Aspects of Structure of Fluidized Bed Mixture of Magnetic and Nonmagnetic Particles in Magnetic Field

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This paper presents experimental data regarding the hydrodynamic of the gas/solid fluidization in a transverse magnetic field of a binary mixture of clay (smectitic acid activated clays) – magnetic particles and of clay particles in classical fluidized bed. The influence of solid (magnetic and non-magnetic particles) characteristics, magnetic field intensity range (0-12000 A·m^{-1}), mass fraction (0-100%) of the magnetic particles, type of the mixture (homogeneous or layered) on pressure drop and porosity of the particulated bed was studied. The results confirm that the magnetic field intensity has a large influence on stability of magnetic particles in the monocomponent bed and in the mixture where it may form special "layers" modifying the whole bed behaviour. The results are promising and the "homogenous" bed operating mode has an interesting potential for application in adsorption of polluted gases on clay based adsorbents.

Keywords: clay, hydrodynamic of binary mixture, magnetic field fluidization

The intense industrial activity of the last decades generates high quantities of gaseous pollutant emissions with negative impact on environment and on human health. This explains the necessity to develop air purification procedures to reduce the pollutants concentration according to the regulations. Among discharged gases from various industrial plants, ammonia is a very reactive and toxic product.

The air purification techniques are based on mass transfer processes; the most used are: selective adsorption (vapours and gases adsorption on nanostructured porous materials), absorption, catalyzed chemical processes, electrochemical procedures, cryogenic purification of residual gases, retention of gases on membranes or biological filters, chemical conversion of pollutants in nontoxic products [1].

Gas purification by adsorption is frequently used due to the higher efficiency and low costs. The classic adsorbent for gaseous and liquid effluents purification is the activated carbon that, even it has a high efficiency (explained by a high surface area, at least 500 m^2/g), presents the disadvantage of being an expensive adsorbent (the price of adsorbent of activated carbon increases with the specific surface area). Such a technique requires an activation procedure leading to important quantities of SO_2 that demand supplementary measures of depollution, while it regeneration is difficult and an important quantity of adsorbent is transformed in CO during the thermal regeneration. After one regeneration cycle, the adsorption capacity could decrease with 25-30% v.s the initial material. These disadvantages explain the necessity of discovering and implementing at an industrial level of alternative adsorbents, largely found in nature and that can be used directly or after application of simples and cheap activation procedures [2, 3].

Due to the higher surface area and surface acidity ([4-6]), the acid activated clays are very good candidates as adsorbents for basic gases as ammonia. Ammonia adsorption by clays presents the advantage of being a simple and inexpensive technique [7, 8]. Hence, different adsorption-regeneration systems were proposed allowing the regeneration of the adsorbent and, in the mean time, pollutant gas recovery [7, 8].

Fluidized bed is a technique used to intensify the mass transfer operations improving the dynamic conditions and increasing the gas-solid contact surface [10-14]. This technique is used in various fields such as: granulation, combustion, crystallization, adsorption, drying [10-18].

Magnetically stabilized fluidized bed (MSFB) is a modern technology developed to eliminate the drawbacks of classical fluidized beds [19]. Fluidization in (electro) magnetically field combines the desirable characteristics of both fluidized and packed beds: a low pressure drop of fluidized bed with the bubble free operation at high gas velocities of packed beds [20], in order to improve the gas-solid contact efficiency. Besides, the, MSFB is a technique that could be utilized to also intensifying the mass transfer in gas-solid systems (adsorption processes) [21, 22].

In order to improve the retention of ammonia by adsorption, we have already proposed [23] to combine the advantages of an efficient and inexpensive adsorbent (acid activated clay) with the advantages of an efficient technique for granular bed stabilization (MSFB). Before implementation of this procedure at an industrial level, a hydrodynamic study to determine the boundary values of some operating parameters and to modulate the hydrodynamic properties of the solid particles (clays and mixture of clays and magnetic particles) are necessary.

