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**FLUIDIZATION CURVES AND ANALYSIS OF POWER SPECTRAL
DENSITY OF POLYPROPYLENE PARTICLES**

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Abstract. *The particulate fluidization process is often present in the heat transfer industry, and it's constantly associated with the different energy transformation methods. In academia, it's possible to find several works referring to the characterization of particles. As a result, we decided to study the fluidization of Geldart D polypropylene particles in an experimental cylindrical bench to find out the fluidization curves under different conditions as well as the predominant frequencies of a piston flow regime. In all the experiments, the normal volume flow and the pressure data of were collected. The fluidization curves were obtained in two different methods: with and without time limits, while the frequency study was made through the application of the Fourier transform to separate the frequency components and specify the frequency with the most power in a Power Spectral Density (PSD) graph with a data collection of 70 seconds. The data was collected at different frequencies, depending on the required results: 1 Hz to the development of the system pressure drop curve, 1 Hz to a fluidization curve without time control, 10 Hz to a fluidization curve with time control and 250 Hz to study the time and frequency domain for the PSD curve. From this research, the obtained results were in according to what was show in the literature. It was found out that the particulates of polypropylene have a small dominant frequency of 2.57 Hz. In relation to the fluidization curves, it was discovered that both processes have very different results, specially in relation to the maximum pressure obtained.*

Keywords: *Fluidized bed, Polypropylene, Fluidization curves, PSD Analysis.*

1. INTRODUCTION

To reduce the waste in energy production, it is important to research and discover new energy generation techniques. 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 (Cremasco, 2018).

Fluidized beds of gaseous solids are used in many industrial processes due to the excellent mixing of solids as well as the high heat and mass transfer rate (Hu et al., 2017). Over the years, many studies have been conducted to understand the phenomenon of fluidization of different particles. These studies, such as those developed by Johnson et al. (2000), using experimental and numerical approaches, showed that many technics are available to determine fundamental parameters related to the fluidization process, such as minimum fluidization velocity through the standard variation method and the dominant frequencies of different particles by the Power Spectral Density (PSD) method.

It was also studied that, in fluidized beds experiments involving liquids in the process, as the liquid saturation increases, the fluidization dynamics are directly affected, resulting in some failures. Therefore, a few works deal with characterizing the transition of the flow pattern of wet particles. Dai et al. (2021) address the effects of liquid saturation, gas velocity, and particle size on the dynamic global fluidization of Geldart D particles by analyzing pressure fluctuations in the fluidized bed. It should be noted that in fluidized beds, pressure fluctuations are an important aspect to be considered since their effects directly affect the results obtained.

In the present work, we explored the fluidization curves of polypropylene particulates characterized by Silva (2019) under different conditions within the same experimental bench with compressed air. Associated with this, the time and frequency domain of the pressure signal of the polypropylene operating in a fluidization condition in a piston regime was also analyzed.

2. METHODOLOGY

2.1 Experimental definitions

The experiments in this article were carried out on the experimental fluidization bench, located in the Laboratory of Unit Operations of the Food Engineering course, in the UNISINOS University. This experimental bench, as described by Pinheiro et al. (2022) has, at the upper part, two acrylic tubes with a 93.25 mm internal diameter, a tube wall thickness of 3.88 mm, and a length of 910 mm. These tubes are connected by flanges secured with nut/bolts. At the lower part, the bed is made up of a 100 mm long cylindrical stainless-steel tube and a stainless-steel semi-cone, through which air is insufflated. The Fig. 1 (a) shows some of the dimensions while Fig. 1 (b) also a schematic drawing of the bed components. Points (A), (B) and (C) were used to collect pressure data. Their heights in relation to the bottom flange are 15.5 mm, 87 mm and 343 mm, respectively.

