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THE EFFECT OF SUPERFICIAL GAS VELOCITY ON BUBBLE SIZE DISTRIBUTION IN DIFFUSED AERATION SYSTEMS

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This paper focuses on bubble size distribution (BSD) in a rectangular column of 0.3×0.3 m cross sectional area and 1.1 m height, equipped with a ceramic porous diffuser of 50 mm diameter. Different values of average bubble size and bubble rise velocities are reported in literature due to the differences in the distributor design, column diameter and range of gas velocities. BSD is an important parameter for determining the volumetric mass transfer coefficient. A high speed digital video camera is used for direct flow visualizations and, combined with image processing, for BSD. Experimental results show that the structure of air-water dispersed system changes with increasing superficial gas velocity, from a homogeneous regime - characterized by small spherical bubbles and low bubble density, to a heterogeneous regime, where bubble deformation and density increase

Keywords: bubble size distribution, dispersed system, superficial gas velocity, flow regimes, image processing.

1. Introduction

In industrial gas–liquid operations (e.g. gas/liquid reactions, agitation by gas injection, fermentations, aeration, etc.) in chemical and biochemical process industries conducted in bubble columns (BC), bubble size represents an important design parameter, since it defines the gas–liquid interfacial area available for mass transfer. In turn, bubble size distribution in gas–liquid dispersions depends largely on column geometry, operating conditions, physico-chemical properties of the two phases and type of gas sparger.

The design of bubble columns has primarily been carried out by means of empirical or semi-empirical correlations based mainly on experimental data. Since the multiphase flow is in general complex in structure, the design and scale up of such type of equipment is still a difficult task and subject to errors (Deckwer and Schumpe, 1993).

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Although the performance of bubble columns has been extensively studied many basic questions remain unanswered such as the mechanisms of bubble formation, the most appropriate correlations for practical applications, the mechanisms of bubble break-up and coalescence, that is important in the evolution of BSD in bubble columns [1].

Depending on the gas flow rate, two main flow regimes can be observed in bubble columns, i.e., the *homogeneous* (bubbly flow) regime encountered at low gas velocities and characterized by a narrow BSD, the *heterogeneous* (churn-turbulent flow) regime observed at higher gas velocities and characterized by the appearance of large bubbles, formed by coalescence of the small bubbles and having a higher rise velocity.

Depending on the type of the gas distributor and the properties of the liquid phase, both regimes can be obtained in the same equipment by varying the gas input flow rate.

Regarding the behavior of *fine porous* plate spargers limited information is available in the literature. Hebrard et al. [2]., that studied the influence of gas sparger characteristics on the hydrodynamic behavior of bubble columns, concluded that bubble size depends on the physico-chemical properties of the liquid phase, the type of gas distributor and the superficial gas velocity.

Zahradnik et al. [3]., investigated the effect of various parameters (i.e., column geometry, distributor type, liquid properties) on the gas–liquid flow regime stability and gas holdup in bubble column reactors equipped, among others, with porous spargers.

The purpose of this work is to study the effect of superficial gas velocity on bubble size distribution in a bubble column equipped with a fine porous diffuser.

Bubble size is a critical parameter in these diffused bubble systems because it determines the interfacial surface area, bubble-rise velocity, and mass-transfer coefficient [4]. In addition, bubble size may vary significantly as the bubbles pass through the system [4].

The detection of regime transition from homogeneous to churn-turbulent flow and the investigation of the transition regime are quite important. As the transition takes place, significant changes are observed in the hydrodynamic behavior of the system. There exists an onset of upward liquid circulation in the column centre and downward liquid circulation near the column wall.

2. Experimental setup and procedure

The experimental set-up (Fig. 1) consists of a vertical rectangular Plexiglas column 1.1 m height, having a square cross-section (side length 30 cm).

