Mass Transfer from Growing and Oscillating Rising Bubbles.

Mariano Martín, Francisco J. Montes, Miguel A. Galán.

Universidad de Salamanca, Departamento Ingeniería Química y Textil, Plaza de los Caídos, 1-5, 37008 Salamanca (Spain), Telf: 00 34 923 294479; Fax: 00 34 923 294574
mariano.m3@usal.es; javimon@usal.es; magalan@usal.es

Abstract.

Mass transfer in gas liquid systems depends on the contact between the entities in which the gas phase is dispersed into the liquid, the bubbles, and the surrounding liquid. Further knowledge of the hydrodynamics of the growing and rising bubbles under mass transfer conditions will help in the understanding of the mass transfer process in bubble columns and in the design of the equipment.

Introduction.

Bubble columns are one of the most common devices for mass transfer operations in chemical engineering due to some advantages like high mass and heat transfer coefficients, easy operation and maintenance.

In order to have further knowledge of the mass transfer process it is of key interest to study the mass transfer from the entities in which the gas phase is dispersed, the bubbles, instead of studying the columns as a whole. This work is going to be divided in two parts, the study of the mass transfer from growing bubbles and from oscillating rising bubbles.

The many studies regarding the hydrodynamics of the growing bubbles have been developed [1 - 6], but the mass transfer from the growing bubbles has been scarcely studied [7]. The hydrodynamic models combined with the mass transfer rate can help in the development of a systematic study of the effect of the physical properties of the liquid on the mass transfer during the growing bubbles, which experimentally is difficult to be carried out due to the size of the particles of interest and the impossibility to change only one property without affecting others.

Once the bubble have detached, inertial forces resulting from the detachment as well as the kinetic energy of the flow in which the bubble moves, make the bubbles oscillate. Studies of the oscillating bubbles in inviscid fluids have revealed that the oscillations enhance the mass transfer rate [8], however, many industrial processes take place in viscous fluids. The study of the effect of the viscosity on the bubble oscillation and its expression on the mass transfer rate can optimize the design if the equipment.

Experimental set up.

The set up consists of an optical table on which the other devices are fixed. Bubbles are generated in a bubble column, which is aligned with a high speed video camera, Redlake Motionscope®, capable of recording up to 1000 frames per second. The liquid was desoxygenated using a flow of nitrogen. The system is illuminated by an optic fibre device which allows the control of the light intensity and its distribution. Images recorded are edited and analysed by means of MOTIONSCOPE® software.

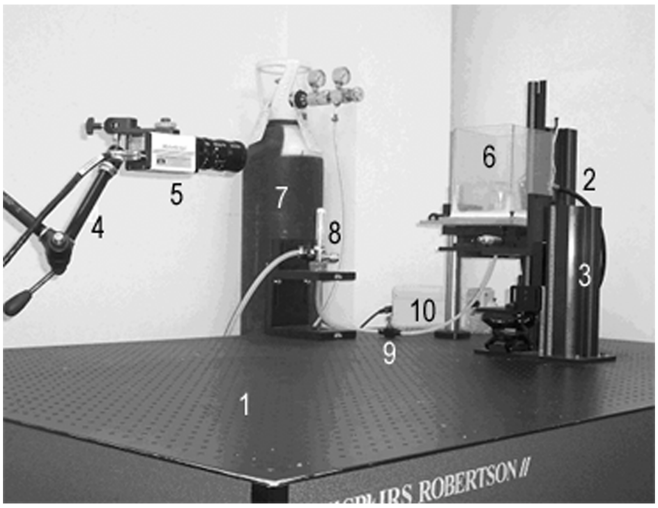

Figure 1.-Experiemental Sep up

1.-Optical table; 2.- Fibre optics; 3.-Supporting structure for the bubble column; 4.-“Magic arm” holding the camera; 5.-High speed video camera; 6.-Bubble column; 7.- Air cylinder; 8.- Rotameter; 9.- Valve; 10.- Illumination source.

In the first place, the effect of the hydrodynamics of the growing of air bubbles on the mass transfer in a desoxygenated media was studied. The work was carried out in desoxygenated water, as Newtonian inviscid fluid, and in a desoxygenated solution of 1.4% CMC in water, as Non Newtonian viscous fluid. The generated bubbles were recorded by means of high speed video techniques.

The rising of the bubbles generated in water and in solutions form 0.4% to 1.6% CMC in water, were recorded to study the effect of the viscosity on the bubbles shape and their oscillation amplitude.

Theoretical background, results and discussion.

