

IMPACT OF STRUCTURED PACKING ON BUBBLE COLUMN MASS TRANSFER CHARACTERISTICS EVALUATION.

Part 3. Sensitivity of ADM Volumetric Mass Transfer Coefficient evaluation

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Abstract

Based on the available concentration profiles the present work discusses the sensitivity of volumetric mass transfer coefficient on axial dispersion coefficient. The calculations were performed for a bubble column without internals, the parameters of ADM were determined with nonlinear regression. The volumetric mass transfer coefficient shows a slight dependence on the axial dispersion coefficient which leads to the conclusion that ADM provides reasonable values for $k_L a$ whenever more or less reliable correlation for E_L is available. Nevertheless, the exact concentration profile evaluation requires E_L to be determined with caution.

Introduction

An extensive experimental study of hydrodynamic and mass transfer characteristics of bubble column, with or without internals, is described in details in Part 1¹ and Part 2.² The experiments were performed in the Plexiglas column with a high length to diameter ratio. The column operated in the cocurrent upflow mode, tap water and oxygen were employed as the flowing phases. Both hydrodynamic regimes, the homogeneous and heterogeneous, were partly covered. The perforated plate served as the gas distributor.

A significant deviation from the ideal plug flow of the liquid phase was experimentally confirmed¹ and validated in the form of axial dispersion number, E_L .

For the evaluation of mass transfer characteristics the measurement of oxygen concentration in the liquid phase were taken under stationary conditions² at four different axial positions along the column. The data were then interpreted with the use of axial dispersion model (ADM) and plug flow model (PFM). The resulting values for the volumetric mass transfer coefficients clearly showed the more realistic response of ADM against PFM.

Axial dispersion model (Part 1,¹ equation 3 to equation 11) involves two parameters, the Stanton number, St, and the Bodenstein number, Bo. At the given operating conditions k_{La} and E_L may be explicitly expressed and used instead. The ADM concentration curves are extremely sensitive to the Stanton number, while the Bo number shows minor effect.³

In the present work the sensitivity of the calculated volumetric mass transfer coefficient based on the available concentration profiles, on axial dispersion coefficients is shown. The calculations were performed on the experimental data for a bubble column without internals, the parameters of the ADM were determined with nonlinear regression procedure by means of the Mathematica.

Results and discussion

The deviation of the calculated profile from the experimental one is expressed as the sum of the differences between the measured and calculated values of the concentration to the square, in all cases.

In Table 1 the k_{La} values as an average along the column were obtained from the adaptation to the measured concentration profiles. For the second parameter of the model, E_L , the experimental values¹ best represented with the following equation:

$$E_L = 129.05 \cdot u_G^{0.191} \quad (1)$$

were put into the model. In the above equation E_L is in cm^2s^{-1} and u_G in cm s^{-1} (with $e_y=8.89\%$ and $\sigma=9.37\%$). The calculated profiles seems to be very close the experimental ones, the sums of the squares lie between 0.74 and 12. At the $u_L=1.81 \text{ cm s}^{-1}$ some irregularities may be observed, the k_{La} values are evidently too high. The examination of the measured profiles was made. Extremely high values of the concentration at the first measuring point were found what could easily corrupt the results.

For comparison the k_{La} evaluated from the last measured concentration in the column² are also presented. Except for the first set of data at the lowest liquid velocity the k_{La} values are very close to those from the profile adaptation, but the deviations of the calculated profiles from the measured ones are about doubled.

In spite of insufficient number of the experimental data for liquid concentration along the column an attempt to optimise both parameters from the concentration profiles was also made. These results are shown in Table 2. In this case the summations of squares are lower than 1 in all runs. The values of the axial dispersion coefficients do not match with the measured coefficients (equation 1). Because the concentration profile is rather insensitive to E_L^3 these values are very uncertain. Surprisingly, the volumetric mass transfer coefficients are nearly identical to those based on the one parameter concentration profile adaptations (within 5%).

Table 1. Results of ADM $k_L a$ values based on the measured concentration profiles.

Run No	u_L (cm s ⁻¹)	u_G (cm s ⁻¹)	E_L^* (cm ² s ⁻¹)	ADM – $k_L a$ optimized from the concentration profile		ADM – $k_L a$ adjusted to the last measured concentration	
				$k_L a$ (s ⁻¹)	Σ (Δc_L) ²	$k_L a$ (s ⁻¹)	Σ (Δc_L) ²
1	1.81	1.81	144.5	0.03116	2.60	0.02795	5.47
2		3.61	165.0	0.08216	9.41	0.05242	38.22
3		5.41	178.2	0.1199	10.87	0.06911	42.68
4		9.0	196.3	0.1817	11.17	0.08247	60.05
5	3.61	1.81	144.5	0.02307	0.74	0.02372	1.026
6		3.61	165.0	0.05080	1.60	0.04850	2.45
7		5.41	178.2	0.07547	4.11	0.06752	7.80
8		9.0	196.3	0.11561	9.60	0.09250	20.42
9	5.41	1.81	144.5	0.02128	1.12	0.02104	1.16
10		3.61	165.0	0.04667	0.90	0.04525	1.98
11		5.41	178.2	0.06739	1.02	0.06485	1.65
12		9.0	196.3	0.10617	4.88	0.09537	9.05

