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IMAGE PROCESSING TO DETERMINE MASS TRANSFER COEFFICIENT FOR GAS BUBBLE

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ABSTRACT

This paper suggests a simple system to study the hydrodynamics in a bubble column reactor and measuring gas-liquid specific interfacial area *a*, individual mass transfer coefficient k_L, gas holdup ε_G, flow regime, bubble size distribution, coalescence of bubbles, and bubble rising velocity for a single bubble by using image processing techniques. The images were taken by a digital camera and then analyzed with MATLAB 2008 to extract the required data of design parameters for the bubble columns. Experiments of bubble column of (0.081m diameter and 1.03 m height) were carried out with air-water. Gas velocity U_G is varied from $(0.22\times10^{-4}$ $-0.22\times10^{-3})$ m/s. This range of values of U_G allows the study the homogeneous flow regimes. To study the flow regime in bubble column the gas velocity changes from (0.00967-0.131521 m/s), afford to study and select the Homogeneous, Transition and Heterogeneous regimes. Transition velocity from bubbly to churn turbulent flow for (air-water) system, was about 0.148982 m/s.

Key Words: Bubble Columns, Mass Transfer, Coalescing, Flow Regime, Image Processing

1. INTRODUCTION

Bubble columns reactors are liquid filled geothermal wells which are aerated usually from the bottom according to [Seeger *et al.* (2001)]. Bubble columns simply structured, but very effective gas-liquid contacting systems. In chemical reactors, the dispersion of gas in the form of bubbles is achieved by passing the gas through multiple orifices into the liquid. Stoyan Nedeltchev *et al.* (2007) define the variables deserving special consideration are the size and shape of the bubbles, their rise velocity, circulation, coalescence, effects of surface-active substances and the rate of mass transfer. Bubble columns reactors are commonly used in various chemical and petrochemical processes fischer –tropsch synthesis, halogenation, waste water treatment, oxidation fermentation, petroleum refining, coal liquefaction, biotechnology and chemical engineering, and used in industrial gas-liquid operations industry. The design parameters for bubble columns are gas-liquid specific interfacial area *a*, individual mass transfer coefficient k_L, gas holdup ε_G, flow regime, bubble size distribution, and coalescence of bubbles. Most studies on bubble columns were devoted to the experimental determination of some of these parameters, and more specifically of the volumetric mass transfer coefficient k_La , which depends fundamentally on the superficial gas velocity and on the physical properties of the absorption phase [Zhao Wei-rong *et al.* (2004)], while the gas holdup value depended on the superficial gas velocity, the flow regime and often is very sensitive to the physical properties of the liquid [Fernando Camacho Rubio *et al.* (1999)].The volumetric liquid-phase mass-transfer coefficient k_La is important parameters for the economy of the processes in bubble columns. The mass-transfer properties of the bubbles in liquids determine the efficiency and dimensions of bubble columns [Stoyan Nedeltchev *et al.* (2007)]. Bubble size and gas holdup are the most important design parameters, which define the interfacial area available for mass transfer. These parameters depend extensively on column geometry, operating conditions, physical properties of the two phase’s physic-chemical properties of the gas-liquid system and type of gas sparger [Kazakis *et al.* (2005)]. Mass transfer is one of the key parameters determining the design and scale-up of slurry bubble column reactors used in a wide spectrum of industrial processes [Ruthiya *et al*. (2005)].

Gas holdup depends mainly on the superficial gas velocity, and often is very sensitive to the physical properties of the liquid. The spatial variation of ε_G, gives rises to pressure variation and eventually results in intense liquid phase motion. These secondary motions govern the rate of mixing, heat transfer and mass [Shah *et al.* (1982)]. The classical penetration model put forward by [Higbie *et al*. (1935)] is the most significant mass transfer theory. In order to calculate the volumetric liquid-side mass transfer coefficient, k_La, one also needs to know how to calculate the interfacial area; *a*. the formula for its calculation depends on the bubble shape. The specific interfacial area *a* [painmanakul *et al*., (2005)].

