HYDRODINAMIC STUDY OF CLAY PARTICLES IN FLUIDIZED BED

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Abstract: The aim of the present study was to establish the optimal operating dynamic parameters in fluidized bed for the sodium clay particles and pillared clay particles. In order to determine the influence of the clay particles on the structure of the fluidized bed, the conditions in which the incipient fluidization appears were determined depending on the: nature, diameter and density of the material, gas velocity and fixed bed height. Experimentally the minimum fluidization velocity, the minimum pressure drop and bed porosity were determined. Correlation relations were established in order to approximate the minimal error for the experimental results.

Keywords: fluidized bed, clay particle, pressure drop, minimum fluidization velocity

1. INTRODUCTION

Fluidization is a fluid-gas contacting procedure with important intensification applications using fluidized bed. Fluidization was first used in 1921 by Winkler in the study of coal gasification [1]. Fluidization is present in all operation based on gas-solid contact in organic and inorganic chemical industry, petroleum industry, metallurgic industry, coal and wood industry, construction materials industry.

Studies concerning the fluidization process continued during this time achieving theoretical and experimental researches for the explication of the concept of fluidized bed [2-4]. Fluidization offers multiple advantages including a high gas-solid contact area, convenient transportation of solid, intense stirring, uniform temperature. A bed is fluidized when a gas flow is injected in a solid particle layer, sustained by a perforated plate acting as a distributor of the fluid phase, and these are brought in a fluidization state. The particle bed acts as a fluid and presents good performances in terms of homogeneity and heat transfer [5-6].

The fluidization phenomenon is a reversible process because if the gas velocity is diminished the layer of particles passes through the same stages but in a reverse succession. Increasing fluid velocity, qualitative differences appear determined firstly by the nature of the fluidization agent and the characteristics of the solid particles [1]. The solid particles of a bed of in a column will behave differently depending on gas velocity. Due to the contact between solid particles and gas, that determines the increase of the contact area, fluidization represents an important intensification technique for operations and processes. The use of fluidized bed to avoid risks was one of the main strategies used for the limitation of harmful gas emanations [7-8].

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This study aims to avoid possible and emergent risks in the case of gas adsorption on clays (pillared and sodium clay) the realization on homogenous fluidized structures by controlling the hydrodynamic parameters. In order to obtain a homogenous fluidization, an individual and uniform distribution of clay particles and a uniform expansion of the bed are followed. Therefore the hydrodynamic properties are studied for the solid particles type pillared and sodium clays.

2. EXPERIMENTAL SETUP

2.1. Materials and methods

For the hydrodynamic study of the clay particles a medium clay sample which was dried and grinded, was taken into account. Through shredding a coarse granulometry was realized for clays and by grinding a small size diameter was achieved. The particles obtained were separated by sieving at different diameters using Retsh AS 200 digit (Fisher Bioblock Scientific, France) at amplitude of 60, for 3 minutes.

The clay particles were separated in 2 granulometric classes: 0.5-1 mm and 1-2 mm. The materials which were used in the classic fluidization were sodium clay and pillared clay particles that act as class D materials (for clays with $d_p=1.5\cdot10^{-3}$ m) and B (for $d_p=0.75\cdot10^{-3}$ m) according to Geldart dimensional-dynamic classification [9-11].

The minimum fluidization velocity necessary for the fluidization of small particles is inferior compared with large size particles. In order to realize fluidization, the nature and dimension of particles must be taken into account.

Hydrodynamic studies were carried out on an installation formed of a cylindrical glass column with an interior diameter of 5 cm and height of 40 cm schematically presented in Figure 1.

The fluidization column presents a graduated scale for the measurement of the fixed bed height. At the bottom there is a porous plate that acts as a distributor for the fluidization agent and as a support for the granular material. Pressure drop measurements were realized using a differential manometer Keller Type Range output Supply connected to a computer. The air flow used is the dry compressed air and the feed flowrate is regulated by flowmeters.

The materials subjected to fluidization were pillared clay notated PILC and sodium clay notated NaClay divided in two granulometric classes.