Bubble rising conditions depend on the growing stage, which determine bubble initial size. Bubble formation time increases with the viscosity and so does its size.

The growing bubbles in Newtonian and Non Newtonian media were also modelled through a finite differences method coupling a force balance in the vertical axis, considering the effect of the presence of the plate, the buoyancy, the drag and the inertial forces, with a momentum balance, to determine the expansion of the bubbles, as a result of the pressure differences between the bubble pressure and the external pressure considering the effect of the viscosity, the surface tension and the mass transfer from the bubble to the liquid. Good agreement was found between the simulated and the recorded bubbles, an example is shown in Fig 2.

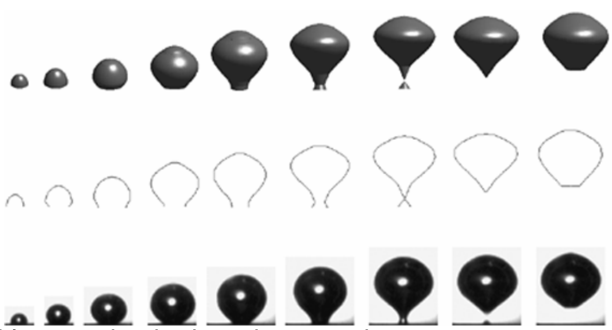

Figure 2.- Bubbles growing in desoxiygenated water. D_o= 2 mm Q_c= $5{\cdot}10^{-6}$ m^3/s

During a fermentation process, physical properties of the liquid change with time. In order to study the isolated effect of each of the physical properties of the liquid on the mass transfer rate, the experimental study is impossible because a change in one physical property also modifies the others, even the transport properties like the diffusivity.

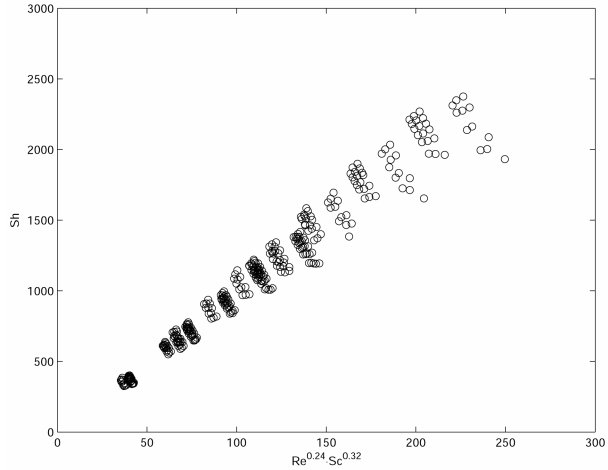

Figure 3.- Fitting of the correlation

The tested model allowed studying the effect of the physical properties of the liquid phase on the Sherwood number. The calculated Sherwood number was correlated against the Reynolds and the Schmidt dimensionless numbers. Viscosity reduces the mass transfer rate as well as the density. Good agreement was found and the correlation exponents resemble those proposed by other authors. Fig. 3

$$\mathrm{Sh} = 10 \cdot \mathrm{Re}^{0,24} \cdot \mathrm{Sc}^{0,32} \qquad (1)$$

Once the bubble has detached, the rising movement depends on its size. The property which changes the most during a fermentation process is the viscosity. The increment in the viscosity of the liquid can even change the rheological behaviour of the fluid. Higher viscosities increase the bubble initial volume, due to the stabilization of the bubble neck, but reduce the deformability of the bubble, their possibility to oscillate, absorbing the inertial and kinetic energy. These oscillations modify the concentration profiles surrounding the bubbles increasing the mass transfer.

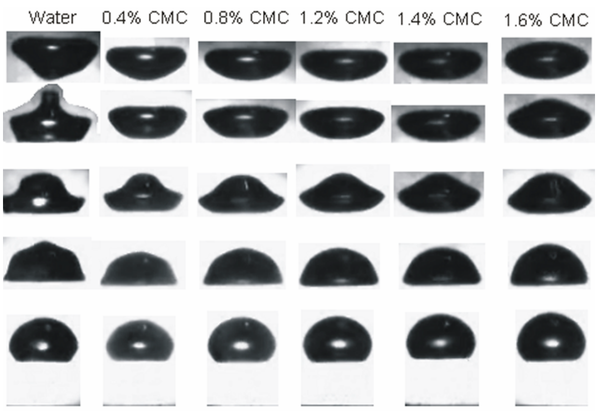

Figure 4.- Bubbles growing in desoxiygenated water. D_o= 2 mm Q_c= $5{\cdot}10^{-6}$ m^3/s

The liquid viscosity reduces the sharpness of the bubbles and absorbs the oscillating energy. A theoretical equation based on the Higbie's penetration theory and the perturbation method, has been developed, considering the bubble oscillation amplitude as a measure of the deformability of the bubbles and the turbulence of the system.

