

Double surface-renewal model for the prediction of mass transfer rates during bubble formation with instantaneous reaction on the liquid side

F. XAVIER MALCATA

Escola Superior de Biotecnologia, Universidade Católica Portuguesa, Rua Dr. António Bernardino de Almeida, 4200 Porto, Portugal

(Received 30 October 1986 and in final form 6 July 1987)

Abstract—Desorption of a component from a gas mixture being injected through a submerged nozzle, during the bubble formation stage, is theoretically studied. The solute is assumed to suffer an instantaneous reaction on the liquid side, the reaction plane being on the liquid/gas interface. The volume elements on the gas bubble are assumed to result from a forced surface renewal coupled with a natural surface renewal, both achieved via gas elements with fresh composition. A surface residence time distribution is thus obtained, and desorption rates are calculated from the relevant variables, assuming non-steady state, unidimensional diffusion in a semi-infinite medium as the main mass transfer mechanism. Comparison of the model with experimental data is reported, physical evidence being predicted better than with previous models.

INTRODUCTION

THE DESORPTION of a component from a gas mixture by bubbling the gas through a reacting liquid has been widely used in chemical engineering practice, for the mass transfer rates are very high. This phenomenon is mainly due to the absence of mass transfer resistance on the liquid side, provided the reaction is assumed instantaneous [1] and the reaction plane lies on the gas/liquid interface.

As pointed out by Rocha and Guedes de Carvalho [2], the mass transfer from bubbles occurs mainly during bubble formation, the contributions for mass transfer arising from the bubble rise stage and the bubble staying in the surface foam being usually negligible. Therefore, mathematical simulation of the gas bubble behaviour during formation will enable the global mass transfer to be predicted in an approximate way. In typical systems, e.g. $\text{NH}_3(\text{air})/\text{HCl}(\text{water})$, formation of the bubble accounts for over 95% of the total desorption.

Until the present time, some theoretical studies on the mass transfer from bubbles, when the resistance to mass transfer is in the liquid phase, have been presented: Calderbank and Patra [3] measured transfer rates during bubble formation, providing a simple theory for mass transfer based on the idea of Beek and Kramers [4]. An alternative theory, leading to very similar results, was presented by Sherwood *et al.* [5], based on an analysis by Levich [6]. Rocha and Guedes de Carvalho [2] attempted a simulation of the bubble with no resistance to mass transfer on the liquid side, using first principles in a way similar to Sherwood *et al.* [5]. Bird *et al.* [7] worked examples of gas absorption from rising bubbles, a similar

approach having been successfully used to predict the mass transfer rates during drop formation.

Very little theoretical work has, indeed, been devoted to the understanding of bubble behaviour during formation, from the gas side point of view.

It is the purpose of this paper to develop a mathematical approach to the phenomena occurring during gas bubble growth using some simple postulates. The concept of two kinds of surface elements is introduced, both of them being generated directly from the gas input stream. Such an assumption leads to an effective desorption surface area greater than the actual bubble surface area. A residence time distribution can then be obtained which, together with the assumption of non-steady state, unidimensional diffusion in a semi-infinite medium as the mass transfer mechanism, leads to an analytical formula, quite useful as a tool for the computation of both the rate of desorption and the number of moles desorbed during bubble formation.

FORMULATION OF THE PROBLEM

To approach the phenomena existing during bubble birth and growth some postulates are assumed to describe the bubble behaviour. The most important of them are presented as follows.

When gas is injected through a nozzle submerged in a quiescent liquid, a bubble is formed, the gas stream being divided into two portions. One of them pushes the already existing gas elements on the gas/liquid interface, so making the actual surface area grow; meantime, the other gets mixed with the remaining gas in the bulk of the bubble. The former portion ensures a continuous forced surface renewal,

NOMENCLATURE

A	area	1	first discrete point
C	entering gas solute concentration	2	second discrete point
D	diffusivity of the solute	3	third discrete point
g	acceleration of gravity	bub	bubble
K	proportionality constant	f	final conditions
n	total number of moles desorbed during a certain time interval	gas	gaseous phase
N	solute molar flux by diffusion	i	initial conditions
N'	number of moles desorbed per unit area during a certain time interval	II	second order
n'	molar flow rate of desorption	max	maximum value
P	interpolating polynomial	ren	continuous natural surface renewal
P_0	operating parameter	s	elapsed at surface
Q	volumetric flow rate	surf	bubble surface
S	cumulative surface residence time distribution	tot	ever occupied by gas elements actually desorbing.
t	time elapsed since bubble birth		
V	volume		
v	renewal speed.		
Greek symbols			
δ	gas bubble surface film thickness		
ϕ	time elapsed since a gas element arrived at the surface.		
Subscripts			
0	entering conditions		
		Superscripts	
		\circ	since bubble birth until bubble release
		*	dimensionless, normalization having been made using the conditions at bubble release
		**	dimensionless, normalization having been made using the conditions at bubble birth
		—	average.

and it increases the total number of gas elements on the surface.