2. EXPERIMENTAL SET-UP

The experimental set-up is schematically represented in Fig. 1-a&1-b**.** The experiments are carried out in a bubble column made of transparent plexi glass of 0.018 m in diameter and 1.03 m height. Porous distributor was used as gas distributor. Tap water at room temperature 31°C (±3°C) was mainly used as liquid phase in the experiments. Gas was taken from the air compressor; the volumetric flow rate was measured using rotameter. The base that holds the column has a regulator screws to ensure exact verticality of the column with effective liquid height of 0.7 m. Runs were performed with different superficial gas velocities with the change from (0.22×10^{-4} -0.22×10^{-3}) m/s. The system were used in this work is air-water. The experiment tools are: Air Compressor to supply the necessary air and rotameter to cover wide range of gas velocities which was from (0.22×10^{-4} -0.22×10^{-3}) m/s.

Figure (1A) The Complete Experimental Apparatus

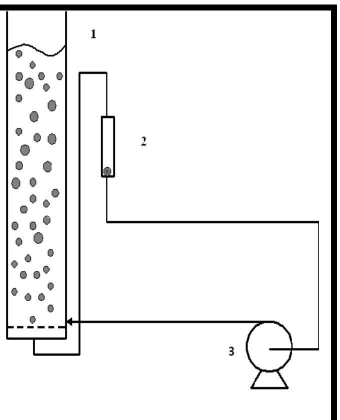


Figure 1-b The Complete Experimental Apparatus

3. FLOW REGIMES

In bubble columns, four types of flow patterns have been observed, homogeneous (bubbly), heterogeneous (churn-turbulent), slug, and annular flow. Researchers have reported the occurrence of a slug flow regime only in small diameter columns. In these different flow regimes, the interaction of the dispersed gas phase with the continuous liquid phase varies considerably. Fig. 2 shows the various flow regimes in bubble columns. However, bubbly and churn-turbulent flow regimes are most frequently encountered. Depending upon the operating conditions, these two regimes can be separated by a transition regime [Urseanu (2000)].

The homogeneous flow regime generally occurs at low to moderate superficial gas velocities. It is characterized by uniformly sized small bubbles traveling vertically with minor transverse and axial oscillations. There is practically no coalescence and break-up, hence there is a narrow bubble size distribution. The gas holdup distribution is radial uniform; therefore bulk liquid circulation is insignificant. The size of the bubbles depends mainly on the nature of the gas distribution and the physical properties of the liquid [Urseanu (2000)].

Heterogeneous flow occurs at high gas superficial velocities. Due to intense coalescence and break-up, small as well large bubbles appear in this regime, leading to wide bubble size distribution. The large bubbles churn through the liquid, and thus, it is called as churn-turbulent flow. The non-uniform gas holdup distribution across the radial direction causes bulk liquid circulation in this flow regime [Urseanu (2000)].

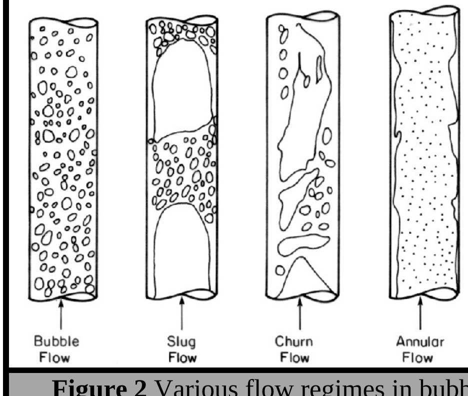


Figure 2 Various flow regimes in bubble column reactors [Urseanu (2000)].

. MASS TRANSFER PARAMETER

A. BUBBLE SIZE DISTRIBUTION

In a gas–liquid/slurry reactor, the bubble size distribution plays an important role in the hydrodynamics and mass transfer behaviors. It determines the bubble rising velocity and gas residence time, and governs the gas holdup and gas–liquid interfacial area. [Wang *et al*. (2005)] compared four typical bubble coalescence and breakup modes, and found that the calculated bubble size distributions were quite different when different bubble coalescence and breakup models were used. The results show that it is very important to include multiple bubble breakup and coalescence mechanisms and choose reasonable models for them to get a reliable prediction of the bubble size distributions in a wide range of superficial gas velocity

B. GAS HOLDUPS

Gas holdup, or void age, is a dimensionless quantity that represents the percentage of total gas-liquid system is occupied by the gas. The gas holdups were measured by recording the levels of an aerated (h_{LG}) gas-liquid mixture during the steady state operation and non-aerated (h_L) liquid in the column after the flow of the phases were simultaneously stopped, thus [Krishna *et al.* (1996)].

$$\varepsilon_G = (h_{LG} - h_L)/ h_{LG} \tag{1}$$

C. GAS-LIQUID INTERFACIAL AREA

Key parameter in the study of the gas–liquid mass transfer the interfacial area depends on the geometry, size of bubble, gas holdup, the operating parameters and the physical and chemical properties of the liquid [Kluytmans *et al*. (2002)].

