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VIDEOGRAMMETRY IN FLUIDIZED BEDS ANALYSIS

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Abstract: *Developed videogrammetric research technique is an optical method for analysis and estimation of gas fluidized bed hydrodynamics. Videogrammetry consists of process visualization, image analysis and stochastic process analysis. The two-phase flow pattern is described by the fluctuation of grey level parameter. Research focuses on the statistical analysis of the behavior of a fluidized bed operating under bubbling to turbulent conditions. Experimental data are collected by the means of a developed dynamic image analysis technique. Study was conducted in transparent, narrow fluidization apparatus. Results show that profiles of the grey level fluctuations and its stochastic parameters are correlated with particular flow pattern. The conformity of the digital flow pattern recognition method gives 82 % reliability.*

Keywords: Fluidization, Two-Phase Flow Pattern, Dynamic Image Analysis, Stochastic Process.

1. Introduction

Specific features of gas-fluidized beds are the exceptional solid mixing rate or distinctive heat and mass transfer properties. They can be related to the presence of certain flow pattern and are dominated by its behavior. Detailed information on two-phase flow pattern of gas-solid mixture is a need everywhere fluidization technology is applied, particularly in industrial processes. Therefore, leading and modernization of industrial system processes or design and development of fluidization devices, require wide range of experimental data according various flow characteristics. This causes the need for multiphase system measurement methods and flow structure estimation, capable of giving particular information about condition of given fluidization system. The most commonly used approach for fluidized bed simulations is Eulerian–Eulerian continuum modelling (Busciglio et al., 2008). In this model of multiphase flows the fluid and solid phases are treated as interpenetrating continuum phases. The balances of continuity, momentum and energy for both phases need to have appropriate boundary conditions and jump conditions for phase interfaces. Even until now the resultant continuum approximation for the solid phase has no equation of state and lacks variables such as viscosity and normal stress (Pain et al., 2001). Therefore certain averaging techniques and assumptions are required to obtain a complete momentum balance for the solids phase. Almost a half of century was not enough to fully develop a theory of particle collision based on the kinetic theory approach (Chapman and Cowling, 1970). The solid-phase momentum equation contains an additional term to account for momentum exchange due to particle–particle collisions (Sinclair and Jackson, 1989). The absence of the stress term of the particle phase in the particulate momentum equation has led to different models adopting different closure methods for local structures (Molerus, 1993), including the kinetic theory model (Gidaspow, 1994) and (Hrenya and Sinclair, 1997). All these problems comes from the lack of experimental data (Anweiler and Ulbrich, 2004). Digital visualization of two-phase flow and dynamic image analysis offers unique possibility for uncovering complexity of the flow pattern, without invading the delicate multiphase equilibrium inside the apparatus (Agarwal et al., 1996). Different image analysis methods allow CFD model verifications (Anweiler and Masiukiewicz, 2016). The aim of presented research work is to draw up digital optical method for two-phase flow structure estimation inside fluidization apparatuses. To obtain the aim, the advantage of high speed video camera and own PC software for image processing and analysis was taken. Developed method - videogrammetry - is based on dynamic analysis of digital image sequences, representing the fluidization process and stochastic analysis of the process (Ulbrich et al., 2002).

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2. Experimental set-up

The experiment was held in vertical, narrow, transparent model of fluidization apparatus, which is shown in Fig. 1a. Visualization of two-phase flow structures was done with the use of high speed (F_{max} = 1800 fps) and high resolution (1024 × 1024 pix), digital CMOS camera. Schematic view of visualization technique is shown in Fig. 1b.

