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ESTABLISHMENT OF AN EXPERIMENTAL FACILITY AND VELOCITY MEASUREMENTS OF AIRFLOW OVER POROUS BED

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Abstract. *Many studies of flow in porous fixed bed are conducted and widely reported in the literature with several applications. Among the several effects caused by the flow dynamics of the porous bed, there is a pressure drop phenomenon caused by the material that formed the bed. This paper aims to describe the construction and validation of an experimental apparatus for the development of research about the air flow over porous medium. The proposed facility reflects the structure of an up-flow reactor used on the amazon biomass gasification process, by using of a rigid structure with basic measuring instruments and an electric fan it was possible to create the air stream within the proposed model. The experimental facility proposed aims to contribute with reliable results to assess the qualitative and quantitative parameters describing the pressure drop behavior provided by a porous bed consisting of biomasses with different geometric configurations and sizes. As a result, the apparatus is proposed and an application of classical Ergun equation for pressure drop was carried out showing a deviation when used on porous structures. The validation of the apparatus was made via data collection and also the comparison of the basic airflow characteristics were done, showing good agreement.*

Keywords: *porous medium, fixed bed, velocity profiles.*

1. INTRODUCTION

In fluid dynamics there are phenomena that motivate research due to many existing applications and the wide optimization of parameters. The flow in porous medium fits this context, showing a distinct behavior, observed through inconsistencies of classic mathematical models and experimental data. Darcy (1856), one of the precursors of experimental work on porous bed, observed that flow rate is dependent on the pressure drop, the dynamic viscosity and the length, in other words, the characteristic dimensions of the porous bed directly influences the head loss, which can change the flow regime. Due to the complexity of this flow and its variables, it escapes the analytical solution to predict the pressure drop, which suggests application of equations with empirical and semi-empirical relations that associate the pressure drop, such as the Ergun (1952) relation, which has been largely employed for the design and treatment of experimental data. Thus, experimental researches that allow the study of airflow behavior in the porous bed are used to correlate with the experimental results, in order to refine analytical solutions of mathematical models.

Although the Ergun equation is most used in the prediction of head loss for flow on porous fixed bed, considerable variations in its coefficients happens due to the use of different materials and particles geometries. Universal values for constants in the Ergun equation have been the subject of considerable speculation, Leva (1947) proposed 200 and 1.75 and Macdonald (1979) 180 and 1.8-4.0, as quoted by Niven (2000). The constants obtained by these authors are due to the fact that the parameters used are functions of the Reynolds number, porosity or particle shape. The constants, respectively, are extremely important, since the equation is divided into two parts, the first one related to the loss of viscous energy and the second part referring to the loss of kinetic energy. Because of this, the determination of the coefficients is given empirically for each porous bed, making the experimental apparatus extremely important, which can provide reliable values for the flow. In this case, the objective is to propose an apparatus who promotes the validation of the research.and that is also useful and simple for future classes whose interests involve this study of case.

2. REFERENCIAL

According with the Carma (1937) and Kozeny (1927,1933) researches, the equation 1 for turbulent flows with specific mass (ρ_f), Particle bed height (L), Pressure Drop (-ΔP), Fluid surface viscosity(μ_f), Velocity (V), Particle diameter (D_p) and Porosity (ε).

$$(-\Delta P)/L = 1.75\ [(\rho_f V^2)/D_p]/[(1-\varepsilon)/\varepsilon^3] \tag{1}$$

In 1952, Ergun suggested a general equation based on his experimental data:

$$(-\Delta P)/L = 150\{[\mu_f V (1-\varepsilon)^2]/\varepsilon^3\} + 1.75\{\ [(\rho_f V^2)/D_p]/[(1-\varepsilon)/\varepsilon^3]\} \tag{2}$$

