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BUBBLING FLUIDIZATION OF BINARY MIXTURES: DETERMINATION OF MINIMUM FLUIDIZATION VELOCITY

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Abstract: The attractiveness of the application of fluidization in various technological operations comes from the fact that it provides features that can be viewed as: intensive mixing of solid particles in a fluidized bed, easy supply and drainage of material, a large contact surface between the gas and solid particles and nearly constant temperature all over the bed. Knowledge of the minimum fluidization velocity is fundamental to optimizing the performance of fluidized beds composed of mixtures. The present work aimed to determine the minimum fluidization velocity of binary mixtures using the characteristic diagram of pressure drop in the bed and to develop an experimental correlation for the minimum fluidization velocity of zeolite and polyethilene binary mixtures. In the case of two-component mixture fluidization, the transition to fluidized condition occurs gradually because the finer particles pass into a fluidized state at lower fluid velocities. Heavier particles transit more slowly to the fluidization state. The transitional area size depends on the physical characteristics of particles and increases with an increasing difference in the physical properties of the particles. The fluidization curve which is obtained at the transition to the fluidized state of two component mixtures is presented.
Keywords: fluidization velocity, binary mixtures, characteristic diagram of pressure drop in the bed

1. INTRODUCTION

Many operations in a fluidized bed are characterized by the processes of heat exchange between the gas and solid particles which include the mass transfer. One of these processes is the material drying in a fluidized bed, which is a technological operation used to change the properties of natural raw materials as a result of application for the use, conservation, new structure, or simply, reduction of the original mass.

The increasing prominence of fluidized beds is due to wellacknowledged advantages of excellent heat and mass transfer, and ease of operation, among others. The process of drying granular material in a fluidized bed with an infill or the socalled inert material, has been of particular interest to many researchers, starting from the 1970s. The purpose of introducing the second component into the fluidized bed was to reduce the time of drying at a defined humidity. An inert medium fluidized bed dryer can be defined as a fluidized bed of fine and coarse particles for fine-grained material drying whereby the coarse particles serve as inert material for heat transfer media.

The minimum fluidization velocity (Umf), which is defined as the superficial gas velocity at which the drag force of the upward moving gas is equal to the apparent weight of the particle bed [1,2], seems to be amore tractable parameter in fluidization. The U_{mf} value is important because it dictates the onset of fluidization [1,3] and phenomena like the extent of segregation in bubbling fluidized beds [4–8].

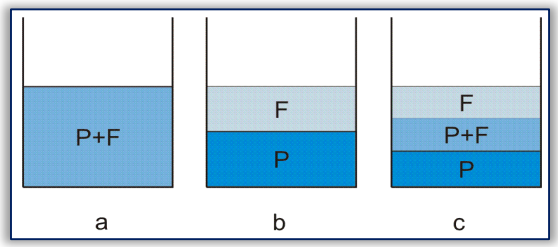

Figure 1. Possible composition of the two-component mixture: a) has been fully mixed b) as a whole stratified c) partially mixed / stratified

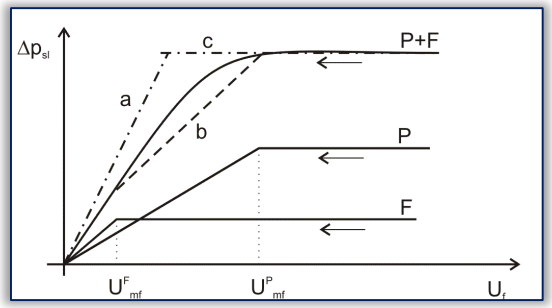

Figure 2. Fluidization curve of a two-component layer a) has been fully mixed b) as a whole stratified c) partially mixed / stratified

2. MINIMUM FLUIDIZATION VELOCITY

Major objectives of the present study were to investigate the effect of the average diameters of the binary mixture components on the fluidization quality, specifically regarding the segregation of particles. In a binary component, generally speaking, the mixing components have different minimum fluidization rates. A component with a slower fluidization velocity – F; a component with a higher minimum fluid velocity - P;

