

Estimation of the Dynamic Parameters of Mono and Bicomponent Granular Particles Beds Fluidization

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Experimental research of dynamic structure of the granular beds of clay, steel and clay- metallic particles mixtures aimed to determine the operating fluidization parameters, to identify optimal conditions for contacting gas - granular material and to intensify mass transfer operations with minimum energy consumption. The main dynamic parameters of fluidization were experimentally determined: the minimum fluidization velocity of pure materials used, the minimum fluidization velocity of mixtures clay- metallic particles (steel) and the minimum pressure drop, depending on the geometric simplex L_p/D and the concentration of different particles in the mixture. Applying regression analysis of experimental data were proposed empirical relationships using the operational parameters.

Keywords: dynamic parameters, fluidization, regression analysis

Air pollution is a topical issue at the global level (greenhouse effect, ozone layer). In order to minimize or eliminate emissions of gaseous pollutants in the atmosphere different adsorption systems based on porous solid (clays, zeolites, activated carbon) are used. Gas adsorption on clay matrix is a subject of intense study in the present, extensive research being dedicated to polluting gas adsorption on natural clays and chemically modified clays.

To optimize the adsorption processes, in terms of duration and energy consumption, intensive techniques of gas-solid contacting, such as fluidization or modified fluidization (in the presence of electromagnetic field) are used fluidization being a technique used to enhance mass transfer by improving the dynamic and increasing gas-solid contact surface [1-4].

A study comparing the structure of fluidized bed mixture of magnetic and nonmagnetic (clay) particles in and without magnetic field was presented elsewhere [2]. Utilizations of bentonite natural clays in the present study is explained by the interesting properties of this material [5-7], a study regarding the utilizations of this type of material in order to obtain modified clays that can be used in polluted gas adsorption being the subject of another paper [8].

The present study aim is to determine the boundary values of some operating parameters of fluidization and to modulate the dynamic parameters of the solid particles (clays and mixture of clays and metallic particles) using regression analysis of the experimental data.

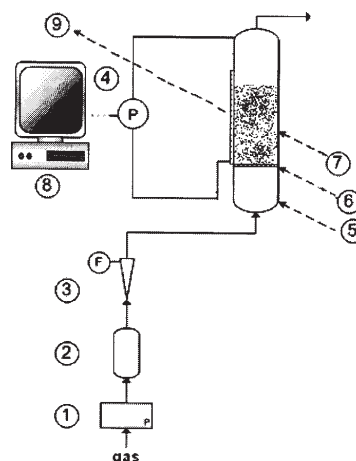
The study was developed because no publications have been found regarding the estimation of the dynamic parameters of acid activated clays-metallic particles (with ferromagnetic proprieties) in classic fluidization.

Experimental part

Materials and methods

The laboratory installation used to study the dynamics of solid layer (clay and clay – metallic particles mixture) in fluidized bed is equipped with measurement devices for the operating parameters: volumetric flow fluidization agent and pressure drop in the bed.

The experiments of this study were carried out with the device presented in scheme 1. The device contains a cylindrical glass vessel with a 0.5 m height and a 50 mm inner diameter, a P2 porous glass plate as gas distributor; the pressure drop according to gas velocity is high enough (3600 Pa at $0.34 \text{ m}\cdot\text{s}^{-1}$) to ensure homogeneous gas inlet in the porous media. The fluidizing fluid used is dry compressed air; the flowrate is regulated with Brooks (GT 1024 and Shorate 1355) flowmeters. Pressure drops across the particles bed were measured with a digital manometer Keller PD 33H (connected to wall pressure taps), linked to a computer with a Keller K-107 transducer.



Scheme 1. Scheme of the studied system

1-pressure regulator; 2 –gas dryer; 3 –flowmeter; 4 –differential manometer (P); 5 – fluidization column; 6 – gas distributor (media bearer); 7 - particle layer; 8 – computer; 10 – height measuring scale.

The materials used in the dynamic study were natural calcium bentonitic clay, NC, provided by Romania and metallic particles, WS, (with ferromagnetic proprieties) provided by France.