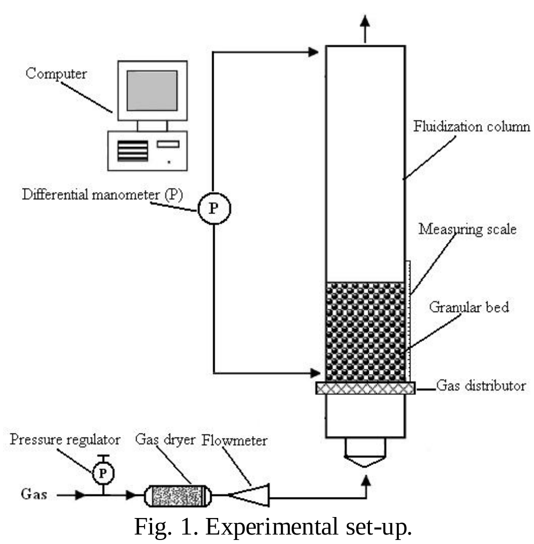

Fig. 1. Experimental set-up.

The experimental research concerning the study of the granular layer of clay particles, led to the determination of the main hydrodynamic parameters like: pressure drop ΔP (Pa) and height of the solid particles layer L_0 (m). The hysteresis phenomenon was analyzed by reading the value of pressure drop and air flow increase through the clay particle layer. Also readings of the fixed bed height were realized.

The physical properties of the clay particles like the medium diameter of particles, d_p, density, ρ_p, and bed initial porosity, ε_0 are presented in Table 1.

Table 1. Physical properties of clay particles.

Type of particles	Notations	d_p (10^{-3} m)	ρ_p (kg·m^{-3})	ε_0 (-)
Pillared clays	PILC	1.5	1232	0.63-0.66
		0.75	982	0.59-0.62
Sodium clays	NaClay	1.5	2394	0.53-0.59
		0.75	2026	0.45-0.50

The bed initial porosity is calculated with equation (1):

$$\varepsilon_0 = 1 - \frac{M_p}{\rho_p \cdot A \cdot L_0} \qquad (1)$$

Where M_p is the mass of the particles in the bed (kg), A is column section (m^2), and L_0 is initial bed length (m).

2.2. Results and discussions

Table 2 presents the experimental parameters for the incipient fluidization pressure drop, ΔP_{min}, minimum fluidization velocity U_{mf}, and the calculated parameters with Richardson (1971) [12] equation for spherical particles and Saxena et. al. (1977) [12] equation for particles with various forms. The equations for the theoretical determination of U_{mf} were applied regardless of the clay bed height and for an intermediary flow regime.

Table 2. Hydrodynamic parameters for incipient fluidization.

Type of particles	d_p (10^{-3} m)	L_0 (10^{-2}m)	Experimental ΔP_{min} (Pa)	Experimental U_{mf} (m·s^{-1})	Calculated U_{mf} (m·s^{-1}) Richardson Equation	Calculated U_{mf} (m·s^{-1}) Saxena and Vogel Equation
Pillared Clay	1.5	2.5	130	0.5088	0.686	0.511
		7.5	550	0.5936		
		12.5	1150	0.7632		
	0.75	2.5	82.5	0.1908	0.261	0.176
		7.5	580	0.2756		
		12.5	862.5	0.3180		
NaClay	1.5	2.5	100	0.5936	1.029	0.782
		7.5	575	0.6784		
		12.5	1050	0.7632		
	0.75	2.5	87.5	0.3180	0.462	0.323
		7.5	575	0.3392		
		12.5	1062.5	0.3392		

Experimental value of minimum fluidization velocity was calculated with equation (2) [4, 12]:

$$U_{mf} = \frac{\mu_g \left(\sqrt{C_1^2 + C_2 \cdot Ar} - C_1 \right)}{\rho_g \cdot d_p} \qquad (2)$$

where μ_g is fluid viscosity (Pa·s), ρ_g fluid density(kg·m^3) and Ar is Arhimede criterium.
The parameters values are presented in Table 3.

Table 3. Parameters values of C_1 and C_2.

Authors	C_1	C_2
Richardson (1971)	25.7	0.0365
Saxena and Vogel (1977)	25.28	0.0571

Experimental values are in good agreement with calculated value.