Various technologies can be found in the literature to define and determine the minimum velocity of fluidization of binary mixtures. Chiba et al. [9] obtained the curves of the dependence of the pressure drop of velocity using the deflification method in the decrease in the velocity of the bed. Noda et al. [10] carried out a rapid defluidization of the bed, after which the dependence of the pressure drop of the velocity was obtained. Bilbao et al. [11] performed experiments in a 80 mm diameter glass column with a porous plate as a distributor. The ambient air temperature was used as a fluidizing agent for different material relations in a two-component blend of quartz sand and chopped straw. From their experimental data, they obtained an empirical equation that can calculate the minimum fluidization velocity of the mixture:

$$\log_{10}\log_{10}\frac{U_{mf}}{U_S}=\log_{10}\log_{10}\frac{U_{SS}}{U_S}+m\log_{10}\left(1-\upsilon_S\right) \tag{1}$$

$$m=0.17\left(\frac{d_{SS}}{d_S}\frac{\rho_S}{\rho_{SS}}\right)^{0.437} \tag{2}$$

The equation shows the dependence of the minimum fluidization velocity on several parameters, such as: sand particle diameter, straw diameter, their density, volume fraction of the sand in the layer, the minimum fluidization velocity of the straw and sand mixture etc

Formisani investigates the specific role of the difference in component density on the process of segregation fluidization of two-component beds. The behavior of such systems is characterized by replacing the traditional concept of a "minimum fluidization rate" of a binary component with a "fluidization rate interval" of a bed limited by the "initial" and "final" fluidization rates.

In the literature there are equations in which the determination of the minimum fluidization velocity in multicomponent materials is based on the granulometric composition of the bed material. Thus Babuha and Rabinovich [12] propose the equation:

$$\mathrm{Re}_{\mathrm{mf}}=\frac{\mathrm{Ar}}{150\frac{1-\varepsilon_{\mathrm{mf}}}{\varepsilon_{\mathrm{mf}}}\mathrm{C}^2+\mathrm{C}\sqrt{\frac{1.75\mathrm{Ar}}{\varepsilon_{\mathrm{mf}}^3}}} \tag{3}$$

where is:

$$\mathrm{C}=1+\mathrm{x}_1\left(\frac{\mathrm{d}_{\mathrm{p\,max}}}{\mathrm{d}_{\mathrm{p1}}}-1\right)+\mathrm{x}_2\left(\frac{\mathrm{d}_{\mathrm{p\,max}}}{\mathrm{d}_2}-1\right)+.....+\mathrm{x}_{\mathrm{n-1}}\left(\frac{\mathrm{d}_{\mathrm{p\,max}}}{\mathrm{d}_{\mathrm{pn-1}}}-1\right) \tag{4}$$

The values for Ar and Re_{mf} are related to the particles of the largest fraction in the material. These authors give the equation for the minimum fluidization velocity determination:

$$\mathrm{U}_{\mathrm{mf}}=\mathrm{cg}^{\frac{\mathrm{n+1}}{3}}\mathrm{v}_{\mathrm{f}}^{\frac{1-2\mathrm{n}}{3}}\mathrm{d}_{\mathrm{pM}}^{\mathrm{n}}\left(\frac{\rho_{\mathrm{M}}-\rho_{\mathrm{f}}}{\rho_{\mathrm{f}}}\right)^{0.6}\Pi^{0.33} \tag{5}$$

$$\Pi=\frac{\sum_{\mathrm{i}}\frac{\mathrm{x_i}\rho_{\mathrm{max}}\mathrm{d}_{\mathrm{p\,max}}^3}{\mathrm{x}_{\mathrm{max}}\rho_{\mathrm{i}}\mathrm{d}_{\mathrm{i}}^3}}{\sum_{\mathrm{i}}\frac{\mathrm{x_i}\rho_{\mathrm{max}}\mathrm{d}_{\mathrm{p\,max}}}{\mathrm{x}_{\mathrm{max}}\rho_{\mathrm{i}}\mathrm{d}_{\mathrm{i}}}} \tag{6}$$

$$\left.\begin{matrix}\mathrm{c}=0.025\\ \mathrm{n}=1.3\end{matrix}\right\}\mathrm{pri}\quad \mathrm{d}_{\mathrm{p\,max}}\left(\frac{\mathrm{g}}{\mathrm{v}_{\mathrm{f}}^2}\right)^{1/3}<3$$

$$\left.\begin{matrix}\mathrm{c}=0.045\\ \mathrm{n}=0.765\end{matrix}\right\}\mathrm{pri}\quad \mathrm{d}_{\mathrm{p\,max}}\left(\frac{\mathrm{g}}{\mathrm{v}_{\mathrm{f}}^2}\right)^{1/3}\geq 3 \tag{7}$$

where x_{max} represents the mass participation of the largest diameter fraction.

