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Online monitoring of mean particle size inside a semi continuous fluidized bed by means of pressure fluctuation analysis

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***Abstract*—Biomass gasification inside semi continuous fluidized beds has recently attracted considerable attention as a promising technology for clean energy production. However, some drawbacks associated with the lacks of available monitoring techniques are still being reported.**

In this paper, we have demonstrated that the use of pressure fluctuation analysis can accurately be used to monitor the change in particle's mean diameter in a cold model semi continuous fluidized bed reactor.

The investigation was performed in a 90mm ID stainless steel column with several sizes of Geldart B glass beads material. First, a new correlation was established linking the mean amplitude to the excess velocity, the bed height, the probe position as well as the mean particle size. In a second part, we have compared between the mean size predicted from our correlation and the mean size obtained from sieve analysis.

Results have shown, for three different sets of experiments, that our model was able to accurately estimate the evolution of the mean particle diameter within an uncertainty of less than 4µm.

Keywords— Fluidized bed, Pressure fluctuations, standard deviation, biomass gasification, online monitoring.

I. Introduction

Fossil fuels are still the most common energy source used all around the planet. It has been reported that over 80% of the global energy consumption counts on petroleum based energy. However, the crucial environmental problems such as high rates of CO_2 emissions into the atmosphere remind us the need to find alternative fuel resources that are renewable, sustainable and eco-friendly **[1]**.

Currently, biomass is the fourth largest source of energy after coal, petroleum and natural gas; it covers approximately 14% of the world's energy demand. Unlike most other renewable sources, biomass can be stored and used on demand to give controllable energy; it is therefore free from the problem of intermittency encountered in wind power in particular **[1]**.

One of the promising technologies of extracting energy from biomass is through its gasification inside fluidized bed reactors which provide an effective mean of gas–solid contact since they promote good mixing and high rates of mass and heat transfers **[2]**.

Fluidized beds gasifiers involve operation during which the mean particle size of the bed materials is subject of a progressive change. As a consequence, finding a tool to estimate this mean particle size at any moment of the operation of fluidization is of utmost importance for the optimal operating of the process **[3]**.

In order to overcome that problem, many researchers have suggested the use of pressure fluctuation signals as a tool for the continuous monitoring of fluidized beds, considering the fact that pressure fluctuation is strongly related to the bed dynamics. The common problem with pressure fluctuation data is that most of the relevant information is hidden in complex unsteady time series, therefore, the use of statistical tools is inevitable **[4]**.

The time series data generated by a transducer can be analyzed in two different kinds of techniques. The first by utilizing Fourier transforms and shifting the signal into the frequency domain, this method is called "frequency domain analysis", while the second is called "the time domain analysis", and is more straightforward.

The standard deviation is a time domain technique, it measures the degree to which the data spreads around an average value. For a temporal signal, the standard deviation reflects the mean amplitude or the width of the signal itself.

For a signal composed of N values, standard deviation is defined as:

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{1}^{N}(x_i-\bar{x})^2}$$

On account to its strong dependence on the particle mean size, the bed height, the measurement position as well as the gas velocity, the standard deviation is ideally suited to online monitor the hydrodynamics of fluidized beds **[4, 5]**.

Few models linking the standard deviation to the working conditions can be found in the literature such as Davies's model that considers only the effect of gas velocity and the sobrino's model which takes into account more parameters and was used to predict the fluidization velocity.

Regarding the restricted applicability domain of the few models found in the literature describing the behavior of the mean amplitude [6, 7], we have proposed a new empirical model based on several experiments. Our model takes into account the effect of gas velocity, bed height, probe position and particle properties. Our model was successfully used in the monitoring of the mean particle size inside a semi continuous fluidized bed reactor.

II. Experimentals

a. Experimental set up

The main component of the system is a stainless steel cylindrical column with a height of **0.75m** and an internal diameter of **90mm**. The air distributor is a perforated plate of 1mm thickness; it is composed of **79** holes with 1mm diameter, a total free area of **1.0%** and a triangular distribution.

Four piezoelectric pressure sensors from Ashcroft, with a **4-20** output mA corresponding to **±2.5KPa** and **0.4%** accuracy, were used to measure the pressure fluctuations at the different positions.