Concerning the hydrodynamics of acid activated clays-ferromagnetic particles in a magnetic field in order to apply the MSFB technique to separate gases by adsorption, no publications have been found in the literature.

Experimental part

Material and methods

All the experiments of this study have been carried out with the device schematically presented in figure 1. The device contains a cylindrical glass vessel with a 0.5 m height and a 50 mm inner diameter, and a P2 porous glass

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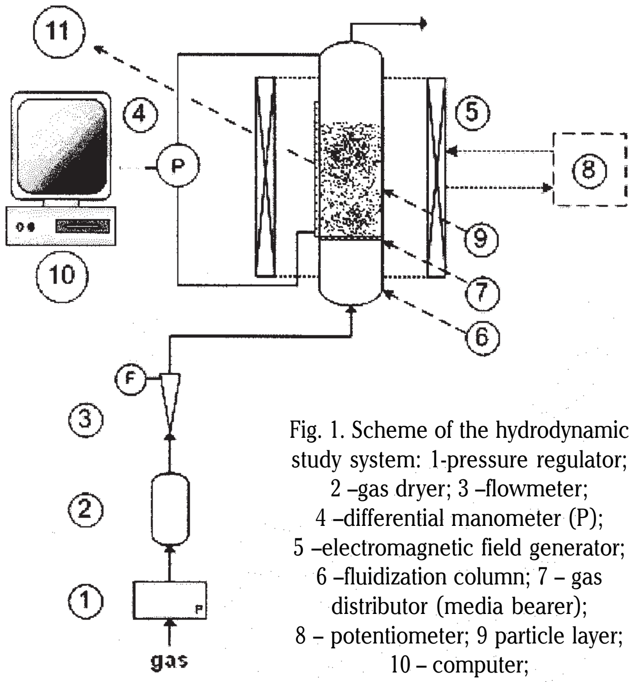

Fig. 1. Scheme of the hydrodynamic study system: 1-pressure regulator; 2 –gas dryer; 3 –flowmeter; 4 –differential manometer (P); 5 –electromagnetic field generator; 6 –fluidization column; 7 – gas distributor (media bearer); 8 – potentiometer; 9 particle layer; 10 – computer; 11 – height measuring scale

plate as gas distributor. The pressure drop according to the gas velocity is high enough (3600 Pa at 0.34 m.s^{-1}) to ensure an uniform gaseous feeding of the porous media. The fluidizing fluid used is the dry compressed air. The feed flowrate is regulated by using Brooks (GT 1024 and Shorate 1355) flowmeters. The scheme of the experimental loop is presented in figure 1.

Pressure drops across the 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. During the experiments the porous media (bed) consist in clay particles and/or mixtures of clays-steel shots, with trade name WS70 and provided by Wheelabrator (Allevard, France).

The clay particles were obtained by a common method presented in literature [7, 24]. Their physical properties (granulometric class-determined with sieving, density) are presented in table 1, where $\bar{d}_p$ is the average diameter of solid particles and ρ_s is the particle density.

The bed initial porosity is calculated with the following equation:

$$\varepsilon_0 = 1 - \frac{M_S}{\rho_s A L_0} \qquad (1)$$

where:

M_s is the mass of solid contained in the bed;

A - the column section;

L_0 - the bed initial length.

The transverse electromagnetic field used in this study is generated by using a saddle coil device, composed of two half cylindrical parts (made of PVC tube, 80 mm inner diameter), on which a 0.8 mm diameter copper wire is winded up to get a saddle coil configuration generating the transverse field. The electrical power is supplied and controlled by a Lambda generator (model FV 345, in the range 0-5 A) to get a certain value of the electromagnetic field intensity (H). This parameter was measured with a Magnet-Physik FH 51 gaussmeter equipped with a HS-TB51 transverse probe, being a function of spatial position and current intensity (I).

The fluidized experiments in the magnetic field were carried out in solid batch/field first mode generaliZed in [25].