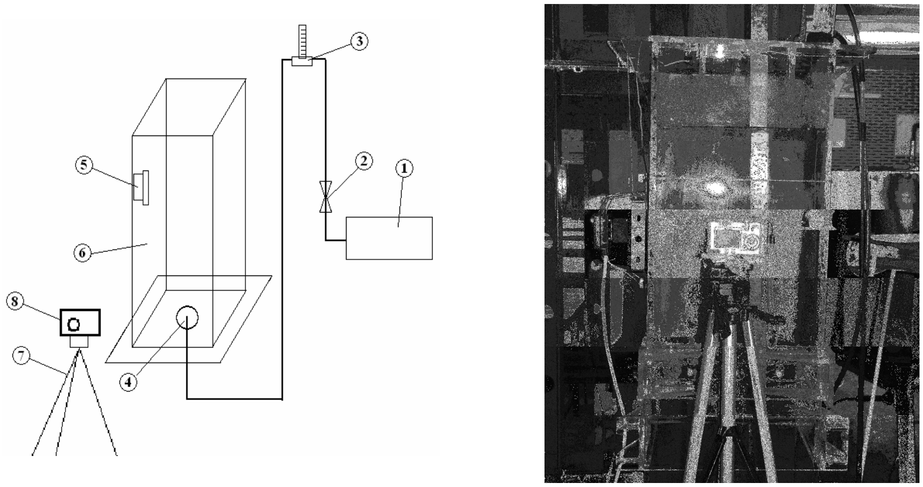


Figure 1. Experimental set-up: 1- compressor, 2- regulating valve, 3- rotameter, 4- porous diffuser, 5- illuminating system, 6- plexiglas rectangular column, 7- tripod, 8- digital camera

The column is equipped with appropriate rotameters for gas phase flow measurement and control. The rectangular geometry was preferred over the cylindrical one, because it facilitates both the direct flow visualization and the use of optical measuring methods by minimizing optical distortion. For the injection and uniform distribution of the gas phase, a *porous diffuser*, i.e., a round ceramic porous disk, 5.0 cm in diameter, is placed at the center of the bottom plate.

The capability of modelling and measuring BSD is often restricted by the limited measuring technique. Conventional measuring techniques have lost their properness due to the fact that the probe must be inserted into the column, so that it interfere the motion of bubbles and the hydrodynamics [5]. The photographic method, based on using a high speed digital camera for bubble size is preferred by researchers because is less expensive than others and it gives much more information on bubble distribution spectrum, flow regimes, bubble shape, bubble dispersion and coalescence.

The photographic method used in this study represents an improvement of that presented in literature. The classical photographic method introduces an “intrinsical” error by measuring all the bubbles uniformly illuminated by a lighting source, some of them situated in other planes than the focussing plane.

In order to eliminate this kind of error, authors have proposed an improved procedure by illuminating a single plane: a cold light passing through a slit determines a light spot on the bubble surface in the focussing plane (fig. 2a), allowing all bubbles situated in that plane to be accurately measured. The camera is fixed on a stand close to the area of observation in such a way that the shooting is perpendicular to the illuminated plane. The calibration of the measuring system is accomplished by measuring a micro-scale placed at the focussing plane (fig.

2b). Subsequent image processing (e.g. noise reduction, brightness improvement, contrast enhancement, shadow and double images removal) results to a sharp bubble–liquid interface.

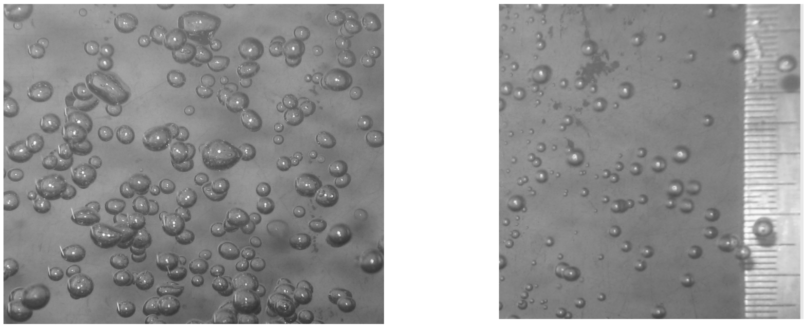


Figure 2. Photographs of the dispersed air-water system: a – bubbles lighted through the slit, b – calibration of the measuring system

Image analysis, using appropriate software (*SigmaScan Pro*), allows bubble size prediction. The bubbles were approximated by ellipses whose major and minor axes (d_H and d_V respectively) were computed by the software. The equivalent bubble diameter d_e is given by

$$d_e = \sqrt{d_H d_V} \ . \tag{1}$$

Approximately 900 bubbles (a number considered to be adequate for statistical calculations) were measured at different air flow rates and heights.

