DETERMINATION OF THE PRESSURE LOSS THROUGH A GASIFIER WITH POROUS FIXED BED

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Abstract. *The flow through porous media has a great practical importance in many applications, including drying the wet biomass particles or grain seeds, the gasification of biomass or coal, ground water movement, regenerative heat exchange, surface catalysis of chemical reactions etc. In all these applications is necessary to predict design parameters such as pressure drop, friction factor, heat transfer coefficients in order to predict optimum operating conditions, size and design of equipment. In most cases Darcian flow is assumed, however some researchers have concentrated into non Darcian flow. The pressure gradient across the porous bed is a function of system geometry, medium porosity, permeability and physical properties of the working medium. In the present work, the focus is on analysis of air flow in an açai bed and on the medium porosity in order to predict flow rate and pressure drop through a gasifier reactor. The experiments were carried out in a low intensity wind tunnel. The analysis in the wind tunnel was made for different lengths of the porous bed, varying with the decrease arithmetic progressions corresponding to half value of the tube diameter used in the test. By varying the frequency of the centrifugal blower in the range of 20 Hz to 60 Hz, we can see the pressure losses due to the porous bed.*

Keywords: *pressure loss, porous bed, açai seed*

1. INTRODUCTION

The wide application of fixed beds in the engineering field, particularly its use in gasifiers reactors, makes the study of fluid flow and the previous pressure loss diagnostic through this kind of equipment indispensable. The relevance of the pressure loss determination provides a broad overview how the flow behaves and how does it influence on the gasifiers performance; despite of that, it is important to investigate the reactor performance according to the biomass physical characteristics and the more appropriate operational mode to improve the process.

On the construction and development of new technologies for gasifiers the operational parameters are still the great challenges which require close attention, so we can improve them and determine the best operational conditions. An observed difficulty is concerned to the pressure loss caused by the fixed porous bed. The length of the porous medium can become impracticable to process or to reduce substantially the reactor performance. An estimative or a determination of the pressure loss caused by the porous bed in order to have knowledge of the phenomena, will enable to improve the gasification process so that it not be an obstacle to the correct functioning of all equipments connected to the gasifier reactor.

Fourmey (1996) have carried out a study on pressure loss characteristics of beds of equilateral and non-equilateral solid cylinders of aspect ratios ranging from 0.5 to 2.0. These studies have exposed the shortcomings of the commonly used Ergun type correlations for predicting the pressure loss in packed systems. An empirical correlation to predict pressure loss in fixed porous bed of cylindrical particles has been developed. In addition, derivatives of cylinders, such as hollow cylinders, have been examined and comparisons have been made with particles such as spheres.

A vast amount of information in the form of empirical and semi-empirical correlations which relate the pressure loss to the hydrodynamic conditions of the packed beds is available. The Ergun (1952) correlation (Eq.6), has been widely used for design or treatment of raw experimental data extracted from certain geometrical configurations. Ergun's correlation accounts for viscous and inertial energy losses and relates them to the dynamic variable, velocity of the fluid, as well as the structure of the bed characterized by the bed mean voidage.

Sharma (2007) has been developed a fluid flow and heat transfer model for the reactive porous bed of the biomass gasifier to simulate pressure loss, temperature profile in the bed and flow rates. The conservation equations, momentum equation and energy equation were used to describe fluid and heat transport in porous gasifier bed. The model accounted to drag the wall and the effects of radial, as well as axial variation in bed porosity predict pressure loss in bed. The results show that the high gas flow, the bed temperature and the reduction in feedstock size is found to cause a marked increase in pressure loss through the gasifier, while the pressure loss is relatively insensitive to the moisture content.

Keyser et al. (2006) focused on the role of coal particle size distribution on pressure loss and gas flow distribution through packed coal beds. This fundamental knowledge is helpful in better understanding the operational behavior of fixed bed dry bottom gasifiers. The results show a general remark that is the well-known Ergun equation for fluid pressure loss through packed beds is not adequate if the coal size distribution becomes too broad. In such a case, the actual pressure loss is higher than the pressure loss predicted by the Ergun equation.

MacDonald et. al. (1979) tested statistically with a large number of experimental data the nondimensional Forchheimer equation of Ahmed and Sunada and the modified Ergun equation. It is concluded that the physical basis of the Forchheimer equation appears to be accurate. The modified Ergun equation, while certainly not rigorous, can be expected to predict experimental results for unconsolidated media with an accuracy of ± 50%. For the wide porosity range from 0.36 to 0.92, the porosity function of the Ergun equation is superior to others proposed in the literature, although others are better over narrower porosity ranges. For nonspherical particles, it is necessary to measure the surface-to-volume ratio or the sphericity.