The porosity of the bed at the minimum fluidization velocity may be determined depending on the pressure drop and the height of the bed at the minimum fluidization velocity according to the equation:

$$\varepsilon_{\mathrm{mf}}=1-\frac{\Delta\mathrm{p}_{\mathrm{sl}}}{\mathrm{h}_{\mathrm{mf}}\,\mathrm{g}\left(\rho_{\mathrm{i}}-\rho_{\mathrm{z}}\right)} \tag{8}$$

3. EXPERIMENTAL RESEARCH

The laboratory apparatus was designed and manufactured to suit the specific requirements of this experimental research [13]. Special attention was directed towards enabling a continuous measurement of operating parameters. The apparatus consists of the following components: variable speed fan (4), sections for air flow

measuring with a metering station, electric heating (2), fluidized bed (1), the device for measurement, regulation and registration process (3, 5).

Table 1. Minimum fluidization velocity

The Author	Equation	Comment
Otero Corella	$U_{mf} = U_{mf}^{F} x^{F} + U_{mf}^{P}\left(1 - x^{F}\right)$	
Goossens	$U_{mf} = \frac{\mu_f}{\rho_f d_M}\left[\left(33.7^2 + 0.0408\,Ar_M\right)^{0.5} - 33.7\right]$	$Ar_M = \frac{d_M^3 \rho_f g(\rho_M - \rho_f)}{\mu_f^2}$; $d_M = \frac{R_0}{R_1} d^P d^F$; $\frac{1}{\rho_M} = \frac{x^F}{\rho_P^F} + \frac{(1-x^F)}{\rho_p^P}$; $R_0 = (1-x^F)\rho_p^F + x^F \rho_p^P$; $R_1 = (1-x^F)\rho_p^F d^F + x^F \rho_p^P d^P$
Kumar SenGupta	$U_{mf} = 0.0054 \frac{d_M^{1.34}(\rho_M - \rho_f)^{0.78} g^{0.78}}{\mu_f^{0.56} \rho_f^{0.22}}$	$d_M = \frac{1}{x^F/d^F + x^P/d^P}$; $\rho_M = x^F \rho_p^F + x^P \rho_p^P$
Cheung	$U_{mf} = U_{mf}^{F}\left(\frac{U_{mf}^{P}}{U_{mf}^{F}}\right)^{(x^P)^2}$	$\frac{d^P}{d^F} < 3$
Rowe Nienow	$U_{mf} = U_{mf}^{F}\left[\left(\frac{\varepsilon_{mf}}{\varepsilon_{mf}^{F}}\right)^3 \left(\frac{1-\varepsilon_{mf}^{F}}{1-\varepsilon_{mf}}\right)^{0.947}\right]^{0.95}\left[x^F + \left(\frac{U_{mf}^{F}}{U_{mf}^{P}}\right)^{0.54}\left(1-x^F\right)\right]^{-1.85}$	For the two-component mixture whose particles differ only in size
Chiba	$U_{mf} = U_{mf}^{F}\left[f_{VF} + (1-f_{VF})\frac{\rho_p^P}{\rho_p^F}\right]^{0.95}\left[x^F + \left(\frac{\rho_p^P U_{mf}^F}{\rho_p^F U_{mf}^P}\right)(1-x^F)\right]^{-1.85}$	$f_{VF} = 1 \Big/ \left[1 + \left(\frac{1}{x^F} - 1\right)\frac{\rho_p^F}{\rho_p^P}\right]$
Chiba	$U_{mf} = U_{mf}^{F}\frac{\rho_M}{\rho_p^F}\left(\frac{d_M}{d_F}\right)^2$ $U_{mf} = \frac{U_{mf}^{F}}{\left(1 - \frac{U_{mf}^{F}}{U_{mf}^{P}}\right)x^F + \frac{U_{mf}^{F}}{U_{mf}^{P}}}$	$d_M = \left[f_{NF} d_F^3 + (1-f_{NF}) d_P^3\right]^{1/3}$; $\rho_M = f_{VF}\rho_p^F + (1-f_{VF})\rho_p^P$; $f_{NF} = \frac{1}{\left[1 + \left((1/f_{VF}) - 1\right)(d_F/d_P)^3\right]}$ It is used for the layer that is completely mixed. It is used for a layer that is completely stratified
Thonglimp	The first form: $Re_{mf} = 1.4 \times 10^{-3} Ga^{0.2} Mv^{0.1}$ $\quad Re_{mf} < 20$ $Re_{mf} = 2.88 \times 10^{-2} Ga^{0.63} Mv^{0.626}$ $\quad Re_{mf} > 20$ Other form: $Re_{mf} = \left(19.9^2 + 0.03196\,Ar_M\right)^{0.5} - 19.9$	$d_M = \frac{x^F \rho_p^P + x^P \rho_p^F}{x^F \rho_p^P d^P + x^P \rho_p^F d^F}$; $\rho_M = \frac{\rho_p^F \rho_p^P}{x^P \rho_p^F + x^F \rho_p^P}$; $Ga = \frac{d_M^3 \rho_f^2 g}{\mu_f^2}$; $Mv = \frac{\rho_M - \rho_f}{\rho_f}$

