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INFLUENCE OF PULSE FREQUENCY ON THE MINIMUM FLUIDIZATION VELOCITY IN A PULSATING BED

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ABSTRACT

A pulsating fluidized bed of zeolite and rice husk was studied; were experimentally determined the minimum fluidization velocities and the influence of pulsating conditions, in the gas dynamic characteristics of the fluidized bed. The experimental study included three different beds of zeolite and one of rice husk, varying the pulse frequency in a range from 0 to 140 pulses per minute, in each bed. Is proposes a factorial experiment of two factors, diameter and pulse rate, taking six levels for frequency and three for the diameter. It was determined the equation to predict the minimum fluidization velocity for pulsating fluidized bed. The empirical equation obtained for the zeolites beds, was applied to the rice husk bed, with good results for prediction of the minimum fluidization velocity.

Keywords: Fluidized Bed; minimum fluidization velocity; pulsating bed; segregation; hydrodynamic.

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1 INTRODUCTION

A granular material is a conglomeration of polydisperse particles in a continuum phase of liquid or gas. Granular materials are all around us, both in nature and industry, including food products such as rice and corn; materials such as sand, gravel, and soil; and chemicals such as coal, plastics, and pharmaceuticals. Because these kinds of materials are widely found in many industries, the transport, mixing, and segregation of these type of materials are important. In the chemical industry, many products are in granular rather than liquid form. This kind of material consists of two different phases and therefore cannot be classified as solid, liquid, or gas. The interactions between particles plays an important role in granular flow mechanics, and this fact distinguishes granular flow from other fluid-solid flows. Collisions between particles or between particles and the boundaries of the system cause a dissipation of a significant fraction of the energy and a momentum transfer in granular flows (Markowich and Toscanil, 2007).

Fluidized beds become more used for different industrial process, like biomass combustion and gasification, to drying and catalytic processes, mainly due to the high mobility of the bed resulting in an increase of the particles area of effective exchange [1, 2, and 3].

However, the use of traditional fluidized bed reactors, with a constant flow of the gasification agent, is often impossible due to fluid-dynamics characteristics of the particles of biomass used as feedstock (rice husk, straw, sugarcane bagasse and wheat). The elongated shape of this kind of particles, cause its orientation in the gas flow direction, forming channels and agglomerations, that impede the formation of an organized fluidized bed [3 ,13 ,15, and 16].

Using a pulsed fluidized bed to organize the particles bed, prevents the formation of channels and decreases the output particle carryover, resulting unnecessary the use of inert material in the reactor bed. The costs associated with fluidization of the inert material are also diminished and the erosion, originated by the constant rubbing reactor with the inert material, is eliminated [4, 7, 8, 9 and 10].

However, one of the most important current issues to achieve the use of pulsed fluidized bed reactors is the lack of experience and knowledge in the hydrodynamic of the mixture formed by fluidization agent and the bed material in these type of reactors. There are not predictive equations of minimum fluidization velocities as function of the pulse frequency, neither to characterize the influence of the pulse rate on the organization of the biomass bed [11, 12, 13 and 11].

2 THE MINIMUM FLUIDIZATION VELOCITY

The minimum fluidization velocity at which a bed of particles fluidizes is one crucial parameter needed for the design of a fluidization apparatus and its prediction is one of the fundamental objectives of numerous researchers.

The expressions of Ergun (Equation 1) and TODEC (Equation 2) are the most commonly used to determine the minimum fluidization velocity of conventional fluidized beds, without pulsation; however there are not report in the scientific literature about its implementation and effectiveness in to predict the minimum fluidization velocity in pulsed beds.

$$R_e = \left[\left(42.857 \frac{C_2}{C_1} \right)^2 + \left(\frac{A_r}{1.75 C_1} \right) \right]^{\frac{1}{2}} - 42.857 \frac{C_2}{C_2} \tag{1}$$

and

$$R_e = \frac{A_r}{1400 + 5.22\sqrt{A_r}} \tag{2}$$

Reyes, A. et. al. [12], reports differences up to 25%, between the experimental values reported and the calculated by the Ergun and Todes formulas, for the case of pulsating fluidized beds, as shown in Figure 1.