Montilett (2006) worked on validating and extending the applicability of an existing correlating equation for predicting pressure loss through packed beds of spheres. A new set of data points out its use for bed geometric aspect ratio D/dpart in the range 3.8–14.5, in the case of dense packings. The case of loose packings is also discussed using literature data.

The aim of the study by Reddy (2008) is computational fluid dynamic (CFD) simulation of the singlephase pressure loss in fixed and expanded beds. A fixed bed with a column to particle diameter ratio (D/dp) of 5 and having 151 particles arranged in 8 layers was taken as a computational geometrical model. As results the author concluded that when the CFD simulation was compared with Ergun’s equation, the predicted CD values in the creeping flow region were found to be higher due to wall friction. In turbulent flow region the predicted CD values were found to be lower due to channeling. In the transition region ($10 < Re < 500$) the agreement was found to be excellent.

The objective of this study is to determine experimentally the pressure loss and to evaluate the pressure difference in porous medium formed by açai seed. The bed porosity was predicted using equations proposed by Ergun (1952). The experimental study was carried out in a low turbulence wind tunnel; the used test section has the same diameter of the gasifier reactor.

The analysis of porous bed should be raised important factors as: porosity, the apparent velocity through the bed under the Darcy’s law and pressure loss caused by the fixed bed. To determine the bed porosity data were collected from a sample of diameters of açai seeds and taken their average value, as well as its specific gravity by weighting each seed and doing general survey to determine the average of these, always obeying the variation of the standard deviation caused by the total samples. These experiments were performed with a fixed bed of açai seed attached to a wind tunnel.

2. EXPERIMENTAL APPARATUS AND METHODOLOGY

During the experimental analysis of porous bed in the wind tunnel, the methodology was to collect data of pressure difference for the analysis of pressure loss. A PVC pipe filled with açai seed was used to simulate the gasifier fixed bed used at the Gasification Laboratory-UFPA. The pressure distribution along the pipe was obtained through pressure taps that were constructed and connected to a processing manometer. By the variation of the porous bed length was possible to observe the behavior of the pressure focusing on different lengths. The porous bed length varies from 0.075m to 0.525m; to keep the seed inside the pipe we fixed them with screens.

The experimental apparatus is an open wind tunnel with a circular PVC pipe connected on it, as it is shown in Figure 1. The PVC pipe has a circular section of 0.15m in diameter and 2.5m in length. The air is supplied by a centrifugal blower powered by an electric motor which is controlled by a frequency controller. The tunnel provides an uniform flow at the entrance of the test section, and in this investigation, the velocity is varied depending on the frequency established by the frequency controller.

Figure 1. PVC pipe connected to the wind tunnel

The porous bed is formed by açai seed, showed in Figure 2, in a random arrangement always obeying the length limit of each section with the aid of screens without interfering on the flow.

The equipment to collect the values of pressure difference and to collect the values of the flow velocity was a digital Micromanometer FC0510, as it is shown in Figure 3, connected by silicone tubes on the pressure taps and a Pitot tube to acquire the velocity values.

Figure 2. Açai seed

Figure 3. Micromanometer FC0510

2.1 Porosity determination

The porosity determination requires the diameter and mass averages of the açai seed. It was used an analytical balance model AL5000 with precision of 0.0001 cm to weight açai seed. The diameter seed was measured with a vernier caliper of 0.05 mm in precision.

The weight of each açai stone was obtained by grouping all the values in a sample of 100 seeds weighing up to average, and always checking the standard deviation fit within a limit below 0.15 for the sample group. The measurements were performed on a sample of 230 açai seeds and represented by the three diameters of the stone, according to direction x, y and z in Figure 4.