Fluidization bed has a circular cross-section with the inner diameter of 120 mm and the height of 600 mm. It was made of plexiglass, which allowed for the visual monitoring of the process. At the bottom of the column is a distributor for air with 2800 holes with a diameter of 0.9 mm evenly distributed over the whole surface. Under the distributor, a canvas prevents degradation of the material and provides for an even distribution of air in the cross-section of the column.

The fluidization air flow was set manually for each experiment, by changing the number of fan revolutions, and determined using the standard method on the basis of the pressure drop measured in the measuring orifice. To calculate the air flow eq. verified by the previous calibration, was used in the examination:

$$L = 1.111 \cdot 10^{-5} \cdot \sqrt{\rho_1 \cdot \Delta p_b} \quad (9)$$

$$U = 0.02357 \cdot \frac{\sqrt{\rho_1 \cdot \Delta p_b}}{\rho_v} \quad (10)$$

The zeolite was initially classified using standard sieves with five size ranges. For preliminary tests of mixture segregation during fluidization, the zeolite was classified into four size: 0.3 mm, 0.5 mm, 0.7 mm i 0.9 mm.

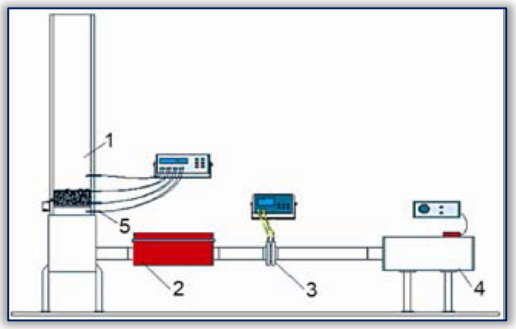

Figure 3. Schematic layout of the apparatus

4. EXPERIMENTAL RESEARCH RESULTS

In these experiments, zeolite was sifted through standard sieves and divided into fractions, whose middle particle diameters were: 0.3 mm, 0.5 mm, 0.7 mm, and 0.9 mm. Each fraction of zeolite was determined by the following characteristics: average particle diameter, actual density, bulk density, porosity of the bed at minimum fluidization, and minimum fluidization velocity (dp, ρ_p, ρ_n, ε_{mf}, U_{mf}).

The inert material was polyethylene (PE) in the form of a cylinder with an oval base of a = 3.8 mm, b = 4.4 mm, and h = 4.0 mm in dimensions. The real and bulk density of zeolite and PE were determined experimentally; the values of the specific heat capacity and thermal conductivity of the material were taken from the reference literature. The minimum fluidization velocity of all fractions of zeolite and PE was determined experimentally.