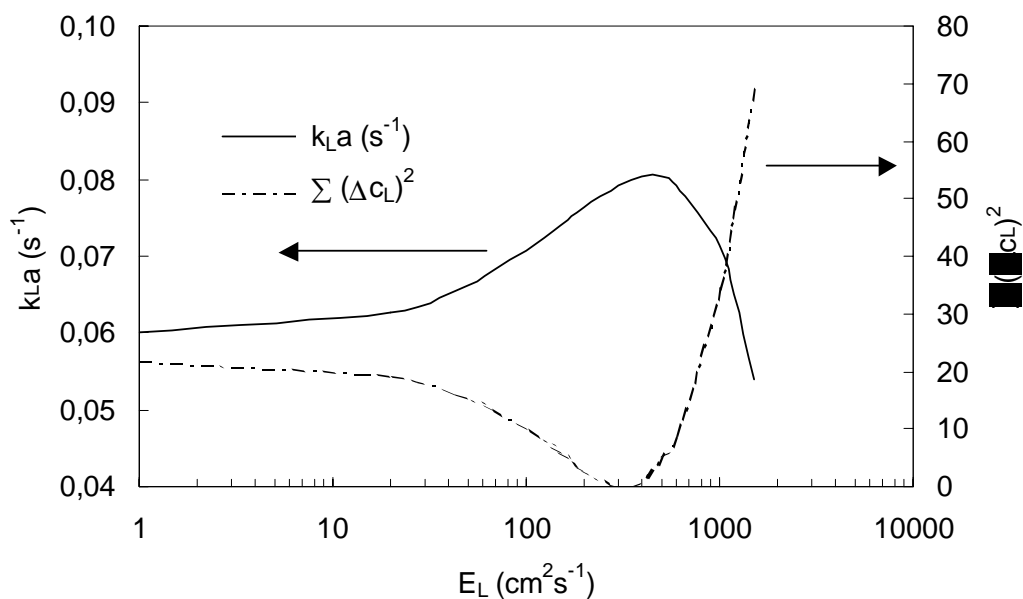
* Equation 1.

For comparison the volumetric mass transfer coefficients evaluated from the PFM are also included in Table 2. These values are adjusted to the last measured concentration in the column. As one can see the coefficients are lower than those from ADM, the summations of squares are between 10 and 100.

In order to test the sensitivity of $k_L a$ on the axial dispersion coefficient the experimental data points from run No. 7 were employed. In these calculations E_L was varied from 1 cm²s⁻¹ to 1500 cm²s⁻¹. The values of the mass transfer coefficient were then optimised to the measured concentration profile (Figure 1).

Table 2. Results of both ADM parameters optimized from the measured concentration profiles and k_{La} values from PFM.

Run No	ADM – E_L and k_{La} optimized from the concentration profile					PFM – k_{La} adjusted to the last measured concentration	
	u_L (cm s ⁻¹)	u_g (cm s ⁻¹)	E_L (cm ² s ⁻¹)	k_{La} (s ⁻¹)	Σ (Δc_L) ²	k_{La} (s ⁻¹)	Σ (Δc_L) ²
1	1.81	1.81	200.1	0.0308	0.0735	0.01938	100.1
2		3.61	396.1	0.0848	0.969	0.02819	166.3
3		5.41	566.7	0.1217	0.276	0.0329	166.3
4		9.0	849.6	0.1730	0.640	0.03522	200.2
5	3.61	1.81	116.6	0.02377	0.089	0.0231	20.54
6		3.61	220.5	0.05125	0.391	0.0394	34.70
7		5.41	330.4	0.0797	0.009	0.0478	56.61
8		9.0	557.0	0.1311	0.162	0.0592	74.70
9	5.41	1.81	107.0	0.02224	0.539	0.0234	10.27
10		3.61	152.9	0.04676	0.872	0.04258	13.54
11		5.41	229.8	0.06801	0.651	0.05591	18.45
12		9.0	470.5	0.1168	0.046	0.07469	35.32

**Figure 1.** Volumetric gas-liquid mass transfer coefficient and the summation of squares as a function of axial dispersion coefficient (experimental concentration data points from run No. 7).

From Table 1 it can be seen that at these operating conditions the experimental value of E_L (equation 1) is 178.2 cm²s⁻¹ and the k_{La} value adjusted to the measured profile is equal to 0.07547 s⁻¹. The sum of the squares is about 4. When E_L is nearly doubled (to 330.4 cm²s⁻¹) the change in the volumetric mass transfer coefficient is within

5% (to 0.0797 s^{-1}). These two values are taken from the two-parameter fit from Table 2. In fact for values of axial dispersion coefficient from 1 to $1000 \text{ cm}^2\text{s}^{-1}$ the volumetric mass transfer coefficients lie within 0.06 s^{-1} and 0.08 s^{-1} (Figure 1). However, the deviation of the calculated concentration profile from the measured one does change significantly, the sum of the squares is first minimised and then goes up to 50, increasing rapidly. In Figure 2 the calculated dimensionless concentration profile at different values of E_L are drawn together with the experimental data points. It is obvious that the $k_{L,a}$ determination is quite insensitive to the value of E_L , while the prediction of the reliable concentration profile along the column requires both parameters to be determined with caution.

