Larisa Aurora Arce Ferrufino
National Institute For Space Research, Combustion and Propulsion Associated Laboratory, Rodovia Presidentre Dutra, km 40, Cachoeira Paulista-SP, Brazil.
gretta@lcp.inpe.br

Abstract

Brazil is the largest producer of sugarcane in the world, being São Paulo state accounts for most. Consequently, large amounts of sugarcane bagasse are generated in the state. Through thermochemical conversion processes (combustion, gasification and pyrolysis), the sugarcane bagasse can be used to produce energy or chemicals. Fluidized bed reactors are characterized by high energy conversion and low emissions of air pollutants and can be applied in the conversion of biomass. However, the bagasse is difficult to fluidize, using an inert material such as contact medium is needed. In the fluidized bed, a major component is the gas distributor, responsible for uniform distribution of the gas in the bed. The literature presents several types of distributors, where the perforated plate is one of the simplest type for industrial use. Thereby, the design of the gas distributor type perforated plate for fluidizing the biomass must consider the characteristics of biomass and inert material, to ensure good fluidization. The aim of this study was to evaluate the influence of the parameters involved in the design of a gas distributor type "perforated plate" for fluidization of sugarcane bagasse-inert mixture. The results have demonstrated that mass fraction of sugarcane bagasse has a considerable influence on the values of the minimum fluidization velocity. However, did not have a significant effect on design parameters of perforated plate type gas distributor.

Keywords: *Perforated plate distributor, fluidization, sugarcane bagasse, sand.*

1. INTRODUCTION

Currently power generation faces the challenge of achieving maximum efficiency considering the environmental and economic aspects involved. The more fuel used in power generation are mineral coal, natural gás and oil, accounting for about 80% of the total energy generated in the world (Saidur et al. 2011). The negative effects of emissions of greenhouse gases (GHG) emissions result from combustion of fossil fuels in power generation has motivated the use of clean energy and renewable. According to Nataly R. Echevarria Huaman and T. Xiu Jun (2014), it is believed that three quarters of the volume of greenhouse gases (GHG) corresponds to carbon dioxide (CO_2).

Recently, biomass has received considerable attention as a renewable energy source, after coal, natural gas and oil, biomass is the fourth power source but abundant carbon-based. The use of biomass in power generation can reduce the consumption of fossil fuels (Demirbas 2005; Dong et al., 2010; Park e Choi, 2013).

In Brazil, sugarcane has a stake of 16.1% in domestic energy supply (Empresa de Pesquisa Energética (EPE/MME), 2014). This large contribution of sugarcane is due to the production of ethanol, sugar for consumption and, more recently, lignocellulosic biomass (bagasse and straw) used as a renewable fuel and cost for energy generation (Santchurn et al. 2014). Roughly a third of the entire area used for agriculture in the state is used for sugarcane cultivation (Egeskog et al. 2014). Regarding the residue there is a growing incentive in their use due to the introduction of new and more advanced agricultural and industrial technologies, likewise, the straw has great potential to generate heat, electricity and cellulosic ethanol production (Santos et al., 2012).

The energy content of the biomass can be exploited through thermochemical conversion processes, such as combustion, gasification and pyrolysis (Park e Choi, 2013). Such processes are usually carried out in fluidized bed reactors due to the high mixing between solid particles and gas, this promotes the development of chemical reactions and promote high heat transfer rates and mass (Kunii e Levenspiel, 1991). However, the biomass is difficult to fluidize, being necessary the use of an inert material as a contact medium (Paudel and Feng 2013).

In the fluidized bed reactor, a major component of the gas distributor is responsible for uniform distribution of the gas in the bed. As appointed by Vakhshouri e J.R. Grace (2010) a successful design of the gas distributor, including orifice size, geometry and spacing (array), plays a key role in the quality of fluidization process.

The effect of the gas distributor on the fluidization behavior can be analyzed by experiments and CFD simulations. Sobrino et al., (2009) investigated the effects of gas bubbles type distributor caps and perforated plate of the fluid-dynamic behavior of a turbulent fluidized bed. Their findings have highlighted the influence of the gas distributor in hydrodynamics. Dong et al., (2009) studied the particle concentration and the pressure drop in the bed by changing the perforated area of the distributor and concluded that the size of the bubbles decreases with the increase of the perforated area of the distributor. They also noted that the pressure drop decreases with increasing perforated area and superficial gas velocity. Jangam et al., (2010) studied the impact of the distributor design specifications in obtaining a uniform distribution through the bed. They noted that the flow pattern can be improved by reducing the percentage open area of the distributor. Moreover, they reported in more uniform gas distribution with the increase in diameter of the holes.