The experimental hydrodynamic parameters for the incipient fluidization in clay particles (pillared clay and sodium clay) were determined. Figures 2-5 present the evolution of the pressure drop for clays with $d_p=1.5\cdot10^{-3}$ m and $d_p=0.75\cdot10^{-3}$ m at different heights of the initial layer L_0.

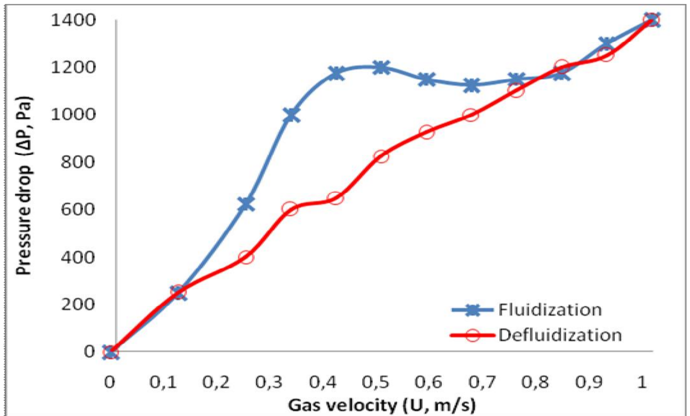

Fig. 2. Pressure drop evolutions according to gas velocity for pillared clay ($d_p=1.5\cdot10^{-3}$ m, $L_0=12.5\cdot10^{-2}$ m).

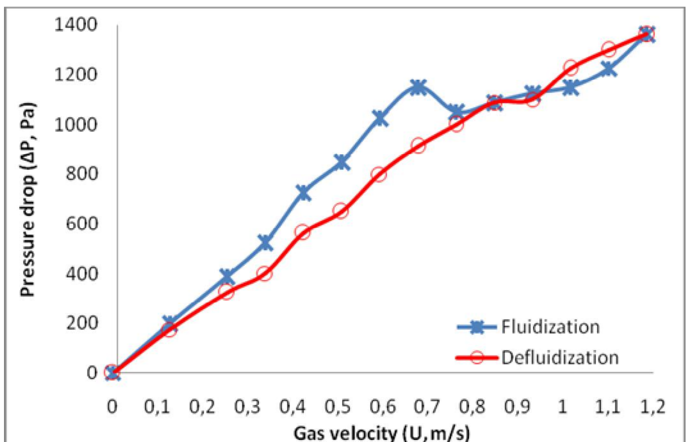

Fig. 3. Pressure drop evolutions according to gas velocity for sodium clay ($d_p=1.5\cdot10^{-3}$ m, $L_0=12.5\cdot10^{-2}$ m).

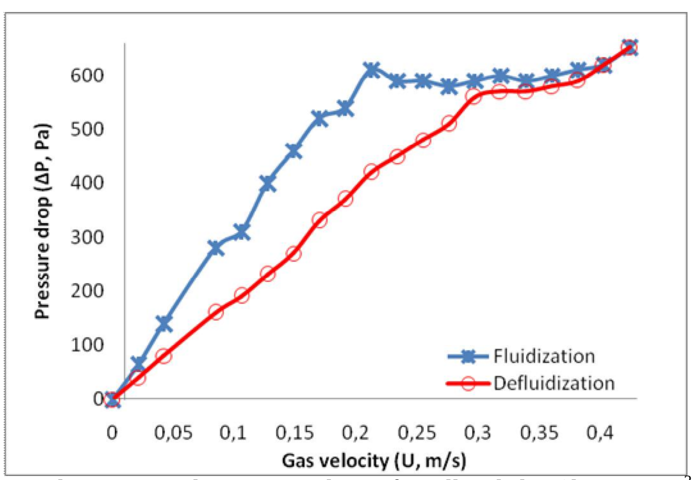

Fig. 4. Pressure drop evolutions according to gas velocity for pillared clay ($d_p=0.75\cdot10^{-3}$ m, $L_0=7.5\cdot10^{-2}$ m).