During the experiments the porous media (bed) was composed of clay particles and/or mixtures clays-steel shots. Tables 1 and 2 present the main characteristics of solids used in the experimental study. In order to obtain a

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Material	Symbol	Average diameter (m)	Sphericity	Particle density (kg·m ⁻³)	Pore volume (cm ³ ·g)	Specific surface area (m ² ·g ⁻¹)
		$\bar{d}_p \cdot 10^3$	Ψ	ρ_p	$V_p \cdot 10^3$	S_{sp}
Acid activated clay	NC	0.35	0.85	1957	~0.1262	46.256
		0.75	0.80	1984		
		1.5	0.75	2125		
Metallic particles (steel shots)	WS	0.35	0.95	7400	-	-
		0.75	0.95	~7400		
		1.5	0.95	~7400		

Table 1
CHARACTERISTICS OF THE SOLID PARTICLES USED IN THE EXPERIMENTAL STUDY

Mixture/ Symbol	Volumetric fraction of metallic / clay particles		Volumetric average diameter	Masic fraction of metallic / clay particles		Mixture average particle diameter	Average density of the mixture
	$x_{v,M}$	$x_{v,Arg}$	$\bar{d}_{v,am} \times 10^3$	x_M	x_{Arg}	$\bar{d}_{p,am} \times 10^3$	$\bar{\rho}_{am}$
AN ⁽¹⁾ -WS ⁽²⁾	-	-	<i>m</i>	-	-	<i>m</i>	kg/m ³
	0.062	0.93	0.578	0.25	0.75	0.58	2428.95
	0.11	0.88	0.564	0.5	0.5	0.48	3129.9
	0.44	0.55	0.476	0.75	0.25	0.4	4398.5

Table 2
CHARACTERISTICS OF THE PARTICLES MIXTURE USED IN THE EXPERIMENTAL STUDY

⁽¹⁾ – refers to NC with $\bar{d}_p = 0.75$ mm; ⁽²⁾ – refers to WS with $\bar{d}_p = 0.35$ mm.

Material	Average particle diameter x 10 ³	L ₀ /D	U _{mf}	ΔP _{mf}	
NC	0,35	-	m/s	Pa	
		1	0,085	250	
		2	0,11	600	
		3	0,12	950	
	0,75	4	0,136	1325	
		1	0,307	287,5	
		2	0,318	667,5	
		3	0,34	987,5	
	1,5	4	0,35	1600	
		1	0,679	350	
		2	0,72	775	
		3	0,764	1225	
	WS	0,35	4	0,849	1650
			1	0,297	1675
			2	0,314	3900
			3	0,318	5750
WS	0,75	4	0,329	8000	
		1	0,679	1700	
		2	0,720	3450	
		3	0,764	5175	
	1,5	4	0,807	6837.5	
		1	0,892	1800	
		2	0,955	3450	
		3	0,977	5200	
		4	0,998	6825	

Table 3
PARAMETERS OF MINIMUM FLUIDIZATION FOR CLAY AND METALLIC PARTICLES

good repartition of metallic particles in mixture bed during the fluidization were chosen two types of particles that proved to have similar minimum fluidization velocities (natural clay with an average diameter of particle of 0.75 mm and steel particles with an average diameter of particles of 0.35 mm, table 2).

Particle density was determined by picnometric method. The metallic particles density was measured by Abrahamsen-Geldart method based on the fact that minimum void fraction is identically for particles with identical shape and dimension [1].

The shape factor was determined as function of the diameter of a sphere with volume equal with the particle volume (d_0) and the area of a sphere with an equivalent perimeter equal with those of the particle (a_p), respectively:

$$\Psi = \frac{\pi d_0^2}{a_p}$$

Binary mixtures (clay - metallic particles) used in this study had a mass fraction of metallic material (x_M) in the range (0.25-0.75).

Results and discussions

Experimental determinations follow the measuring, for each gas velocity value, of pressure drop and bed height; minimum fluidization velocity was determined from diagrams ΔP - U, completed by visually observations (table 3-4).

Analyzing the experimental data presented in tables 3 and 4, at minimum fluidization state, we observe the following: the pressure drop increases with particle density and with the bed height (ratio L₀/D); minimum fluidization velocity increases with particle diameter.