The gas elements on the surface undergo a continuous toroidal movement in the direction of the gas flow lines, which causes the older elements to leave the surface and go into the bulk, while new ones, with fresh composition, arrive at the surface. This can be called a continuous natural surface renewal, and it does not modify the total number of gas elements on the surface.

These two kinds of surface renewal mechanisms are depicted in Fig. 1.

The speed at which continuous natural surface renewal occurs must be proportional to the ratio between the volume occupied by the surface film and the total volume of the bubble, for this ratio is a statistic measure of the gas availability to exist on the surface. This fact can be expressed as

$$v_{\text{ren}} = K \frac{\delta A_{\text{surf}}}{V_{\text{bub}}} \quad (1)$$

where v_{ren} is the continuous natural surface renewal speed (dimension: area/time), K a proportionality constant, A_{surf} the area of the bubble surface, V_{bub} the bubble volume and δ the thickness of the gas film over the bubble interface.

When the bubble starts to form, its volume is prac-

tically nil, so the existing volume corresponds only to the bubble surface film on the gas side; therefore, the gas elements on the surface are removed at the same speed at which new gas elements arrive. Assuming the constant K does not depend on the bubble volume then equation (1) can be written as

$$v_{\text{ren}} = \frac{Q_{\text{gas}} A_{\text{surf}}}{V_{\text{bub}}} \quad (2)$$

where Q_{gas} is the gas volumetric flow rate.

The elementary variation of the area occupied by gas elements actually desorbing on the surface, dA_{tot} , is then given by summing up the elementary variation of the bubble surface area due to forced renewal, dA_{surf} , and the elementary variation of the area due to natural surface renewal, dA_{ren} . Using the definition of the continuous surface renewal speeds yields

$$dA_{\text{tot}} = \left(\frac{dA_{\text{surf}}}{dt} \right) dt + v_{\text{ren}} dt \quad (3)$$

where t is the time elapsed since bubble birth. Assuming the spherical shape for gas bubbles allows one to write

$$v_{\text{ren}}^* = t^{*-1/3} \quad (4)$$

as long as one makes

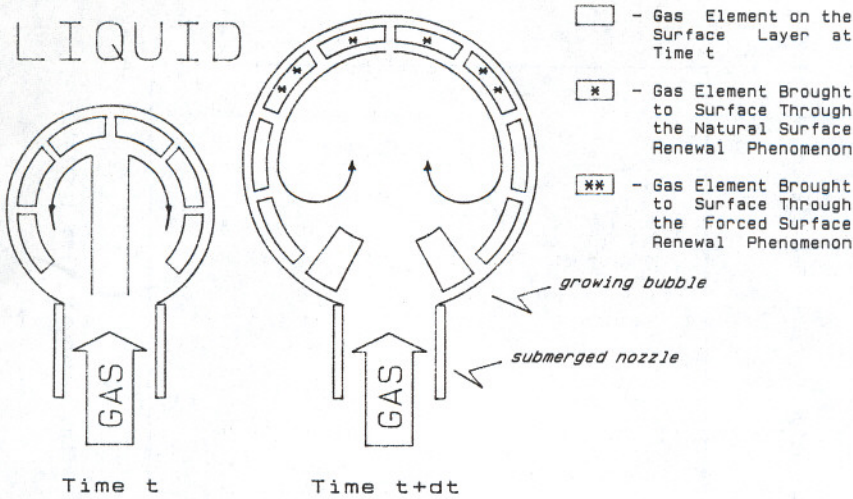


FIG. 1. Schematic representation of the two mechanisms of surface renewal.

$$t^* = \frac{t}{t^\circ} \tag{5}$$

and

$$v_{ren}^* = \frac{v_{ren}}{(36\pi)^{1/3} Q_{gas}^{2/3} t^{\circ-1/3}} \tag{6}$$

where t° is a reference time, defined here as the time elapsed since bubble birth until bubble release. The value for t° may be computed through the equation of Davidson and Schüller [8]

$$t^\circ = 1.138 Q_{gas}^{1/5} g^{-3/5} \tag{7}$$

where g is the acceleration of gravity.

For each gas element on the surface, the desorption takes place from time t_i until time $t_f(t_i)$. This latter value can be obtained from

$$A_{surf}(t_i) = \int_{t_i}^{t_f(t_i)} v_{ren}(t) dt \tag{8}$$

for each value of t_i . Using the normalized time and a dimensionless area defined by

$$A_{surf}^*(t^*) = \frac{A_{surf}(t)}{A_{surf}(t^\circ)} = t^{*2/3} \tag{9}$$

in equation (8) gives

$$t_i^{*2/3} = \int_{t_i^*}^{t_f^*} v_{ren}^*(t^*) dt^* \tag{10}$$

and finally

$$t_f^*(t_i^*) = (5/3)^{3/2} t_i^*, \quad t_i^* < (3/5)^{3/2} \tag{11}$$

$$t_f^*(t_i^*) = 1, \quad t_i^* > (3/5)^{3/2} \tag{12}$$

The values of $t_f^*(t_i^*)$ vs t_i^* can be observed in Fig. 2. The variation of both natural and forced surface renewal speeds is sketched in Fig. 3.