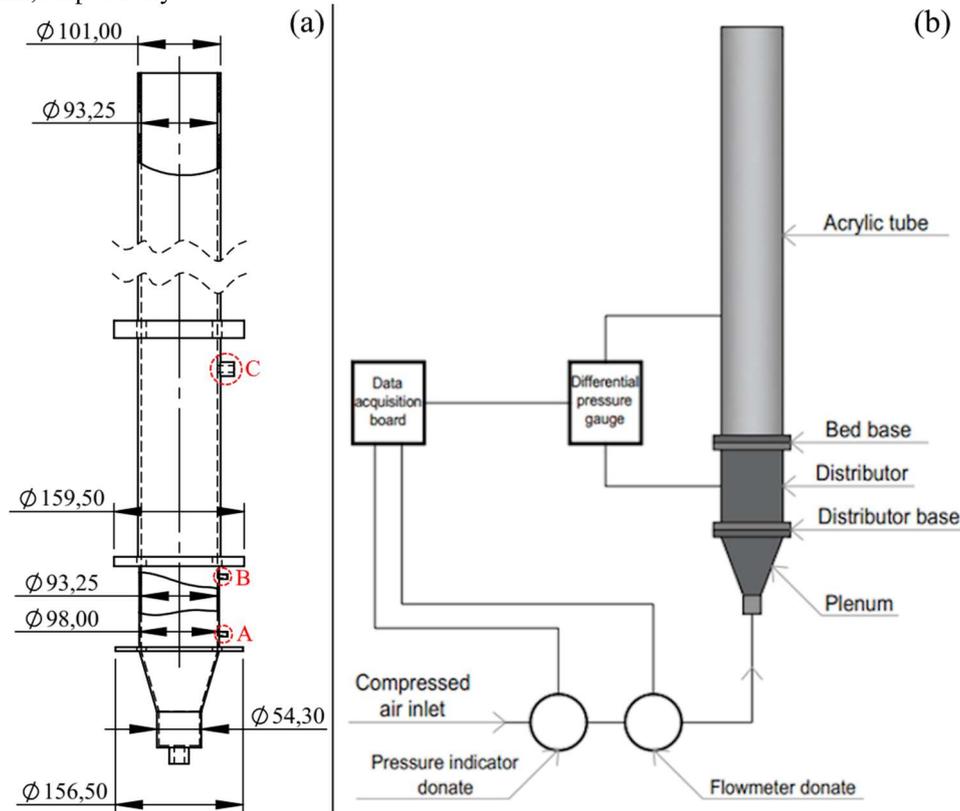


Figure 1. Fluidization bench (a) measurements and (b) schematic with sensors.

During the experiments, the particulate adopted was polypropylene. An approximate height of 93.25 mm of the experimental bench was filled, which represents 1 unit of internal diameter of the acrylic tube. The total mass of particles occupying this volume was 406.95 g, a value that remained constant in all experimental tests performed.

2.2 Pressure drop of the system

To determine the pressure drop of the system, a triplicate of tests with the experimental bench without any particles was performed. The data collection rate used was 1 Hz. In addition, the pressure measurement was obtained from points A and B, in Fig. 1.

First, it was ensured that there were no polypropylene particles inside the acrylic tube. Then, the valve was opened until an intermediate flow was obtained. After the stability of the pressure and volumetric flow in relation to time was verified, we recorded the instant and the value of these monitored parameters, as shown in Fig. 2. Once we obtained around 6 data points, we used a regression polynomial method to get the pressure drop curve of the system, which is the fluidization empty curve.

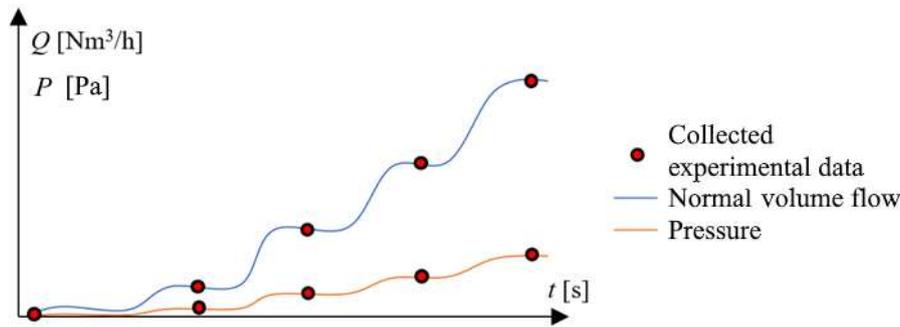


Figure 2. Representation of the data collection of the normal volume flow and the pressure (Schematic figure).