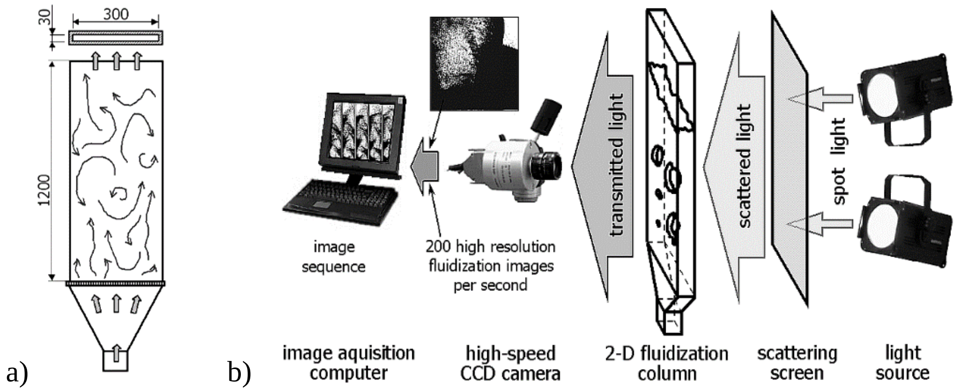

Fig. 1: Experimental setup: a) the dimensions of the fluidized bed chamber; b) two-phase flow pattern visualization technique.

The column was filled with polyethylene spherical particles (d = 6.0 mm; ρ_S = 1050 kg/m^3; Ar = 7.84 x 10^6; u_{mf} =1.4 m/s; Geldart group D). Geldart particle groups are one of the criterions of physical similarity for solid particles. Archimedes number (Ar) is one of the criterions of hydrodynamic similarity for solid particles and is given according to (Lim et al., 1995). Modified Archimedes number ($Ar^{1/3}$) was used and another criterion of similarity – dimensionless gas velocity (u_G*) according to (Bi et al., 1995).

3. Methods

The experiment consisted of three steps. First – visualization of the fluidization process. Second – dynamic image analysis of obtained fluidization images. Third – stochastic analysis of grey level fluctuations. Dynamic image analysis is the key feature of described method and consists of average brightness level of pixel calculation (M_k) in the specified area of the image according to Eq. (1).

$$M_k = \frac{1}{(n-l)(o-m)} \sum_{j=l}^{n} \sum_{i=m}^{o} p_{j,i}^{k} \qquad k = 1,2,\ldots,N \tag{1}$$

where: (l, m, n, o) – examination area coordinates, $p^k_{j,i}$ – grey level value for single pixel with (j, i) coordinates for the (k) image number, which is a part of sequence with (N) images.

Stochastic analysis of the brightness fluctuation is made to find stochastic character of the process. This allows determination of periodic and random events and was done using autocorrelation function (ACF) according to Eq. (2) and probability density function (PDF) according to Eq. (3)

$$R_{xxr} = \frac{\frac{1}{N-1}\sum_{i=0}^{N-1}(x_i - \bar{x})(x_{i+r} - \bar{x})}{R_{xx0}} \qquad r = 0,1,\ldots,N-1 \tag{2}$$

$$P(x) = \lim_{\Delta x \to 0} \frac{\lim_{T\to\infty} \frac{T_x}{T}}{\Delta x} \tag{3}$$

4. Results and discussion

The result of two-phase flow pattern investigation, is precise visualization of fluidization pattern, as shown in Fig. 2, which demonstrates partial sequences of acquired images for turbulent fluidization. For each frame of the sequence (movie), dynamic image analysis gives a set of instantaneous grey level values. With the use of different measuring areas, the flow structure can be analyzed in various modes.

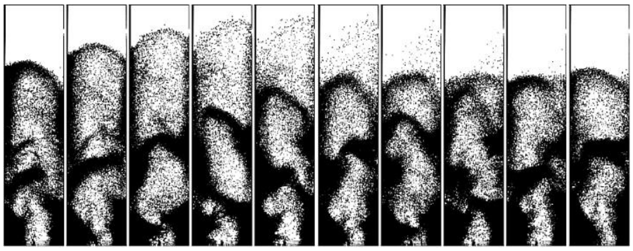

Fig. 2: Image sequence (visualization) of plug flow pattern in classical fluidized bed (Δτ = 0.05 s).

The area can act as a local or global event tracking device. The result of that analysis is set of grey level fluctuation time courses, as shown in Fig. 3. Various placement of measuring areas (L_1, L_2, L_3) generates different grey level fluctuation signals. The profile of grey level changes is basis for flow regime estimation and two-phase structure recognition. Further data processing is grounded on the theory of stochastic process.