The data acquisition system was composed of a SC-2345 board with **16 bits** of resolution (National Instruments®) and a computer containing the VIRTUEL-BENCH acquisition software.

b. Experimental procedures

Three sets of experiments were conducted in the **90mm** ID fluidized bed, which was initially loaded with **700g** of glass beads belonging to one specific class. After each **5min**, a small amount of **50g** of a different class of glass beads was poured at a constant flow rate. The solid flow rate was controlled using a control orifice.

The adding of the second class induces a change in the mean particle size of the bed material. The new mean diameter can be calculated at each step since the mass of each class as well as their mean sizes are well known.

The pressure signal was recorded during all the experiment that lasts for **20min**. The sampling frequency was set at **100Hz [4]** and the standard deviation at any time was calculated using the previous **12000** data points (equivalent to **2min** sampling time).

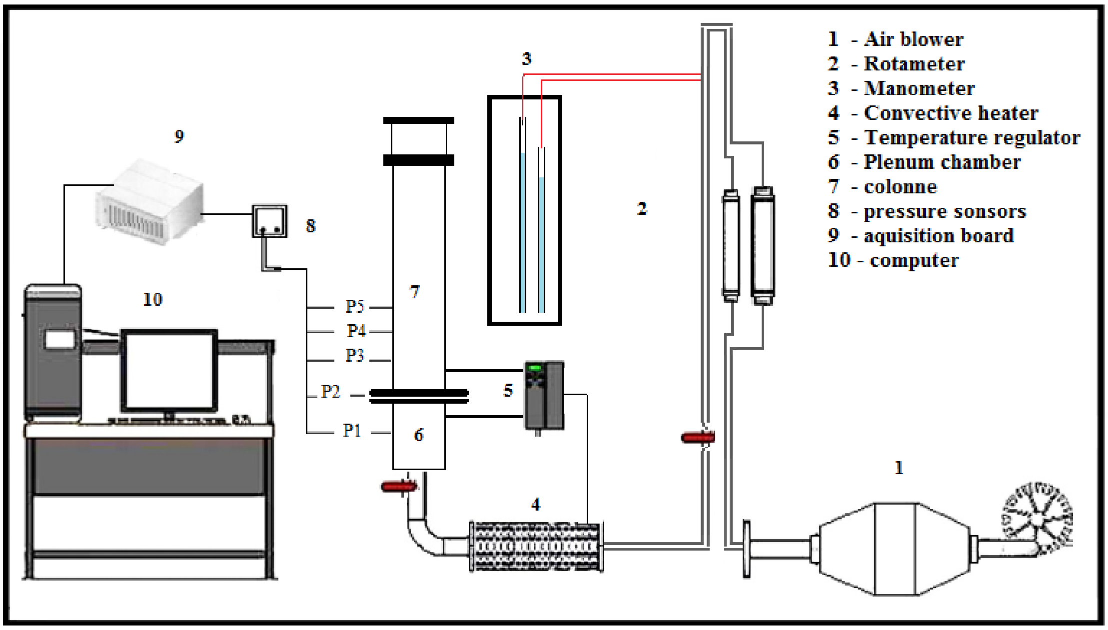

Fig. 1 Experimental set up.

III. Results and discussions

a. Modeling the mean amplitude of the pressure time signal

As displayed in **figures 2** and **3**, we have found that the mean amplitude of the pressure signal, for the different mean diameters, is linear to excess gas velocity up to a velocity of **2.5U$_{mf}$**, the same found in the literature **[4, 8]**.

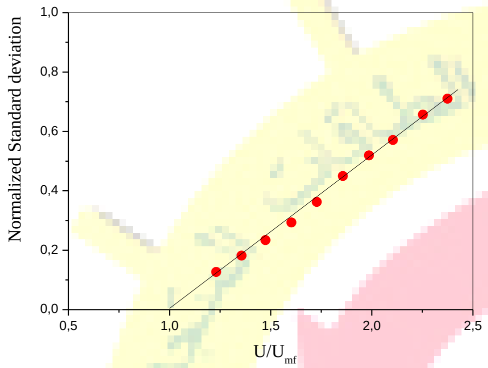

Fig. 2 The evolution of mean amplitude against gas velocity.