On fluidization and defluidization it can be observed the hysteresis phenomena at the pressure drop measuring; in

Mixture	L_0/D	X_M	U_{mf}	ΔP_{mf}
AN ⁽¹⁾ -WS ⁽²⁾	-		<i>m/s</i>	<i>Pa</i>
	1	0.25	0.3	375
		0.5	0.31	450
		0.75	0.312	525
	2	0.25	0.31	725
		0.5	0.315	812.5
		0.75	0.32	1075
	3	0.25	0.311	975
		0.5	0.314	1225
		0.75	0.319	1412.5
	4	0.25	0.312	1587.5
		0.5	0.318	1985
0.75		0.324	2375	

⁽¹⁾ – refers to NC with $d_p = 0.75$ mm; ⁽²⁾ – refers to WS with $d_p = 0.35$ mm.

Table 4
PARAMETERS OF MINIMUM
FLUIDIZATION FOR MIXTURE OF
CLAY AND METALLIC PARTICLES

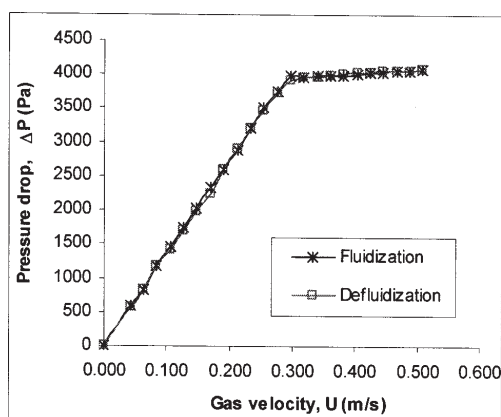


Fig. 1. Pressure drop evolutions according to gas velocity for clay particles ($d_p = 0.75$ mm, $L_0/D = 2$)

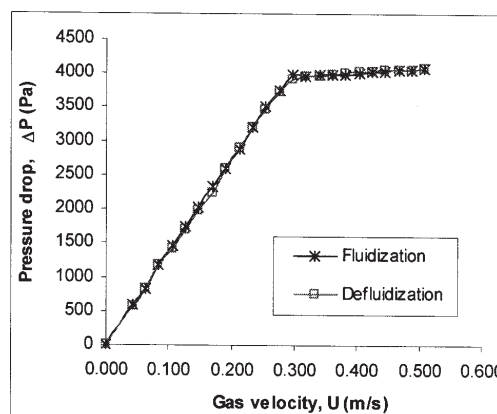


Fig. 2. Pressure drop evolutions according to gas velocity for metallic particles ($d_p = 0.35$ mm, $L_0/D = 2$)

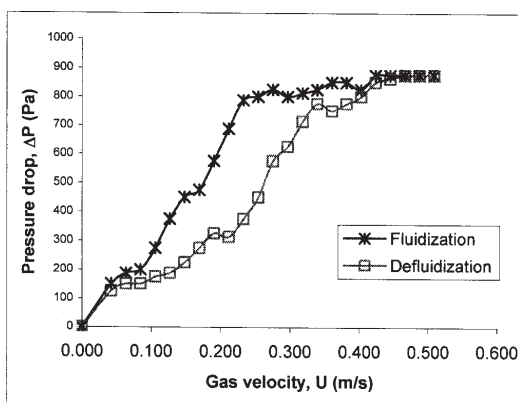


Fig. 3. Pressure drop evolutions according to gas velocity for mixture NC ($d_p = 0.75$ mm) - WS ($d_p = 0.35$ mm):
 $L_0/D = 2$, $x_M = 0.5$

figures 1-3 are presented some examples of diagrams $\Delta P - U$ for the tested materials.