Normalizing variables in equation (3) and integrating with the limiting condition

$$t^* = 0, \quad A_{tot}^* = 0 \tag{13}$$

gives

$$A_{tot}^*(t^*) = (5/2) t^{*2/3} \tag{14}$$

where A_{tot}^* is the dimensionless counterpart of A_{tot} .

For each bubble age, t^* , the surface residence time of the gas element which arrived at the surface at time t_i^* , $t_s^*(t_i^*)$, is given by

$$t_s^*(t_i^*) = t_f^*(t_i^*) - t_i^*, \quad t_i^* < (3/5)^{3/2} t^* \tag{15}$$

$$t_s^*(t_i^*) = t^* - t_i^*, \quad t_i^* > (3/5)^{3/2} t^*. \tag{16}$$

The upper bound for the surface residence times is found to be

$$t_{s,max}^*(t^*) = [1 - (3/5)^{3/2}] t^*. \tag{17}$$

The cumulative residence time distribution at time t^* can be expressed as

$$S(t^*, t_s^*) = \frac{\int_0^{t_s^*(t^*)} \left(\frac{dA_{tot}^*(t^* = t_i^*)}{dt_s^*(t_i^*)} \right) dt_s^*(t_i^*)}{\int_0^{A_{tot}^*(t^*)} dA_{tot}^*(t^*)}, \quad t_s^* < t_{s,max}^*(t^*) \tag{18}$$

dA_{tot}^* denoting the elementary portion of the total surface area (at time t^*), which arrived at the surface between times t_i^* and $t_i^* + dt_i^*$. The derivative in the integrand function can be easily computed through

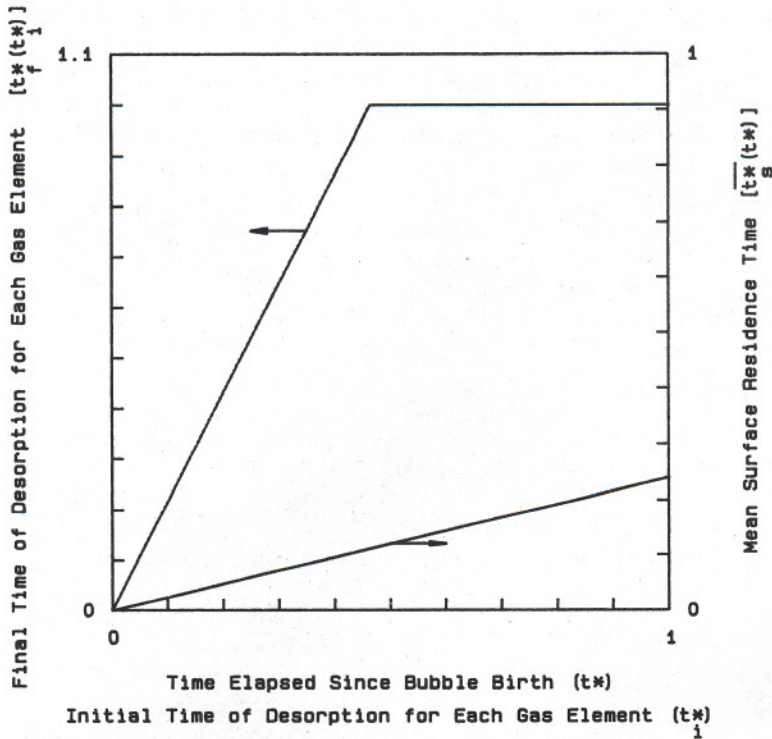


FIG. 2. Final time of desorption for each gas element vs initial time of desorption, and mean surface residence time vs total time elapsed since bubble birth.

the auxiliary equation

$$\frac{dA_{\text{tot}}^*(t^* = t_i^*)}{dt_s^*(t_i^*)} = \frac{dA_{\text{tot}}^*(t^* = t_i^*)/dt_i^*}{dt_s^*(t_i^*)/dt_i^*} [t_i^* < (3/5)^{3/2}t^*] \\ - \frac{dA_{\text{tot}}^*(t^* = t_i^*)/dt_i^*}{dt_s^*(t_i^*)/dt_i^*} [t_i^* > (3/5)^{3/2}t^*]. \quad (19)$$

Using equations (11) and (14)–(16) in equation (19), and using the outcoming result in equation (18) finally yields

$$S(t^*, t_s^*) = \{ [(5/3)^{3/2} - 1]^{-2/3} t_s^{*2/3} \\ + t^{*2/3} - (t^* - t_s^*)^{2/3} \} t^{*-2/3}, \quad t_s^* < t_{s,\text{max}}^*. \quad (20)$$

The cumulative surface residence time distribution is shown in Fig. 4 for several bubble ages.

