23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

MONITORING THE FLUIDIZATION QUALITY IN A FLUIDIZED BED PASTE DRYING USING PRESSURE FLUCTUATION MEASUREMENTS

Flavia Tramontin Silveira Schaffka
Mechanical Engineering Department, Federal University of Technology- Paraná
Monteiro Lobato Avenue, km 04, CEP: 84016-210, Ponta Grossa, Brazil
e-mail: flatramontim@hotmail.com

Carlos Alexandre Moreira da Silva
School of Chemical Engineering, University of Campinas
Av. Albert Einstein, 500, CEP 13083-852, Campinas, SP, Brazil
e-mail: camseq2010@gmail.com

Frederic Conrad Janzen
Electronic Engineering Department, Federal University of Technology- Paraná
Monteiro Lobato Avenue, km 04, CEP: 84016-210, Ponta Grossa, Brazil
e-mail: fcjanzen@utfpr.edu.br

Maria Regina Parise
Chemical Engineering Department, Federal University of Technology- Paraná
Monteiro Lobato Avenue, km 04, CEP: 84016-210, Ponta Grossa, Brazil
e-mail: parise@utfpr.edu.br

Abstract. *In all gas-solid fluidized bed processes, it is necessary to maintain the fluidization quality, in order to assure the temperature and moisture uniformity, the high rate of heat and mass transfer. For the paste drying process, for example, the injection of a paste in a fluidized bed can lead to local zones of poor mixing, and reduction in fluidization quality. Based on this fact, the purpose of the present work is to monitor the fluidization regime transitions during the course of the paste drying process using standard deviation and power spectrum analysis, which are based on pressure fluctuations measurements in the plenum. The experiments were conducted in the bench-scale fluidized bed unit constructed in Plexiglas of 0.11 m in inner diameter and 1.0 m in height, which was instrumented with a pressure transmitter connected to a data acquisition system in order to record the pressure fluctuations of the gas-solid flow. Aluminum beads with mean particle diameter of 1.55 mm were used as inert particles and the calcium carbonate suspension (concentration of 9%) was used as a liquid paste sprayed onto the bed. The results showed that the fluidization quality can be monitored by the standard deviation and power spectrum techniques.*

Keywords: *gas-solid fluidized bed, paste drying, pressure fluctuation measurements.*

1. INTRODUCTION

The chemical, food and pharmaceutical industries have used fluidization in several processes due to effective contact between solid and fluid phases resulting in high rates of heat and mass transfer. In gas-solid fluidized bed processes, it is crucial to maintain the stability of the fluidization state, in order to guarantee the stable variables in fluidized bed systems, such as, temperature, moisture content and particle size uniformity (Anderson and Jakson, 1968; Batchelor, 1998; Koch and Sangani, 1999; Didwania, 2001; Chirone et al., 2006; Silva et al., 2011; Zhong et al., 2012).

However, high temperatures, excessive moisture content of the particles and the introduction of liquid in the fluidized bed can often lead to instabilities in the fluid-dynamic regime and cause partial or total collapse of the bed, reducing the efficiency of the process (Maronga, 1998). Therefore, to identify the initial moments when the bed is tending to defluidization, it is possible to act in the process and to return the fluidization in the appropriate condition (Parise, 2007).

The several forms of processing of the pressure fluctuation signals collected in a fluidized bed can be used to analyze fluid dynamic regime transitions and detected unstable behaviors. This technique has been widely employed because the ability to provide important information of the bed dynamic, besides this it is not intrusive and economically viable (van der Schaaf et al., 2002). The pressure fluctuations signals are easy to obtain, requiring a pressure transducer connected to the measurement point in the fluid bed (Brown and Brue, 2001). According to Schouten and van den Bleek (1998), the signals can be evaluated by three methods: chaos analysis, which is done in the state space of the systems; spectral analysis, involving the frequency domain; statistical analysis using the time domain.