Corrections to the Ergun and Todes formulas were performed to fit the case of pulsating fluidized beds. The results of the corrected equation were compared to the experimental results, showing a maximum error of 15.2% in the case of TODEC and 17.9% for the case of Ergun [4], which is a better approximation to the real values but significantly higher to apply in the equipment designs.

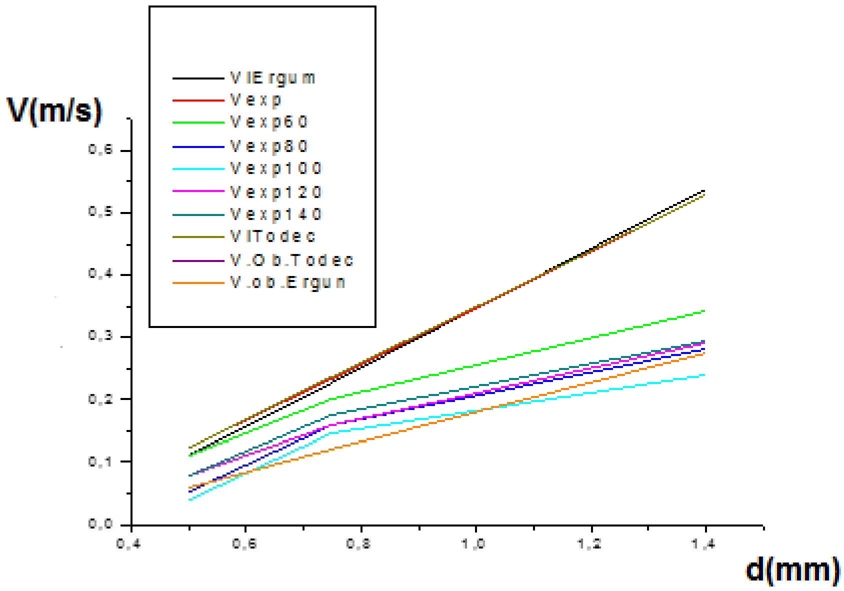

Figure 1: Minimum fluidization velocity as a function of the average diameter of the solid particles.
(diameter in mm and speed in m/s)

3 EXPERIMENTAL PROCEDURE

With the aim of study the effects produced by the pulsations on minimum fluidization velocity in a pulsed bed, 3 samples of zeolite were prepared with diameters of 0.41, 0.75 and 2.0 mm respectively, and a sample of rice husks, as a control sample of the results obtained for the zeolite. The zeolite is a material with easily fluidization, allowing the use to run fluidization experiment without pulsation.

Multi-level factorial design was used, with two factors: frequency and average particle diameter of each zeolite fractions used. Were analyzed three levels of the average diameter and six levels for the pulse frequency of air applied to the reactor. All experiments were carried out at 20 ºC of temperature. The factorial design was performed using the Stat graphics and were performed 18 experimental runs. Figure 2 shown the experimental installation used in the study.

