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The Gaussian spectral pressure distribution applied to a fluidized bed

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ABSTRACT

The present work applies the methodology proposed by Parise et al. [M.R. Parise, O.P. Taranto, P.R.G. Kurka, L.B. Benetti, detection of the minimum gas velocity region using Gaussian spectral pressure distribution in a gas–solid fluidized bed, Powder Technol. 182 (2008) 453–458], as an alternative to the spectral analysis of pressure fluctuation measurements to find the region where the minimum velocity gas takes place in a gas–solid fluidized bed, that is, the zone where the bed is tending to defluidization. The technique is applied to analyze the effect of fixed bed height and particle density in defluidization conditions for particles of microcrystalline cellulose and sand. Tests are carried out for three fixed bed heights (0.15, 0.20 and 0.25 m) and two particle densities (980 and 2650 kg/m^3). Experiments show that the best conditions for identifying the defluidization zone are obtained with lower bed aspect ratios (H/D) and lower particle density. The results indicate the high potential of the proposed method for industrial applications, especially for on-line control of gas–solid fluidized bed processes where the defluidization phenomenon needs to be detected and avoided.

1. Introduction

Fluidization is an important technology employed in industrial processes, such as coal and biomass combustion, drying of solids, particles coating, material processing and biotechnology [1].

An adequate mixture of gas and particles is essential in fluidized bed processes. In practical terms, however, the mixing of particles may become inefficient during operation. The process of drying of solids or particles coating, for example, may suffer the undesired effect of agglomeration of particles due to the presence of moisture, subsequently followed by defluidization of the bed, which may cause critical situation leading to an inevitable process shut down.

The superficial gas velocity is responsible for the formation and maintenance of the fluidized bed condition. If the velocity is not kept to a sufficiently high value, the defluidization of the bed may occur affecting the process. Such a phenomenon may happen so abruptly, that its detection by simple visualization is just not possible.

A more appropriate way to perform the identification of the minimum gas flow to avoid the defluidization is through the analysis of pressure fluctuations, which are usually originated by the formation, rise and eruption of bubbles, gas turbulence, bed mass oscillation and bubble coalescence [2,3].

Pressure fluctuations have been used to describe the fluidized beds characteristics, such as the quality of fluidization [3], bubble frequency [4], transition from bubbling to turbulent fluidization [5], differentiation of states of typical fluidization [6], the minimum fluidization gas velocity [7–10], and the minimum fluidization gas velocity region [11]. Normally, time series data originated from pressure fluctuations are treated by statistical analysis, by spectral analysis, and by chaos analysis [3].

Parise et al. [11] developed a methodology to identify the region where the bed is tending to defluidization, in order to be applied in gas–solid fluidized bed processes. This technique is based on Fourier transform and Gaussian distribution, using pressure fluctuation measurements.

The objective of this work is to verify the influence of the fixed bed height and the solid density on the methodology proposed by Parise et al. [11], specifically for microcrystalline cellulose and sand particles.

2. Normal spectral distribution in the fluidization process

The stages of fluidization carry different dynamic characteristics that can be observed in the spectral distribution of the plenum pressure. The dynamics of a fixed bed tends to be that of a bulk or "heavy" body, displaying lower frequencies in the pressure spectral range. The transition bed has a combination of the dynamics of bulk and light bodies, displaying a few frequencies that are higher in the spectral range, together with the characteristic low frequencies of the fixed bed behavior.

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The pressure spectrum in a fluidization process, except at the slugging regime, does not present predominant frequencies. Spectral amplitudes obtained in a fluidized behavior are randomly spread out through most frequencies, suggesting that the dynamic analysis of the pressure signal must take into account the statistical distribution of its spectrum. In the fluidized bed condition, the dynamics of light bodies is predominant, inducing faster oscillations of the pressure and a higher range of spectral frequencies. The statistical distribution of the spectral lines is a better indicator of the fluidization state of the process. A Gaussian curve fitted to the pressure amplitude spectrum illustrates the stage of the fluidization process. Low mean frequency values of the normal distribution indicate fixed bed behavior and higher mean frequency values indicate a fluidized bed.

The normal distribution curve has the following expression:

$$G(f_k) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(f_k - f_m)^2/2\sigma^2} \tag{1}$$

where f_m is the mean frequency value, σ is the standard deviation of the spectral distribution and $k = 0, 1, \ldots, M-1$.

Amplitudes of the frequency spectrum are the data for fitting the Gaussian curve. The range of frequencies used in the Gaussian curve fit may be limited to the low-pass filter cut off frequency. The cost function θ is minimized through a mean square procedure shown below

$$\theta = \sum_{k=0}^{M-1} \left(A(f_k) - \frac{1}{\sigma\sqrt{2\pi}} e^{-(f_k - f_m)^2/2\sigma^2} \right)^2 \tag{2}$$

where $A(f)$ is the measured amplitude of the pressure spectrum.