The specific interfacial area a is a function of the number of bubbles,N_B the bubble surface area,S_B and the total dispersion volume,V_{total}:

$$a= N_B\, S_B/ V_{total} \tag{2}$$

D. MASS TRANSFER COEFFICIENTS

It is a global parameter and insufficient for understanding the mass transfer mechanism. The separation of *kl* and *a* allows in identifying which one of *kl* and *a* controls the mass transfer rate (Bouaifi et al., 1998; Yang et al., 2001;Garcia-Ochoa and Gomez, 2004), and can provide an insight into the mass transfer mechanism In general, the mass transfer coefficient increases with the superficial gas velocity and average bubble size.

The variation in the mass transfer coefficient with the bubble size is different from the results of (Alves *et al.* 2006) for a single bubble, where the mass transfer coefficient was found to decrease with an increase in the bubble size. The predicted mass transfer coefficient in the bubble column is lower than that of a single bubble.

$$k_L =(4D_L/\text{л}\; t_c)^{0.5} \tag{3}$$

E. VOLUMETRIC MASS TRANSFER COEFFICIENT

The intensity of interfacial mass transfer is characterized by the volumetric liquid-side mass transfer coefficient, $k_l a$. The $k_l a$ value in gas-liquid contacting equipment has mostly been determined by the oxygen physical absorption or desorption technique, and it is determine if one knows how to estimate the liquid-side mass transfer coefficient k_l,and the interfacial area *a*, both parameters depends on the bubble diameter. [Stoyan *et al*. (2006)].

$$k_{La}= k_L \times a \tag{4}$$

5. IMAGE ACQUISITION AND TREATMENT METHOD

The bubble diameter generation is photographed with digital camera. Images are visualized on the acquisition computer through the Matlab 7. Fig. 3 presents a typical sequence of image treatment. This treatment is based on a transformation of the acquired image into a binary image, followed by different arithmetical and geometrical operations. Then the images are given uniform surface treatment (bubble area) and superfluous images are removed. The bubbles are spherical at low gas flow rates but become ellipsoidal at high gas flow rates [painmanakul *et al*., (2005)].

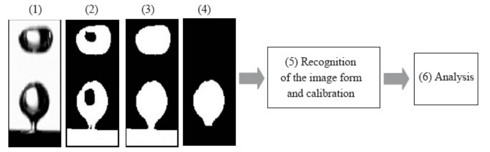
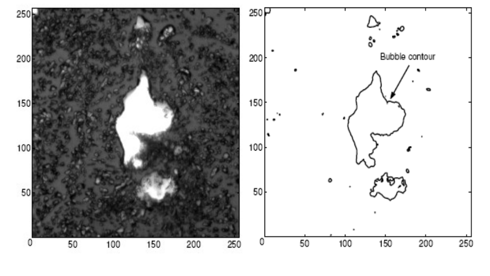


Figure 3 Typical sequence of image treatment: (1) image acquisition (2) image binarization; (3) image completion; (4) border image delation, painmanakul *et al*., (2005)

A. IMAGE ANALYSIS PROCEDURES

Image processing software has been developed to calculate bubble size distributions, specific gas-liquid interfacial areas of the gas bubbles, and bubble rise velocities. The image processing routines are programmed in (MATLAB 7) [Krishna *et al.* (2000)], and make use of standard image processing routines from the image processing toolbox. We will briefly illustrate the diversity and capabilities of the image processing techniques and methods in the study of some hydrodynamic features of bubble columns. The images which were captured with the digital camera are gray valued images with a size of

256x256 pixels Figure 4-a; this means that the images are stored as a 256x256 matrix, in which each element denotes the gray value of the corresponding pixel, ranging from 0 (black) to 255 (white). The Image Data is Stored in the IDS format .The IDS file contains only the pixel values of the captured images. A separate header file, the ICS file, contains information about the image size (256x256), the number of images in the IDS file (default 10.000 images), and additional information about the specific experiment. The IDS file is a binary file which can be opened in [Matlab 7], after which the separate images can be plotted. Each time a 256x256 matrix is plotted using a gray value color map Fig. 4-a [Krishna *et al.* (1999)].



