Chemical Engineering Journal 163 (2010) 331–336

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Experimental interfacial area measurements in a bubble column

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ARTICLE INFO

Article history:
Received 24 June 2010
Received in revised form 31 July 2010
Accepted 3 August 2010

Keywords:
Bubble column
Interfacial area
Holdup
Bubble size
Flow regimes

ABSTRACT

Gas holdup, bubble diameter and gas–liquid interfacial area were measured in a bubble column, during the absorption of CO_2 in DEA solutions in batch conditions, as a function of column height, operating time, gas flow rate and amine concentration. The experimental measurements of bubble diameter were carried out using a video technique combined with image processing. The gas flow rate was varied in the range 10–25 L/h, and the amine concentration between 0.05 and 1 M. The results show that the interfacial area is influenced with the amine concentration and gas flow rate through the column. Additionally, an empirical equation is proposed to relate the interfacial area to time and column height for each system. Furthermore, a generalized correlation based on dimensionless groups for the prediction of gas holdup in homogeneous regime was proposed and found to be in good agreement with available data.

1. Introduction

Bubble columns are widely used in industrial gas–liquid operations (e.g. gas–liquid reactions, fermentations) in chemical and biochemical processes industries, due to their simple construction, low operating cost and high-energy efficiency. In all these processes, gas holdup and bubble size are important design parameters since the gas–liquid interfacial area available for mass transfer is defined by these variables. In turn, bubble size distribution and gas holdup in gas–liquid dispersions depend largely on column geometry, type of gas sparger, operating conditions and physico-chemical properties of the two phases [1]. Furthermore, if the absorption process is accompanied by a chemical reaction, the effect of time on the interfacial area should too be analyzed.

Dispersion of the gas into the column is critical in determining the performance of gas–liquid systems. Small bubbles and a uniform distribution over the cross-section of the equipment are desirable to maximize the interfacial area and to improve the mass transfer rate [2]. For that reason, the formation of bubbles at orifices submerged in a liquid has been the subject of many theoretical and experimental works [3–5]. In the publications cited above, the main focus of research was on the bubble formation at a single orifice. However, other authors [2,6] have studied experimentally the influence of the distance between holes and of the number of holes on the bubble diameter.

Despite considerable studies of bubble column performance, many basic questions concerning the effect of important operational parameters remain unanswered. For instance, although bubble column characteristics have been studied extensively over the last few decades, there is still a fair amount of uncertainty regarding the prevailing mechanisms of bubble formation. Break-up and coalescence of fluid objects play a crucial role in a broad spectrum of multiphase flow processes such as the evolution of the bubble size distribution in stirred tanks and bubble columns [7]. Consequently, the bubble size distribution in a vessel is not constant, but rather, may change due to bubble–bubble interactions leading to breakage or coalescence. The latter is the reason why bubble size distributions measurements are not so common in literature. Moreover, almost all the published data refer to the evaluation of a mean bubble diameter inside the column usually estimated from a one-height measurement [6,8–12]. Others authors [1,2,13–17] have measured the bubble size distribution at different distances from the sparger in order to study the coalescence and breakage.

Different techniques have been developed in order to measure the bubble dimensions and shapes in equipments where gas–liquid transfer is important. Some authors have used the video technique for studying the bubble size and the gas holdup [1,2,13,14,16,17–22]. These studies were carried out in systems with air like gas phase and water, electrolyte solutions, ethanol, butanol and pentanol aqueous solutions or glycerine aqueous solutions like liquid phase. In these systems, there is no chemical reaction. Therefore, it seems interesting to contribute to a study on the subject.

In this work, the absorption process of carbon dioxide (CO_2) into diethanolamine (DEA) aqueous solutions is studied. The interfacial area and the gas holdup are measured at for several gas flow rates and several DEA concentrations. The influence of height column

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doi:10.1016/j.cej.2010.08.011

Nomenclature

a	interfacial area, m^{-1}
A	parameter in Eq. (12), s^{-1}
Ar	Archimedes number
d	bubble diameter, m
d_C	column diameter, m
d_{32}	Sauter mean diameter, m
e	ellipsoid minor axis, m
E	ellipsoid major axis, m
Eo	Eötvos number
Fr	Froude number
g	gravity acceleration, m s^{-2}
H_L	liquid level, m
n	number of bubbles
t	time, s
u_G	gas superficial velocity, m s^{-1}
V_L	liquid volume, m^3
w	parameter in Eq. (12), s^{-1}
x_C	parameter in Eq. (12), s^{-1}
Y_0	parameter in Eq. (12), s^{-1}

Greek symbols

ε	gas holdup
ρ	liquid density, kg m^{-3}
μ	liquid viscosity, Pa s
σ	surface tension, N m^{-1}

and operating time on interfacial area will be analyzed. The motivation for the present work was in part the small amount of work found in the literature on the study of the interfacial area variation with height column and time, since these parameters have been identified as key parameters defining the value of the volumetric mass transfer coefficient (k_La) [23].