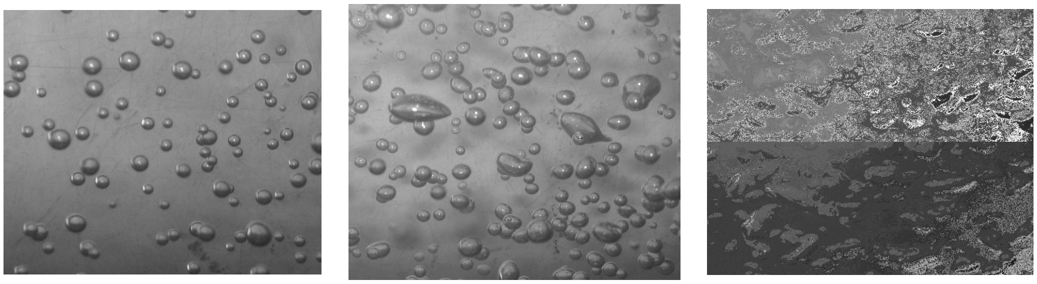
3. Results and discussions

Figure 3 shows photographs of air-water system at different superficial gas velocity. Changes in flow structure occur with increasing the superficial gas velocity, defined as:

$$w = \frac{Q}{A} \tag{2}$$

where Q is the gas flow rate and A the column cross section area.

The homogeneous flow regime is obtained at low superficial gas velocities, (figure 3a) [6] [7]. This flow regime is characterized by bubbles of relatively uniform small sizes and rise velocities [8]. A uniform bubble distribution and relatively gentle mixing is observed over the entire cross-sectional area of the column [9]. There is practically no bubble coalescence or break-up, thus bubble size in this regime is almost completely dictated by the sparger design and system properties [10].



a) w = 0,011 cm/s b) w = 0,055 cm/s c) w = 0,272 cm/s

Figure 3. Photographs of air-water system at different flow regimes: a) homogeneous, b) transitions, c) heterogeneous regimes for a disc porous diffuser Ø 50 mm.

When the superficial gas velocity w reaches the value w_{trans}, coalescence of the bubbles takes place to produce the first fast-rising "large" bubble. The appearance of the first large bubble changes the hydrodynamic picture significantly. This is called the transition regime (figure 3b).

The hydrodynamic picture in a gas–liquid system for velocities exceeding w_{trans} is commonly referred to as the *heterogeneous flow regime*. In the heterogeneous regime, small bubbles combine in clusters to form large bubbles that travel up through the column at high velocities (in the range 1–2 m/s), in a more or less plug flow manner. This regime is maintained at higher superficial gas velocities (figure 3c). This regime is characterized by the disturbed form of the homogeneous gas–liquid system due to enhanced turbulent motion of gas bubbles and liquid recirculation. As a result unsteady flow patterns and large bubbles with short residence times are formed by coalescence due to high gas throughputs. This flow regime is thus sometimes referred as coalesced bubble flow regime, indicating the much different sizes of the bubbles [8].

Figure 4 shows histograms for BSD in air-water system at homogeneous (a, b), transition (c) and heterogeneous regimes (d). The mean bubble diameter increases with the superficial gas velocity, and the BSD histograms become asymmetric. This fact is more emphasized in figure 5: the range for equivalent bubble diameter becomes wider with increasing superficial gas velocity and the curves representing the bubble frequency number move to higher values of bubble diameter.

By bubble coalescence and break-up, a wide bubble size distribution is attained (figure 4 c, d). The average bubble size is governed by coalescence and break-up which is controlled by the energy dissipation rate in the bulk [10]. Wide bubble size range, intensive mixing and bubble cluster formation were also pointed out by Hyndman et al. [5]. Matsuura and Fan [11] reported that this regime consisted of a mixture of small and larger bubbles with diameters ranging from a few millimeters to a few centimeters. For the porous diffuser tested in this study the equivalent bubble diameter ranges for the homogeneous and heterogeneous regime from 0.5 to 5 mm and from 0.1 to 30 mm respectively.