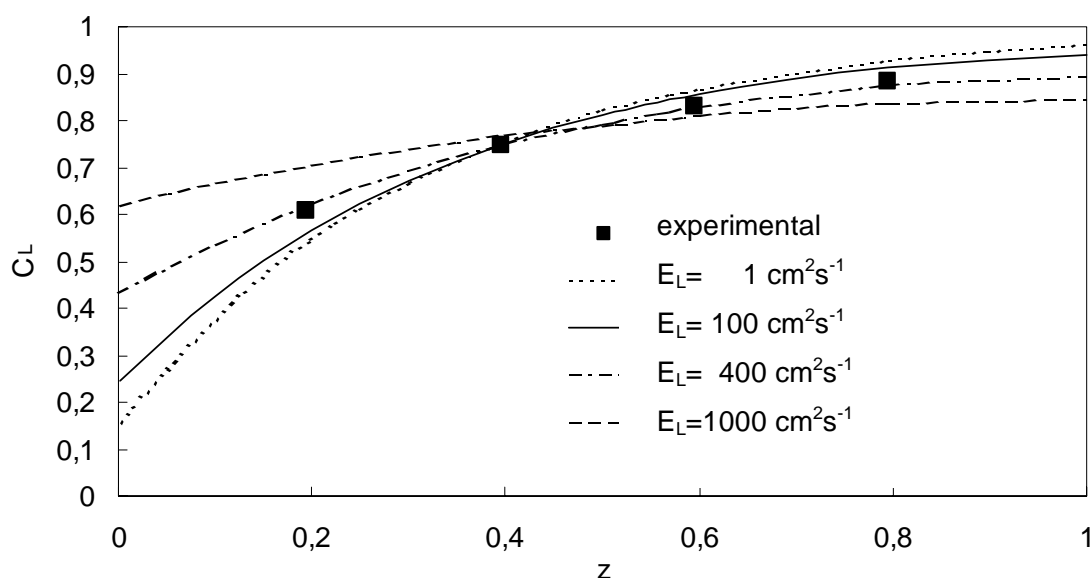


Figure 2. Calculated concentration profiles at different values of axial dispersion coefficient (experimental concentration data points from run No. 7).

Conclusion

The sensitivity of the volumetric mass transfer coefficient on the axial dispersion coefficient was examined. The experimental data were taken from the previous studies.^{1,2} The use of axial dispersion model in $k_{L,a}$ evaluation based on the measured concentration profile, or even one single measured concentration, gives the satisfactory result as long as more or less reliable correlations for E_L are available. Nevertheless, the estimation of the exact concentration profile requires also E_L to be determined with caution.

Acknowledgements

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Nomenclature

C	dimensionless oxygen concentration, c/c^* , /
c	oxygen concentration, mg l^{-1}
E_L	dispersion coefficient, m^2s^{-1}
e_y	mean relative error, $\left(= \frac{100}{N} \sum_{i=1}^N \left \frac{y_{\text{MES}}(i) - y_{\text{PRED}}(i)}{y_{\text{MES}}(i)} \right \right)$, %
$k_L a$	volumetric gas-liquid mass transfer coefficient, s^{-1}
L	column length, m
N	number of experimental data
Pe_L	modified Peclet number in the liquid phase, $\frac{u_L L}{E_L(1 - \epsilon_G)}$, /
St	Stanton number, $k_L a \frac{L}{u_L}$, /
u	superficial velocity, ms^{-1}
z	dimensionless length of a column, /
<i>Greek letters</i>	
ϵ	phase hold-up, /
σ	standard deviation, $\left(= 100 \cdot \sqrt{\frac{1}{N-1} \sum_{i=1}^N \left[\left \frac{y_{\text{PRED}}(i) - y_{\text{MES}}(i)}{y_{\text{MES}}(i)} \right - e_y \right]^2} \right)$,
<i>Subscripts</i>	
G	gas phase
L	liquid phase
*	in equilibrium
MES	measured value
PRED	predicted value

References

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Povzetek

Dvoparametrski aksialno disperzni model je primeren za določitev volumetričnega koeficienta snovnega transporta na osnovi eksperimentalno posnetih koncentracijskih krivulj. Sama vrednost $k_L a$ kaže rahlo odvisnost od vrednosti aksialno disperznega koeficienta, tako da E_L lahko ocenimo iz razpoložljivih korelacij. V primeru, ko nas zanima eksakten koncentracijski profil vzdolž kolone, nenatančnost v oceni aksilno disperznega koeficienta doprinese k znatni napaki.