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Effect of surfactants on liquid-side mass transfer coefficients

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Abstract

In the present paper, the effect of liquid properties (surfactants) on bubble generation phenomenon, interfacial area and liquid-side mass transfer coefficient was investigated. The measurements of surface tension (static and dynamic methods), of critical micelle concentration (CMC) and of characteristic adsorption parameters such as the surface coverage ratio at equilibrium (s_e) were performed to understand the effects of surfactants on the mass transfer efficiency. Tap water and aqueous solutions with surfactants (cationic and anionic) were used as liquid phases and an elastic membrane with a single orifice as gas sparger. The bubbles were generated into a small-scale bubble column. The local liquid-side mass transfer coefficient (k_L) was obtained from the volumetric mass transfer coefficient (k_La) and the interfacial area (a) was deduced from the bubble diameter (D_B), the bubble frequency (f_B) and the terminal bubble rising velocity (U_B). Only the dynamic bubble regime was considered in this work ($Re_{OR} = 150$–1000 and $We = 0.002$–4).

This study has clearly shown that the presence of surfactants affects the bubble generation phenomenon and thus the interfacial area (a) and the different mass transfer parameters, such as the volumetric mass transfer coefficient (k_La) and the liquid-side mass transfer coefficient (k_L). Whatever the operating conditions, the new k_La determination method has provided good accuracy without assuming that the liquid phase is perfectly mixed as in the classical method. The surface coverage ratio (s_e) proves to be crucial for predicting the changes of k_L in aqueous solutions with surfactants.

Keywords: Surfactants; Bubble diameter; Bubble formation frequency; Interfacial area; Volumetric mass transfer coefficient; Liquid-side mass transfer coefficient; Surface coverage ratio

1. Introduction

In gas–liquid reactors, mass transfer from the gas phase to the liquid phase is a key parameter of the process. Classically, gas is released in the form of small bubbles to yield a large surface area and also an efficient mass transfer between gas and liquid phases. Depending on the industrial operating conditions, various gas spargers can be used as aeration systems (perforated plate, porous disk diffuser, membrane gas sparger). To improve the mass transfer efficiency, the interfacial area and the liquid-side mass transfer coefficient have to be controlled closely. The objective of the present study is to evaluate the effect of surfactants on interfacial area and liquid-side mass transfer coefficient. Only the dynamic bubble regime will be considered here ($Re_{OR} = 150$–1000 and $We = 0.002$–4).

Several studies about the bubble diameters (D_B) present in bubble columns and generated from different types of gas spargers have been recently published (Rice et al., 1981; Loubière and Hébrard, 2003; Hébrard et al., 1996; Couvert et al., 1999; Painmanakul et al., 2004); in particular, it is interesting to note that the interfacial area (a) can be experimentally determined by using detached bubble diameters

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(D_B), bubble formation frequencies (f_B) and terminal bubble rising velocities (U_B) as Painmanakul et al. (2004).

The effects on bubble generation of liquid-phase properties, such as density and viscosity, have been widely evaluated (Li, 1998) whereas little investigation has been carried out on the liquid surface tension. Loubière and Hébrard (2004) have studied the influence of surfactants on the bubble formation at different gas spargers, especially on the generated bubble diameter (D_B), the associated bubble frequency (f_B) and the interfacial area (a). In this study, the liquid phases were characterized in terms of static and dynamic surface tensions, critical micelle concentration (CMC) and characteristic adsorption parameters (surface coverage ratio at equilibrium (s_e), adsorption constant at equilibrium (K) and surface concentration when it is saturated (Γ_∞)). These authors have observed that the effect of surface tension on the bubble generated depends on the type of orifice (flexible and rigid) and should be analyzed in terms of dynamic surface tension and of kinetics of surfactant molecule adsorption and diffusion.

The literature about mass transfer parameters shows that there is a very limited number of qualitative data related to the influence of surface tension on the volumetric mass transfer coefficient $(k_L a)$; moreover, the $k_L a$ values are often global and thus insufficient to understand the gas–liquid mass transfer mechanisms (Vázquez et al., 1997; Akosman et al., 2004). In this purpose, it becomes essential to separate the parameters, especially the liquid-side mass transfer coefficient (k_L) and the interfacial area (a) (Bouaifi et al., 2001; Zhao et al., 2003a,b); however, there is a lack of studies dealing with this separation in the presence of surfactants (Vasconcelos et al., 2003; Vázquez et al., 2000; Cents et al., 2001).

To fill this gap, the general aim of this present study is to propose a local experimental approach which enables the mass transfer efficiency to be effectively controlled whatever the operating conditions. The scope of this work is as follows:

- Characterization of several liquid phases in terms of static and dynamic measurements of surface tension, CMC and their associated characteristic adsorption parameters.
- Application of the new experimental method to determine the local volumetric mass transfer coefficient, the local interfacial area and thus the local liquid-side mass transfer coefficient.
- Quantification of the effect of surfactants on the bubble generation phenomenon, the interfacial area and the associated local mass transfer parameters ($k_L a$ and k_L).

For this purpose, this paper will firstly present the material and the experimental methods used in this work. Then, the characterization of liquid phases under test will be described as well as the local mass transfer parameter determination (interfacial area provided by a sparger, volumetric mass transfer coefficient obtained with the new method, liquid-side mass transfer coefficient). Finally, the influence of the surfactants on the bubble generation and on the different mass transfer parameters will be shown; a simple model for estimating k_L will be proposed and applied whatever the operating conditions.

2. Material and methods

2.1. Experimental set-up

The experimental set-up is schematically represented in Fig. 1. The experiments are carried out in a glass bubble column (6), 0.05 m in diameter, 0.40 m in height. This column is fixed into a glass parallelepiped vessel (4), 0.40 m in width, 0.40 m in length, 0.30 m in height. The flow of air is monitored by a pressure gauge (1) and regulated by a gas flow meter (2). The pressure drop created by the membrane sparger is determined using an electronic manometer type BIOBLOCK 915PM247 (3). The average gas flow rate is measured using a soap film meter (7), through a funnel (1.5 cm diameter) put on the orifice. Nitrogen flow (employed for oxygen elimination in the liquid phase and for oxygen elimination at the top of the bubble column) is controlled by a pressure gauge (11). The UNISENSE oxygen microsensor, whose response time is very fast (as low as 50 ms), is used to measure the change in dissolved oxygen concentration (9). All chemical solutions (8) are injected at the top of the column. The operating conditions are as follows: liquid height $H_L = 25$ cm and temperature $T = 20\,^\circ$C.

In this work, pieces of 60 mm diameter of an industrial (Dégremont®) rubber membrane sparger are used as gas spargers. The bubbles are generated by a single puncture located at the membrane centre. As punctures were initially distributed over the entire surface sheet, it was necessary to close several holes without modifying the elastic membrane properties (Castaignede, 2001). For this purpose, a silicone elastomer glue applied on the inner surface (gas chamber side) was used (Fig. 2a).

The membrane is assembled on a circular clamping ring composed of two jaws (Fig. 2b); this fixing system coupled with the use of a dynamometric spanner enables the same initial tension to be applied, thus giving reproducible results. The physical characteristics of the membrane sparger and the operating conditions are reported in Table 1.

2.2. Image acquisition and treatment method

The bubble diameter generation is photographed with a Leutron LV95 camera (120 images/s). Images are visualised on the acquisition computer through the Leutron vision software. The image treatment is performed with the Visilog 5.4 software (C^{++} program).

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