This paper addresses the use of some of the main techniques of monitoring and fluidizing regime control. Research on the hydrodynamic monitoring area of fluidized beds based on processing pressure fluctuation signals have received strong acceptance by the international scientific community due to its great potential application for the identification of agglomeration problems in coating processes and granulation solid fluidized bed (Talu et al., 2001; Chaplin et al., 2005; de Martín et al., 2011; Nunes et al., 2011).

Parise et. al (2008) developed a methodology to identify the defluidization region, which was based on spectral analysis. The technique adjusts the power spectrum obtained from pressure fluctuation measurements to an exponential function similar to the Gaussian normal distribution. In such study, it was observed that the central frequency parameter can be used to detect the defluidization condition in a gas-solid fluidized bed. Silva et. al (2011) applied the Gaussian spectral pressure distribution in order to detect the defluidization phenomenon in a fluidized bed coating process. The results showed that the defluidization of particles could be clearly identified in almost all experiments performed.

The aim of this present work is to monitor the fluidization regime transitions during the course of the fluid bed paste drying using standard deviation and power spectrum analysis of the pressure fluctuation signals. Aluminum beads of 1.55 mm in diameter were used as inert particle and the calcium carbonate suspension (concentration of 9%) was used as a pasty material sprayed onto the bed. It is worth to emphasize that this work is new in the literature, since there are not studies about the monitoring of the fluidization regime in fluid bed paste drying.

2. MATERIAL AND METHODS

The experiments were carried out in a Plexiglas fluidized bed dryer which consists of a vertical column of 0.11 m in inner diameter and 1.0 m in height. A photography of the experimental setup used in the present study is given in Fig. 1. Air flow from a 3kW blower was regulated by a frequency inverter (WEG®, CFW080160T2024POA1Z) and metered by an orifice plate of 0.028m in orifice diameter. Two differentials pressure transducers were used to measure the pressure drop across the orifice plate and the up-wind pressure of the gas (Cole Parmer®, 68071-14, range 0 to 6227 Pa and Cole Parmer®, 68073-14, range 0 to 12454 Pa, respectively). The experimental unit was equipped with a peristaltic pump (Vallair®, model SVP4H2B1SZAA) to feed continuously the dilute suspension (paste) to be dried into the bed of inert material by a double fluid nozzle atomizer (Spraying Systems®, SU11-SS). In order to atomize the suspension, it was used an air line composed by a compressor (Schulz®, model 821410, 2 HP) and a pressure regulator (Fluir®, model AW200002U).

The fluidization air was heated by electrical resistances and maintained at 70^{o}C during all experiments. The pressure fluctuations signals from the fluidized bed dryer were measured in a point localized at the plenum chamber using a differential pressure transducer (Cole Parmer®, 68071-14, range 0 to 6227 Pa). All pressure transducers were connected to a data acquisition system (NI USB 6211 - National Instruments™), and the pressure data were acquired and processed by the LabView 10.0 ™ software.

The dried powders were collected by a Swift cyclone which was connected by a pulse jet bag filter.