This equation known as the Ergun equation and is valid for fixed bed flows, where particles are the same size and are randomly arraged. However, the equation is not restricted to spherical particles only. Another important point is that under turbulent flow conditions, the second term of the Ergun equation (1952) becomes dominant and the pressure gradient is proportional of the fluid surface velocity who is independent of viscosity. Based on the above equations, one of the most important value is porosity, which a dimensionless relationship between tube's volume (v_{tube}), empty volume (v_{empty}) and bed volume (v_{bed}), defined by equation 3:

$$\varepsilon = v_{empty} / v_{total} = (v_{total} - v_{bed}) / v_{total} \tag{3}$$

Where the relation between the bed mass and the particle mass with the particle volume obtains the v_{bed}, through equation 4:

$$v_{bed} = v_{particle}\ (M_{bed}/m_{particle}) \tag{4}$$

3. METHODOLOGY

Based on the previous model of the apparatus as Cruz (2013), some structural changes were made to give more stability to the apparatus. Firstly, MDF wood was purchased to be placed in the lower and upper part of the structure where the PVC pipe is located and also in the back, all properly screwed in order to prevent as much as possible the vibration of the structure. Figure 1 is a schematic made in SolidWorks software for easy visualization of the structure.

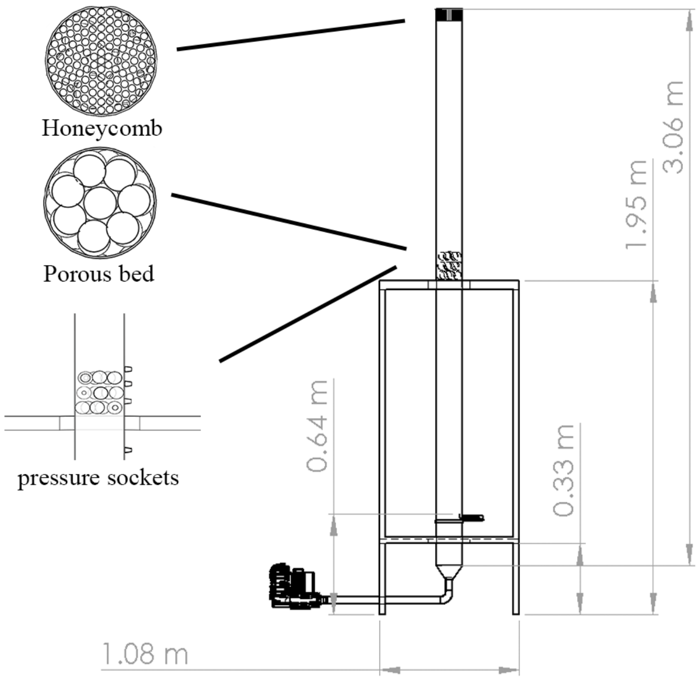

Figure 1. Schematic drawing of the structure.

As can be seen in the figure, a PVC pipe with a circular section of 0.15 m in diameter with a length of 3 m was used. This tube was sectioned in two parts and connected by a PVC sleeve. This glove, together with a metal structure, comprises the porous bed composed of smooth spheres with a diameter of 40 mm and each sphere has a weight of 2.74g. The metal structure has the role of keeping the porous medium fixed at a certain height and avoiding a possible displacement of that bed. At the top of the tube, a 10cm high hive was installed to reduce turbulence at the inlet of the tube. To generate the airflow, a centrifugal fan was connected at the bottom of the PVC pipe. This fan has a power of 5hp with a maximum rotation of 3,500 RPM.

This fan creates a suction current, its speed being adjusted with a TOSHIBA frequency inverter in a range of 0Hz to 60Hz connected to the fan motor, so that the different air flows through the porous medium were determine. The table 1,2 and 3 with its specifications are presented below.

For the validation of the apparatus, it was necessary to obtain the mean velocity profiles and the pressure drop inside the tube by evaluating the absence and presence of the bed, which consists of smooth beds supported by a metal structure, as previously mentioned. The tests were made for heights equivalent to 0.5D and 1D with amounts of spheres respectively equal to 18 and 39. Heights are determined based on the diameter of the PVC pipe.