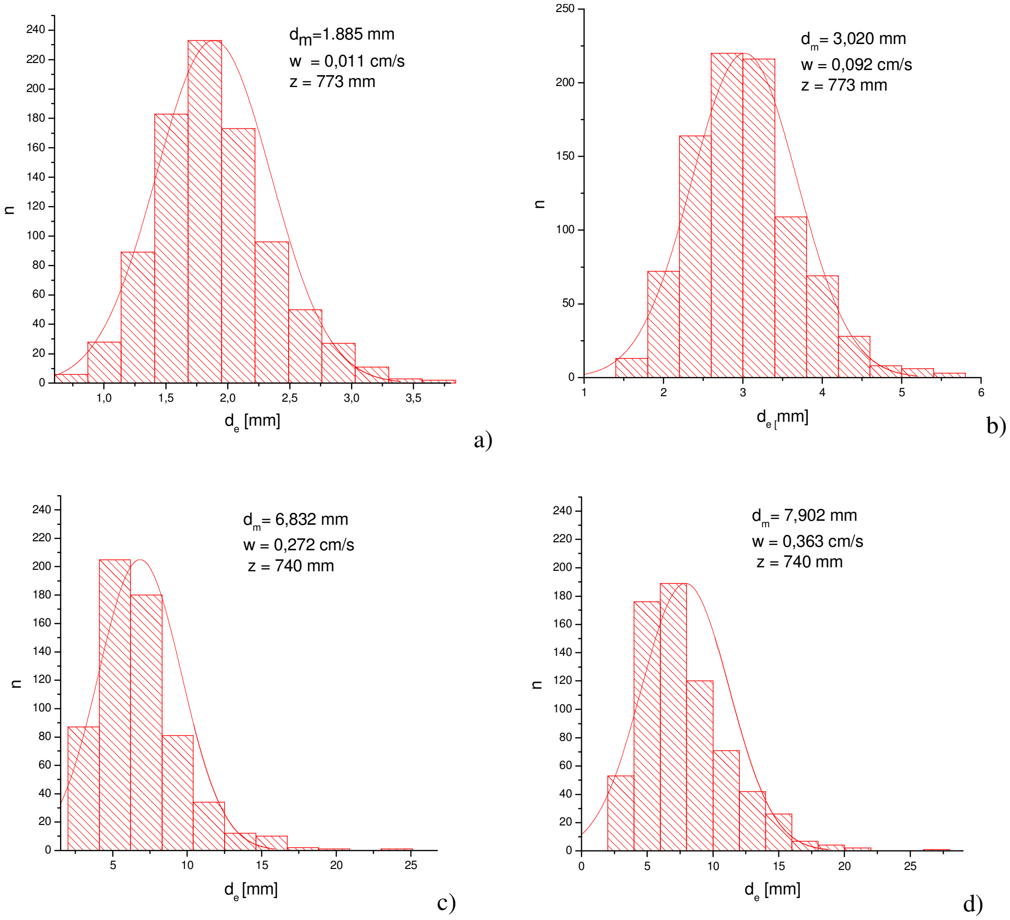


Figure 4. Histograms for BSD in air-water system at different superficial gas velocities for a porous diffuser Ø 50.

Churn-turbulent flow is generally observed in industrial-size, large diameter columns [5]. It has been shown that the gas–liquid mass transfer coefficient is lower at churn-turbulent (heterogeneous) regime as compared to homogeneous flow. Bubble columns are mostly operated under heterogeneous flow conditions in the chemical industry. For these models, information on the hold up fractions, contributions to the overall flow, rise velocity and superficial gas velocity fractions are required for small and large bubbles.

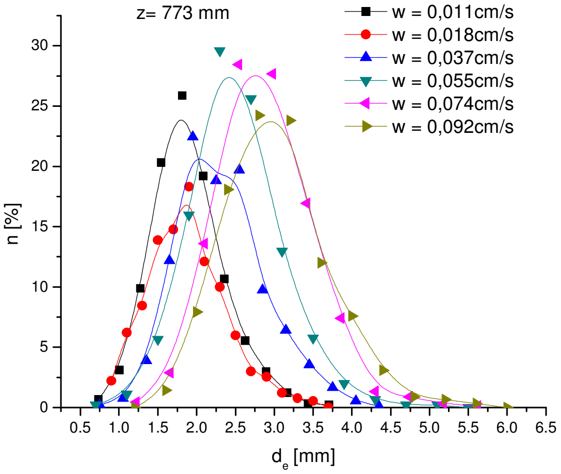


Figure 5, Comparison of bubble size distributions in the homogeneous regime, porous diffuser Ø 50 mm

The Sauter bubble diameter (d_S), defined as

$$\overline{d}_S = \frac{\sum_{1}^{m}(n_i \cdot d_i^3)}{\sum_{1}^{m}(n_i \cdot d_i^2)} \tag{3}$$

is an usual representation of the mean bubble size.