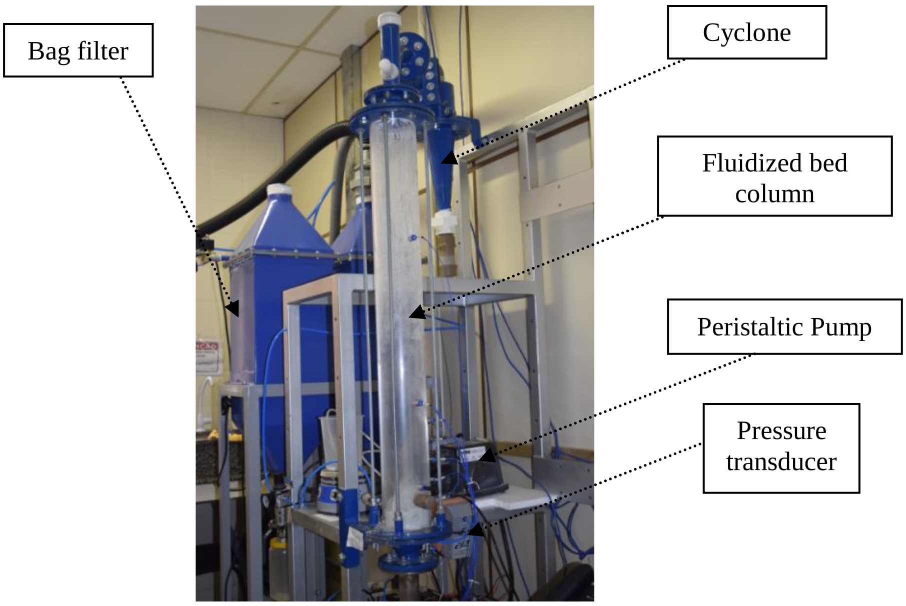


Figure 1. Photo of the experimental fluidized bed dryer

The inert material used was aluminum beads with apparent density of 2692,6 kg/m^3, mean particle diameters of 1.55 mm. The dilute suspension (paste) was composed by calcium carbonate ($CaCO_3$) and distillate water. The Table 1 summarizes all process parameters.

Table 1. Experimental parameters.

Experiment	$m_{aluminum\_beads}$ (kg)	u_o/u_{mf}	$C_{dilute\_suspension}$ * (%)	$Q_{dilute\ suspension}$ (mL/min)
1	1.60	1.4	9.0	12.0
2			9.0	15.0

*C (Concentration) = (mass of $CaCO_3$)/(volume of solution)

During the experiments, 2048 data points of pressure were acquired in the plenum chamber at a sampling rate of 400 Hz. These pressure signals were filtered by a digital filter (IRR- infinite impulse response- Butterworth type, order 20 and 20 Hz cutoff frequency) and distributed following a mean centring procedure. The Fast Fourier Transform algorithm (FFT) was applied on the mean centring pressure data and the power spectrum was obtained.

3. RESULTS AND DISCUSSION

3.1 Standard deviation of pressure fluctuation signals

Figure 2 (a) and (b) show the profile of standard deviation of pressure fluctuation signals in the plenum during the paste drying process using calcium carbonate suspension flow rate of 12.0 ml/min and 15.0 ml/min, respectively. In Fig. 2(a) and (b), the standard deviation of pressure fluctuation decreases along the drying time, which is related to a reduction of the amount of air bubbles. The content of liquid sprayed into the bed causes changes in motion of the particles, reflecting on irregular pressure fluctuation in the plenum, consequently, a reduction in values of standard deviation. From visual observation during the paste drying process, it was found that the movement of the inert particles decreased gradually, and in case of Fig. 2 (a), at around 800 s of experiment, the bed collapsed and absence of air bubbles was observed, which resulted in accentuated drop of the standard deviation. In Fig. 2 (b), the increase of suspension flow rate resulted in a fall of standard deviation values much more pronounced than in the case of Fig. 2 (a), due the reducing movement of the inert particles.

