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# EVALUATION OF MINIMUM FLUIDIZATION VELOCITIES FOR VARIOUS PARTICULATES AND OPERATING CONDITIONS

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**Abstract.** *Advances in research on the use of fluidized bed reactors in thermal conversion demonstrate that this technology is promising and widely used for the most diverse forms in the energy and fuels segment. Fluidization is a two-phase flow process in which a fluid phase produces an upward flow, percolating a bed of particles towards the upper portion of the equipment, making this bed fluidized. In this context, the present work aimed to analyze the properties that interfere in the minimum fluidization velocity of the cylindrical particles, with different configurations of distributor plates, varying the arrangement of orifices at the base of a fluidized bed by compressed air. Through the tests, a pattern was observed in which the longer configuration cylinders tend to present higher minimum fluidization velocities, due to their aspect ratio and physical arrangement inside the bed. Models of distributors with central orifice made favorable the occurrence of a spouting fluidization regime with lower minimum fluidization velocities, however, in an unstable fluidization process. Distributor configurations with multiple orifices provided a similar regime, but with higher fluidization velocities than the central orifice configuration. In the configuration with a wire mesh distributor, bubbling fluidization was observed, with higher minimum velocities compared to the other two configurations.*

**Keywords:** *Fluidized bed, Minimum velocity fluidization, Distributor plate configuration.*

## 1. INTRODUCTION

The rising consumption of energy and fossil fuels in recent years demonstrates how dependent we are on new energy and fuel production lines. For (Ocanha et al., 2019), the use of biomass in certain sectors tends to be a well-explored scenario, especially in Brazil. In 2020, the use of biomass had a share of 9.10% in the Brazilian electricity matrix, which represented an increase of 7.69% compared to 2019.

To reduce waste in energy production, it is important to research and discover new energy generation techniques, taking into account the different processes involved. Advances in research on the use of the fluidized bed as an innovation for several areas of activity demonstrate that this path will be widely used for the most diverse forms in the energy and fuels segment. Fluidized beds are used in industrial processes for providing mixtures between fluid and particulate phases, resulting in high heat and mass transfer rates, and providing uniform temperature distribution and concentration of the phases inside. Some examples of industrial fluid bed applications include coal combustion and gasification, catalytic reactions, and synthesis (Cremasco, 2018).

Despite the widespread employment in industries, the underlying fundamental physics is still not fully understood. The motion, heat transport, mass transport, and chemical reaction of non-spherical particles are quite different from spherical particles (Gao et al., 2020). Understanding the effect of particle shape on fluidization behavior is important for the design, optimization, and scale-up of industrial applications. However, relevant studies on the fluidization of non-spherical particles are extremely lacking in the literature when compared with the fluidization of spherical particles (Wang et al., 2020). In the experimental studies of Zou et al. (2017); Buist et al. (2017); Vollmari et al. (2016); Yang et al. (2008) the fluidization behavior of non-spherical particles is investigated.

Fluidization bench practices are essential for the development and innovation of fluidized bed reactors, demonstrating how great the application of fluid dynamics can be and what physical and morphological characteristics of the particles influence the experimental process (Michelotto, 2018). This study aims to develop tests in a fluidized bed bench to determine the pressure drop and minimum fluidization velocities, as well as to analyze the fluid dynamic behavior of the bed.

## 2. METHODOLOGY

Particulate fluidization was performed in a bench bed designed by (Genehr et al., 2020). This bed is located in the Pneumatics laboratory in the Polytechnic School of UNISINOS University. At the top, the bed is composed of two cylindrical acrylic tubes with an internal diameter of 94 mm, a tube wall thickness of 3 mm, and a tube length of 910 mm, connected by flanges with the union by nut/bolts. At the bottom, the bed is formed by a cylindrical stainless-steel tube, with a length of 100 mm, and a stainless-steel semi cone, through which the air is insufflated. Inside this stainless-steel cylinder, 9 mm diameter glass spheres were placed to standardize the airflow. In Fig. 1 there is a schematic drawing of the bed components.