(a) (b)

Figure 4 a recorded image of 256×256 pixels a) Gary image b) Contour image, Krishna *et al.* (1999)

B. IMAGE CONVERSION

In order to make a good distinction between the gas and the liquid phase, the gray valued image is converted to a binary image. This is achieved by choosing a threshold value, which denotes a gray value in between the gray values of the gas phase and the liquid phase. Gray values above the threshold value are turned *on* in the binary image the pixel is given the value of 1, while gray values below the threshold value are turned *off* equaling the value of 0 in the binary image [Kluytmans *et al*. (2002)].

C. CONTOUR PLOT

The circumference of the bubbles is calculated from the contour of the bubble. The contour represents an iso-threshold line which is a line connecting points of equal threshold value. An example of a bubble contour is shown in Fig.4-b whereas the threshold analysis in the previous paragraph is restricted to pixels, the iso-threshold lines are represented as lines with actual coordinates. Therefore, the length of the contour can be calculated with high accuracy [Kluytmans *et al*. (2002)].

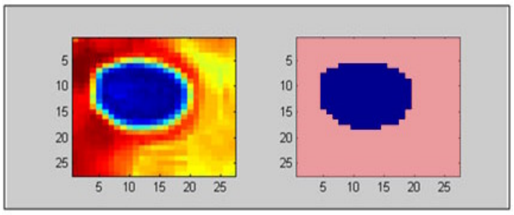
6. RESULTS AND DISCUSSION

6.1 EXPERIMENTAL WORK

In this work, a bubble column of 0.081 m diameter was used with the aid of air-water at atmospheric pressure. The air inlet velocity was varied between $(0.22\times10^{-4} - 0.22\times10^{-3})$ m/s with water inlet velocity equal to zero.

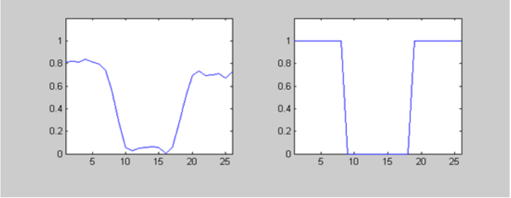
6.2 IMAGE PROCESSING

The digital camera was positioned vertically upon the bubble column and multiple snapshots were taken at different instants during the work.The grayscale images were entered to MATLAB and by applying a threshold value, the image was converted to the binary form, as shown in Figure 5-a. MATLAB program function at this instance was to estimate and plot the diameter of the bubble for both the original grayscale and the binary one, as shown in Figure 5b. Then the program was used to evaluate the contour of the bubble and it's length in the two cases, as shown in Figure 5-c & 5-d.



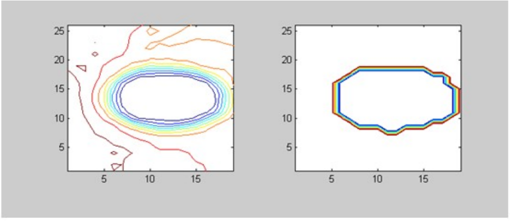
Gray Scale Image Binary image

a. Image Entered and Processed in MATLAB

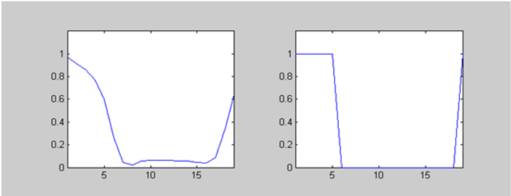


b. A Plot Bubble Diameter Estimation

c.