2. Materials and methods

2.1. Experimental set-up

The experimental set-up (Fig. 1) consists of a vertical rectangular polymethyl methacrylate column 1.03 m height (1), having a square cross-section (side length 6 cm). A rectangular geometry was preferred over a cylindrical one because it simultaneously facilitates 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 gas sparger (7), i.e., a porous plate of 4 mm in diameter was installed at the centre of the bottom plate (6). This plate has another orifice for liquid outlet (5). The top plate has three orifices: gas outlet (3), liquid inlet (2) and a thermometer (4).

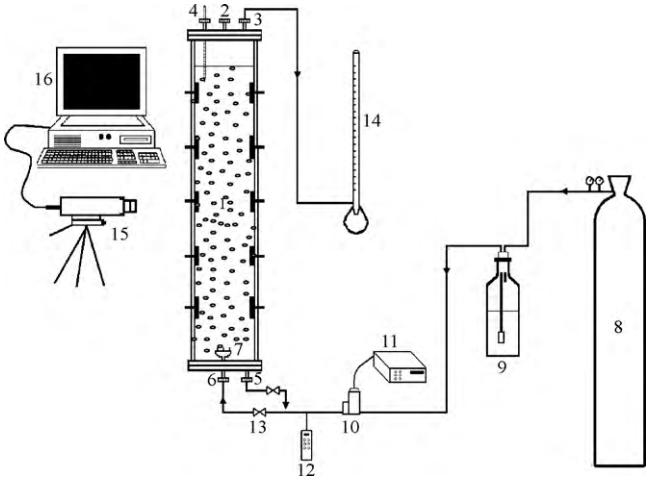

Fig. 1. Experimental set-up. (1) Bubble column; (2) liquid inlet; (3) gas outlet; (4) thermometer; (5) liquid outlet; (6) gas inlet; (7) sparger; (8) gas cylinder; (9) humidifier; (10) flow meter; (11) flow controller; (12) digital manometer; (13) gas valve; (14) soap meter; (15) video camera; (16) computer.

Aqueous diethanolamine (DEA) solutions of different concentrations were employed as liquid phase, while the gas phase was carbon dioxide with a different gas flow rate for each run. The following DEA concentrations were employed: 0.05, 0.1, 0.3 and 1.0 M. Gas flow rates of 10, 15, 20 and 25 L/h ($u_G = 7.7 \times 10^{-4}$ to 1.9×10^{-3} m/s) were used.

All the experiments were conducted at ambient pressure and temperature conditions and under batch conditions. Each experimental run was started by filling the column with appropriate liquid phase up to 100 cm above the sparger. The feed of pure carbon dioxide (8) was passed through a humidifier (9) at the ambient temperature to prepare the gas phase. This procedure removes the gas-side mass transfer, thus allowing evaluation of resistance to transfer from the gas phase to the liquid phase. The gas flow, before entering the bubble column, was metered by a flow meter (10) and controlled with a flow controller Brooks 0154 (11). All the experiments were performed with no liquid throughput, while the gas phase was injected and distributed into the liquid phase by the porous plate. Before going into the column, the pressure was measured with a digital manometer Testo 512 (12). The gas flow in the outlet was measured with a soap meter (14).

A high-speed digital video camera (SONY DCR-TRV9E) (15) was used, both, for direct flow visualization, and for the bubble size and holdup measurements. The images obtained were converted into an AVI format file using STUDIO Version 7 software (16) and processed using *UTHSCSA Image Tool* software to obtain the bubble size. The images were taken, alternatively, at three positions (20, 45 and 85 cm above the sparger) for different operating conditions until the liquid saturation was reached and therefore, the CO_2 is not already being removed. In that moment, the amount of carbon dioxide in the inlet and outlet is the same. The number of bubbles measured in each section was always higher than 30 and the standard deviation was between 0.5 and 0.7 depending on the section, gas flow rate and reaction time.

2.2. Determination of physical properties

The densities, ρ, and viscosities, μ, of the different solutions were measured at 20, 25 and 30 °C using a Anton Paar DSA 5000 densimeter, with a precision of $\pm 10^{-5}$ g cm^{-3}, and a Shott-Gëratte AVS 350 automatic viscometer, with a precision of ±0.01 s, respectively. The experimental values were correlated simultaneously with the amine concentration and with the temperature, obtaining the following expressions:

$$\rho = 12.26 \cdot C_{B_0} + 915.65 \cdot \exp^{25.3/T} \quad (1)$$

$$\ln \mu = 0.3 \cdot C_{B_0} - 19.7 \cdot \exp^{-308.5/T} \quad (2)$$

The surface tension, σ, of the different solutions were obtained using the equation proposed by Álvarez et al. [24] and Vazquez et al. [25].

3. Results and discussion

The purpose of this work is to study the variation of interfacial area in a bubble column with the time, height of the column, gas flow rate and amine physical properties. The gas holdup and the