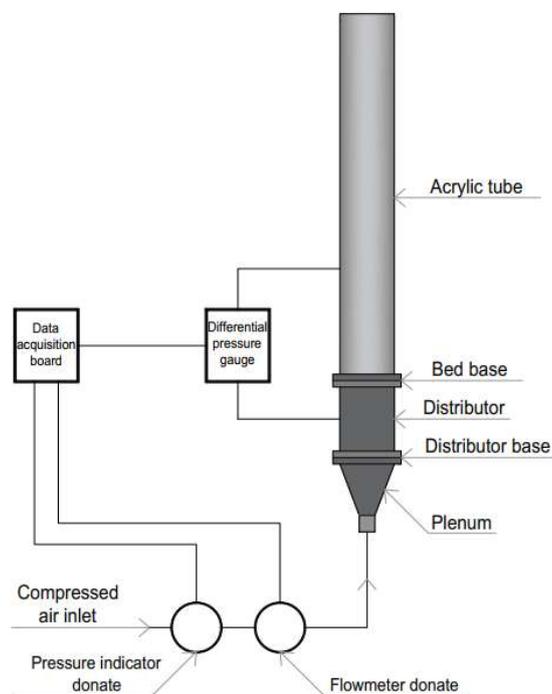


Figure 1. Schematic drawing of the bed.

In the experiments present in this work, two air distributor plates were used, both made of polypropylene (PP), over a metallic screen with a known mesh size, as shown in Fig. 2:



Figure 2. Distributor plate and metallic screens.

The materials used in the fluidizations were cylindrical bamboo particles, with uniform dimensions and two different sizes: 2 mm in diameter by 4 mm in height and 2 mm in diameter by 8 mm in height, as shown in Fig. 3:



Figure 3. Bamboo particles - 4x2 mm (left) and 8x2 mm (right).

These particles were deposited in the bed up to a height of approximately 94 mm, which represents once the internal diameter of the bed.

Both the distributor plates and the wire mesh were inserted into the bed to help distribute the air and support the material. The choice of the multi-orifice distributor plate is in line with Michelotto (2018), where it was found that this plate model is suitable for fluidizing cylindrical and large-sized granular materials, obtaining a good fluid dynamic behavior, according to Silva (2019).

The tests were carried out in triplicates according to the settings shown in Tab. 1.

Table 1. Settings between particles and distributors.

Particles	Distributors		
Bamboo particles 4x2 mm	Wire mesh	Wire mesh + multi-orifice plate	Wire mesh + Center hole plate
Bamboo particles 8x2 mm	Wire mesh	Wire mesh + multi-orifice plate	Wire mesh + Center hole plate

The fluidizations occurred with a slow and constant increase in the flow of air injected into the bed, controlled through the use of a manual valve, with the material initially compacted. The data relating to defluidization were generated during the gradual closing of the valve until the complete interruption of the airflow. Information related to flow and pressure drop was collected at millisecond intervals. The values referring to the differential pressure of air in the bed were measured using an instrument of the brand NOVUS, model HUBBA 699. The flow of injected air was determined through a flow meter of the brand IFM, model SD6050. Finally, data acquisition was performed using a NOVUS brand reading and recording module, the Fieldlogger model. Differential pressure and flow were collected every 100 ms.

The purpose of determining the pressure drop at no load is to discount the fixed head loss of the bed, resulting from the distributor and the fluidization column. According to (Kesterling et al., 2017), the pressure drop is dependent on the speed and type of distributor used. Figure 4 presents the graphs of the fluidizations under vacuum for the center hole plate and multi-orifice distributor, respectively. The pressure drop from the wire mesh distributor is negligible.

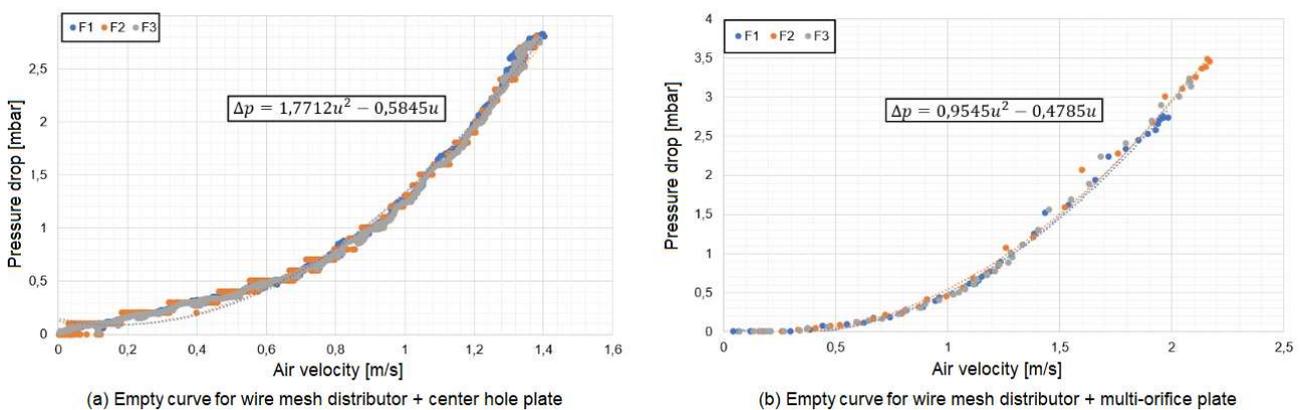


Figure 4. Empty bed fluidization curve.