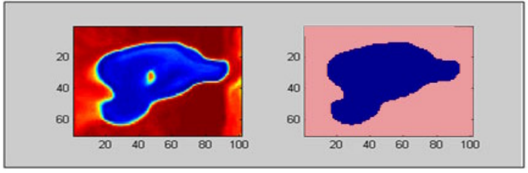


d. Bubble Contour Evaluation



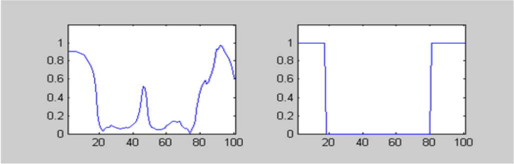
e. A Plot of Bubble Contour Diameter Estimation

Figure 5 Results at 0.22×10^{-4} m/s gas velocity

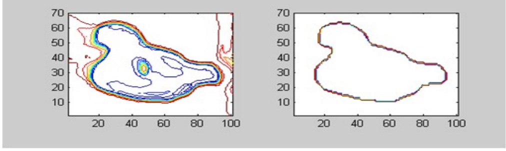


Gray Scale Image Binary image

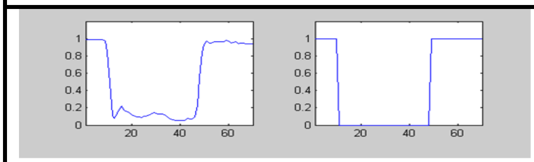
a. Image Entered and Processed in MATLAB



b. A Plot Bubble Diameter Estimation



c. Bubble Contour Evaluation



d. A Plot of Bubble Contour Diameter Estimation

Figure 6 results at 0.000198 m/s gas velocity

Figure 7 show the transition velocity between the flow regimes for (air-water) system by use drift flux method.

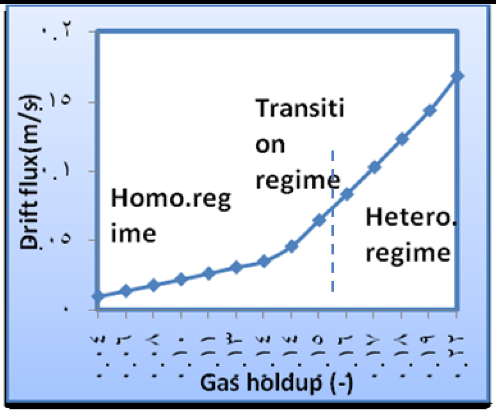


Figure 7 Gas holdup vs. drift flux

As shown in Fig.8 computational results have been compared to the experimental data.

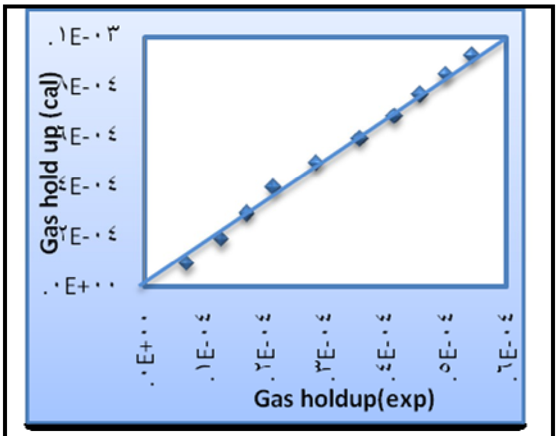


Figure 8 Gas holdup experiment vs. Gas holdup calculated.

CONCLUSIONS

1. Transition velocity from bubbly to churn turbulent flow for (air-water) system, it was about 0.148982 m/s.
2. a good agreement for the calculated gas holdup with the estimated values by image processing.

RECOMMENDATION

1. Using 3D fluid dynamic using other liquids such as alcohol.
2. The effect of adding solids on gas holdup, transition velocity, and mass transfer coefficient.
3. This study concerned only with measuring the mass transfer coefficient only with air-water system. Therefore studies to cover the mass transfer using the electrolytes system.

NOMENCLATURE

a	Specific gas-liquid interfacial area based on aerated volume	m^{-1}
D_L	Molecular diffusivity of solute in liquid phase	$m^2.s^{-1}$
H		
h_L	Aerated liquid level	m
h_{LG}	Liquid level	m
K_L	Aerated liquid level	m
K_{La}	Individual mass transfer	m/s
N_B	coefficient	s^{-1}
SB	Volumetric mass transfer	-
U_G	coefficient	m^2
V_{total}	Number of bubbles in the	m/s
ε_G	dispersion	m^3
	Bubble surface	-
	Superficial gas velocity	
	Dispersion volume	
	Gas hold up	

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