Results and discussions

In table 2 are plotted the experimental parameters of incipient fluidization pressure drop of gas, ΔP_{min}, and minimum gas velocity, U_{mf}, in absence of electromagnetic field and the calculated minimum velocity of fluidization. Experimental values are in good agreement with predicted ones, according to [27] relationship:

$$U_{mf} = \frac{\mu_f\left(\sqrt{29{,}5^2 + 0{,}0357Ar} - 29{,}5\right)}{\rho_f\, d_p},$$

where:

μ_f represent the fluid viscosity;

ρ_f - the fluid density;

Ar - Archimede criterium.

Table 1
PHYSICAL PROPERTIES OF THE PARTICLES

Particle type	Composition	$\bar{d}_p$ (10^{-3} m)	ρ_s (kg.m^{-3})	ε_0 (-)
AAC	Acid activated clay	1.5	990	0.57-0.58
		0.75	980	0.56-0.565
		0.35	950	0.545-0.55
WS 70	Magnetic particles	0.35	7450	0.43-0.44

Table 2
PARAMETERS OF MINIMUM FLUIDIZATION

Particle type	$\bar{d}_p$ (10^{-3} m)	L_0 (10^{-2} m)	Experimental ΔP_{min}	Experimental U_{mf} (m.s^{-1})	Calculated U_{mf} (m.s^{-1})
AAC	1.5	10	400	0.39	0.393
	0.75	10	350	0.149	0.142
	0.35	10	400	0.042	0.049
WS 70	0.35	10	1675	0.3	0.29

Hydrodynamic parameters in clay particles fluidized bed

As for the case of magnetic particles dynamic characteristics [23], in the clays particles case (table 2) we can notice two distinct parts of the pressure drop evolution: a zone where pressure drop increases linearly with the gas velocity (the fixed bed region) and a part where it is rather constant, corresponding to the fluidized bed regime. Figures 2-3 show an example for pressure drop and porosity evolutions vs. the gas velocity, for clays particles with d_p = 1.5 . 10^{-3}m, and different values of initial bed height, L_o.

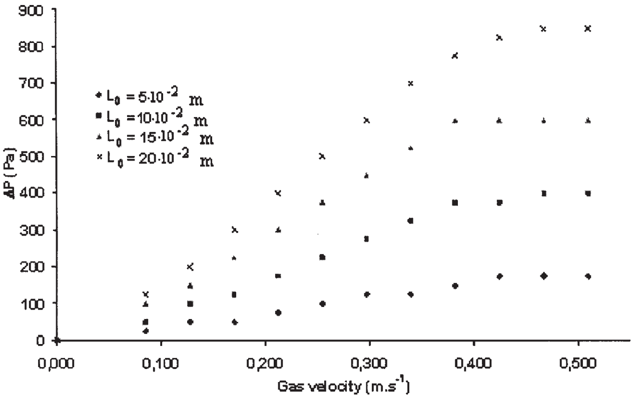

Fig. 2. Pressure drop evolutions according to gas velocity for clay particles (d_p = 1.5 . 10^{-3}m)

In each experiment, pressure drop values at the fluidization "plateau" are of 75 Pa less than the theoretical value (corresponding to apparent weight par square unit), due to the pressure tap position. In the case of 1.5 mm clays particle, slugging phenomenon was absent in the studied gas velocity range, but it appears for the small particle case (of ca. 0.75 . 10^{-3} m size).

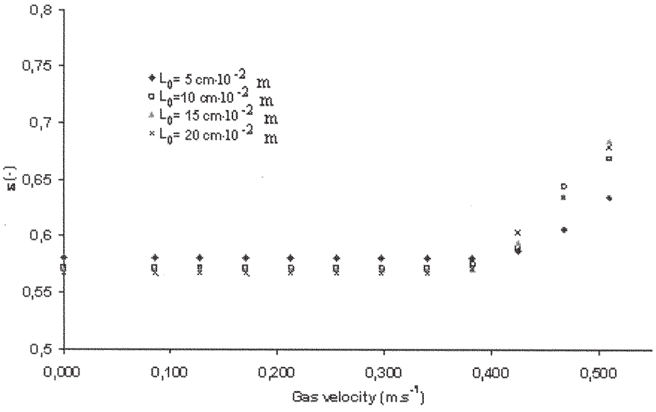

Fig. 3. Porosity evolution according to gas velocity and different bed heights for clays particles of d_p = 1.5 . 10^{-3} m