With the pressure drop equations as a function of air velocity generated in Fig. 4, the adjustment of the real bed pressure drop is obtained, according to Eq. (1):

$$\Delta p_{bed} = \Delta p_{full} - \Delta p_{empty} \quad (1)$$

where  $\Delta p_{full}$  is the value of the pressure drop of the bed filled with the particulates, and  $\Delta p_{empty}$  is the value of the pressure drop of the empty bed. Thus, substituting the empty bed pressure drop equations in Eq. (1):

$$\Delta p_{bed (mo)} = \Delta p_{full} - (0.9545u^2 - 0.4785u) \quad (2)$$

$$\Delta p_{bed (c.h)} = \Delta p_{full} - (1.7712u^2 - 0.5845u) \quad (3)$$

where  $\Delta p_{pbed (mo)}$  and  $\Delta p_{pbed (c.h)}$  represent the bed pressure drop when using the multi-orifice and the center hole plate distributors, respectively, while  $u$  represents the air superficial velocity.

### 3. RESULTS AND DISCUSSIONS

The characterization of bamboo particles was performed by Michelotto (2018) to determine the properties of the particulate material, such as real density, mean diameter, aspect ratio, and sphericity. Table 2 shows the characterization values of bamboo particles.

Table 2. Characterization of particulate material.

Particles	$D_p$ [mm]	$\rho$ [kg/m <sup>3</sup> ]	Aspect ratio [-]	Sphericity [-]
Bamboo particles 4x2 mm	2.03	879	2.309	0.816
Bamboo particles 8x2 mm	2.05	879	4.208	0.744

The particles were also classified according to their sizes and densities, using the Geldart particle classification. Geldart (1973) classifies particles into four groups, A, B, C, and D, according to their density and diameter, as shown in Fig. 5. Geldart Group A particles are mainly known as fine particles. The sand and lots of small grains generally belong to the Geldart Group B particles. Geldart Group C particles are ultrafine particles or also known as viscous particles. Geldart Group D particles are generally larger than 600  $\mu\text{m}$  in diameter with relatively high density, and most common biomass particles, such as wheat and maize, belong to Group D particles (Zhou et al., 2022).

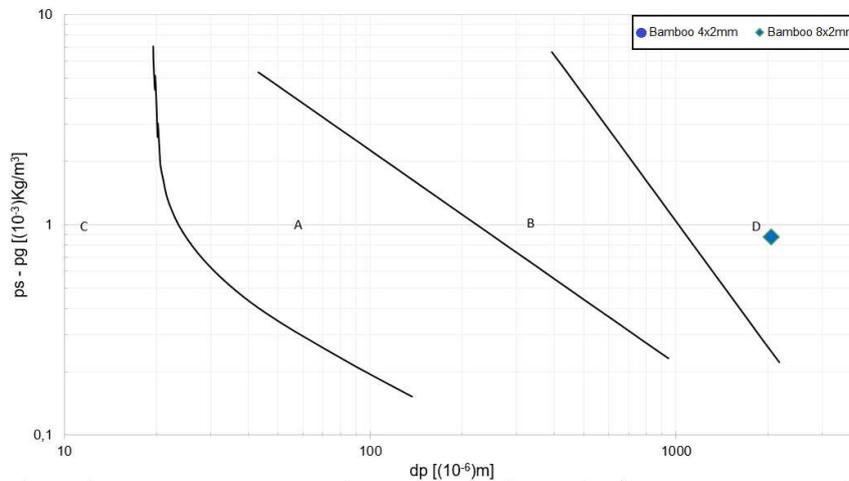


Figure 5. Geldart classification for bamboo particles.

Through Fig. 5, it is possible to verify that both the 4x2 mm and the 8x2 mm configuration of the bamboo particles were arranged in category D, characterized by spouting fluid dynamics.