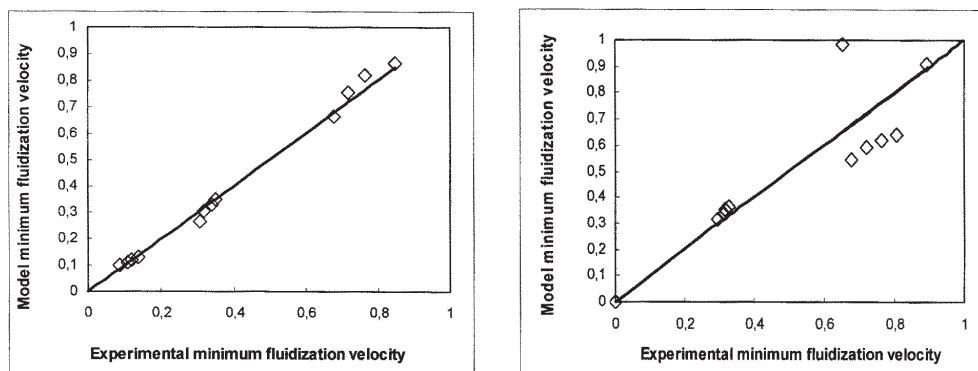
Applying regression analysis of the experimental data obtained for calculation of the minimum fluidization velocity and pressure drop, for pure particles bed (clay and metallic particles) and for mixture of natural clay and metallic particles were obtained empirical relationship

using the operational parameters from tables 3 and 4. These empirical relationships were plotted in table 5.

For each parameter the relationships proposed in table 5 estimate well the experimental results. The obtained empirical relationships approximate the experimental data with an acceptable error.

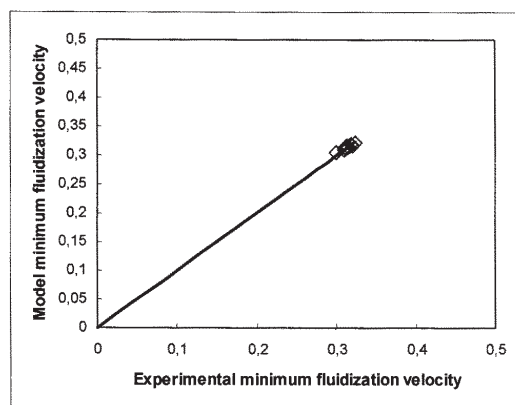
Material	Empirical relationship	Values of empirical relationship coefficients	Average error, %
AN	$U_{mf} = C \cdot \left(\frac{L_0}{D}\right)^{a_i} \cdot \bar{d}_p^{b_i}$	$a_1 = 0.192; b_1 = 1.312; C_1 = 0.00336$	1.9
WS		$a_2 = 0.183; b_2 = 0.0807; C_2 = 0.951$	0.3
AN ⁽¹⁾ - WS ⁽²⁾	$U_{mf} = C \cdot \left(\frac{L_0}{D}\right)^{a_i} \cdot X_M^{b_i}$	$a_3 = 0.023; b_3 = 0.0033; C_3 = 0.316$	0.33

Table 5
EMPIRICAL RELATIONSHIPS FOR ESTIMATION OF THE MINIMUM FLUIDIZATION VELOCITY OF MONO- AND BI-COMPONENT GRANULAR PARTICLES BEDS FLUIDIZATION



(a)

(b)



(c)

Fig. 4. The comparison between the experimental data and values obtained from empirical model for minimum fluidization velocity for (a)-NC, (b) - WS and (c) - mixture NC - WS

Material	Empirical relationship	Values of empirical relationship coefficients	Average error, %
AN	$Eu_{mf} = C_i \cdot Ar^{a_i} \cdot Re_{mf}^{b_i} \cdot \left(\frac{L_0}{D}\right)^{d_i}$	$a_1 = 1.497; b_1 = -2.973;$ $d_1 = 1.381; C_1 = 2.066$	3
WS		$a_2 = 0.709; b_2 = -2.097;$ $d_2 = 1.025; C_2 = 1.804 \cdot 10^3$	0.9
AN ⁽¹⁾ - WS ⁽²⁾	$Eu_{mf} = C_i \cdot Ar^{a_i} \cdot Re_{mf}^{b_i} \cdot \left(\frac{L_0}{D}\right)^{d_i} \cdot X_M^{e_i}$	$a_3 = 0.343; b_3 = 0.087;$ $d_3 = 0.981; e_3 = 0.272$ $C_3 = 90.319$	0.8