The mean surface residence time, $\bar{t}_s^*(t^*)$, can be calculated as follows:

$$\bar{t}_s^*(t^*) = \left[\int_0^{t_{s,\text{max}}^*(t^*)} t_s^* \left(\frac{dA_{\text{tot}}^*(t^* = t_i^*)}{dt_s^*(t_i^*)} \right) dt_s^*(t_i^*) \right] / \left[\int_0^{A_{\text{tot}}^*(t^*)} dA_{\text{tot}}^*(t^*) \right] \quad (21)$$

the definition being apparent from equation (18). The following equation

$$\bar{t}_s^*(t^*) = (2/5)[(5/3)^{3/2} - 1]^{-2/3} t^{*2/3} - 2/3 t_{s,\text{max}}^{*5/3} \\ - t_{s,\text{max}}^*(t^* - t_{s,\text{max}}^*)^{2/3} t^{*-2/3} \\ - (3/5)[(t^* - t_{s,\text{max}}^*)^{5/3} - t^{*5/3}] t^{*-2/3} \quad (22)$$

may be derived from equation (21) in a similar fashion to equation (20) from equation (18). Using equation (17) in equation (22) and performing some algebraic work gives

$$\bar{t}_s^*(t^*) = \frac{2}{5} \left\{ \frac{[1 - (3/5)^{3/2}]^{5/3}}{[(5/3)^{3/2} - 1]^{2/3}} + (3/5)^{5/2} \right\} t^*. \quad (23)$$

The mean surface residence time is shown in Fig. 2 as a function of t^* .

Assume now that the gas elements on the bubble surface remain in a non-steady state of desorption, being described by the equation of diffusion in a semi-infinite medium. Assuming the solute concentration on the liquid side of the gas/liquid interface is nil and the bulk solute concentration in the gaseous phase is the input gas concentration, C_0 , enables the solute molar flux by diffusion, N , to be calculated via

$$N = C_0(D_{\text{gas}}/\pi\phi)^{1/2} \quad (24)$$

where D_{gas} is the diffusivity of the solute in the gaseous phase and ϕ the time elapsed after arrival of the gas element at the surface. The number of moles desorbed per unit area, after a time interval of amplitude t_s is computed after integration of equation (24), according to

$$N'(t_s) = 2C_0(D_{\text{gas}}/\pi)^{1/2} t_s^{1/2}. \quad (25)$$

Normalizing the integrated molar flux by the integrated molar flux after a time equal to the global

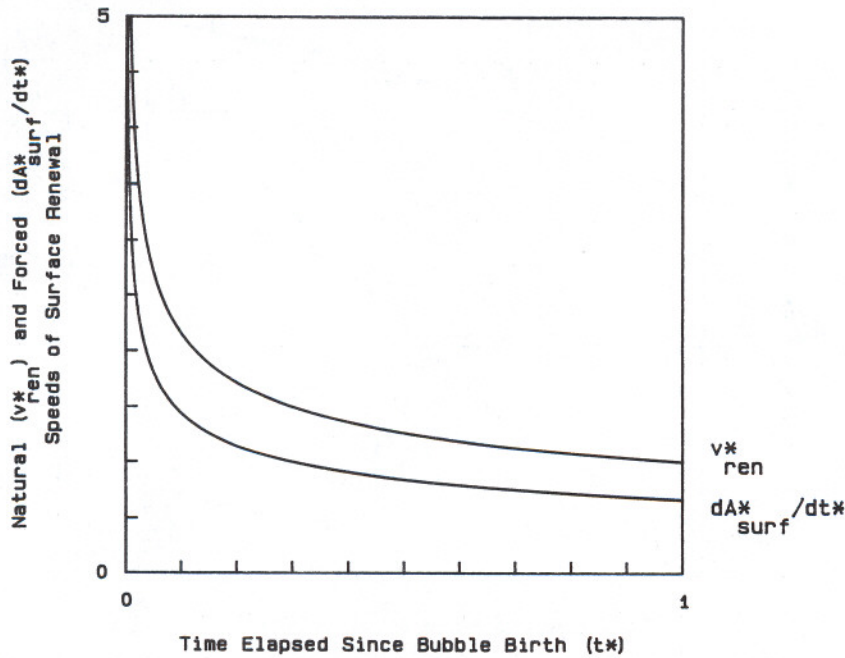


FIG. 3. Variation of continuous natural and forced surface renewal speeds with bubble age.