The determination of the minimum fluidization velocities ( $U_{mf}$ ) was based on the graphical analysis methodology used by Michelotto (2018), which uses a curve fit through a high-order polynomial. Fig. 6 shows the fluidization and defluidization curves for the 8x2 mm and 4x2 mm bamboo particles.

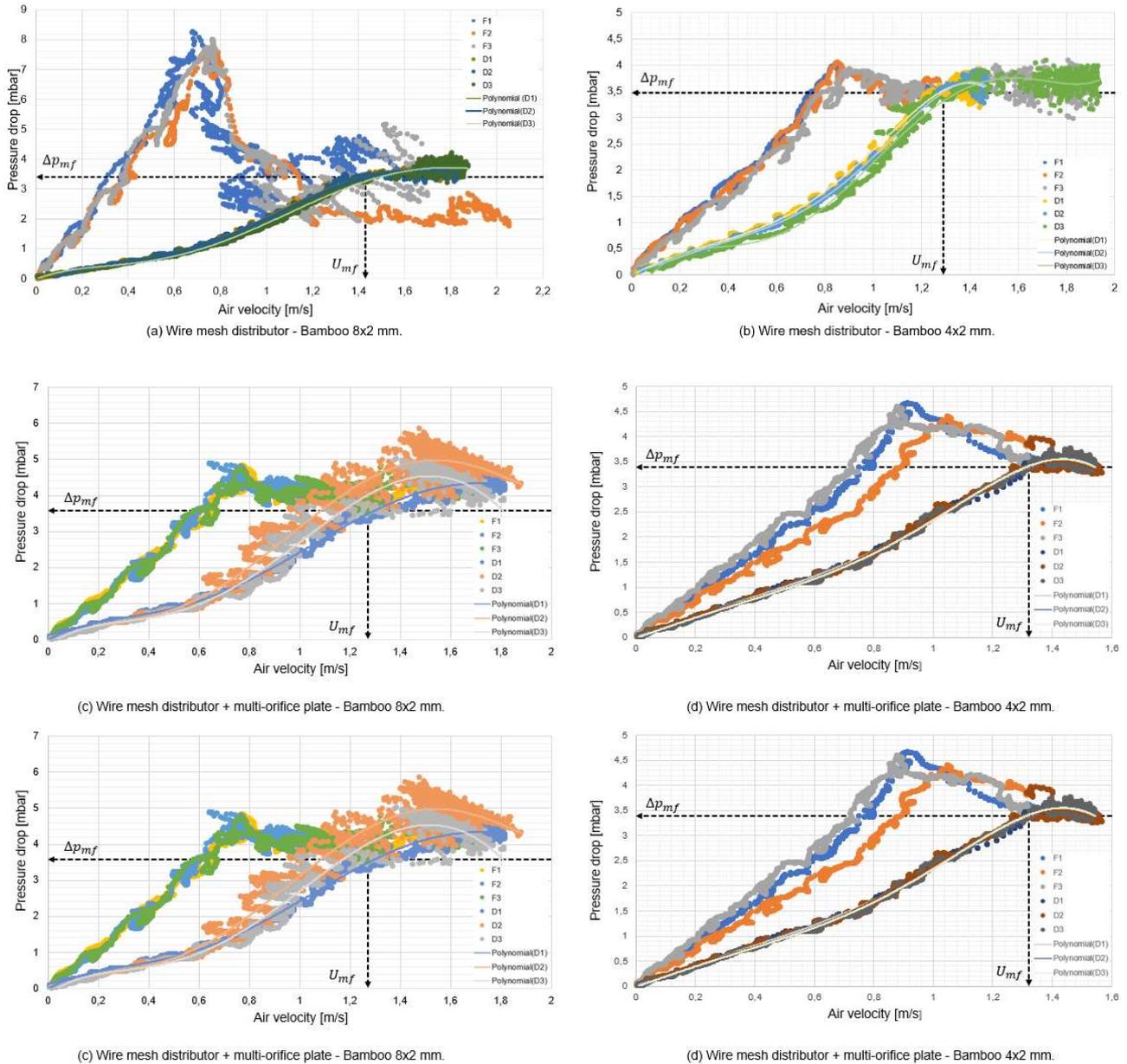


Figure 6. Fluidization and defluidization curves for different distributor models.