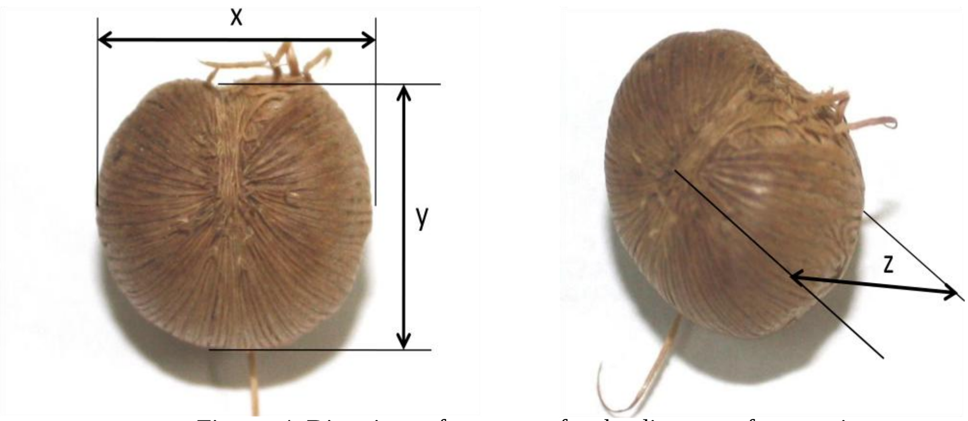

Figure. 4, Directions of measures for the diameters from açai.

To porosity study of the açai stone was necessary to carried out an experiment to find out the volume of voids left in bed. We can determine how much space is left empty for this by relating the volume of a core nucleus of açai (V_{seed}), the relation between the stone mass ($m_{açaí}$) and the weight of porous bed ($M_{açai}$) “Eq.1”.

$$V_{açaí}=V_{seed}\ x\ M_{açaí}/m_{açaí} \tag{1}$$

The sampling was done with a tube of 1.5m long, containing 14.02 kg of açai seed without fiber. The values of average diameter of the seeds and the average weight of açaí without fiber are required to determine the volume occupied by the biomass.

The porosity (ε), as cited by Nield and Bejan(1992), is the percentage of volume occupied by air or air voids (V_{empty}) caused by not completely filling the seeds in the reactor, within a certain total volume which corresponds to the internal volume of our reactor (V_{total}), according Eq.2.

$$\varepsilon=V_{empty}/V_{total} \tag{2}$$

The volume occupied by air, or air voids, is determined by the difference between the volume occupied by the açaí seeds and the total volume of the reactor, according Eq.3.

$$V_{vazio}=V_{total}-V_{açaí} \tag{3}$$

3. RESULTS

3.1 Porosity

According to the statistical survey described above, the results for porosity are shown in Table 1. If we adopt the core of acai as a perfect sphere for purposes of calculation, we take an average for the three directions in diameter, and thus getting only an average value of the average diameter of açai seeds as 1.0313975cm. Average diameter of açai seeds, correspondent from directions X, Y and Z.

The results of the porosity calculated by the relation from Eq. 2 were arranged for different lengths of bed, so it is possible to see the influence that the compaction of the seed is available as increasing the length of the bed and changes caused by this, as it is shown in Fig. 5.

Table 1. Average diameter of açai seed in a sampling of 230 seeds.

Directions	X	Y	Z
Diameters medium	1.1554545	0.9737879	0.96495
Standard deviation	0.0684712	0.0834465	0.0644459

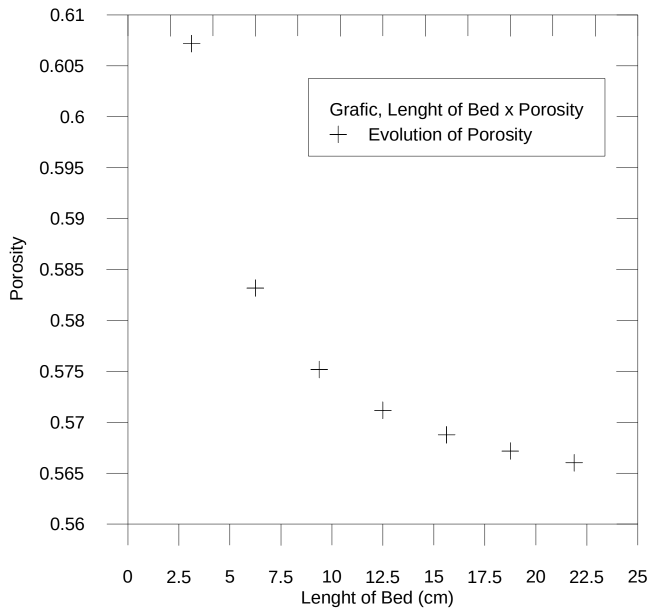

Figure.5. Porosity evolution of the porous bed.

