Analysis of hydrodynamic parameters of air lift bioreactors with immobilized cells

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Introduction

Biotechnology is currently a rapidly expanding field of interdisciplinary research. This is apparent amongst others from the development of a number of new types of bioreactors. The traditional stirred-tank reactor is no longer a priori the standard bioreactor, mainly because of economic considerations and the intrinsic properties of the bio-phase used [1-6]. Air-lift bioreactors (ALR) are a relatively new type of fermentor, offering several advantages for large-scale aerobic bioprocesses, for animal and cell culture in particular. In many cases immobilized biocatalysts or microorganisms are used. However, bio-phase could form complex aggregation structures. The optimization of cell growth includes the optimization of micro-environmental conditions, i.e., saturated oxygen concentration and pH, as well as substrate concentration, and mass transfer. The quality of the local mixing pattern is an estimate of the optimal mass transfer conditions. Numerous investigations have been carried out on the mass transfer capability of air-lift contactors but the results so far do not yield much more than empirical correlations [1, 2]. The principal goal of this study was to examine the influence of the geometry of the reactor on the mixing quality for two-phase systems. Slip velocity was used as a measure of local mixing quality. The various correlations proposed in the literature were considerd for two-phase systems [4,7-9], which could be applied for three-phase systems with solid content less than 20 % and where often the third phase is immobilized biocatalysts or microorganisms. The main goal was to clarify which operation parameters and geometrical characteristics are of special importance for the ALR optimization.

Material and methods

Surface gas velocity is the major independent hydrodynamic parameter and is correlated with slip velocity. Slip velocity prediction, for various flow regimes, is of major importance for better mass transfer realization and ALR optimization and could be used as a quantification of local mixing quality. Correlation of slip velocity with reactor geometry as well as hydrodynamic parameters would be useful. Various slip velocity based models have been considered [4,7-9]. Experimental data were examined in order to determine the most accurate correlations for the prediction of slip velocity. The method of theoretical analysis includes determination of hydrodynamic parameters from the experimental data [10-15]. Correlations from the literature were used for prediction of values of slip velocity. Predicted values were compared with the experimental data. Experimental data covered a wide range of hydrodynamic conditions and geometrical characteristics of reactors.

A general treatment of dispersed flow systems has been introduced [8], in which the relative velocity between phases is the essential parameter, as there is a difference between the real local relative velocity and that defined by:

$$V_S = \frac{V_g}{\varepsilon} - \frac{V_l}{1-\varepsilon} \qquad (1)$$

where V_S is slip velocity, V_g is superficial gas velocity, V_l is superficial liquid velocity, ε is gas hold up.

Results and discussion

Our model equation is based on equation (1) which for low gas holdups can be simplified to:

$$V_S = \frac{V_g}{\varepsilon} - V_l \qquad (2)$$

In this equation gas holdup and liquid superficial velocity can be correlated with equations from the literature that we found in a previous work to be among the most accurate [13]. For gas holdup this is the well known balance equation [16]. For prediction of the superficial liquid velocity Glennon et al. [11] proposed an equation that we have found to give good results for different regimes and geometries [13]. Based on this equations our model equation has two different expressions:

for $V_g < 0.05$ m/s (homogeneous flow):

$$V_S = V_g^{0.16}\left(\frac{0.967}{k^{0.182}} - 1.017k^{-0.409}V_g^{0.26}\right)$$

for $V_g \geq 0.05$ m/s (heterogeneous flow):

$$V_S = V_g^{0.315}\left(\frac{1.851V_g^{0.055}}{k^{0.146}} - 0.735k^{-0.427}\right)$$

where V_g is the superficial gas velocity and the k parameter is a function of reactor geometry: $k = \frac{K_f}{2gH}\left(\frac{A_r}{A_d}\right)^2$ where K_f is total losses coeficient, H hight of reactor, A cross section of riser and downcomer section.

Calculated slip velocity as a function of V_g in the homogeneous and the heterogeneous regime, for various values of k is shown in Figure 1 and Figure 2.

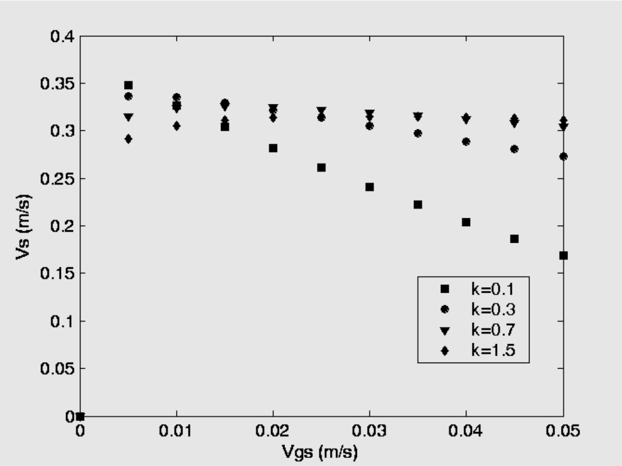

Figure 1. Slip velocity as a function of the superficial gas velocity for various values of the parameter k in the homogeneous regime.