2.3 Acquisition of pressure and velocity curves without time control

The second stage of the experiments was the determination of the velocity and pressure curves of the polypropylene with the constant opening and closing of the air flow control valve and without time control, considering points A and C of Fig. 1. The procedure performed is shown in Fig. 3: the start of the procedure is made with the opening of the valve at the initial time t_0 , followed by the visual determination of the start of fluidization at time t_1 and record of the value indicated by the sensor. Then, we stop of opening the valve at time t_2 for the flow rate specified in the test, collect the data for 1 minute and begin to close the valve at time t_3 . In the end, we record the final time of the fluidization process at time t_4 .

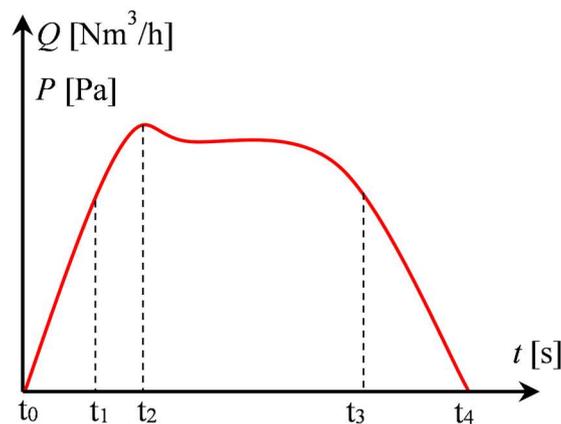


Figure 3. Procedure of pressure and volume flow data acquisition without time control.

The transformation of pressure and volumetric flow data by time into pressure and velocity was carried out the pressure drop curve of the system and the dimensions of the experimental bench.

2.4 Acquisition of pressure and velocity curves with time control

To simulate and validate in the future numerical models of fluidization in the commercial packages ANSYS Fluent and ANSYS Rocky, we also made experiments of fluidization and defluidization with a total time limitation of 20 seconds.

Figure 4 shows the procedure adopted. Initially, for 5 seconds, the valve was opened to reach and exceed the minimum fluidization velocity of the polypropylene. Then, the valve was kept still during the 10 s interval. Finally, for the last 5 seconds, the valve was closed until the entrance of compressed air completely ceased. In this case, due to the work with a small time interval, the collection rate was increased to 10 Hz.

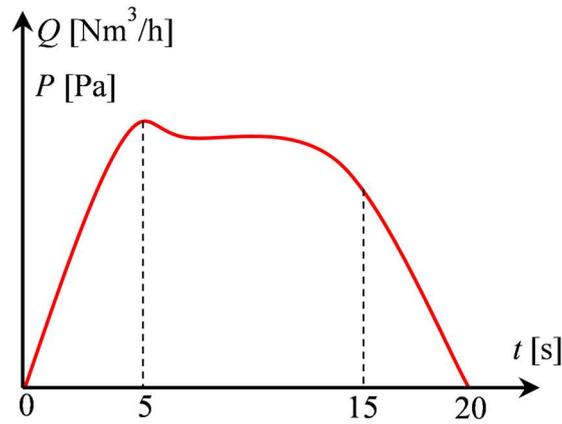


Figure 4 - Procedure of pressure and volume flow data acquisition with time control.