Zhu et al., (2011) showed that the gas distributor design affect the distribution of solids over circulating fluidized bed. Akbari et al., (2014) performed simulations of a reactor with perforated plate type gas distributor to validate and assess the impact of distributor features in fluidization behavior in a polymerization reactor. The results showed that heterogeneous flow patterns are created in the perforated plate due to the greater kinetic energy and the formation of jets above the distributor. They also noted that a dead zone region is formed near the edges of the distributor.

Despite its practical importance, few studies can be found in the literature involving the behavior of fluidization sugarcane bagasse and inert material mixtures. In addition, the literature provides no method for the gas distributor design for biomass-inert fluidized mixtures in fluidized bed. Thus, the aim of this study was to examine the parameters involved in the type gas distributor plate perforated design for fluidizing a sugarcane bagasse and inert material mixture. In this study the gas distributor type perforated plate was choice, because is one of the simplest for industrial use.

2. MATERIALS AND METHODS

2.1 Materials

Figure 1. shows sugarcane bagasse and sand IPT (Instituto de Pesquisas Tecnológicas) considered for the study of fluidization of binary mixtures

Figure 1. Sugarcane bagasse and sand ITP.

In the design of gas distributor it is important to know the physical properties such as real density and particle diameter. The real density of the material was determined by pycnometry technique to Helium (He). The tests were performed in a pycnometer Micromeritics - UltraPyc1200e. Samples were pre-dried in an oven for 5 hours at 105 °C. For the sand IPT, 2 tests were performed considering 10 repetitions each, however, due to the heterogeneous nature of sugarcane bagasse and in order to ensure its results were performed 3 tests regarding 10 repetitions each.

Based on work Perez et al. (2014), the most suitable diameter of sugarcane bagasse particle to perform a thermochemical process (gasification) in fluidized bed should be within the range of 0.8 a 1.2 mm. Thus, this study adopted a mean value within that range. Table 1 shows the physical properties of sugarcane bagasse and sand IPT.

Table 1. Physical properties of sugarcane bagasse and sand IPT.

Material	ρ_p (kg/m^3)	d_p (mm)
Sugarcane bagasse	1311	1.000
Sand IPT	2500	0.250

2.2 Minimum fluidization velocity of binary mixture

The minimum fluidization velocity (U_{mf}) is an important parameter in the determination of the minimum flow rate of the blower or gas compressor to achieve a regime of fluidization. According to Zhang et al. (2011) the literature presents various empirical correlations for the determination of U_{mf}. Equation (1) shows the Rao e Bheemarasetti (2001) correlation used in this work. A feature of this correlation is the determination of effective density (Eq. 2) and diameter (Eq. 3) of mixture. Thus, for the determination of Umf is considered the physical properties of the mixture which is a function of mass fraction of each material. Moreover, it also has a correction factor (Eq. 4) depending on the diameter of the inert material. Thus, the study of the minimum fluidization velocity of binary mixtures of biomass and inert material, evaluated a mass fraction of biomass by 15% (Zhang et al. 2011; Paudel e Feng 2013).

$$U_{mf.m} = \frac{dp_{eff}^2 (\rho_{eff} - \rho_g) g}{1650\mu} \tag{1}$$

$$\rho_{eff} = \frac{w_1 \rho_1 + w_2 \rho_2}{w_1 + w_2} \tag{2}$$

$$dp_{eff}^2 = k \left\{ dp_1 \left[\left(\frac{\rho_1}{\rho_2} \right) \left(\frac{dp_2}{dp_1} \right) \right]^{w2/w1} \right\}^2 \tag{3}$$

$$k = 20\, dp_1 + 0.36 \tag{4}$$

2.3 Minimum slugging velocity

The minimum slugging velocity (U_{ms}) is another important parameter because to estimate the superficial gas velocity which initiates the formation of large bubbles, which can reach up to 2/3 of bed diameter. In practice, large bubbles present a problem by causing a reduction in heat and mass transfer rates. The literature does not show a correlation for Ums dedicated to binary mixtures. Thus, the Ums applied to monodisperse systems was used as a reference. Equation (5) can determine the Ums in fluidized beds with an internal diameter up to 0.3 m.

$$U_{ms} = U_{mf} + 0.07\sqrt{gD} \tag{5}$$

3. RESULTS AND DISCUSSION

The gas distributor design is based on the methodology proposed by Yang (2003) for the design of perforated plate gas distributor for monodisperse system. The value of the required superficial gas velocity in the gas distributor design is the average between the minimum fluidization velocity (lower limit) developed for biomass and sand mixtures, moreover minimum slugging velocity for monodispersed system (upper limit), to ensure a bubbling regime. For the study of gas distributor, we adopts a diameter equivalent to 0.157 m based on the work of Ávila (2008).