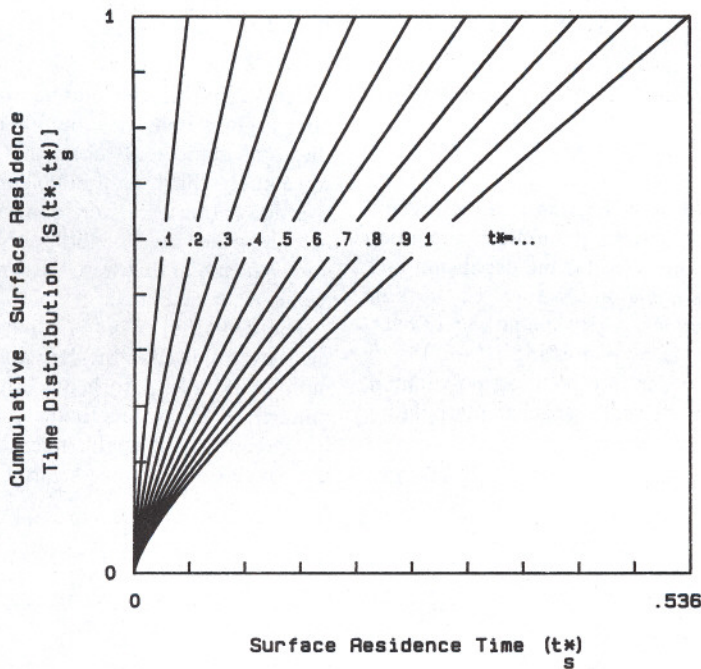


FIG. 4. Cumulative surface residence time distribution vs surface residence time, between zero and the maximal surface residence time, for various values of time elapsed since bubble birth.

growth time of the bubble, allows N^* to be obtained, defined by

$$N^*(t_s^*) = \frac{N'(t_s)}{N'(t_s = t^c)} = t_s^{*1/2}. \quad (26)$$

The total number of moles desorbed, n^* , since the initial time of bubble formation until bubble age, t^* , can be obtained from

$$n^*(t^*) = \int_0^{(3/5)^{3/2}t^*} N^*\{t_s^* = [(5/3)^{3/2} - 1]t_i^*\} \times \frac{dA_{tot}^*(t^* = t_i^*)}{dt_i^*} dt_i^* + \int_{(3/5)^{3/2}t^*}^{t^*} N^*\{t_s^* = t^* - t_i^*\} \times \frac{dA_{tot}^*(t^* = t_i^*)}{dt_i^*} dt_i^*. \quad (27)$$

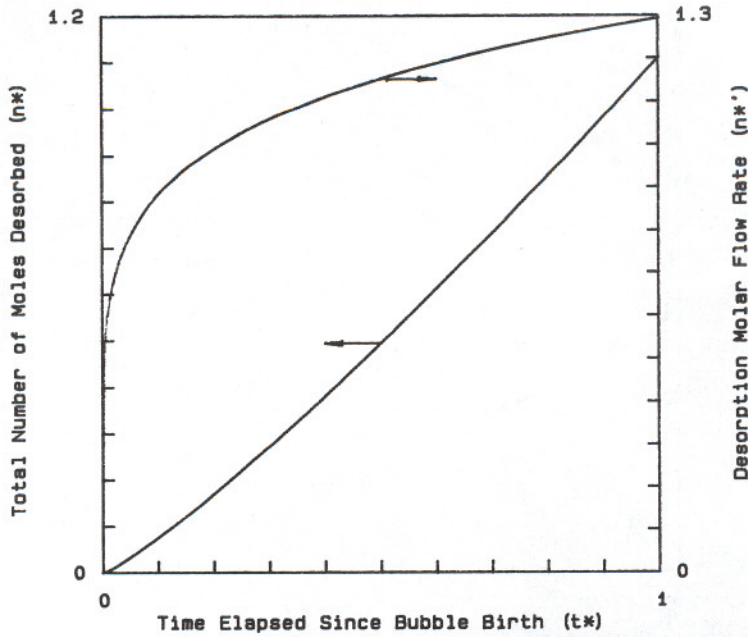


FIG. 5. Total number of moles desorbed and desorption molar flow rate vs time elapsed since bubble birth.

Using equation (26) together with equations (15) and (16) in equation (27) gives

$$n^*(t^*) = (10/7)[(5/3)^{3/2} - 1]^{1/2} (3/5)^{7/4} t^{*7/6} + (5/3) \int_{(3/5)^{3/2} t^*}^{t^*} (t^* - t_i^*)^{1/2} t_i^{*-1/3} dt_i^* \quad (28)$$

According to Piskounov [9], the defined integral stated above is not expressible as a finite combination of elementary functions. Besides the expansion as a Taylor series about any point within the working interval is not convergent. A reasonable way of overcoming the problem is by expressing $(t^* - t_i^*)^{1/2}$ by means of a second-order interpolating polynomial, $P_{11}(t^*, t_i^*)$, using three equally spaced interpolating points, t_{11}^* , t_{12}^* and t_{13}^* , defined by

$$t_{11}^* = (3/5)^{3/2} t^* \quad (29)$$

$$t_{12}^* = \frac{[(3/5)^{3/2} + 1] t^*}{2} \quad (30)$$

$$t_{13}^* = t^* \quad (31)$$

The following equation is then obtained:

$$P_{11}(t^*, t_i^*) = 0.3836 t^{*1/2} + 1.7320 t^{*-1/2} t_i^* - 2.1156 t^{*-3/2} t_i^{*2} \quad (32)$$