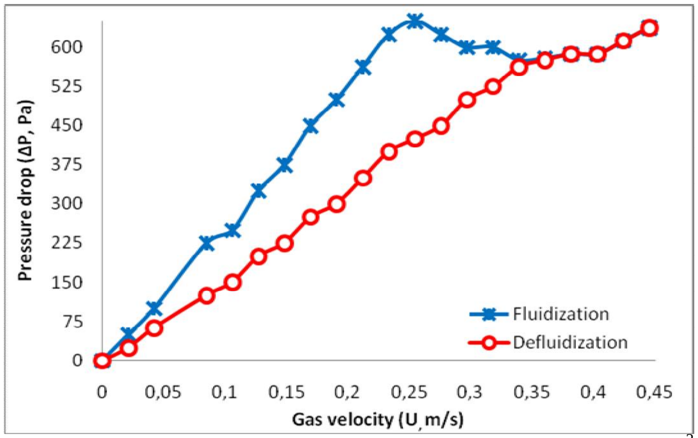

Fig. 5. Pressure drop evolutions according to gas velocity for sodium clay (d_p=0.75·10^{-3} m, L_0=7.5·10^{-2} m).

At low gas velocity the fluid strains through the clay particles without displacing them, the pressure drop varies linearly with the gas velocity and the bed remains fixed presenting the same porosity.

Increasing gas velocity to the minimum fluidization velocity, the clay particles layer expands easily and homogeneous. The particles, even though, are maintained in contact acquire a certain degree of freedom in movements, vibrating around their fixed position. All figures presented show an increase for the pressure drop up to a certain value and afterwards remains constant. Clay particles with d_p=1.5·10^{-3} m and L_0=12.5·10^{-2} m register a pressure drop around 1200 Pa which corresponds to a gas velocity of 0.5 m·s^{-1} and afterwards remains constant. For clay particles with d_p=0.75·10^{-3} m and L_0=7.5·10^{-2} m, pressure drop remains constant until 620 Pa at a gas velocity of 0.22 m·s^{-1}.

In a bed formed of spherical, rigid and uniform clay particles, fluidized with a fluid that presents a density close to that of pillared and sodium clay particles, the bed enters in the homogenous fluidization domain and the pressure drop remains practically constant.

The increase of gas velocity determines the slight increase of the pressure drop due to the friction between particles, these separate, don't mutually sustain and accentuate their movement and they rearrange as to provide minimal resistance to flow. Due to this behavior the pressure drop registered for particles with d_p=0.75·10^{-3} m was lower than the pressure drop measured for particles with d_p=1.5·10^{-3} m.

This state called incipient fluidization is characterized by the fact that the bed of clay particles behaves as a boiling viscous liquid. From this moment the minimum fluidization velocity which corresponds to incipient fluidization is determined. The figures presented show that clay particles with d_p=1.5·10^{-3} m register a U_{mf} of 0.7632 m·s^{-1} and clay particles with d_p=0.75·10^{-3} m register a lower U_{mf} ranged between 0.2756-0.3392 m·s^{-1}.

On further increase of gas velocity a part of the clay particles are entrained above the dense phase by the fluid and an inhomogeneous fluidization occurs.

The control of the hydrodynamic parameters in fluidized bed is aimed to obtain a homogenous bed with the purpose to intensify the remediation process of gasses through adsorption.

3. CONCLUSIONS

Results are according to previous studies shows that the minimum fluidization velocity, pressure drop and bed porosity are the main parameters that lead to use the fluidized bed as an intensive process.

The minimal fluidization velocity does not depend on the height of the bed; the minimal pressure drop increases depending on the height of the bed and the structure of the bed at the end of the fludization-defluidization process modifies due to increased porosity, the bed remaining in a loose form.

The hydrodynamic study proved that particles with d_p=0.75·10^{-3} m can be easily maintained in a fluidization stage with a minimum fluidization velocity of 0.2756 m·s^{-1} for the pillared clay particles respectively of 0.3392 m·s^{-1} for the sodic clay. Maintaining the system of clay particles in a fluidized stage requires relatively low energy consumption.

Operating at low gas velocities clay particles with d_p=0.75·10^{-3} m present a uniform homogeneous mixing of the particles and a large gas-solid contact surface in order to intensify the adsorption process.

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