2.5 Analysis in the pressure and frequency domain of the system

The last step of the experiment was the analysis of the pressure and frequency domain of the system. For that, we worked with a data collection frequency of 250 Hz, a interval of 70 s and a flow rate of approximately 55 Nm³/h. The data transformation was carried out by subtracting the collected points referring to pressure and its mean, to obtain a pressure difference curve, as shown in Eq. 1:

$$\Delta P_n = x_n - \bar{x}, \quad (1)$$

where n represents the n -th pressure point collected, x the pressure signal and \bar{x} the pressure average of the entire signal. Subsequently, as Jaiboon et al., 2013, we used Eqs. 2 and 3 were to acquire the Fourier transform autocorrelation sequence of the time signal $x(n)$ estimative, as well as the *PSD* results:

$$F(f) = \sum_{x=1}^N x(n) e^{-j2\pi n f}, \quad (2)$$

$$P_{xx}^i(f) = \frac{1}{\sum_{n=1}^N w^2(n)} [\sum_{n=1}^N x_i(n) w(n) e^{-j2\pi n f}]^2, \quad (3)$$

where N is the total sample size, f is the frequency, x is the pressure signal, w is the window function and j is the multi resolution level.

3. RESULTS

3.1 Determination of the fluidization empty curve and fluidization curves with and without time control

Figure 5 shows the empty fluidization curve. Note that, due to the great proximity between the extracted points and the regression curve, it was possible to reach a very high R^2 regression coefficient, which proves the suitability of the model.

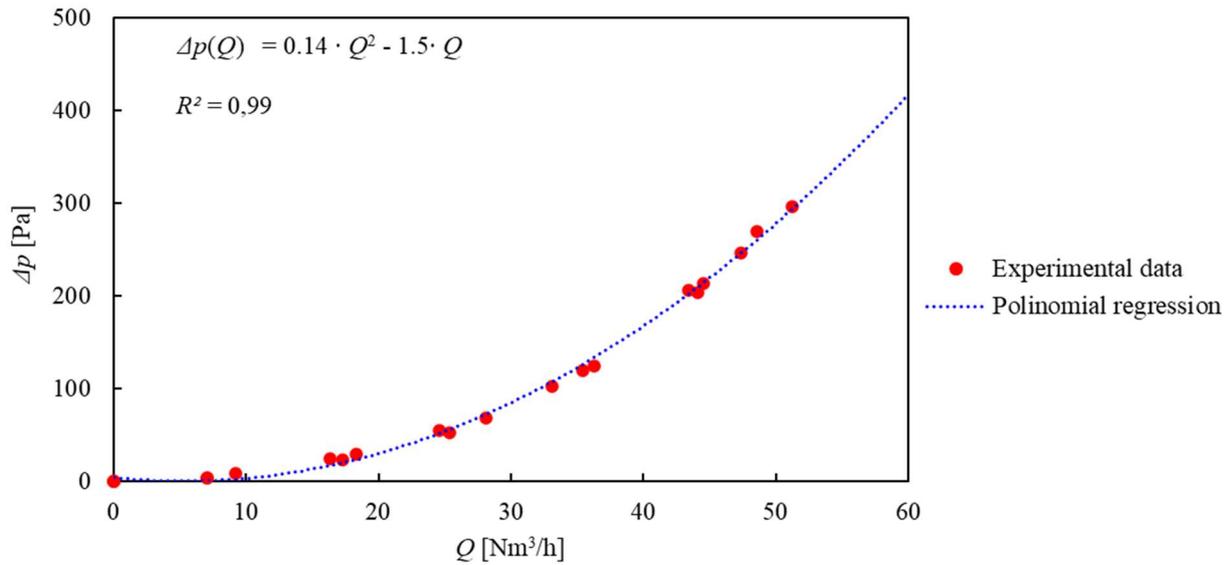


Figure 5. Empty fluidization curve.

With this, the fluidization curves with and without time control were obtained. Fig. 6 presents the results of both cases for a maximum flow rate of approximately 55 Nm³/h. Note that in the test with time control, a lower maximum pressure was reached when compared to the test without time control. Furthermore, the defluidization curves of both cases follow a different path in such a way that tests without time control have an overlap between fluidization and defluidization. This occurs because in the first case there are less abrupt conditions in the operation in relation to the second.