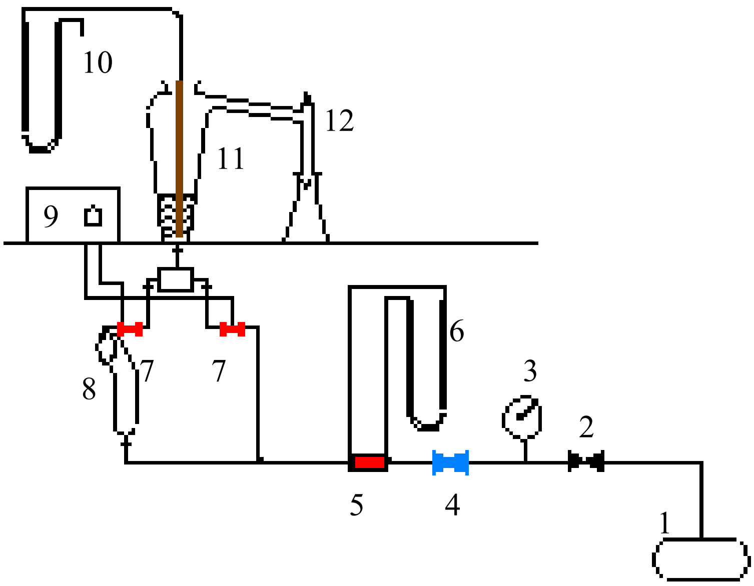

Figure 2: Experimental installation

Where:

1. Compressor
2. Pressure regulator
3. Gauge
4. Flow control valve
5. Gas flow measurement
6. Differential manometer
7. Air Heater
8. Electric valves
9. Frequency Pulse Generator
10. Differential manometer to measure pressure drop across the bed
11. Reactor
12. Cyclone for collect particles

4 RESULTS

Experimental runs for the determination of the minimum fluidization velocity was performed for both, increasing and decreasing values of the velocity of the fluidization gas in the reactor and its influence on the pressure drop in the bed, for each model of factorial combinations.

Table 1 – Average minimum fluidization velocity (in m/s) at different fluidization frequencies

Frequency (pulses /min)	**Zeolite**						**Rice husk**	
	Sample 1		*Sample 2*		*Sample 3*		*Sample 4*	
	invers	direct	invers	direct	invers	direct	invers	direct
0	0,125	0,15	0,233	0,253	0,53	0,553	-	-
60	0,11	0,112	0,2	0,23	0,344	0,306	0,298	0,26288
80	0,054	0,045	0,16	0,165	0,281	0,31025	0,32196	0,32196
100	0,042	0,055	0,147	0,1405	0,24	0,281	0,281	0,298
120	0,08	0,083	0,16	0,16	0,332	0,344	0,3369	0,3181
140	0,08	0,095	0,176	0,15	0,293	0,32196	0,281	0,26288

Table 1 shown the average minimum fluidization velocity (in m/s) for each sample at different fluidization frequencies increasing the velocity of the fluidization agent (direct) and decreasing the velocity of the fluidization agent (invers).

Figure 3, shows the behavior of the pressure change with speed increment for the sample of zeolite with average diameter of 0.75 mm. It show that the ΔP remains practically constant for higher air speeds than minimum fluidization velocity and the curves overlap for all pulse frequencies used, which agrees with the results reported by other authors [4, 5 and 6].

From the experimental results is possible to appreciate, a certain regularity with the variation of the minimum fluidization velocity with the increment of the pulse rate for all samples of zeolites.