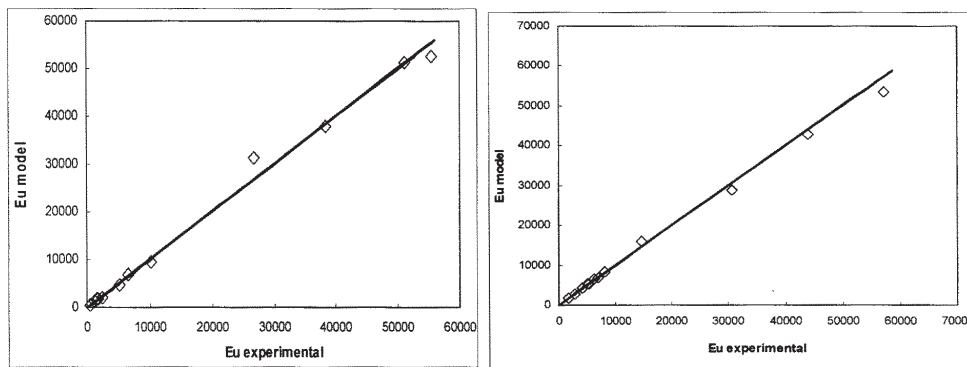
Table 6
EMPIRICAL RELATIONSHIPS FOR ESTIMATION OF THE MINIMUM FLUIDIZATION PRESSURE DROP OF MONO- AND BI-COMPONENT GRANULAR PARTICLES BEDS FLUIDIZATION

Figures 4 (a, b, c) present the comparison between experimental and calculated values for minimum fluidization state.

Table 6 presents the empirical equations obtained for the pressure drop in minimum fluidization conditions.

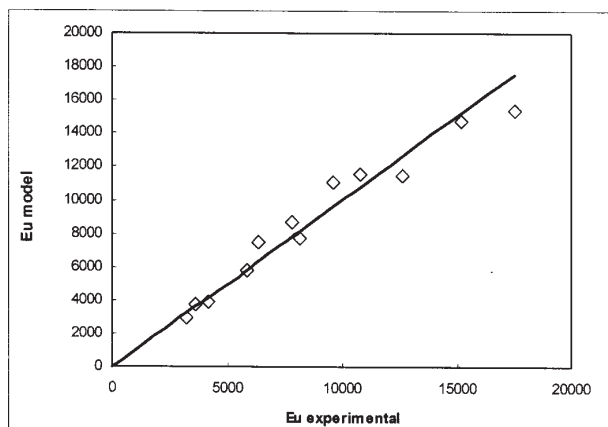
Figures 5 (a, b, c) evidenced the deviations of the empirical equation from the experimental data.

From the figures 5 (a, b, c) it can be observed that the model proposed for the empirical equations of Eu criteria



(a)

(b)



c

Fig. 5. The comparison between the experimental data and values obtained from empirical model for minimum pressure drop for (a)-NC, (b) - WS; (c) - mixture NC - WS

allows a better approximation for the experimental data in condition of minimum fluidization state.

Conclusions

On the basis of the experimental results and analysis of this investigation, the following conclusions are made about the main operating parameters of the fluidized bed, corresponding to the minimum fluidization state: velocity and pressure drop (enclosed in Euler criteria in the empirical equations).

The empirical relationships obtained for the main operating parameters of the fluidized bed approximate the experimental data with an acceptable error.

The clays, between pure substances, are harder to model, due to the small dimensions of the particles which induce interparticular forces, easily observable due to the large hysteresis present in the fluidization diagrams.

The metallic particles, due to their properties (especially high density, perfect sphere form) give models for the fluidization parameters which approximate very well the experimental data obtained, because these particles present a homogeneous fluidization.

For the mixtures, the equations determined in the incipient state of fluidization estimate well the experimental data, because these correspond to a homogeneous fluidization (with a perfect mixing in the bed, without segregation).

Notations

$\bar{d}_{p,am}$ - Mixture average particle diameter (m);
 x_M - mass fraction of metallic material (-);

$x_{v,M}$ - Volumetric fraction of metallic particles (-);
 $x_{v,Arg}$ - Volumetric fraction of clay particles (-);
 U_{mf} - minimum fluidization velocity ($m\cdot s^{-1}$);
 U - gas velocity ($m\cdot s^{-1}$);
 ψ - Sphericity (-);
 ρ_{am} - Average density of the mixture ($kg\cdot m^{-3}$);
 ρ_p - Particle density ($kg\cdot m^{-3}$);
 ΔP_{mf} - pressure drop corresponding to minimum fluidization velocity (Pa).

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