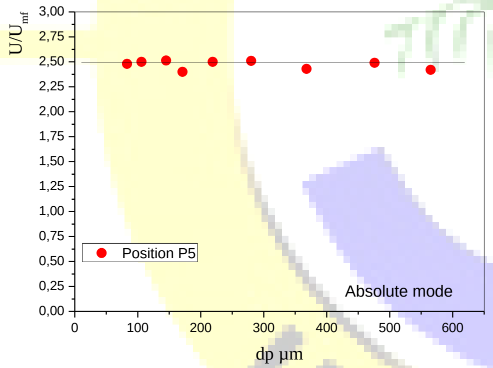

Fig. 3 The linearity interval for the different glass beads classes

We have also studied the evolution of mean amplitude against bed height and found that they are proportional within all the interval of the study going up to a height equal to three times the reactor diameter, see **figure 4-a.**

Our result matches that of Bi et al., displayed in **figure 4-b**, who found that the standard deviation increases linearly with bed height until the latter reaches four times the bed diameter, afterward it becomes constant **[9]**.

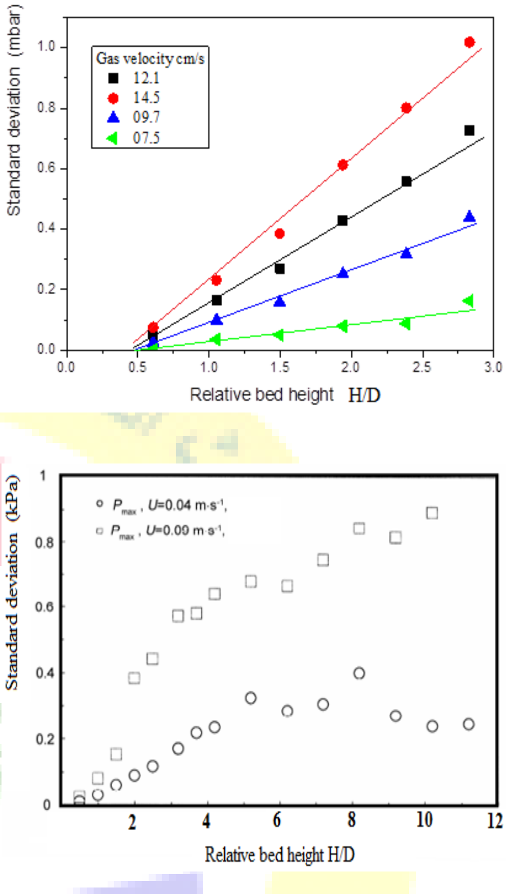

Fig. 4 Evolution of mean amplitude against relative bed height at different velocities. a) Experiment using GB280 and z/H = 0.75, b) literature, Bi and Chen [9].

As shown in **figure 5**, for the three measurement positions, the standard deviation is found to be strongly dependent on the mean particle size. We have found that, at constant velocity and bed height, the mean amplitude is proportional to $d_p^{0.6}$. It was close to Sobrino's result who found the standard deviation proportional to $d_p^{0.5}$ **[7]**.

We have proposed an empirical model, based on several experiments, in which the mean amplitude is expressed as follows:

$$\sigma = K\left(U - U_{mf}\right) H\, d_p^{0.6}.$$

Where K is a system constant that may depend on the geometry of the bed, the bed diameter and some other particle properties.