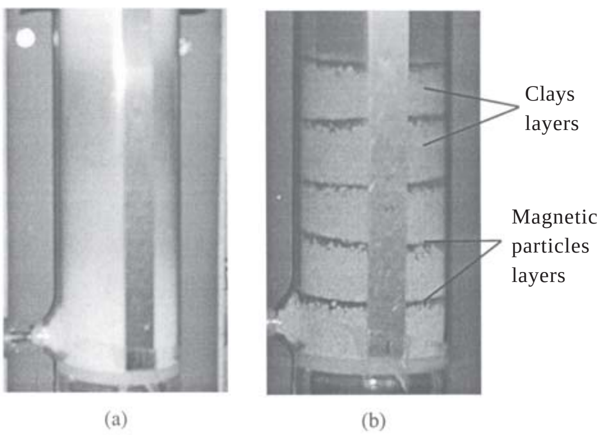

Fig. 4. Photographs of a "homogeneous" bed (a) and a "layered" bed (b) before fluidization

Hydrodynamic behaviour of mixtures

According to the experimental results obtained during monocomponent hydrodynamic test, clays particles (1.5 . 10^{-3} m, later use for adsorption) are paired with WS70 (d_p=0.35 . 10^{-3} m), as their minimum fluidization velocity are similar. However due to high density and differences in particle sizes (even for the same material), segregation phenomenon occurs. The fluidisation of such a mixture leads to a two layered bed, with a clay rich layer at the upper part (flotsam) and WS70 rich one at the lower part (jetsam), corresponding to a case in Chiba et al. classification [26].

Therefore, different strategies have been used to study the mixture behaviour under the magnetic field: "homogeneous" mixture (fig. 4 (a)) and "layered mixture", the later consisting in the alternation of clay and metal particle layer (fig. 4 (b)).

"Homogeneous" mixture beds

For "homogeneous" beds, experiments were carried out with various ratios of magnetizable particles (X), at a constant clay mass. The results are presented in figure 5.

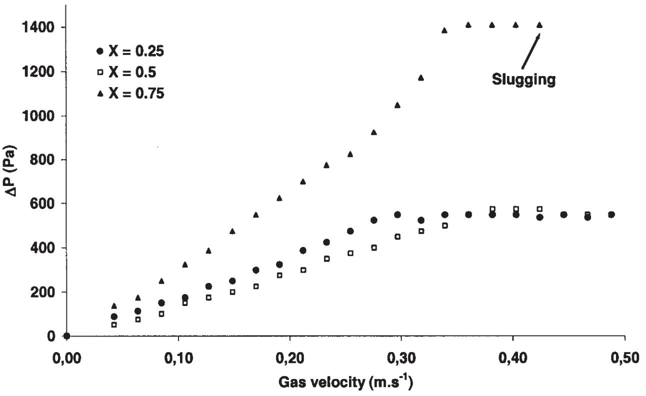

Fig. 5. Pressure drop through different magnetic particle mass fraction without applied field

As the mass fraction of ferromagnetic particles increases, the total weight of the bed raises, leading to higher fluidization "plateau" level of ΔP. However, the "homogenous mixture" of clay-magnetic particles arrangement appears to be very sensitive to the pouring or mixing conditions, as indicated by the X=0.25 and X=0.5 experiments. Besides the rich ferromagnetic particle bed (X = 0.75) presents a behaviour close to monocomponent bed, i.e. the presence of slugging phenomenon. After a full cycle of fluidization-defluidization, the mixture is roughly segregated, as can be observed in figure 6.