Based on the perturbation theory, [9] and the studies of Lochiel [10] with the study of the decay of the oscillation in viscous fluids Valentine, 11], a new equation was proposed. Eq. (2)

$$\mathrm{Sh} = \sqrt{\frac{2}{\pi}} \cdot \mathrm{N_{Pe}}^{1/2} \cdot \mathrm{I_S}^{1/2} \qquad (2)$$

The integral of shape (I_S) depends on the viscosity of the liquid and on the oscillation amplitude.

This equation is capable of predicting the values of the volumetric mass transfer coefficient exposed by other authors without fitting parameters which is of great help in the scale up process, for which the geometric dependences in the design equations must be avoided in order to secure the effectiveness of the full scale equipment. An example for non Newtonian liquids is shown in figure 5, were the results of the equation were compared to those of small rigid bubbles predicted by some authors [12, 13]. Good agreement was found considering that the studied bubbles were not completely rigid.

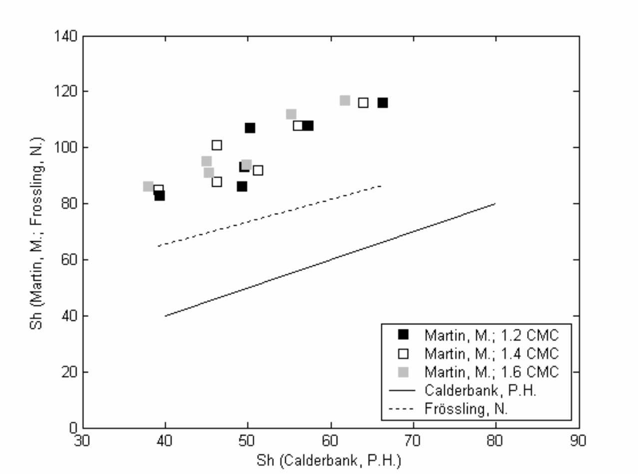

Figure 5.-Expirical - theoretical comparison for the Sherwood number in viscous fluids [12,13,14]

Coalescence process is an important disadvantage in the bubble columns due to the decrease in the specific area, [15]. It can occur when growing or rising due to the collisions among bubbles in their movement through the column. However, the coalescence generates bigger bubbles, oscillating bubbles. The study of the effect of the coalescence on mass transfer, the increment in the oscillation amplitude on the mass transfer rate and the possibility of reducing the loss of efficiency due to the coalescence process in bubble columns is of key importance.

It was critical in this study to allow and forbid the coalescence process without the addition of surfactants in order to directly compare the mass transfer in absence and presence of coalescence for the same gas – liquid system, so different configuration of holes were use to secure and avoid coalescence in the experimental bubble column. It was found that, for certain initial bubble volumes, the loss of specific area can be balanced with the increment in the oscillation amplitude resulting from the coalescence process not only in invicid but also in viscous fluids.

Acknowledgment: The support of the Ministerio de Educación y Ciencia of Spain providing a F.P.U. fellowship to M. Martín is greatly welcomed. The funds from the project reference PPQ2000-0097-P4-02 are also appreciated.

Nomenclature.

d_{eq}: Equivalent diameter (m)
D_o: Orifice diameter (m)
D_L: Liquid diffusivity ($m^2 \cdot s^{-1}$)
k_L : Liquid resistance ($m \cdot s^{-1}$).

I_s: Integrate of Shape

N_{Pe} : Peclet number: $N_{Pe} = \frac{U \cdot d_{eq}}{D_L}$

Q_c: Gas flow rate ($m^3 \cdot s^{-1}$).

Re: Reynolds number $Re = \frac{\rho \cdot u_o \cdot d_{eq}}{\mu}$

Sc: Schmidt number $Sc = \frac{\mu}{\rho \cdot D_L}$

Sh: Sherwood number $Sh = \frac{k_L \cdot d_{eq}}{D_L}$

U: Rising velocity ($m \cdot s^{-1}$)
u_o: Gas velocity across the orifice ($m \cdot s^{-1}$)
μ: Dynamic viscosity (Pa·s)
ρ: Liquid density (Pa·s)

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