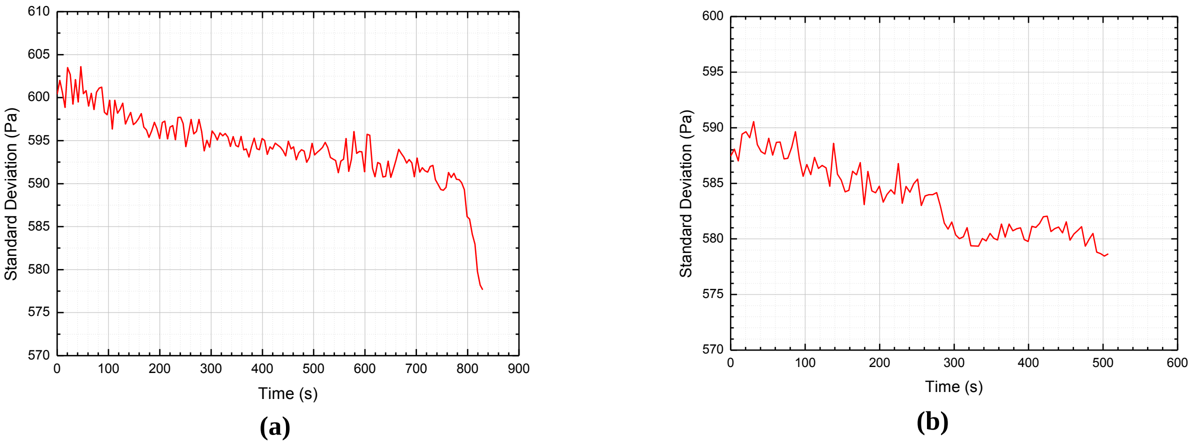


Figure 2. Standard deviation of pressure fluctuation signals during the paste drying process. Operational conditions: $m_{aluminium\_beads}$ = 1.6 kg, u_o/u_{mf} = 1.4, $T_{inlet-air}$ = 70^{o}C; $P_{atomization}$ = 0.1 MPa.
a) $Q_{CaCO3-suspension}$ = 12 mL/min; b) $Q_{CaCO3-suspension}$ = 15 mL/min.

3.2 Power spectrum analysis

Figure 3 and 4 illustrate the power spectrum obtained for stable regime (a), tending to instability (b), unstable (c) and (d, Fig. 3) for the operational conditions of experiment 1 and 2 (Table 1), respectively. Analyzing the evolution of spectrums, one can observe the stable fluidized bed regime is characterized by peaks of dominant frequency around 5.5 Hz. However, when the fluidization regime shows instabilities due to the content moisture excess in the bed, a gradual reduction in the peak of dominant frequency occurs, and simultaneously, the high frequency region (> 7.5 Hz) equates [Fig. 3 (c)] and then overlaps [Fig. 3 (d)] the frequency related to the stable bed. The appearance of multiple peaks with high amplitudes distributed in the region from 7.5 to 20 Hz is indicative of the fluid- dynamic instabilities. Similar results are related by Gómez-Hernández et al. (2014), when the evolution of the spectral frequency content, using sand particles with water sprayed into the fluidized bed.The lowering of the dominant frequency is related to reducing the bubbling, because the interaction between dilute phase (broth - gas) and the concentrated phase (cluster - particles) reduces with excess moisture from the bed. The emergence of peaks in the high frequency region is related to particle-particle interactions and the equipment (blower vibration), which now have greater importance next to fixed bed regime [Guo et al (2002);. Guo et al. (2003)]. The same behavior was observed in both Fig. 3 and 4.