Using equation (32) in equation (28) and performing the integration leads to

$$n^*(t^*) = 1.1088 t^{*7/6} \quad (33)$$

The dimensionless molar flow rate of desorption, $n^{*'}$, is then given by

$$n^{*'}(t^*) = 1.2936 t^{*1/6} \quad (34)$$

The variation of both n^* and $n^{*'}$ vs t^* may be observed in Fig. 5. Using equations (7), (9), (25) and (26), it can be verified that

$$n^* = \frac{n}{6.3452 C_0 D_{\text{gas}}^{1/2} Q_{\text{gas}}^{9/10} g^{-7/10}} \quad (35)$$

which means n^* is the total number of moles desorbed after a given time since bubble birth, normalized by the total number of moles that would be desorbed since bubble birth until bubble release if all the effective desorption area were constant and equal to the actual surface area of the bubble at bubble release, and if the molar flux were the same for all gas surface elements, at each time.

The definition of n^* is a natural consequence of the steps followed in the derivation. Nevertheless, the number of moles desorbed is often normalized by the number of moles fed to the forming bubble, since bubble birth until bubble release. Using the notation n^{**} for this dimensionless variable, it follows that

$$n^{**} = \frac{n}{C_0 Q_{\text{gas}} t^0} \quad (36)$$

Using equations (7) and (35) in equation (36), it can be stated that

$$n^{**}(n^*) = 5.5757 P_o n^* \quad (37)$$

where P_o is an operating parameter defined by

$$P_o = \frac{D_{\text{gas}}^{1/2}}{Q_{\text{gas}}^{3/10} g^{1/10}} \quad (38)$$

Replacing equations (33) and (38) in equation (37), and putting t^* equal to unity, yields

$$n^{**} = 6.1823 \frac{D_{\text{gas}}^{1/2}}{Q_{\text{gas}}^{3/10} g^{1/10}} \quad (39)$$

which might be useful for design purposes. Parameter P_o is a measure of the ratio of the solute molar flow

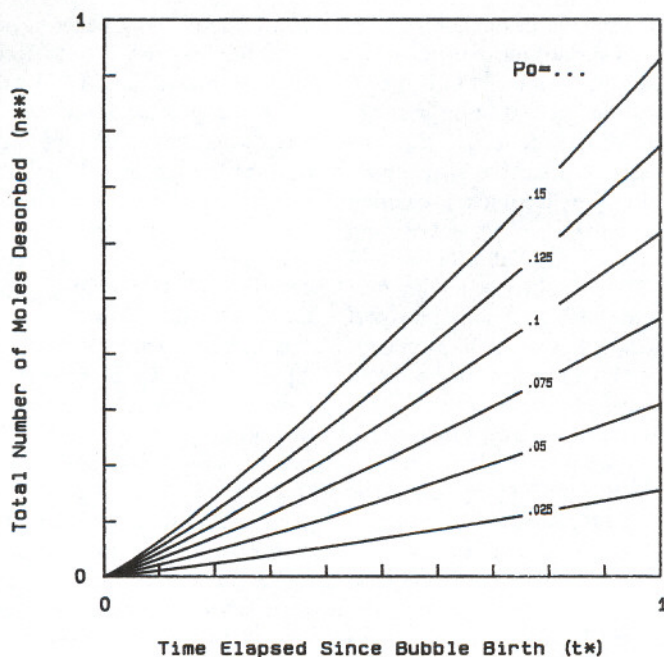


FIG. 6. Total number of moles desorbed vs time elapsed since bubble birth, for various values of Po .

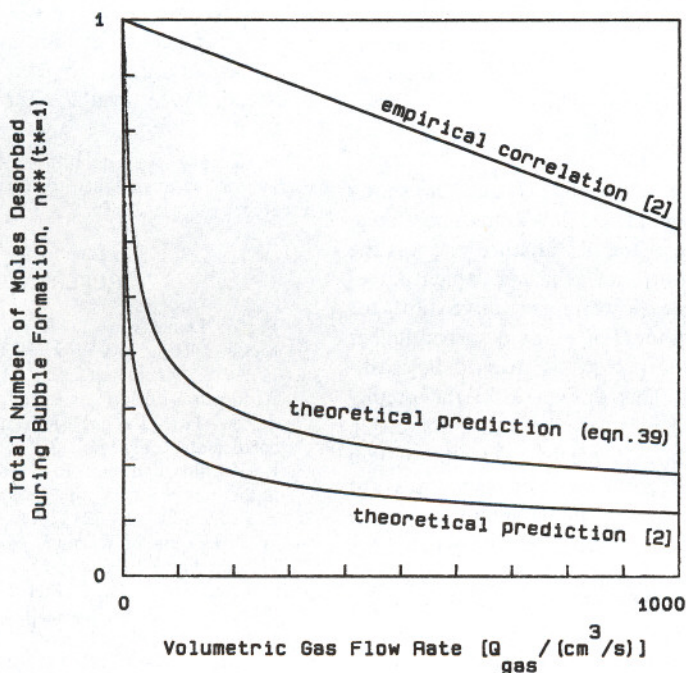


FIG. 7. Theoretical predictions and empirical correlated data of the fractional number of moles desorbed, for various volumetric gas flow rates.

due to diffusion flow, to the bulk solute molar flow. The variable n^{**} is plotted vs t^* in Fig. 6.