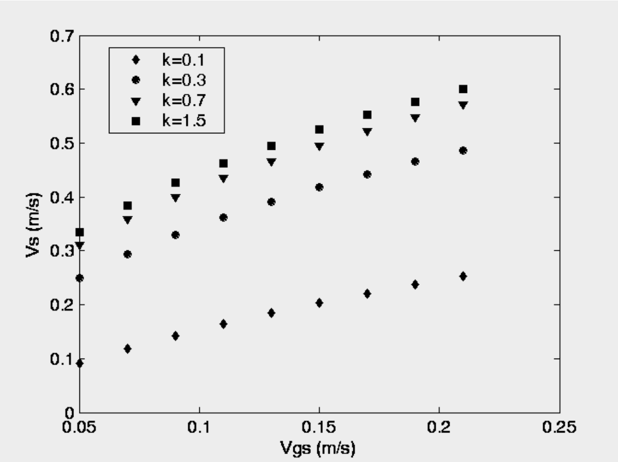

Figure 2. Slip velocity as a function of the superficial gas velocity for various values of the parameter k in the heterogeneous regime.

Figure 3 shows experimental values of slip velocities for different reactor geometries and gas velocities. It can be seen that it is impossible to correlate slip velocity with a one-parameter model. Lines represent values of slip velocity predicted by our model. Results of Bugarski [3] and Milivojevic [13] were not included in Figure 3 because these experiments were carried out with very low values of gas velocities. This regime of gas velocities gives slip velocities below 0.1 m/s and could not be predicted by our or other correlations except by the correlation of Gomezplata et al. [8], which was originally developed for similar working conditions.

The correlations for slip velocity from literature, as well as, our correlations were tested with the experimental data. The listed correlations and the corresponding mean absolute errors at different regimes are given in Table 1.

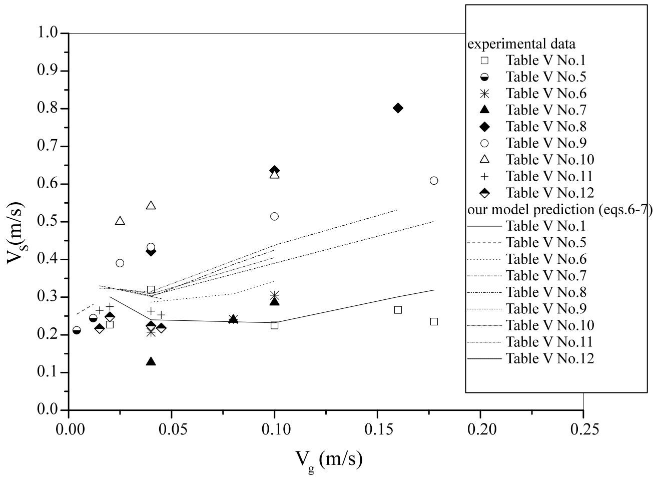

Figure 3. Comparison of experimental data with the predictions of our model equations.

Table 1. Comparison of the predictions of the various models with experimental data

Flow regime	Most accurate equations	Absolute error (%)
V_g <0,01 m/s	1) Towell et al., [8]	0,6
	2) van der Lans (a), [8]	6,2
	3) van der Lans (b), [8]	6,3
	4) Joshi et al., [4]	11,6
	5) Wallis, [8]	13,8
	6) Lockett and Kirkpatric, [4]	14,6
0,01 m/s < V_g < 0,05 m/s	1) Lockett and Kirkpatric, [4]	33,0
	2) Wallis, [8]	33,3
	3) Our correlation (eqs. 6,7)	35.0
	4)Joshi et al., [4]	35,1
	5) Garcia Calvo, [7]	36,4
0,05 m/s < V_g < 0,10 m/s	1) Garcia Calvo, [7]	30,6
	2) Our correlation (eqs. 6,7)	30.8
	3) Joshi et al., [4]	32,3
	4) Zuber and Findlay, (slug flow),[9]	37,8
	5) Wallis, [8]	37,9
V_g > 0,10 m/s	1) Our correlation (eqs. 6,7)	25.1
	2) Zuber and Findlay, (slug flow), [9]	34,4
	3) Joshi et al., [4]	44,1
	4) Garcia Calvo, [7]	44,9

Analysis of the results listed in Table 1 shows that in the homogenous regime a number of correlations could be used for slip velocity prediction. The main reason for this is the fact that in the homogenous regime slip velocity has a value of about 0.25 m/s (±20 %). Generally, the choice of the correlation for slip velocity predictions depends on the regime. There is no particular correlation suitable for all regimes. The most accurate ones are Joshi et al., [4], Garcia-Calvo et al., [7], Wallis, [8] and our correlations (eqs. 2-4). For reactors with riser diameter larger than 0.14 m, and riser to downcomer area ratio larger than 4, the correlation of Towell et al. [8] gives good results, since it was developed for reactors with larger riser diameters. Our correlation also give good results for those cases.

Conclusions

Higher value of slip velocity ensures better mixing quality and mass transfer conditions and it could be realized with: higher values of superficial gas velocity in the heterogeneous regime, down-comer to riser cross-section ratio higher than 4, reactor diameter larger than 0.14 m, lower values of k parameter in the homogeneous regime. From Figures 1 and 2, it can be seen that in the homogeneous regime it is better to work with lower values of V_g, if we can achieve values of k less than say, 0.3, and if not it is better to work with higher V_g and k. In the homogeneous regime, for values of k lower than 0.5, it is easier to achieve large slip velocities by increasing k than with increasing V_g. For values of k larger than 1, further increase of k would not give significant increase in slip velocity.

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