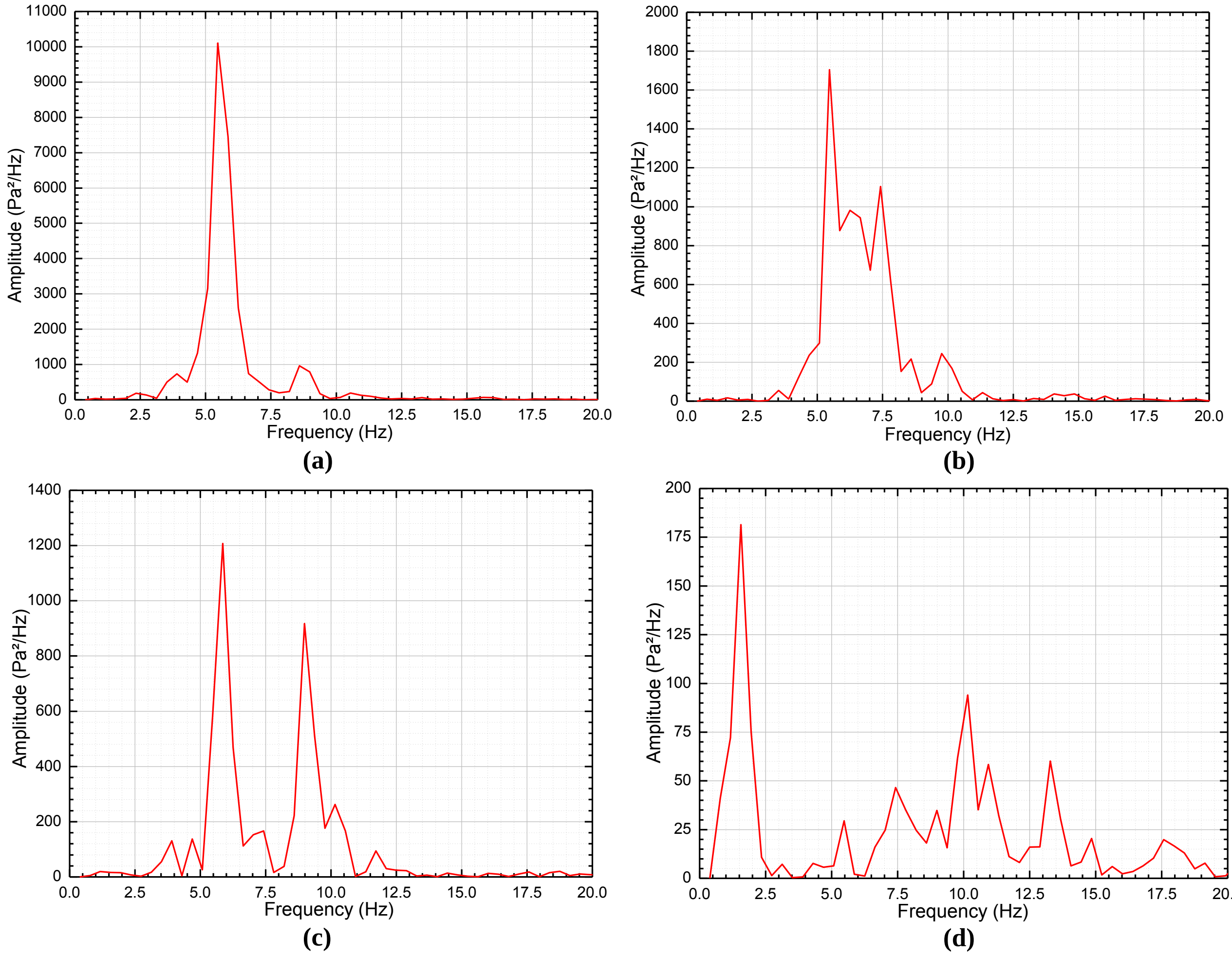
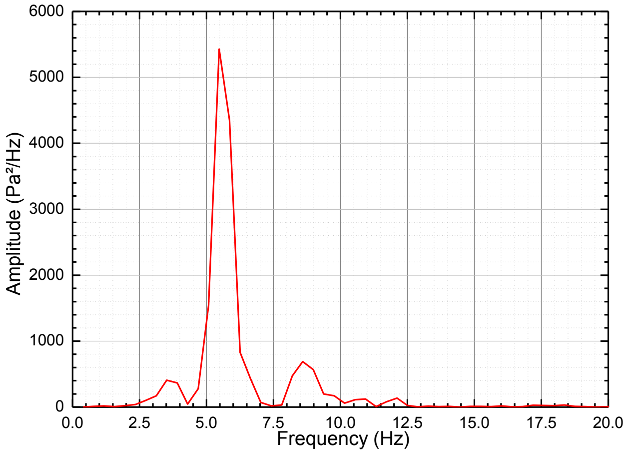
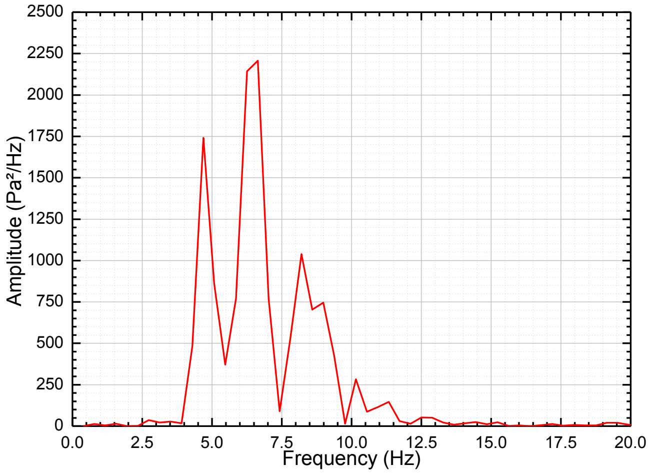