As illustrated in Fig. 6, it is possible to verify the variation of the minimum fluidization speeds, according to the distributor configuration. The average of the polynomials equations related to the defluidization curves are illustrated in the Eq. (4), (5), (6), (7), (8) and (9) for wire mesh distributor bamboo 8x2 mm, wire mesh distributor bamboo 4x2 mm, wire mesh distributor with multi-orifice plate bamboo 8x2 mm, wire mesh distributor with multi-orifice plate bamboo 4x2 mm, wire mesh distributor with center hole plate bamboo 8x2 mm and wire mesh distributor with center hole plate 4x2 mm bamboo, respectively:

$$y = 2,2612x^5 - 12,394x^4 + 22,883x^3 - 16,273x^2 + 5,892x - 0,368 \quad (4)$$

$$y = 4,394x^5 - 22,767x^4 + 40,462x^3 - 28,405x^2 + 9,024x - 0,571 \quad (5)$$

$$y = 2,260x^5 - 13,451x^4 + 24,674x^3 - 15,623x^2 + 5,000x - 0,161 \quad (6)$$

$$y = -2,284x^5 + 5,615x^4 - 3,390x^3 + 0,350x^2 + 2,055x - 0,011 \quad (7)$$

$$y = 0,209x^5 - 1,589x^4 + 4,249x^3 - 5,415x^2 + 3,666x - 0,085 \quad (8)$$

$$y = -1,707x^5 + 4,335x^4 - 1,090x^3 - 4,728x^2 + 4,964x - 0,073 \quad (9)$$

Table 3 shows the values of the pressure difference,  $\Delta p_{mf}$ , and the minimum fluidization velocity,  $U_{mf}$ , for each experimental setup along with the fluidization regime during the tests.

Table 3. Results of experiments.

Distributor plate configuration	$\Delta p_{mf}$ [mbar] Graphical analysis	$U_{mf}$ [m/s] Graphical analysis	$U_{mf}$ [m/s] Experimental visualization	Fluidization regime
(1) Wire mesh - 4x2 mm	3.47	1.29	1.28	Bubbly
(2) Wire mesh + multi-orifice plate - 4x2 mm	3.40	1.32	1.40	Spout
(3) Wire mesh + center hole plate - 4x2 mm	1.71	1.00	1.04	Spout
(4) Wire mesh - 8x2 mm	3.40	1.43	1.32	Bubbly/ Spout
(5) Wire mesh + multi-orifice plate - 8x2 mm	3.57	1.27	1.24	Spout
(6) Wire mesh + center hole plate - 8x2 mm	2.57	1.18	1.12	Spout

By reading the results presented in Tab. 3, it is possible to observe a good agreement between the minimum fluidization velocities obtained through graphical analysis and experimental visualization for all distributor configurations and particulate sizes. The smallest relative difference found was 0.78%, referring to case (1), and the biggest difference was for case (4), with a value of 8.33%.

A pattern was observed in which the particulate with a more elongated configuration tends to present higher minimum fluidization speeds, due to their aspect ratio and physical arrangement inside the bed, which require higher surface speeds to suspend the particulate material. However, in case (2), there is a different behavior, with a higher  $U_{mf}$  for the configuration of the 4x2 mm to the configuration of the 8x2 mm, 1.32 m/s, and 1.27 m/s, respectively.

In addition, cases (1) and (4) showed changes in their fluid dynamic behavior, moving between the spouting and bubbling bed regimes, due to the distributor plate used (wire mesh), which favors the homogenization of the fluid flow through the bed.

#### 4. CONCLUSION

Through the tests, it was possible to evaluate the fluid dynamics of a fluidized bed for cylindrical particulate materials with different air distributors. The results found showed convergence among themselves, enabling the understanding of the phenomena that occur during fluidization.

The graphical analysis via polynomial adjustment of the fluidization curve showed a good performance in predicting the minimum fluidization velocity and the pressure drop in the minimum fluidization condition, with precision ranging between 0.78% and 8.33% according to the size of the particulate material and the distributor plate used.

The variation of the configurations in the bed allows the change of the fluidization regime, as well as the fluidization start speeds. Thus, models of distributors with central orifices favor the occurrence of a fluidization regime of the spouted type, Geldart D, while configurations of distributors with more distributed orifices provide a fluidization regime of the bubbling type, Geldart B. However, it was observed the change in the fluidization regime of a particulate material Geldart D to Geldart B, when using the wire mesh type distributor, was due to the uniformity of distribution of the orifices.

Therefore, in this paper it was possible to evaluate and understand the effects of the morphology of the particulate material, as well as the characteristics of the distributor plate in the fluidization regime, emphasizing the importance of understanding the phenomena that involve the fluidized bed technology.

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