3.2 Pressure loss

The experimental analysis was carried out in the wind tunnel for different height porous bed of açai seeds, there were collected 112500 values of pressure drop and velocity incoming on the fixed bed so that we can obtain the experiment with repeatability. The values we collected and treated so that we have the average values for the observed phenomenon. The pressure loss values were obtained for each height bed by varying the flow velocity. The behavior of these results is represented graphically in Fig.6. The behavior of the velocity within the porous bed is shown in Fig.7.

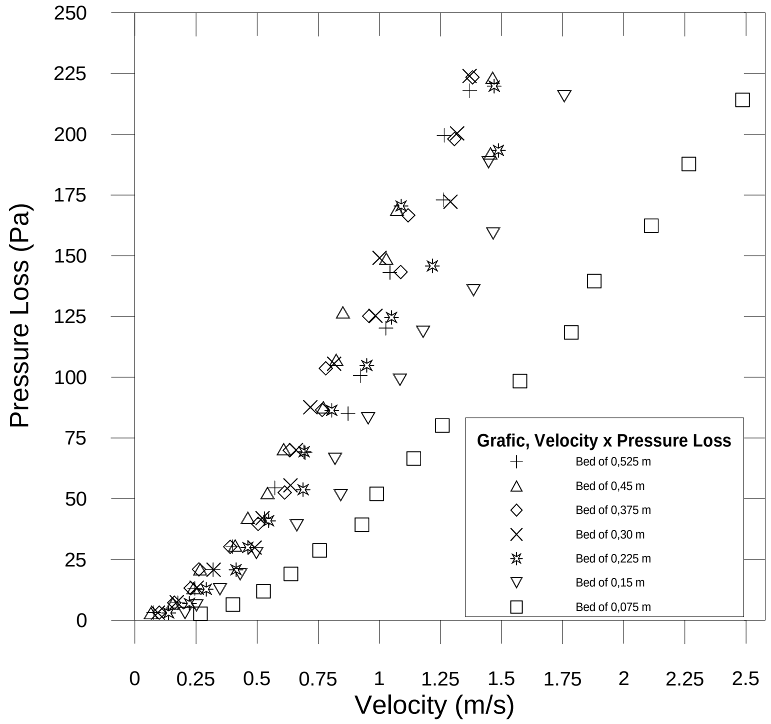

Figure 6. Pressure Loss for different velocities.

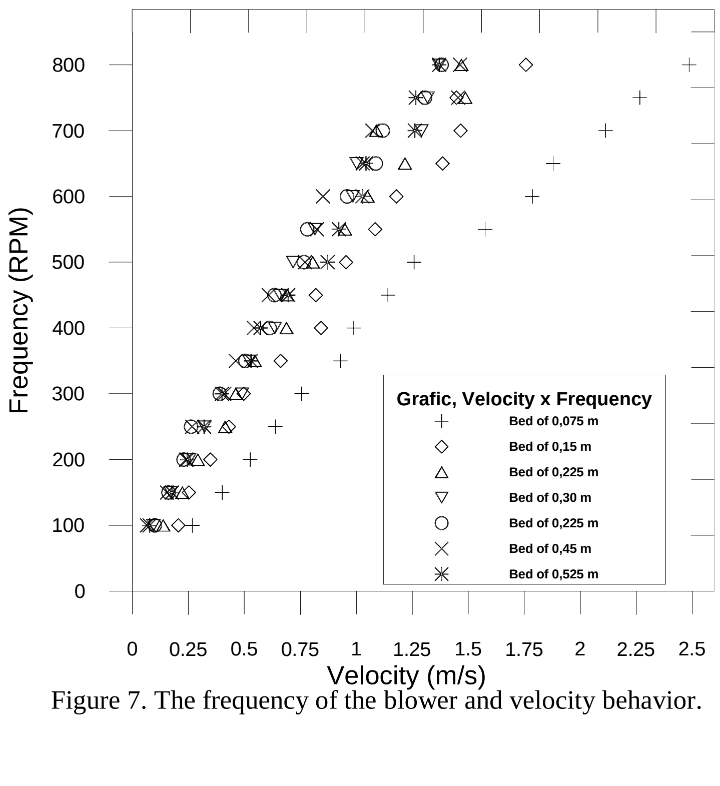

Figure 7. The frequency of the blower and velocity behavior.