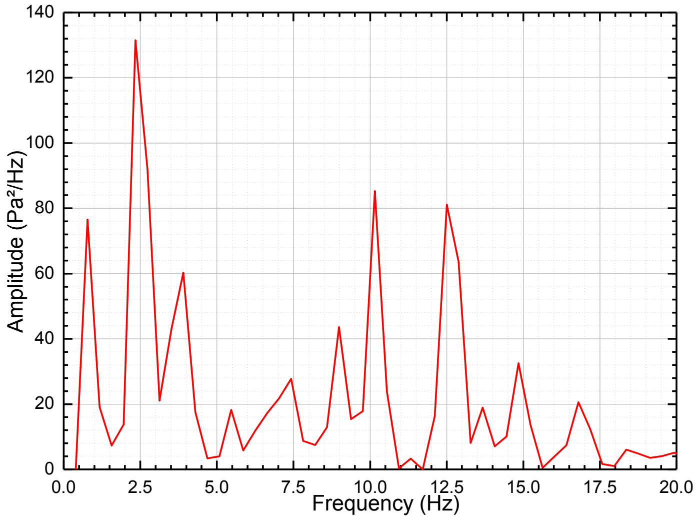
Figure 3. Power spectrum of pressure fluctuation. Operational conditions: $m_{aluminium\_beads}$ = 1.6 kg, u_o/u_{mf} = 1.4, $T_{inlet-air}$ = 70°C; $P_{atomization}$ = 0.1 MPa, $C_{dilute\_suspension}$ = 9% ; $Q_{dilute\_suspension}$ = 12 mL/min. a) without atomization; b) atomization time: 310 s; c) atomization time: 435 s; d) atomization time: 854 s



(a)



(b)



(c)

Figure 4. Power spectrum of pressure fluctuation. Operational conditions: $m_{aluminium\_beads}$ = 1.6 kg, u_o/u_{mf} = 1.4, $T_{inlet-air}$ = 70°C; $P_{atomization}$ = 0.1 MPa, $C_{dilute\_suspension}$ = 9.0 % ; $Q_{dilute\_suspension}$ = 15.0 mL/min. a) without atomization; b) atomization time: 368 s; c) atomization time: 512 s

4. CONCLUSIONS

The experimental study was carried out to monitor the fluidization regime transitions using standard deviation and power spectrum analysis during the fluidized bed paste drying. The results show that the standard deviation decreases along the time of drying due to the hydrodynamic instability related to the liquid accumulation on the bed. In the case of power spectrum analysis, for stable regime, the peak of dominant frequency is around 7.5 Hz, and peaks between 7.5 to 20 Hz indicate fluid dynamic instabilities. These techniques can be useful for indicating the initial moments of stability during fluidized bed paste drying.

5. ACKNOWLEDGEMENTS

The authors thank the National Council of Technological and Scientific Development (CNPq), Araucaria Foundation of Parana State and the Federal University of Technology (UTFPR) for the financial support given to this research.

6. REFERENCES

Anderson, T.B. and Jakson, R., 1968. "Fluid Mechanical Description of Fluidized Beds. Stability of State of Uniform Fluidization". *Industrial & Engineering Chemistry Fundamentals*, Vol. 07, p. 12-21.

Batchelor, G.K., 1998. "A New Theory of the Instability of a Uniform Fluidized Bed". *Journal of Fluid Mechanics*, Vol. 193, p. 75-110.

Brown, R. and Brue, E. 2001. "Resolving dynamical features of fluidized beds from pressure fluctuations", *Powder Technology*, Vol. 119, p.117-127.

Chaplin, G., Pugsley, T. and Winters, C., 2005. Monitoring the Fluidized Bed Granulation Process Based on S-Statistic Analysis of a Pressure Time Series. *AAPS PharmSciTech*, Vol. 6, p. 198-201.