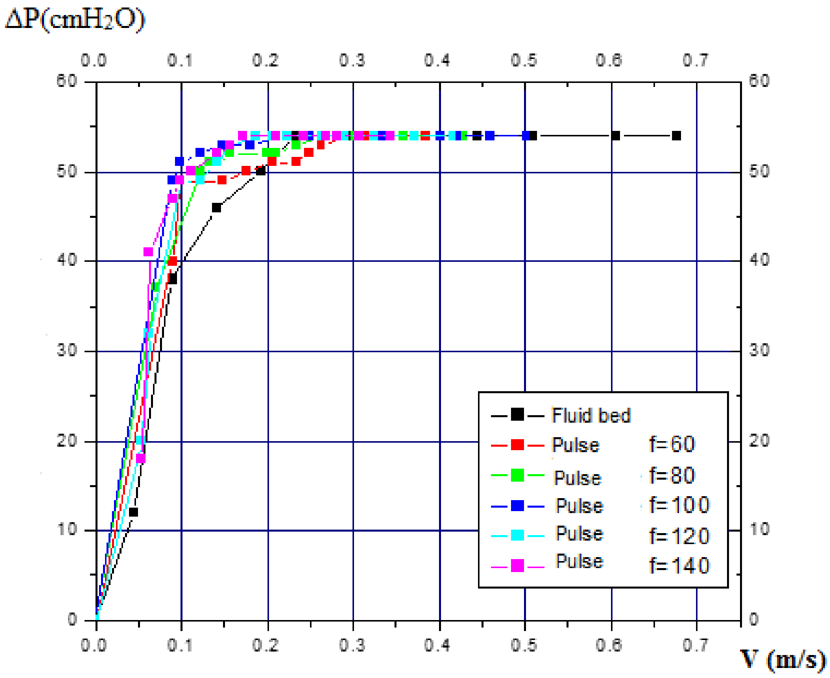

Figure 3: Dependence of the pressure drop (cmH2O) with the average gas velocity in the reactor (m/s)

4.1 Processing Experimental Data

Table 2 shows the values obtained experimentally for the minimum fluidization velocity, in the area of increasing the pressure against flow rate curve for each of the 18 experimental runs.

Table 2 – Experimental runs performed as factorial design

Block	Frequency (F)	Average diameter (d) mm	Minimum fluidization velocity (W)
1	60	0.41	0.112
2	140	2.0	0.322
3	120	2.0	0.344
4	80	0.41	0.045
5	100	0.41	0.055
6	100	2.0	0.281
7	140	0.75	0.150
8	80	2.0	0.281
9	0	0.41	0.150
10	120	0.41	0.083
11	0	0.75	0.253
12	0	2.0	0.553
13	80	0.75	0.141
14	140	0.41	0.095
15	120	0.75	0.160
16	60	2.0	0.306
17	100	0.75	0.141
18	60	0.75	0.230

The processing of the experimental data was performed using the statistical package Statgraphics and the application of a 2-factor linear model. The Pareto chart (Figure 4) shown statistical significance for both, diameter and pulse rate.

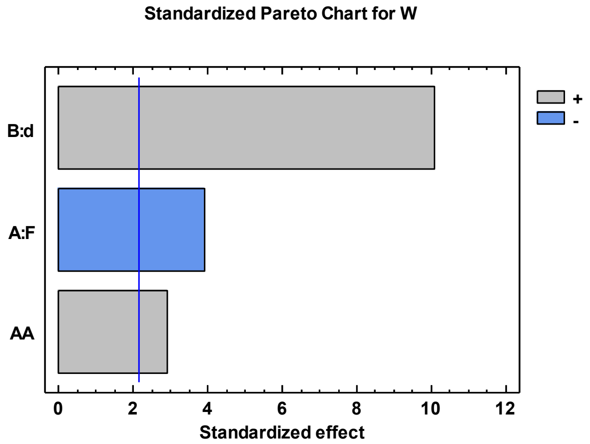

Figure 4: Pareto Graphic standard for frequency and diameter

The interaction between frequency and diameter factors (Figure 5) showed no statistically significant values, although there is some interaction between them.

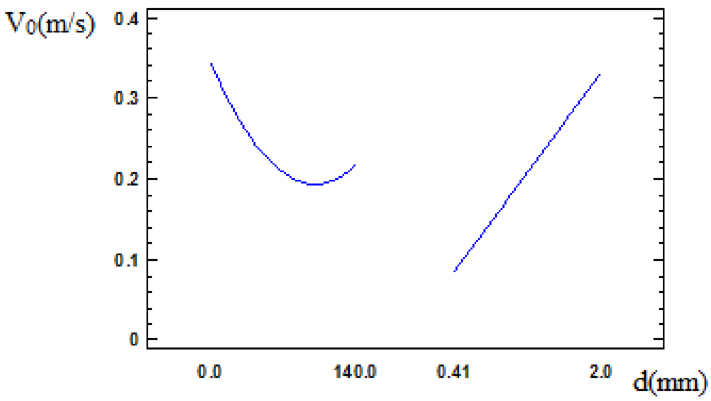

Figure 5: Principal effect of dependence of the minimum fluidization velocity with diameter and pulse rate (holding constant the second factor)

Is possible observe a point of inflection of the minimum fluidization velocity for the pulse frequencies of fluidization agent, between 80 and 90 pulses per minute.