To obtain the profile, 12 points were analyzed inside the duct, moving the Pitot tube that was fixed in a metallic support, totally fixed by a steel strap, thus avoiding the displacement (figure 2) with a ruler duly graded that assists in the determination from the position where the Pitot is inside the tube.

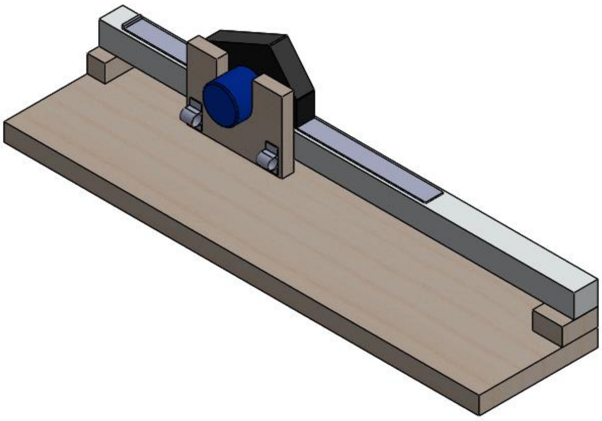

Figure 2. Stand for Pitot tube.

All the Pitot movement is done manually. The points are spaced apart by 1 cm, the first and last point are 1.5 cm away from the tube wall due to a limitation in the geometry that is related to the Pitot tube. For each point, 95 samples were collected, all recorded in video and later the points were plotted, so that the mean velocities for each point were obtained. For each sample, a statistical analysis was performed, that is the standard deviation, the standard error and the confidence interval T.

For the head loss, 180 samples of the pressure were obtained and four pressure intakes were made, 1 after the bed with a distance of 15 cm and three of those sockets made above the bed, obeying the height of 0.5D, or at a distance from each outlet of 7.5cm.

4. RESULT ANALYSIS

For each velocity profile, there was a frequency change provided by the frequency inverter to the fan. With this, three different frequencies provided three velocity profiles with and without the porous medium in order to verify if it would be according to the literature. The following table shows the mean maximum velocity at the center of the tube for each frequency worked, as well as the Reynolds number at that point, considering a 30 ° C in ambient temperature for a flow without the porous medium.

Table 1. Average speed without bed.

Frequency (Hz)	Velocity (m/s)	Conf. Interv. T (Vel)	Standard Error (Vel.)	Reynolds (Re)
50	7,0300	0,050	0,025	50,350
55	7,7308	0,056	0,028	55,369
60	8,3300	0,053	0,027	59,660

The same procedure was repeated using the porous medium, always maintaining the configurations for each frequency worked as can be observed in Tables 2 and 3. The graphs for the velocity profiles for the 50, 55 and 60 Hz frequencies are shown in Figure 3.

Table 2. With 0.5D bed.

Frequency (Hz)	Velocity (m/s)	Conf. Interv. T (Vel)	Standard Error (Vel.)	Reynolds (Re)
50	5,8890	0,051	0,026	42,177.80
55	6,5202	0,070	0,035	46,698.54
60	6,9819	0,071	0,036	50,005.30

Table 3. With 1D bed.

Frequency (Hz)	Velocity (m/s)	Conf. Interv. T (Vel)	Standard Error (Vel.)	Reynolds (Re)
50	5,629	0,086	0,043	40315,8
55	6,1753	0,079	0,040	44228,01
60	6,6914	0,087	0,044	47924,59

By comparing the graphs, it was observed how much the porous medium influences the concavity of the velocity profile. This is due to the loss of load provided by the bed, thus causing the speed decrease with the addition of bed 0.5D and 1D.

Comparing figures 3, 4 and 5 the behavior of the velocity profile is in accordance with the literature, which consists of a parabolic profile for a circular section. Point 1 and point 12 were not perfectly symmetrical in both graphs, perhaps because the spheres were more concentrated for a given point due to their randomness.