3.1.1 Mixture minimum fluidization velocity

Figure 2 shows the behavior of the Umf as a function of the proportion of biomass and the diameter of the inert material. We considered three different diameters of inert material being 250, 500 and 1000 μm respectively. It is observed a gradual increase in the value of the Umf as a function of the percentage of biomass, and from 5% of biomass the U_{mf} is affected significantly. The value of the U_{ms} increases in proportion to the value of U_{mf}. In Fig. 2, can be seen that an increase in diameter of the inert material (sand) also causes a considerable increase in the value of Umf and Ums.

In Figure 2 (a) it is noted that the superficial velocity values of the gas are low and there is a notable difference between the values of Umf and Ums. From Figure 2 (b) it can be seen that increasing the diameter of the inert material twice produces a significant increase in Umf and Ums. However, the values of Umf and Ums are becoming closer. In Fig. 2(c) it can be observed that the values of Umf and Ums are very close. It could mean that reached the minimum fluidization regime, the additional increase in superficial gas velocity would cause the formation of sluggings.

This result must be supported by experimental tests, as the expression used for calculate the Ums was developed for monodisperse systems and not for binary mixtures.

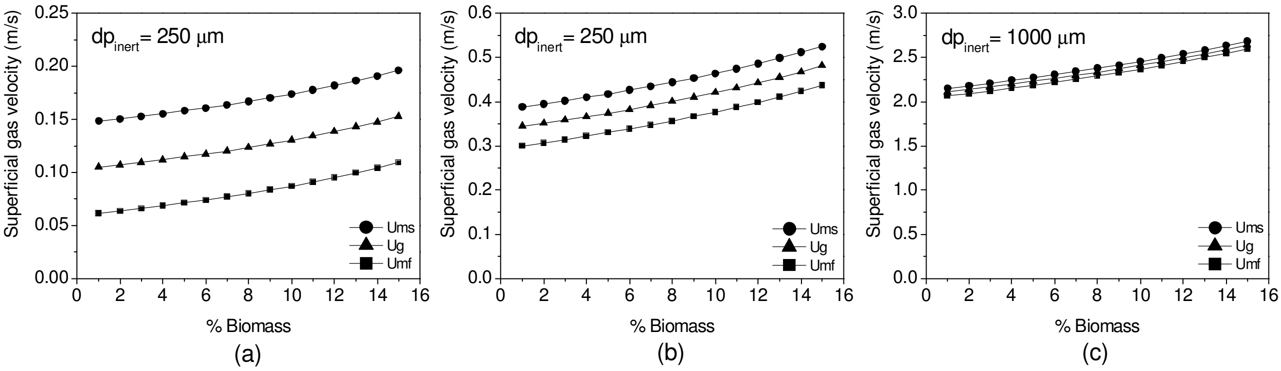


Figure 2. Minimum fluidization velocity (U_{mf}), minimum slugging velocity (U_{ms}) and averaged gas velocity (U_g) for biomass-sand mixture.

3.1.2 Gas distributor parameters

The methodology used in the design of perforated plate gas distributor was proposed by Yang (2003). Among the parameters to be determined are, the hole diameter, the holes number, the distance and distribution (pitch). According to Basu (2006) the diameter of the hole in the perforated plate type gas distributor may be not less than1.5 mm, based on practical experience of fluidized beds. Thus, in this work we adopt this orifice diameter value for the calculation.

Figure 3. shows the superficial orifice gas velocity in function of biomass mass fraction. The superficial gas velocity at the orifice does not exhibit a substantial variation of its value in function of the percentage of biomass and even with different diameter sizes of the inert particle. However, in the gas distributor design, the superficial gas velocity in the orifice cannot overcome the value of 40 m/s, this in order to reduce the effect of friction at holes (Yang 2003; Basu 2006).

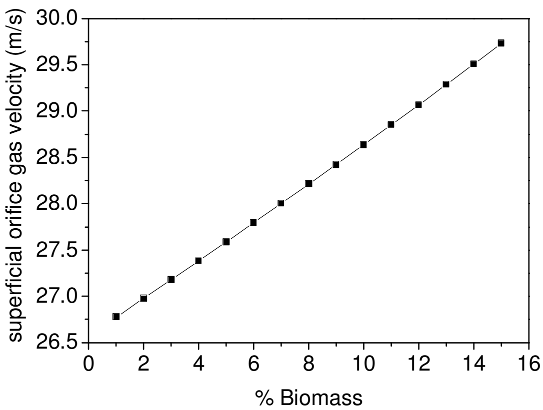
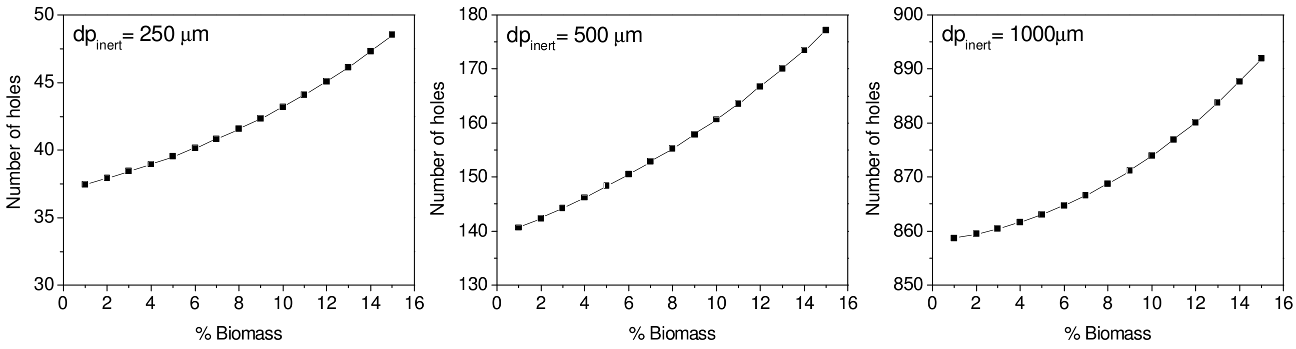