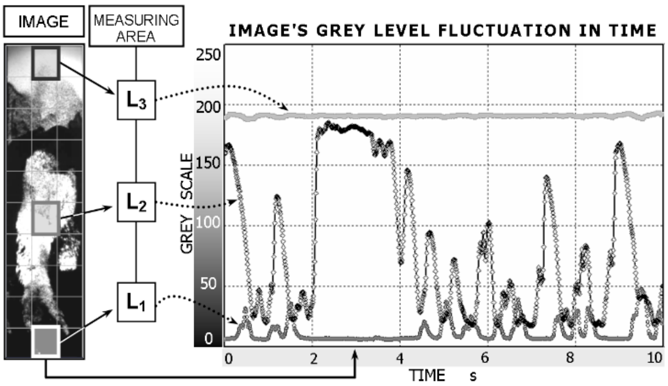

Fig. 3: Dynamic image analysis (pixel brightness) in specified area of the image, generates different grey level fluctuation time signals (depend on used area, i.e. L1, L2, L3).

The results of stochastic analysis are shown in Fig. 4. The profiles of the fluctuation courses and values of the functions are correlated with particular flow pattern.

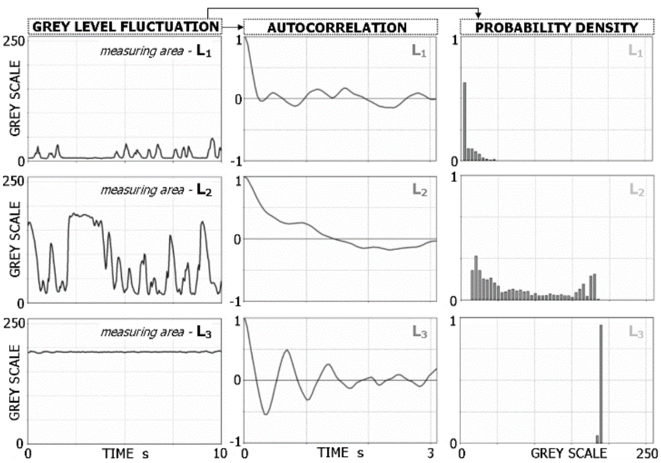

Fig. 4: Example results of stochastic analysis of grey level fluctuations obtained from image analysis.

5. Conclusions

The analysis of presented results provides many detailed information about the two-phase flow pattern, such as the intensity of bubbling, size, shape and speed of the bubbles, void fraction, coalescence/dispersion of gas/solids and more. Final step of the research work and summary of the investigation is compatibility analysis of the method. The proper identification of the two-phase gas-solid flow pattern according to visualized flow structures was done by correlation of the visualization results with measurements and recognition data. The analysis of method's detection efficiency is shown in Tab. 1. For each two-phase pattern the stochastic functions and parameters were determined in time, space and gas velocity domain. For each case there is also a video recording of real flow pattern. From one side there are visually observed structures, from the other side there are recognized flow structures. Recognition was based on digital image analysis. Tab. 1 shows the efficiency analysis with the use of stochastic parameters technique for classical fluidization. The conformity of the digital recognition method is high and gives 82 % reliability.

Behavior of the fluidized bed depends on many factors. To estimate it's condition, there is a need for a versatile, non-invasive and operational safe measurement technique. Videogrammetry, as optical method for two-phase, gas-solid flow pattern estimation has all these advantages. Dynamic image analysis meets general requirements for investigation of fluidized bed condition. This method is also suitable for design and troubleshooting of new devices or process monitoring. The results could be used for comparison of different processes, which will allow creation of automated monitoring system for process analysis and maintenance, i. e. preservation of desired flow pattern in various types of fluidized beds and other multiphase flow devices.

Tab. 1: Example of the conformity test for elaborated optical estimation method for two-phase flow pattern – correlation of observed (visualized) flow pattern and identified flow structure with the use of dynamic image analysis.

Classic fluidization						
No. of identified objects		Observed flow structure				
		Filtration	Bubble	Plug	Turbulent	Σ
Identificated flow structure	Filtration	3				3
	Bubble		5	3		8
	Plug		1	8	1	10
	Turbulent		1		5	6
	Σ	3	7	11	6	27
Efficiency		100%	71%	73%	83%	82%

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