There is another factor that has to be taken into account. The entrance orifice where the Pitot tube is located may cause a slight loss of charge, causing the average velocity for point 12 to be less than point 1.

Another point to be raised is the tube mounting. As the tube has been sectioned to facilitate the addition of the spheres that will make up the bed at the time that it is necessary to assemble, there is a possibility of incorrect fitting on the sleeve, which is responsible for the joining of the sections.

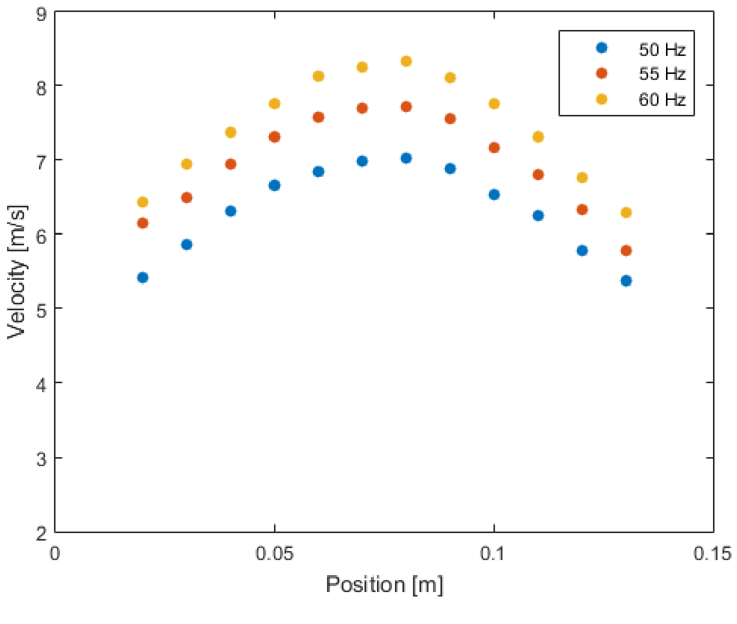

Figure 3. Velocity profile without porous bed.

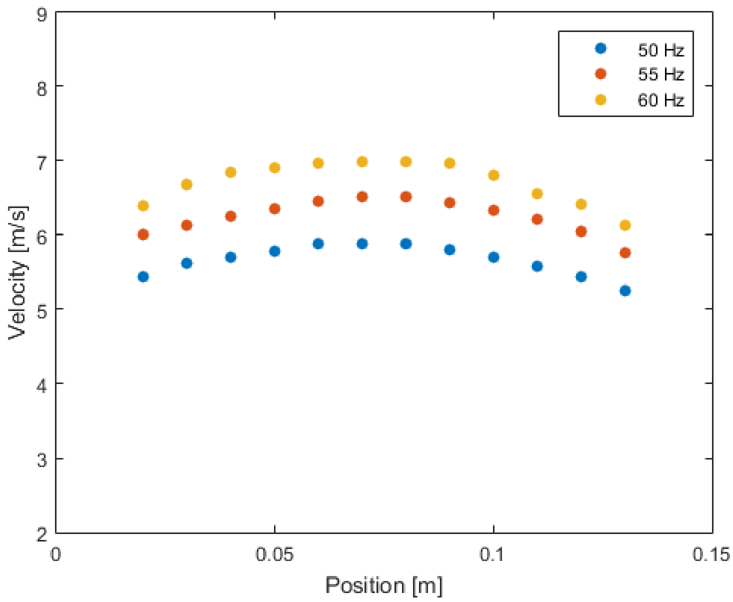

Figure 4. Velocity profiles with porous bed 0.5D for 3 frequencies.