The values for n^{**} as predicted by the developed theory, and via a previous theory and an empirical correlation [2] are plotted in Fig. 7, as n^{**} vs Q_{gas} , assuming $D_{gas} = 0.222 \text{ cm}^2 \text{ s}^{-1}$ and $g = 980 \text{ cm s}^{-2}$.

CONCLUSIONS AND DISCUSSION

For bubbles of moderate size growing at a nozzle tip submerged in a liquid, with no surface-active agents, the gas in the bubble undergoes a toroidal circulation, as suggested by Bird *et al.* [7]. Such surface

gas streams get mixed in the bulk of the bubble after completion of the toroidal surface movement, so the concentration gradient in the bulk tends to be negligible when compared to the concentration gradient on the surface film. It should be noted that the diffusion layer near the bubble surface is relatively thick on the gas side; also, significant gas circulation is present inside the bubble, so the gas elements remain on the surface for short times [2]. Diffusion in non-steady state conditions is, thus, likely to be the most important contribution to the overall mass transport phenomenon. Besides, the surface gas film remains relatively stagnant [7], so it can be assumed to be in laminar flow and to maintain its identity.

Dilute gas mixtures are usually used in industrial practice, so the molar flux of solute resulting from the bulk motion of the fluid remains at very low levels [10], even if the solute is totally removed by chemical reaction. Therefore, the model developed does not fail for only considering Fick's law in its simplest expression.

The mass transfer rate between adjacent gas elements on the surface is negligible, due to the very small contacting area and concentration gradient, when compared to the mass transfer rate in the radial direction, where the largest contacting areas and steepest gradients occur. The assumption of a unidimensional field of concentrations is then acceptable.

The equation of Davidson and Schüller [8] was used because it approximates experimental data reported elsewhere [2] closely enough and it has a physical basis.

A general look over equations (37) and (38) shows that the larger the volumetric flow rate or the lower the solute diffusivity in the gas mixture, the less the fractional solute desorption achieved, which agrees with physical evidence. However, very large values for Po would lead to amounts of solute desorbed higher than those fed to the nozzle, as stressed by extrapolation on Fig. 6. This drawback in the prediction procedure has been reported elsewhere [2], but is as low as about $5 \text{ cm}^3 \text{ s}^{-1}$ for the system $\text{NH}_3(\text{air})/\text{HCl}(\text{water})$, being mostly accounted for by the lack of validity of the assumptions made (especially the non-steady state for diffusion in a semi-infinite medium).

The increase of desorption due to a larger number of elements on the surface tends to be balanced by the decrease of the continuous natural surface renewal speed. In fact, the mean surface residence time tends to get larger as the bubble grows (see equation (23)), and larger desorption times mean lower desorption rates, as emphasized by equation (24).

It can be stated from equation (14) that the effective area that suffered desorption for any time interval during the bubble growth is two and a half times larger than the actual bubble surface area. This larger

area of desorption, which is not apparent from previous models, may help to account for the enhanced rates of mass transfer. In fact, the simple theory developed predicts accurately the desorption at not too low gas flow rates, but underpredicts the rates of transfer for higher gas flow rates, according to the empirical correlation presented elsewhere for the system $\text{NH}_3(\text{air})/\text{HCl}(\text{water})$ [2]. It leads, however, to theoretical values for the fractional number of moles desorbed (n^{**}) closer to the experimental values than the ones obtained from the simulation using first principles, as reported by Rocha and Guedes de Carvalho [2] (see Fig. 7). The high deviations found for large gas flow rates are mainly due to the disruptive presence of the injection nozzle and bubble formation with tearing, the turbulence resulting from the strong coalescence during continuous bubbling; these phenomena are not easy to simulate. The decrease of mass transfer rate with the increase of gas flow rate or the decrease of solute diffusivity in the gas phase is, nevertheless, qualitatively predicted. The fact that larger effective desorption areas lead to results closer to experimental data, coupled with the same functional relationship found using two different methods of derivation, suggests that more involved patterns for the gas circulation inside the bubble will eventually be able to predict the overall behaviour for instantaneous chemical absorption from bubbles. Enhanced rates of mass transfer are then understood as a result of extended areas available for mass transfer.

Acknowledgements—The author is grateful to Dr F. A. N. Rocha for his availability to discuss some details of this research.