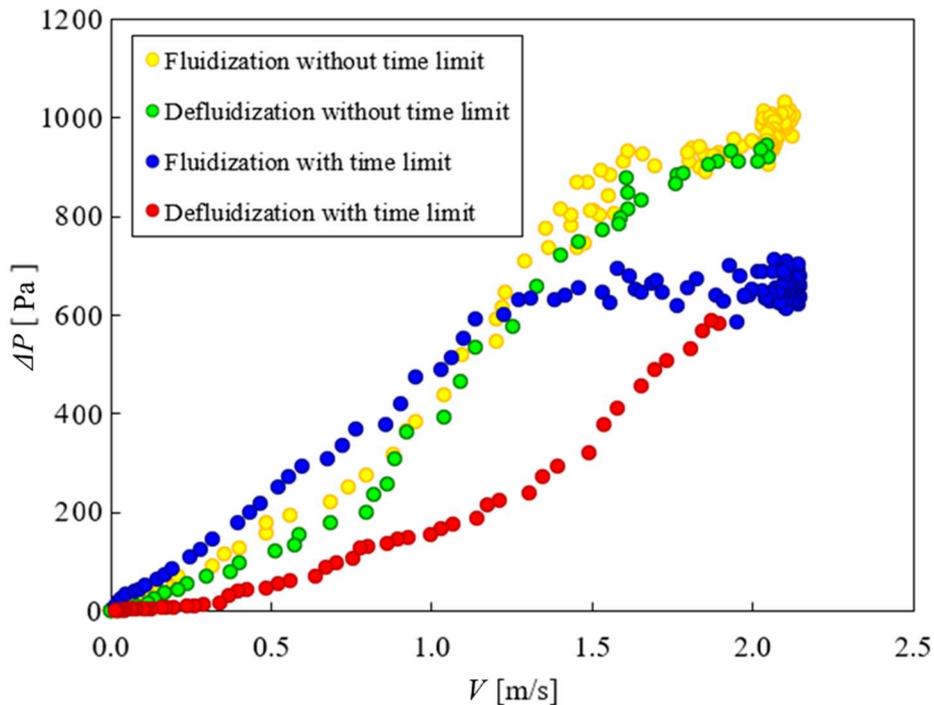


Figure 6. Comparison between limited time test and unlimited time test.

3.2 Time and frequency domain

Figure 7 presents a time fraction of 10 seconds in which the oscillatory behavior captured during pressure data collection is observed.