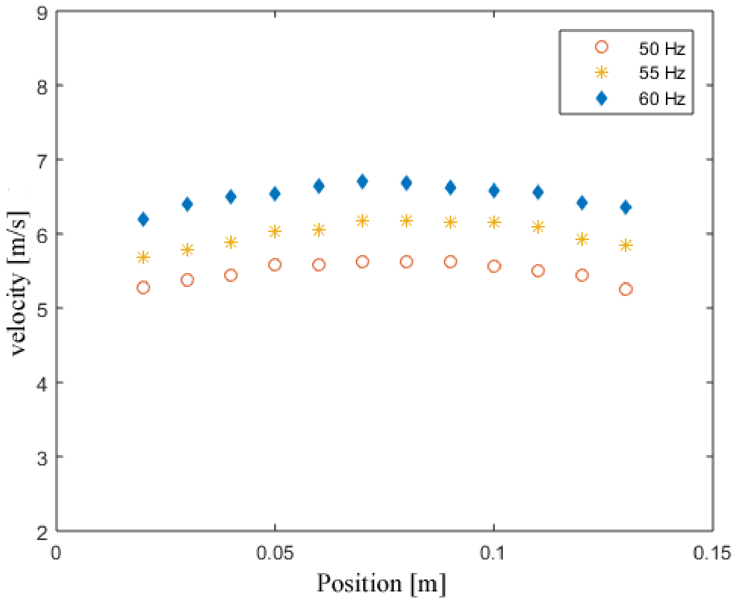

Figure 5. Velocity profile with 1D bed.

3.1. PRESSURE DROP IN THE POROUS BED

For the loss of load, the same frequencies were used to obtain the velocity profile. Porosity is one of the most important factors to study because it indicates the influence of pore geometry on the loss of load and how it can interfere in the development of the flow. Table 4 shows the characteristics of the particle:

Table 4. Particle characteristics.

Properties	Value
Diameter (m)	0.040
Mass (kg)	0.00274
Volume (m^3)	0.00003351032

For each height bed, a specific amount of spheres (as stated in the methodology) was considered and with table 4, volumes and masses were calculated for 0.5D, 1D and 1.5D (table 5). Subsequently, the volume of the tube was calculated without and with the presence of each bed (table 6). With these data, the porosity was obtained according to the table 7.

Table 5. Volumes and masses for each porous bed.

Bed	Mass (kg)	Volume (m³)
0.5D	0.04932	0.00060318579
1D	0.11782	0.001440944

Table 6. Trough volume related to bed height

Bed Length (m)	Tube volume (m³)
0.075	0.001325359
0.150	0.002650719

Table 7. porosity for each bed.

Bed Length (m)	Porosity (ε)
0.075	0.5449
0.150	0.5070

It can be noticed that the porosity was decreasing with the bed height, this is due to the fact that the spheres ratios for each length was not kept constant. The ideal case is that the porosity remained the same, independently of bed length. With the obtained data one can develop the graphs of load loss for each bed:

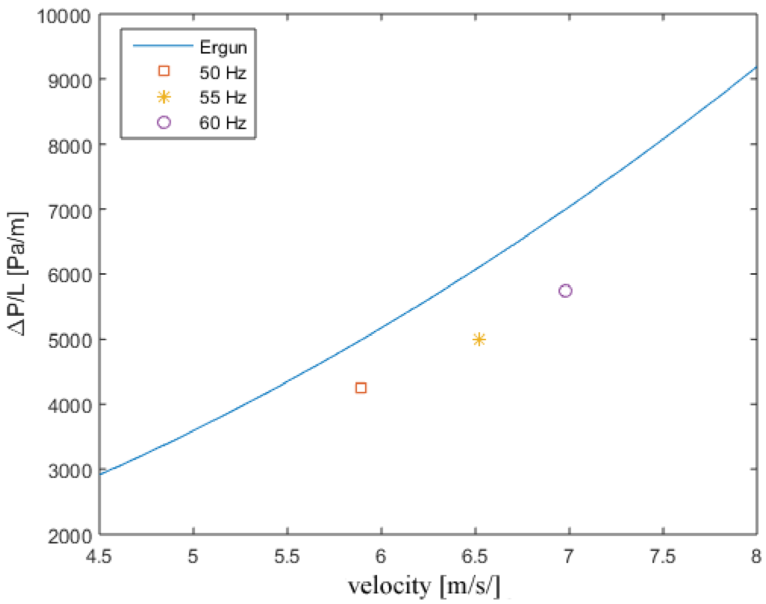

Figure 6. Load Loss versus Velocity for 0.5D.