REFERENCES

1. P. V. Danckwerts, *Gas-Liquid Reactions*, p. 133. McGraw-Hill, New York (1970).
2. F. A. N. Rocha and J. R. F. Guedes de Carvalho, Absorption during gas injection through a submerged nozzle—Part I: gas side and liquid side transfer coefficients, *Chem. Engng Res. Des.* **62**, 303–314 (1984).
3. P. H. Calderbank and R. P. Patră, Mass transfer in the liquid phase during the formation of bubbles, *Chem. Engng Sci.* **21**, 719–721 (1966).
4. W. J. Beek and H. Kramers, Mass transfer with a change in interfacial area, *Chem. Engng Sci.* **16**, 909–921 (1962).
5. T. K. Sherwood, R. L. Pigford and C. R. Wilke, *Mass Transfer*, p. 73. McGraw-Hill, New York (1975).
6. V. G. Levich, *Physicochemical Hydrodynamics*. Prentice-Hall, Englewood Cliffs, New Jersey (1962).
7. R. B. Bird, W. E. Stewart and E. N. Lightfoot, *Transport Phenomena*, pp. 537–542. Wiley, New York (1960).
8. J. F. Davidson and B. O. G. Schüller, Bubble formation at an orifice in a viscous liquid, *Trans. Instn Chem. Engrs* **38**, 144–154 (1960).
9. N. Piskounov, *Cálculo Diferencial e Integral*, Portuguese translation from the Russian Edition, pp. 405–408. Edições Lopes da Silva, Porto (1983).
10. R. B. Bird, Theory of diffusion. In *Advances in Chemical Engineering*, Vol. 1. Academic Press, New York (1956).

MODELE A DOUBLE RENOUVELLEMENT DE SURFACE POUR LA PREDICTION
DU TRANSFER THERMIQUE PENDANT LA FORMATION DE BULLE AVEC
REACTION INSTANTANEE DU COTE DU LIQUIDE

Résumé—On étudie théoriquement la désorption d'un composant d'un mélange gazeux injecté à travers un orifice submergé, pendant l'étape de formation de la bulle. Le soluté est supposé subir une réaction instantanée du côté du liquide, la réaction étant à l'interface liquide/gaz. Les éléments de volume sur la bulle de gaz sont supposés résulter d'un renouvellement forcé de la surface couplé avec un renouvellement naturel. Une distribution de temps de résidence à la surface est obtenue et les flux de désorption sont calculés à partir des variables actives en supposant une diffusion variable unidimensionnelle dans un milieu semi-infini, comme mécanisme principal du transfert de masse. On compare le modèle aux données expérimentales et on constate une meilleure prédiction qu'avec les modèles antérieurs.

EIN MODELL MIT ZWEIFACHER OBERFLÄCHENERNEUERUNG ZUR
BERECHNUNG DES STOFFÜBERGANGS WÄHREND DER BLASENBILDUNG
MIT GLEICHZEITIGER REAKTION AUF DER FLÜSSIGSEITE

Zusammenfassung—Es wurde die Desorption einer Komponente aus einer Gasmischung, die durch eine eingetauchte Düse eingeblasen wird, theoretisch für die Blasenbildungsphase untersucht. Es wird angenommen, daß sich der gelöste Stoff sofort an einer Reaktion auf der Flüssigseite beteiligt. Die Reaktionsebene liege dabei in der Flüssig/Gas-Grenzfläche. Weiter wird angenommen, daß die Volumenelemente der Gasblase aus einer gemischten Oberflächenerneuerung (erzwungene und natürliche) resultieren. Beide Effekte werden mit Hilfe von Gaselementen frischer Zusammensetzung ermittelt. Die Oberflächen-Verweilzeit-Verteilung und die Desorptionsströme werden aus den maßgebenden Variablen berechnet, wobei instationäre, eindimensionale Diffusion im halbumendlichen Medium als bestimmender Stofftransportmechanismus angenommen wird. Ein Vergleich des Modells mit experimentellen Daten wird durchgeführt. Die physikalische Aussagekraft ist besser als mit anderen Modellen.

МОДЕЛЬ ДВОЙНОГО ОБНОВЛЕНИЯ ПОВЕРХНОСТИ ДЛЯ РАСЧЕТА
ИНТЕНСИВНОСТИ МАССОПЕРЕНОСА ПРИ ЗАРОЖДЕНИИ ПУЗЫРЬКОВ И
МГНОВЕННОЙ ХИМИЧЕСКОЙ РЕАКЦИИ В ЖИДКОСТИ

Аннотация—Теоретически исследуется десорбция компонента из газовой смеси, вдуваемой через затопленное сопло, в режиме образования пузырьков. Предполагается, что растворенное вещество мгновенно вступает в жидкости в химическую реакцию, причем плоскость реакции находится на границе раздела газ-жидкость. Предполагается, что на газовом пузырьке появляются объемные образования из-за принудительного обновления поверхности, которое происходит одновременно с аналогичным естественным процессом обновления, причем в обоих случаях газ в таких образованиях имеет новый состав. Таким образом получено распределение времени пребывания объемных образований на поверхности пузырька. Скорость десорбции рассчитывается по соответствующим переменным в предположении, что основным механизмом переноса массы является неустановившаяся одномерная диффузия в полубесконечной среде. Приведено сопоставление результатов расчета по модели с экспериментальными данными. По сравнению с имеющимися моделями предлагаемая модель лучше описывает физику процесса.