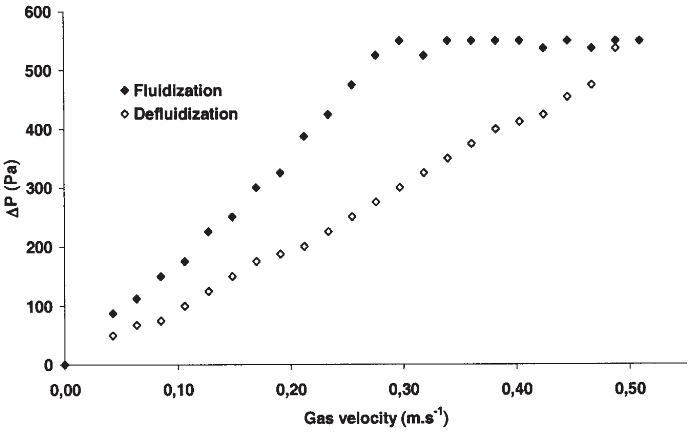

Fig. 6. Pressure drop hysteresis in segregating bed (X_{WS} = 0.25)

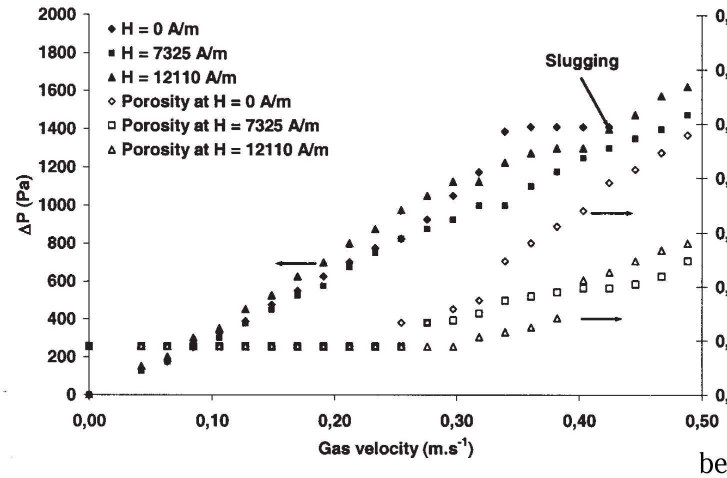

Fig. 7. Pressure drop and porosity through "homogeneous" bed at(X = 0.75) different H applied field intensity

For a highly segregated bed, the defluidization curve can be apriori constructed by joining the fluidization curves of pure jetsam and pure flotsam [26].

As can be seen, application of a magnetic field to fluidized ferromagnetic particle bed is a way to suppress slugs, bubbles (seen as gas by-pass), or at least to decrease their magnitude, and finally leading to a better contact between gas and solid.

For example, in the same way as for WS 70 bed, application of a magnetic field eliminates the slugging phenomenon, thus the pressure to continuously increase according to the gas velocity (fig. 7).

As bed being squeezed during the pouring operation, the bed expansion depends on the gas velocity, an effect not seen for the pre-expanded bed (section 3.2). Without a magnetic field, particles tend to segregate at 0.34 m.s^{-1} velocity. In contrast, under magnetic field although the bed began to expand, the clay upper layer being fluidized. It is observed a kind of cohesion, and the components are more homogeneously distributed at the end of the fluidization-defluidization cycle, according to a bacon structure (alternating layers of clay and metal particles) [28].

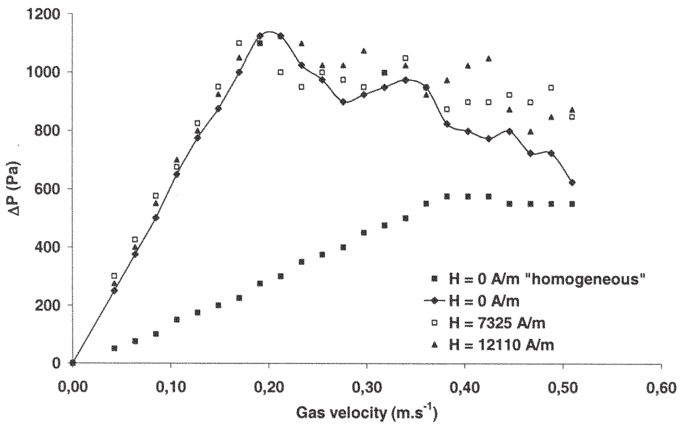

Fig. 8. Pressure drop comparison between "homogeneous" and layered bed (X =0.5)

This final bacon like bed structure encourages us to test the behaviour of an initially layered bed.