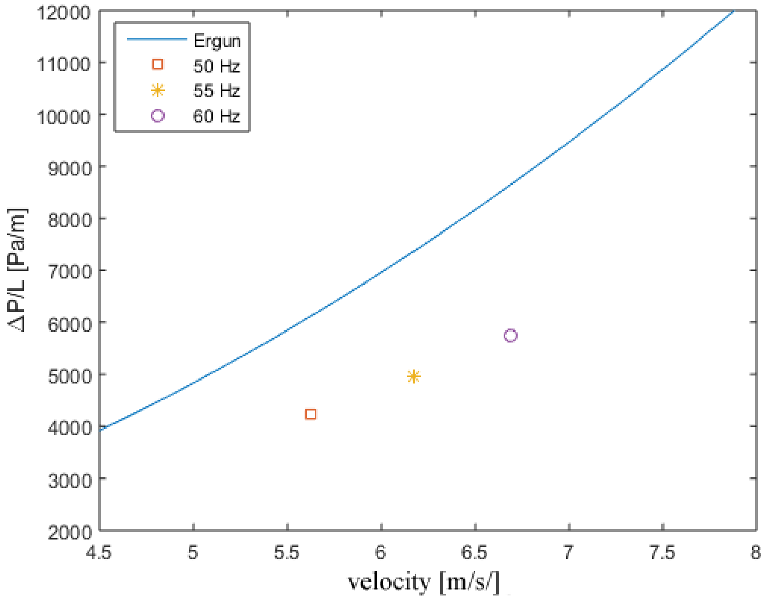

Figure 7. Load Loss versus Velocity for 1D.

As can be seen in figure 6, the experimental points were very close to the analytical curve of the Ergun equation (2) for a bed of 0.5D, evidencing that the possible errors could be due to the diameter of the spheres being too large, directly influencing their packaging.

For an increase of 0.5D, as we can see in figure 7, the load loss increases, causing the points to move away from Ergun's analytic curve. For 1D, it was not possible to maintain a same ratio of spheres addition, that is, 18 spheres for each 0.5D of bed length, and it was expected that with increasing length that same amount of spheres could be added. However, maintaining this number of spheres, there would be some large interstices that would influence the velocity profile for 1D, thus causing deflections at certain points where these interstices would be larger. In order to avoid this, it was necessary to add three more spheres to close these points, causing an increase in this length of the bed due to the diameter of the sphere, this being one of the reasons for the distance of the points from the analytical curve of Ergun.

5. CONCLUSION

The present work had as objective to improve the experimental apparatus structurally and to use the Ergun equation as validation, in order to obtain satisfactory experimental data for the flow in porous fixed bed.

In the matter of structural improvement, there was always a concern of keeping the apparatus reliable with regard to the interpretation of the results that were obtained. The addition of MDF wood at strategic points in the structure, to avoid any type of vibration that could significantly influence the results, was of utmost importance together with the development of a pitot tube support, thus ensuring reliability for the verification of these results.

Regarding the validation, as can be observed by the velocity profile plots, it was found that the porous bed flow agrees with what is available in the literature, since for a circular section the flow behavior has characteristics of a parabolic profile. Evaluating the pressure drop results for the 0.5D bed, the experimental results were close to the Ergun analytical curve, showing that the quantity of samples, given some limitations in the equipment present in the laboratory, was sufficient to characterize the pressure drop in porous fixed bed flow. For the 1D bed, the results moved further away from the Ergun analytical curve, while maintaining the same increasing characteristic of the curve. The analyzed values were the maximum velocities in the center of the tube for the frequencies already stipulated in the methodology.

6. ACKNOWLEDGMENTS

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