Chirone, R., Miccio, F. and Scala, F., 2006. "Mechanism and prediction of bed agglomeration during fluidized bed combustion of a biomass fuel: effect of the reactor scale". *Chemical Engineering Journal*. Vol. 123, p.71-80.

de Martín, L. van den Dries, K. and van Ommen, J.R., 2011. "Comparison of Three Different Methodologies of Pressure Signal Processing to Monitor Fluidized-Bed Dryers/Granulators". *Chemical Engineering Journal*, Vol. 172, p. 487-499.

Didwania, A.K., 2001. "A New Instability Mode in Fluidized Beds". *Europhysics Letters*, Vol. 53, p. 478-482.

Guo, Q., Yue, G. and Werther, J., 2002. "Dynamics of Pressure Fluctuation in a Bubbling Fluidized Bed at High Temperature". Industrial & Engineering Chemistry Research, Vol. 41, p. 3482-3488.

Guo, Q., Yue, G., Sudac, T. and Satoc, J., 2003. "Flow characteristics in a bubbling fluidized bed at elevated temperature". Chemical Engineering and Processing, Vol. 42, p. 439-447.

Gómez-Hernández, J., Sánchez-Prieto, J., Briongos, J.V. and Santana, D., 2014. "Wide band energy analysis of fluidized bed pressure fluctuation signals using a frequency division method". Chemical Engineering Science. Vol. 105, p. 92-103.

Koch, D.L. and Sangani, A.S., 1999. "Particle pressure and marginal stability limits for a homogeneous monodisperse gas-fluidized bed". *Journal of Fluid Mechanics*, Vol. 400, p. 229-263.

Maronga, S. 1998. *On the Optimization of the Fluidized Bed Particulate Coating Process*. Ph.D. thesis, Royal Institute Of Technology, Stockholm.

Nunes, J.F., Silva, C.A.M., Moris, V.A.S., Rocha, S.C.S. and Taranto, O.P. 2011. "Spectral Analysis of Pressure Drop Fluctuation in Vibrofluidized Bed Coating", *Chemical Engineering Transactions*, Vol. 24, p. 649-654.

Parise, M. R. 2007. *Application of the normal spectral distribution in a gas-solid fluidized bed*. Ph.D. thesis, University of Campinas, Campinas, Brazil. In portuguese.

Parise, M.R., Taranto, O.P., Kurka, P.R.G. and Benetti, L.B. 2008. "Detection of the minimum gas velocity region using Gaussian spectral pressure distribution in a gas–solid fluidized bed". *Powder Technology*, Vol. 182, p. 453-458.

Schouten, J.C. and van den Bleek, C.M. 1998. "Monitoring the quality of fluidization using the short-term predictability of pressure fluctuations". *AIChE Journal*, Vol. 44, p. 48-60.

Silva, C. A. M., Parise, M. R., Silva, F. V. and Taranto, O. P., 2011. "Control of fluidized bed coating particles using Gaussian spectral pressure distribution". *Powder Technology*, Vol. 212, p. 445-458.

Talu, I., Tardos, G.I. and van Ommen, J.R. 2001. "Use of Stress Fluctuations to Monitor Wet Granulation of Powders". *Powder Technology*, Vol. 117, p. 149-162.

van der Schaaf, J., Schouten, J.C., Johnsson, F. and van den Bleek, C.M., 2002. "Nonintrusive determination of bubble and slug length scales in fluidized beds by decomposition of power spectral density of pressure time series". *International Journal of Multiphase Flow*, Vol. 28, p. 865-880.

Zhong, Y., Wang., Guo, Z. and Tang, Q., 2012. "Defluidization behavior of iron powders at elevated temperature: Influence of fluidizing gas and particle adhesion". *Powder Technology*, Vol. 230, p. 225-231.

7. RESPONSIBILITY NOTICE

The authors: Flavia Tramontin Silveira Schaffka, Carlos Alexandre Moreira da Silva, Frederic Conrad Janzen and Maria Regina Parise are the only responsible for the printed material included in this paper.