Figure 3. Superficial orifice gas velocity.

Figure 4 shows the number of holes as a function of diameter of the inert particle. In Fig. 4, it can be seen that an increase in the mass fraction of biomass has a negligible increase in the value of the number of holes, however, an increase in diameter of the inert particle causes a considerable increase in the number of holes. Technically a large number of holes can cause some problems such as a reduction in material strength as reduce the resistance in the weight of the support material in the bed.



(a) (b) (c)

Figure 4. Number of holes as a function of diameter of the inert particle.

Figure 5 shows the number of pitch as a function of diameter of the inert particle. Pitch is regarded as the arrangement and the distance between the holes. To increase the uniformity of fluidization, it is common to lay out the holes in triangular or square pitch (Yang 2003). It can be seen that the pitch is inversely proportional to the number of holes of the gas distributor plate type distributor. The reduced pitch depending on the diameter of the inert material could affect the fluid dynamics of the gas-solid flow in the fluidized bed. For having the injection of fluidizing air through holes in close proximity could induce premature coalescence of bubbles above the gas distributor giving rise to the formation of slugging. In this work we used the triangular pitch due to simple the distribution of the orifices in the distributor surface area.

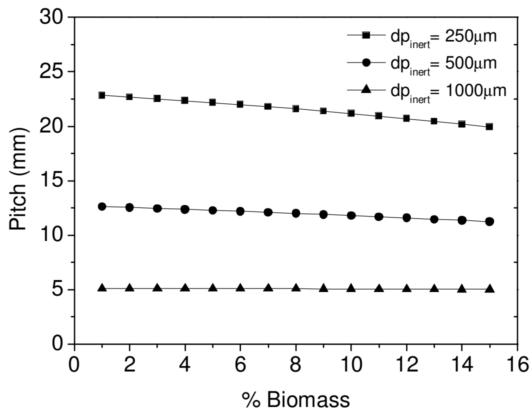


Figure 5. Pitch as a function of diameter of the inert particle.

Figure 6 shows the perforated plate type gas distributor with 48 holes and triangular pitch designed for a mixture between sugarcane bagasse and sand IPT. The project considered the largest mass fraction of biomass (15%) in a mixture and an inert material 250µm in diameter.

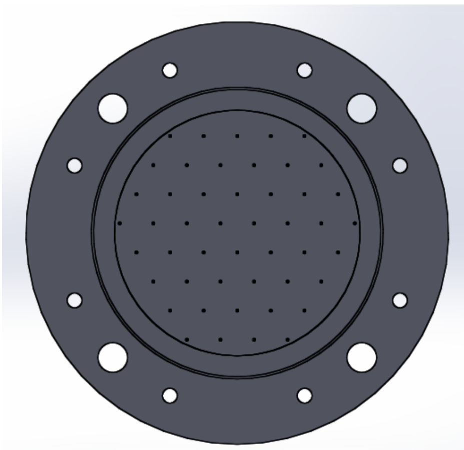


Figure 6. Gas distributor type perforated plate.

4. CONCLUSIONS

This paper presents the study of a gas distributor type perforated plate for fluidizing sugarcane bagasse and sand mixtures. From the results it can be concluded that the mass fraction of biomass has a considerable influence on the values of the minimum fluidization velocity, however, did not have a significant effect on the number of holes or the pitch value.

The diameter of the inert particle causes a significant increase in Umf and Ums. Therefore, it would be convenient to use an inert material with a large particle diameter, it would require a higher gas velocity for causing fluidization of the particles of the mixture, moreover increase proportionally the application of the blower or air compressor. Furthermore, an increase in diameter of the inert material causes a significant increase in the number and pitch of holes.

In terms of different values of ρ_{eff} and dp_{eff}, it can be seen that the dp_{eff} is the most influential parameter in the design of gas distributor type perforated plate.

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