As presented in figure 6, an increase in the superficial gas velocity leads to an increase in mean bubble diameter and Sauter diameter. The transition from homogeneous to heterogeneous regime is represented by the inflexion point on the curves $d_m=f(w)$ and $d_s = f(w)$. Transition occurs at w = 0.2 cm/s.

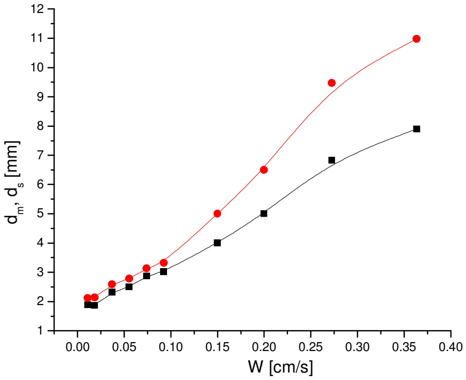


Figura 6 Mean bubble diameter and Sauter diameter as a function of superficial gas velocity.

4. Conclusions

- This study presents improvements to the photographic method used for measuring BSD in bubble columns by eliminating the "intrinsical" error of the classical method.
- The transition between homogeneous and heterogeneous regime determines radical changes in the two phase flow reflected in bubble size distribution. The *homogeneous regime* is characterized by a narrow BSD and a roughly uniform bubble size, for the tested porous ceramic diffuser Ø 50 in the range 0.2 ÷ 6 mm, and for the *heterogeneous regime* a wider BSD is obtained in the range 0.2 ÷ 30 mm.
- The optimum operating conditions of a bubble column would be the ones that enhance mass transfer and this is accomplished by maximizing the gas/liquid interfacial area. Consequently, the homogeneous bubbly flow regime encountered at lower gas flow rates is most desirable for increasing aeration efficiency.

REFERENCES

[1]. *J.-M. Delhaye and J. B. McLaughlin*, "Appendix 4: report of study group on microphysics", in International Journal of Multiphase Flow, **vol. 29**, 2003, pp. 1101–1116.

[2]. *G. Hebrard, Bastoul, D. and Roustan, M.,* "Influence of gas sparger on the hydrodynamic behaviour of bubble columns", in Transactions of the Institution of Chemical Engineers, **vol. 74**, 1996, pp. 406–414.

[3]. *J. Zahradnik, Fialova, M., Ruzicka, M., Drahos, J., Kastanek, F. and Thomas, N.H.,* "Duality of the gas-liquid flow regimes in bubble column reactors", in Chemical Engineering Science, **vol. 52**, 1997, pp. 3811-3826.

[4]. *M. Motarjemi and Jameson GJ.* "Mass transfer from very small bubbles—the optimum bubble size for aeration", in Chem Eng Sci, **vol. 33**, 1978, pp.1415–23.

[5]. *M. R. Widyanto, Utomo, M.B., Kawamoto, K., Kusumoputro, B. and Hirota, K.,* "Local gas hold up measurement of a bubble column using SONIA-ultrasonic non-invasive method", in Sensors and Actuators, **vol. A 126**, 2006, pp. 447–454.

[6]. *J.H. Hills,* "Radial non-uniformity of velocity and voidage in a bubble column", in Ind Eng Chem. Process Des Dev, **vol. 20**, 1974, pp. 540–545.

[7]. *L. S. Fan,* Gas–Liquid–Solid Fluidization Engineering, Boston, Butterworths, 1989.

[8]. *A. Schumpe and Grund G.* "The gas disengagement technique for studying gas holdup structure in bubble columns", in Can J Chem Eng, **vol. 64**, 1986, pp. 891–6.

[9]. *C. L. Hyndman, Larachi F and Guy C.* "Understanding gas-phase hydrodynamics in bubble columns: a convective model based on kinetic theory", in Chem Eng Sci, **vol. 52**, 1997, pp. 63–77.

[10]. *B. N. Thorat and Joshi JB.* "Regime transition in bubble columns: experimental and predictions", in Exp Therm Fluid Sci, **vol. 28**, 2004, pp. 423–30.

[11]. *A. Matsuura and Fan LS.* "Distribution of bubble properties in a gas–liquid–solid fluidized bed", in AIChE J, **vol. 30**, 1984, pp. 894–903.