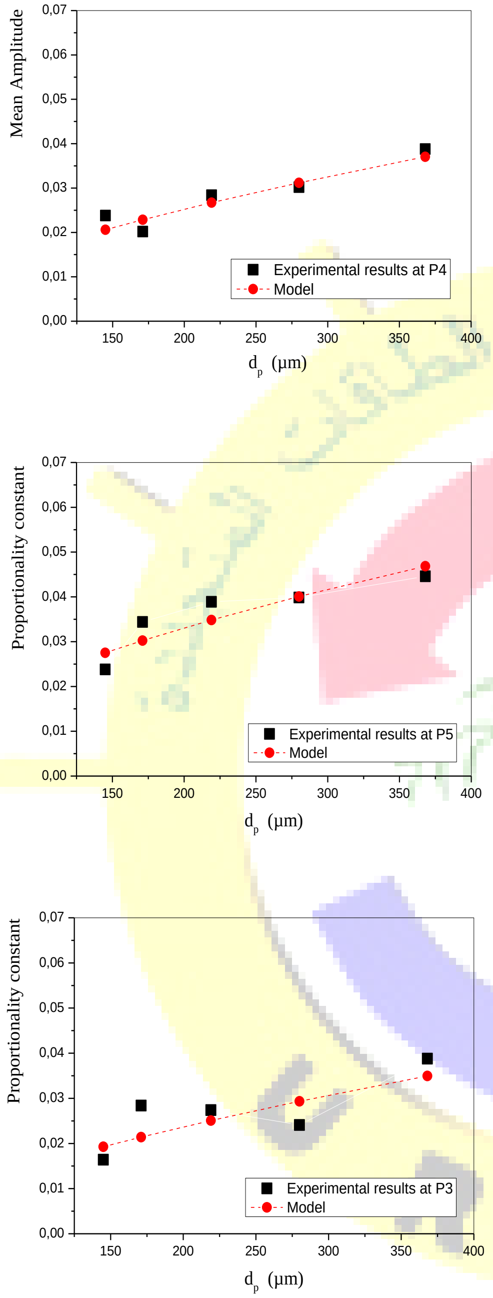

Fig. 5 Evolution of the proportionality constant against particle diameter for different measurement positions, m=1Kg.

b. Continuous estimation of the mean particle size

Following the experimental procedure explained in the previous section, we have conducted three experiments; in each one, the standard deviation being continuously calculated, we were able to estimate the mean particle size using the correlation of Sobrino et al. [7] as well as the correlation that we have proposed.

The accuracy of the estimations was analyzed by comparing them to the calculated mean diameter.

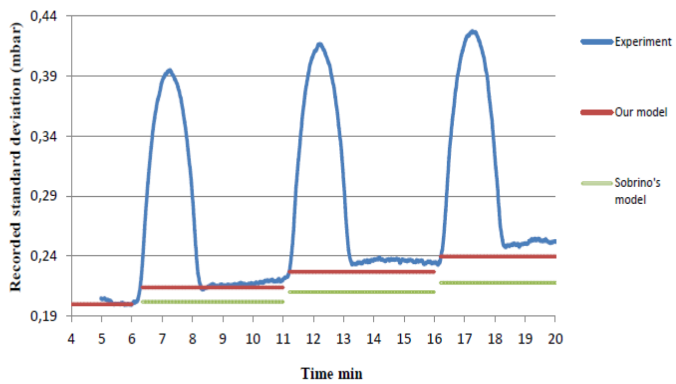

Fig. 6 Evolution of the measured and predicted standard deviations during the experiment 1 (GB225 with GB450).

Figure 6 displays the measured mean amplitude compared to that estimated from our correlation and from the correlation of Sobrino.

We can notice that at each moment when the solid is poured, the standard deviation increases and then decreases as a Gaussian pick. This pick shows up because we were operating at a semi continuous process.

As the solid is poured into the reactor, the height of the bed increases, which causes the static pressure to increase.

The calculated standard deviation will be obviously affected by this change because it uses a wide range of data (**12000** points).

The deviation of Sobrino's results is mainly due to the evolution of bed height. This correlation fails to predict the evolution of standard deviation against the height of the bed. On another hand, the results of our correlation seem to be much closer to the experimental results.

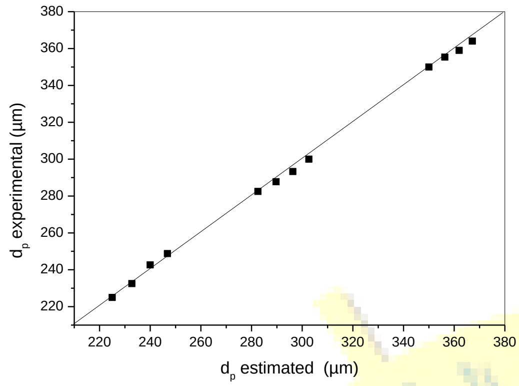

Fig. 7 Comparison between the experimental and predicted mean diameters.