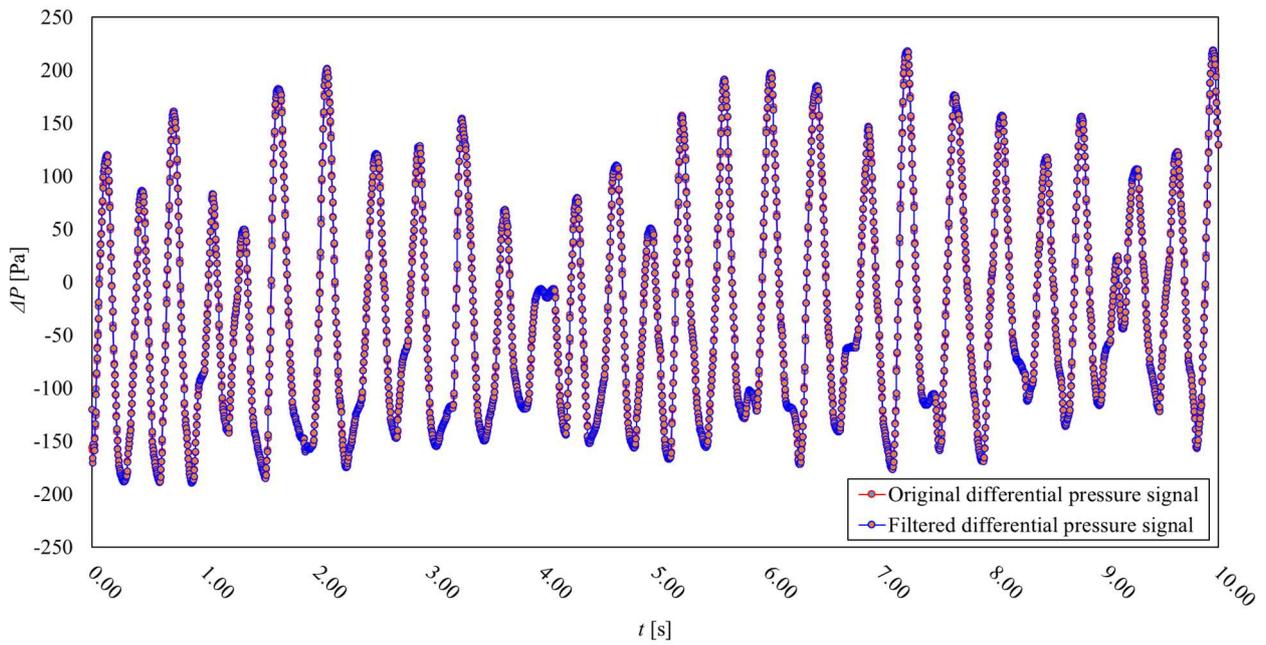


Figure 7. Sample of Δp variation in 10 seconds.

To verify the suitability of the results, we tried to apply a high-pass filter of 62.50 Hz. However, little difference can be identified visually. Through the application of the Eqs. 2 and 3, all collected data (including pressure data with the filter application) were transformed using the PSD method and the result can be seen in Fig. 8.