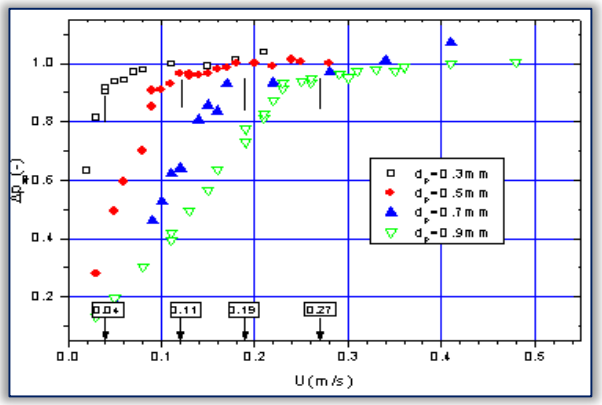

Figure 4. The minimum fluidization velocity of zeolite

The figures show the results of an experimental determination of the minimum fluidization velocity of zeolite and polyethylene.

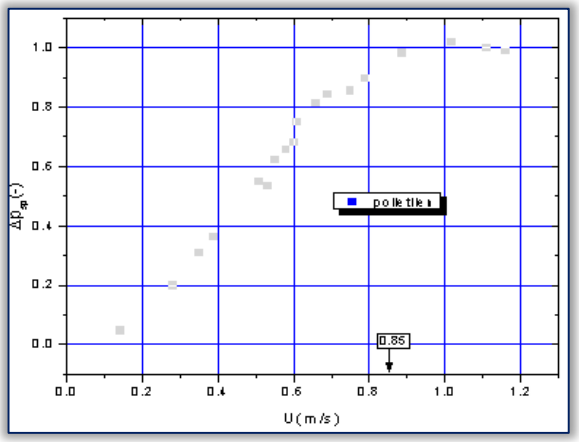

Figure 5. The minimum fluidization velocity of polyethylene

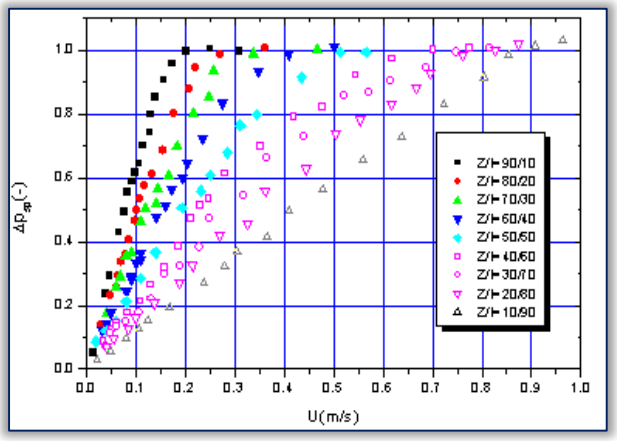

Figure 6. The minimum fluidization velocity mixture of zeolite (dp = 0.5mm) and polyethylene

5. CONCLUSIONS

The fluid dynamic behavior of binary mixtures composed of zeolite and polyethilene was investigated. The minimum fluidization velocities were determined. The fluid dynamic behaviors of binary mixtures in fluidization systems are directly related to the zeolite size and shape.

Regarding the inert material, understanding the effect of particle diameter on the mass ratio of zeolite/inert is fundamental to understanding the fluidization system.

The ratio of the diameters of the inert and zeolite significantly influences the segregation of the system, with a higher ratio, leading to more pronounced bed segregation and a reduction in the fluidization quality.

Note

This paper is based on the paper presented at INTERNATIONAL CONFERENCE ON APPLIED SCIENCES – ICAS 2018, organized by UNIVERSITY POLITEHNICA TIMISOARA, Faculty of Engineering Hunedoara (ROMANIA) and UNIVERSITY OF BANJA LUKA, Faculty of Mechanical Engineering (BOSNIA & HERZEGOVINA), in cooperation with the Academy of

Romanian Scientists, Academy of Sciences Republic of Srpska, Academy of Technical Sciences of Romania – Timisoara Branch and General Association of Romanian Engineers – Hunedoara Branch, in Banja Luka, BOSNIA & HERZEGOVINA, 9 – 11 May 2018.

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ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665