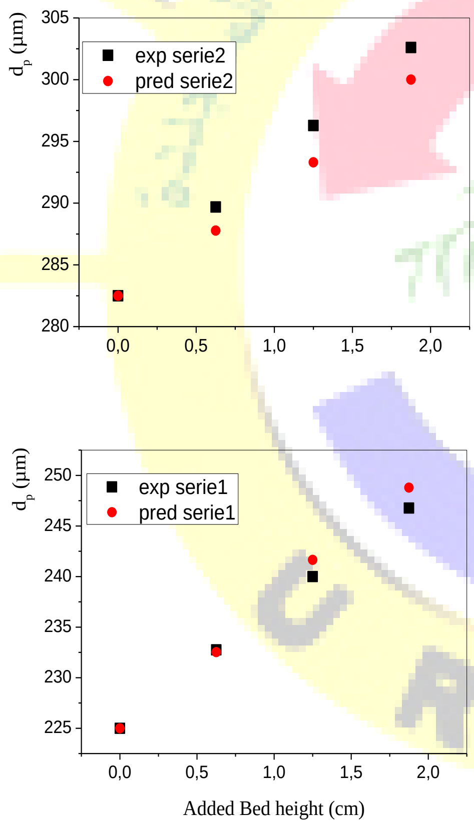

Fig. 8 Comparison between the experimental and predicted mean diameters as the bed high increases.

The mean particle diameter was estimated from our correlation and then the results were compared to those obtained by sieve analysis. The comparison, for the three experiments, is displayed in **Figure 7.**

We can notice that even they were close to the experimental values; the estimations have shown an increasing deviation as the bed height increases. **Figure 8** shows the evolution of the error with the bed height.

This error must be induced by the hypothesis that the standard deviation remains constant whatever the relative probe height is. We have predicted that this assumption may introduce some uncertainty in the estimations.

IV. Conclusion

In this work, pressure fluctuation data recorded during experiments carried out in a laboratory scale fluidized bed under diverse condition, were analyzed in time domain and domain. It has led to several remarks and conclusions:

We have proposed an empirical correlation that takes into account the effect of gas velocity, bed height, probe position and particle properties:

$$\boldsymbol{\sigma = K\left(U - U_{mf}\right) H\, d_p^{0.6}}$$

This model can be applied for velocities lower than **2.5U$_{mf}$,** and bed heights lower than **H** < **4D**. It has also been built upon the assumption that the mean amplitude is insensitive to the probe position, which can be tolerated for relative probe positions **z/H** ranging from **0.5 up to 0.8**.

We have used that correlation to predict a controlled change of mean particle size inside a semi continuous fluidized bed; we have found that our model was able to estimate the mean diameter with an error less than **4µm**.

Therefore, the most important conclusion this experimental investigation has lead to is that standard deviation measurement can be harnessed to monitor the change in mean diameter inside semi continuous bubbling fluidized bed reactors.

This technology has a big potential to be used in biomass gasification fluidized beds in order to overcome the control problems and further increase their efficiency.

REFERENCES

[1] Z. Alauddin, P. Lahijani, M. Mohammadi, A. Mohamed, Renwable and Sustainable Energy Reviews, **2010**, 14, 2852-2862.

[2] A. Gomez-barea, B. Leckner, Process in Energy and Combustion Sci., **2010**, 36, 444-509

[3] C.E. Davies, F.K. Fenton, IPENZ Transactions, **1997,** Vol. 24, No. 1 EMCh.

[4] H.T. Bi, Chemical Engineering Science, **2007,** 62, 3473 – 3493.

[5] J. R. van Ommen, S. Sasic, J. Van Der Schaaf, S. Gheorghiu, F. Johnsson, M. Coppens, Intern. J. of Multiphase Flow, **2011**, 37, 403–428.

[6] C. Davies, A. Carroll, R. Flemmer, Powder Technology, **2008**, 80, 307–311.

[7] C. Sobrino, S. Sánchez-Delgado, N. García-Hernando, M. de Vega, Chem. Eng. research and design, **2008,** 86, 11236–1242.

[8] C.A.S. Felipe, S.C.S. Rocha, Powder Technology, **2007,** 174, 104–113.

[9] H. Bi, A. Chen, CHINA Particulogy, **2003,** Vol. 1, No. 4, 139-144.