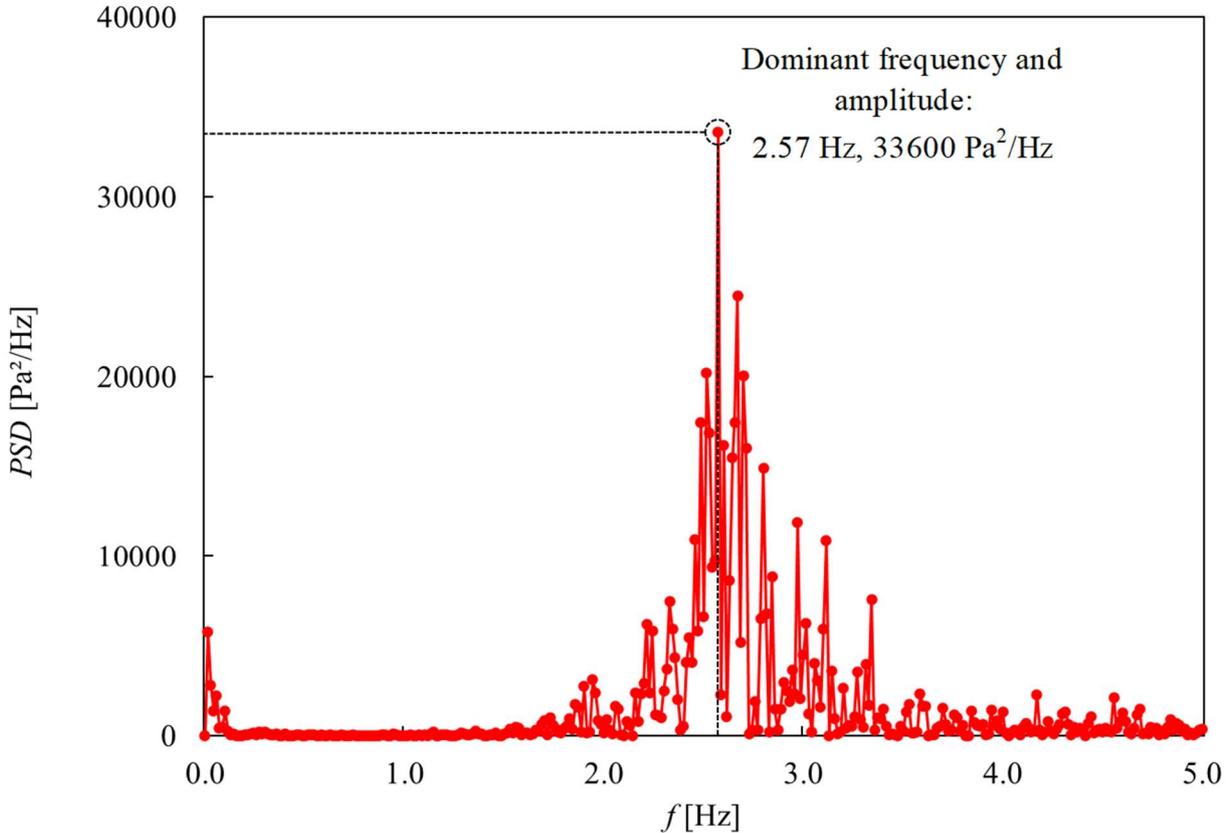


Figure 8. PSD application in the Δp variation in relation to the frequency f .

The frequency f whose result is maximum, is 2.57 Hz, a result that agrees with what was found experimentally and by CFD studies in the literature. It's also possible to see that, in general, the frequencies between 2.0 and approximately 3.5 Hz have the highest PSD values, except for the frequencies close to 0 Hz, which shows a similar pattern.

4. CONCLUSIONS

In the present article, we sought to investigate the behavior of polypropylene particles in a fluidization process in the UNISINOS experimental bench, considering its head loss and its respective fluidization curves. A notable difference was noticed in relation to the polypropylene fluidization and defluidization curves when time was considered, in such a way that, for the same volumetric input flow, a lower maximum pressure was reached in experiments with a time limit when compared to experiments without time control. It is possible to highlight in this case that these differences can be crucial during the establishment of some important parameters for the fluidization process, such as the minimum fluidization velocity.

Regarding the analysis of the pressure by time and pressure by frequency domains, a behavior like that described in the literature was verified: a phenomenon of oscillating pressure around 0 with a certain periodicity. The pressure and frequency domain revealed another important piece of information for the fluidization process: the dominant frequency and amplitudes.

For future work, methods for determining essential parameters for characterizing the polypropylene fluidization process can be investigated, such as the minimum fluidization velocity.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

- Cremasco, M. A., 2018. *Operações unitárias em sistemas particulados e fluidomecânicos*. Blucher, 3rd edition.
- Dai, L., Yuan, Z., Guan, L., Wu, K., Gu, C., 2021, Fluidization dynamics of wet Geldart D particles by pressure fluctuation analysis, *Powder Technology*, Vol. 388, pp. 450-461.
- Geldart, D., 1973. "Types of gas fluidization". *Powder Technology*, Vol. 7, pp. 285-292.
- Hu, D., Han, G., Lungu, M., Huang, Z., Liao, Z., Wang, J., Yang, Y., 2017, Experimental investigation of bubble and particle motion behaviors in a gas-solid fluidized bed with side wall liquid spray, *Advanced Powder Technology*, Vol. 28, pp. 2306-2316.
- Jaiboon, O., Chalermssinsuwan, B., Mekasut, L., Piumsomboon, P., 2013, Effect of flow pattern on power spectral density of pressure fluctuation in various fluidization regimes, *Powder Technology*, Vol. 233, pp. 215-226.
- Johnsson, F., Zijerveld, R. C., Schouten, J. C., van den Bleek, C. M., Leckner, B., 2000, Characterization of fluidization regimes by time-series analysis of pressure fluctuations, *International Journal of Multiphase Flow*, Vol. 26, pp. 663-715.
- Pinheiro, J. F. B., Nóbrega, E. S. B., Silva, A. R. S., Zinani, F. S. F., 2022. "Evaluation of minimum fluidization velocities for various particulates and operating conditions". In *Proceedings of the XIX Brazilian Congress of Thermal Sciences and Engineering – ENCIT 2022*.
- Silva, Á. R. S., 2019. *Modelagem experimental e computacional DEM-CFD da fluidização de partículas Geldart-D com formato irregular*, Master's thesis, Universidade do Vale do Rio dos Sinos, São Leopoldo, Brasil.

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