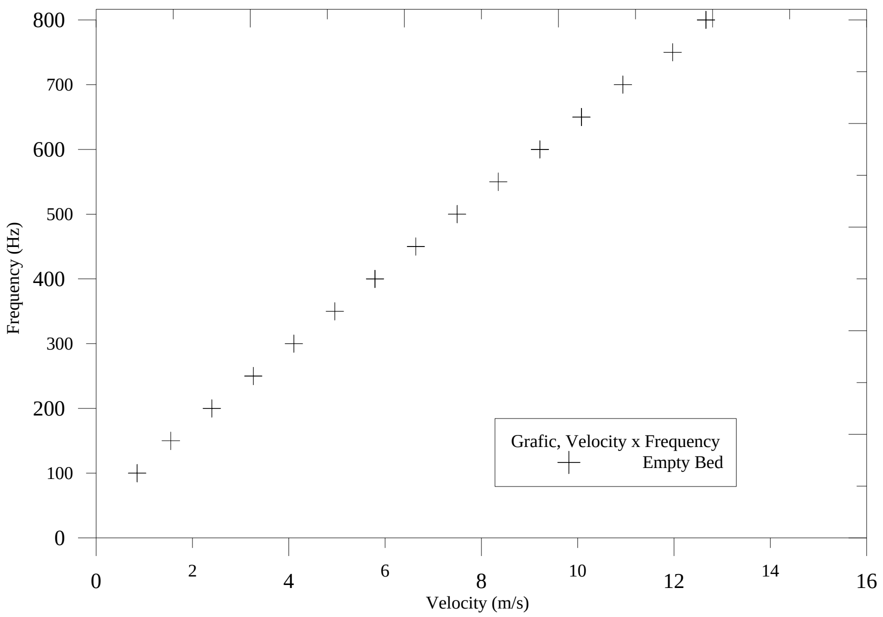

Figure 8. Velocity x frequency for empty bed.

It was made a comparison between the graphs of Figure.7 and 8. This comparison shows how the porous fixed bed consisting of açai seed can influence the flow velocity and therefore cause the pressure loss.

As we consider that the fluid is incompressible, and the methodology used when referring to the inlet and outlet of the flow does not vary, we can say that the pressure loss is invariably equal to the load loss as the Bernoulli equation, Eq.4.

$$\Delta P=\rho.[(V_1)^2-(V_2)^2/2\,]+g.\rho.(Z_1-Z_2)+(P_1-P_2) \qquad (4)$$

Where ρ is density, V_1 and V_2 inlet and outlet velocities of the porous bed, g is the gravity, Z_1 and Z_2 altitudes of entry and exit of the bed, P_1 and P_2 pressures at the entrance and exit of the bed.

So, we will have the law of mass conservation, where the pressure loss is equal to the load loss as Eq.5.

$$\Delta P=P_1-P_2 \qquad (5)$$

It can be observed that the pressure loss is proportional to the length of the porous medium and each curve has an equation of second order. This gives the equation in agreement with Ergun(1952), Eq.6.

$$\Delta P=L.[(150.\mu.V/D^2.\varepsilon^2).(1-\varepsilon)^2/\varepsilon^2]+[(1{,}75.\rho.V^2/D.\varepsilon).(1-\varepsilon)/\varepsilon^2)] \qquad (6)$$

Finally, the expected results for the pressure loss behavior provided by each bed height were obtained.

4. CONCLUSIONS

As we can see the porous bed formed by açai stones presents an important role for the pressure loss and is a phenomenon that cannot be neglected. According to data obtained by sampling, the pressure loss can determine the variation of velocity on the bed, as the length of the porous bed varies.

It was observed that the pressure loss is closely linked to the porosity of the porous medium characteristics since the porosity is based on the number of voids not occupied by açai seeds.

For the construction of downdraft gasifiers, we can identify what would be the optimum velocity range of incidence to the porous bed, this parameter has a great importance to fix the velocity that will be necessary to provide the gasification. The results of this study provide to note the inadequacy of the commonly used Ergun correlations. As a general rule the mean voidage of the bed reduces by decreasing the particle size, thereby it increases the pressure loss across it. A predictive correlation for pressure loss in packed beds incorporating the size of solid with cylindrical particles and their proportion to the reactor tube is a future study by the present authors. This is a preliminary study on pressure loss in a fixed porous bed gasifier using açai seed by EBMA group.

5. ACKNOWLEDGEMENTS

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