3. Materials and methods

The experimental set-up used in this work is shown in Fig. 1. The Plexiglas column is 0.143 m in inner diameter and 0.71 m in height. The gas distributor is made of a 1.62-mm thick stainless steel perforated plate with 1 mm holes on a triangular pitch. The size of the pitch of holes in the distributor is 8.5 mm. A fine screen is installed above the distributor to avoid particles from falling into the plenum. The rotation of a 3-kW air blower is regulated by a frequency inverter (Danfoss VLT, 2800). The air flow rate is obtained through an orifice plate. A pressure transmitter (Cole Parmer, 07356-01, range: 0–210.8 kPa) and a differential pressure transmitter (Smar, LD301, range: 0.125–5 kPa) are used in order to measure the up-wind pressure of the orifice plate and the pressure drop across the bed, respectively. The bed pressure is measured in the plenum employing a differential pressure transmitter (Cole Parmer, 68014-18, range: 0–6.2 kPa, response time of 250 ms).

The pressure data is acquired through a PCI 6024 E data-acquisition system (National Instrument). LabView 7.1 software is used for all data acquisition and signal processing.

The pressure in the plenum, the up-wind pressure of the orifice plate and the pressure drop across the bed are sampled at a frequency of 400 Hz, with 8192 data points. The data acquisition rate of 400 Hz is chosen in accordance to other previous works that study fluidized bed [12]. The number of 8192 data points yields a frequency resolution of 0.048 Hz, which is convenient for analysis in the low-frequency range of the spectrum.

The relevant pressure amplitudes observed in fluidized bed applications occur in the approximate range 0–10 Hz [12]. A practical range 0–20 Hz is hence adopted in the present paper for the frequency analysis. The low-pass filter cut-off frequency is set accordingly to 20 Hz.

Two types of the solid particles are tested: microcrystalline cellulose (MCC) and sand. The properties of such particles are given in

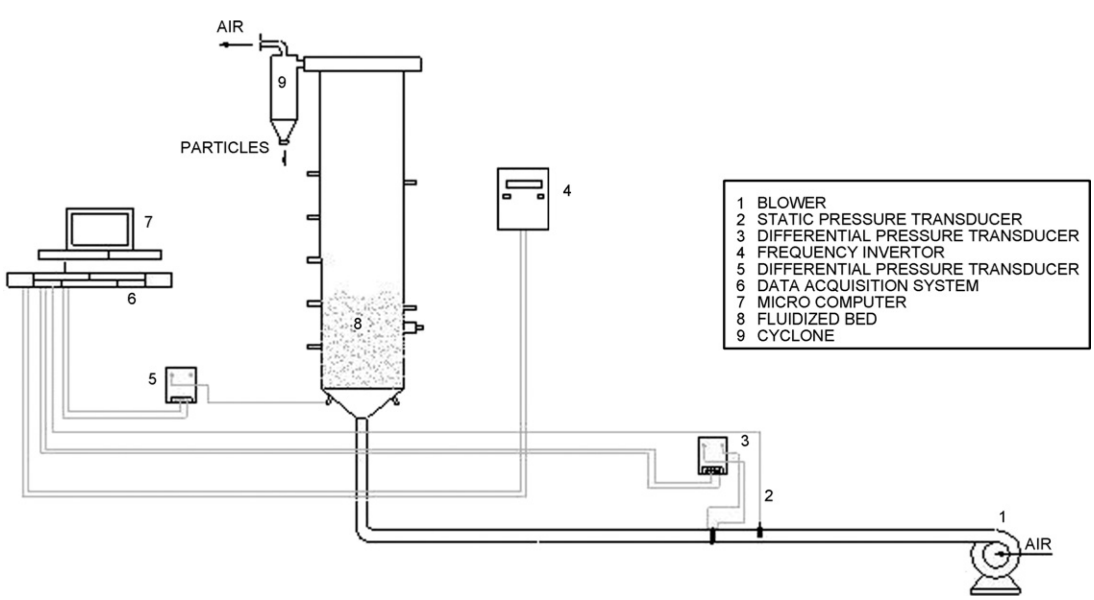

Fig. 1. Experimental set-up.

Table 1
Characteristics of solid materials

Solid particles	d_p (μm)	H (m)	ρ_s (kg/m^3)	u_{mf} (m/s)
Microcrystalline cellulose	325 (300–350)	0.15, 0.20 and 0.25	980	0.06
Sand	325 (300–350)	0.15, 0.20 and 0.25	2650	0.12