Layered beds

The layered bed was divided into 5 clay layers and 5 WS 70 layers, beginning by a clay layer at the bottom of the bed, and a WS70 layer at the top (fig. 3 (b)). Pressure drop experiments were carried out without or with the use of a magnetic field. The fixed bed regime can be easily seen. For comparison, experiment with the same amount of material but mixed "homogeneously" is also presented in figure 8.

As displayed, the behaviours of homogeneous and layered bed are very different, mainly due to pouring and particle organization in the layer. As the flowrate increases, differences among phases decrease and a subsequent raise of pressure drop, is recorded. This can be explained by the bed reorganization, and by the progressive movement of the bed layers due to the gas flow, more "mobile" and "mixed" clay layers disturbing progressively the alignment of WS particles. As the flowrate increases, layered bed in "no field" experiment tends to reach the same pressure drop as for the homogeneous on field experiment.

In the pictures of figure 9, one can notice the aspect of the bed: at the initial state and for two different values of the magnetic field intensity.

Evolution of the bed expansion, according to magnetic field intensity, has not been clearly identified, as the layer pouring operation plays an important role in the bed behaviour. As a result, and to avoid this uncontrolled

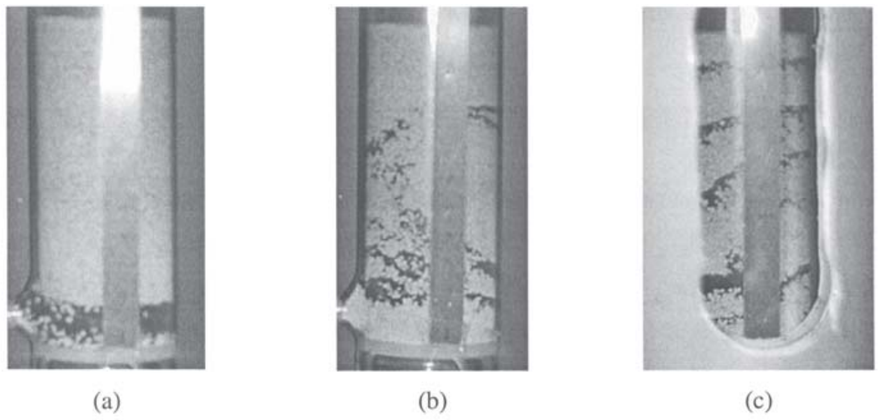
(a) (b) (c)

Fig. 9. Photographs of layered bed at the end of fluidization-defluidization cycle 0 A/m (a), 7325 A/m (b), 12110 A/m (c)

squeezing factor, it is preferable to obtain an apparent "homogeneous" bed in order to intensify the gas depollution process by adsorption.

Conclusions

Fluidization experiments were carried out using clays or mixtures of clays and ferromagnetic particles (in various proportions). Monocomponent beds (clays particles) exhibited classical behaviour: filtration and fluidization regimes, the minimum fluidization velocity being in agreement with the literature recommended correlations.

A mixture of clay and ferromagnetic particles, with different particle diameters but close the minimum velocity of fluidization, was also studied and obviously presents segregation phenomena whatever the kind of mixture (initially layered or homogeneous bed) in the non-magnetic field experiment.

Using magnetic stabilisation of the mixture bed, significant changes in the bed behaviour, have been observed delaying of segregation and slugging, leading to a higher stability, all being favourable in the gas depollution processes by adsorption.

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