Table 3 – Analysis of variance for the minimum fluidization speed (W)

Factors and Interactions	***Sum of squares***	***Degrees of freedom***	***Mean squares***	***F***	***P***
A:F	0.0352277	1	0.0352277	25.04	0.0003
B:d	0.204351	1	0.204351	145.27	0.0000
AA	0.0168896	1	0.0168896	12.01	0.0047
AB	0.00664598	1	0.00664598	4.72	0.0505
BB	0.00417679	1	0.00417679	2.97	0.1105
Total Error	0.0168801	12	0.00140667		
Total (corr.)	0.278788	17			

The analysis of variance shown significance for the frequency and the sample diameter, and some level of interaction between these two factors. For values of $P < 0.05$ the effect is significant.

In the case of the interaction between frequency and diameter the value of $P = 0.05$ placing it on the border of statistical significance. The Table 3 shown an analysis of variance for the minimum fluidization speed.

The normal second order model was used to obtain the dependence of the fluidization velocity as function of the average diameter and the pulse rate of the fluidization agent, the results correlation are given in Table 4.

Table 4 – Calculation of the P values (probability) for the significance of each of the factors

Factors	*Chi-Square*	*Degrees of freedom*	*P-Value*
d	12.1842	1	0.0005
F	12.0443	1	0.0005
d^2	3.97967	1	0.0460
d*F	5.97555	1	0.0145
F^2	12.4817	1	0.0004

The results of Table 4 shows a significant dependence of W to all factors with an error of 5%. The following dependence was obtained:

$$W = 0.0189063 + 0.406797*d - 0.00234958*F - 0.0800699*d^2 - 0.00062002*d*F + 0.000014972*F^2 \quad (3)$$

To verify the application of this formula to the case of non-spherical particles, the mixture of rice hulls with 5 mm of length and with equivalent diameter calculated considering a diameter of a sphere of equal volume. The calculation of the equivalent diameter calculated was de = 2.83 mm and a form factor of Øs = 0.6. Table 5 shows the results of theoretical and experimental values of minimum fluidization velocity for different pulse rates for the rice husks.

Table 5 – Comparison of theoretical and experimental values of minimum fluidization velocity of) for each pulse rates

Pulse frequency	W theoretical	W experimental
60	0.28	0.328
80	0.322	0.302
100	0.285	0.288
120	0.32	0.285
140	0.272	0.295

Experimental and theoretical values were adjusted to a linear regression of the type:

$$W_T = a * W_{Exp} \quad (4)$$

And with the help of Stargraphics program, the following dependence was obtained:

$$W_{Theorical} = 1.00819 * W_{Exp} \quad (5)$$

With a linear correlation coefficient of 0.995 with an error of 5% for the coincidence between experimental and theoretical values; showing a very good correlation between the theoretical values obtained by the empirical equation and the experimental data.

5 CONCLUSIONS

Was demonstrated that the use of a pulsating fluidization agent in fluidized bed reactors, reduces the values of minimum fluidization velocities in relation to the value obtained in traditional fluidization bed reactors without pulsation. Rice husks not fluidizes in a conventional fluidized bed, however it fluidizes with the use of a pulsating fluidization agent in fluidized bed and is obtained a superior organization in the bed without channeling.

Using TODEC equation for predicting the minimum fluidization velocity in pulsating fluidization beds, reflects better results than the Ergun equation. Was obtained a correlation for the minimum fluidization velocity as a function of the pulse frequency and average diameter of the particles.

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