OXYGEN ABSORPTION INTO ELLIS LIQUID IN A BEAD COLUMN

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Liquid side mass transfer coefficient was measured for absorption of oxygen in non-Newtonian liquids. The experiments were carried out in a laboratory absorption bead column in which the liquid flowed over a single vertical row of spheres without vertical spaces between elements and/or with spaces of 0·2 cm between elements. The results were described by correlation equations involving dimensionless groups modified for Ellis flow model.

Our preceding works[1,2] dealt with absorption of oxygen by polyacrylamide solutions in a model absorber unit with a wetted spherical body. In our previous work[3] the liquid side mass transfer coefficient for absorption of oxygen by polyacrylamide solutions in a bead column was reported. Results obtained for power flow model were compared with those obtained previously[1].

The tested aqueous solutions of polyacrylamide showed a pseudoplastic behaviour, however especially at low polymer concentrations their pseudoplasticity was not marked. Therefore, the three-parameter Ellis flow model was used to describe the flow curves more accurately. For the case of absorption of a slightly soluble gas into an Ellis liquid in an absorber with a wetted sphere, the dependence of the intensity of mass transfer on hydrodynamic conditions and mass properties of liquid phase was expressed earlier[2] by the criterion equation in the form

$$Sh = a_0 \pi_1^{a_1} \pi_2^{a_2} \pi_3^{a_3} \,. \qquad (1)$$

The dimensionless groups, π_1, π_2, and π_3, were derived for the relation between the shear rate and the shear stress in the form

$$\dot{\gamma} = \phi_0 \tau + \phi_1 \tau^{\alpha} \,. \qquad (2)$$

The criterion

$$\pi_1 = 4\dot{V}\varrho\phi_0/\pi d \qquad (3)$$

characterizes the hydrodynamic conditions, further

$$\pi_2 = d^{2\alpha-2}\phi_0^{\alpha}/D^{\alpha-1}\phi_1 \qquad (4)$$

involves also the diffusivity of gas absorbed in an Ellis liquid, whereas

$$\pi_3 = d^{2\alpha-2}\phi_0^{2\alpha-1}\varrho^{\alpha-1}/\phi_1 \qquad (5)$$

involves only the characteristic dimension of the bed particles, the density of the liquid, and the parameters of the Ellis flow model.

In the present work, the results obtained for oxygen transfer into polyacrylamide solutions in a bead column with two various arrangements of spherical particles are described by correlation criterion equations involving dimensionless groups derived for Ellis flow model.

EXPERIMENTAL

The experiments were carried out in a laboratory column with the inner diameter 2·5 cm. The column contained a single vertical row of spheres having a diameter of 1·5 cm. The spheres were made of polystyrene and their surface was modified by sulphonation leading to an improvement of wetting. The first type of packing consisted of 62 spheres and the total height of the packing was 91 cm and the second type consisted of 54 spheres with clearances of 0·2 cm between adjacent spheres and the total height of the packing was 90 cm. Observations through the glass jacket ensured complete and uniform wetting of the spheres in all the runs. Pure oxygen was passed on bottom of the column and its linear rate was 10 cm s^{-1}. The liquid from a desorption column was fed through a jet located above the uppermost packing element. The measurements were performed within a range of liquid flow rates from 0·83 to 4·17 cm^3 s^{-1}. The temperature of the liquid was maintained at 20°C. The concentrations of oxygen in the exit liquid as well as in the liquid entering the column were measured by means of a polarograph connected with linear recorder. Every measurement under constant conditions (for six different liquid flow rates and two arrangements of packing) was performed altogether five times. Tap water and polyacrylamide solutions were used as tested liquids. The polyacrylamide solutions were prepared by dissolving polyacrylamide (its general trade name is Neuperm WF; VEB Fettchemie, Karl-Marx-Stadt, G.D.R.) in tap water and their concentrations were 1·0, 2·5, and 5·0 wt.%, respectively. The flow characteristics of the polymer solutions were measured using a rotary cylindrical viscometer (Rheotest II). The parameters of the Ellis flow model, ϕ_0, ϕ_1, and α, for the Neuperm solutions were evaluated from the flow curves data in the range of shear rates approximately corresponding to those reached in the experiments. The relevant values of the Ellis flow model parameters are given in Table I. The diffusivity of oxygen in the Neuperm solutions was determined experimentally by the laboratory absorber unit with wetted spherical body; details of the evaluation procedure have been reported in our previous work[4].

RESULTS AND DISCUSSION

Since oxygen absorbed was practically pure, the gas film resistance must be absent. The effect of the solvent vapour on the rate of absorption can be assumed to be negligible. Under these conditions, the overall mass transfer coefficient can be considered nearly identical with the liquid side mass transfer coefficient, k_L. Figures 1 and 2 show the average values of the liquid side mass transfer coefficient plotted against the liquid flow rate for absorption of oxygen in water and polyacrylamide solutions. The values of k_L in polyacrylamide solutions are lower than those in tap water and decrease with increasing concentration of polyacrylamide at all levels of the liquid flow rate. The spaced packing gives values of k_L somewhat higher than the unspaced packing. This agrees with the conclusions obtained by Norman and Sammak[5,6] who studied absorption of carbon dioxide and sulphur dioxide in several Newtonian liquids. This seems to imply that stream lines are mixed at the points of clearances between the spheres of spaced packing, in contrast to unspaced packing

TABLE I

Physical properties of tested Neuperm solutions at 20°C

c wt. %	ϱ kg m^{-3}	ϕ_0 kg^{-1} m s	ϕ_1 kg$^{-\alpha}$ m$^{\alpha}$ s$^{2\alpha-1}$	α	$D \,.\, 10^9$ m^2 s^{-1}
1·0	1 000·2	359·8	12·08	1·70	4·16
2·5	1 002·4	170·4	6·08	1·90	4·37
5·0	1 006·1	56·1	2·00	1·92	5·51

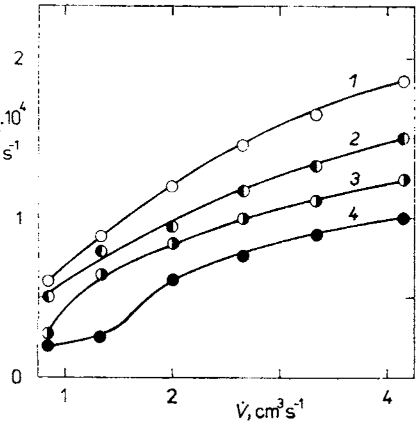

FIG. 1

Influence of the liquid flow rate on the liquid side mass transfer coefficient in column with unspaced packing. Neuperm concentration (wt. %): *1* 0 (water); *2* 1·0; *3* 2·5; *4* 5·0

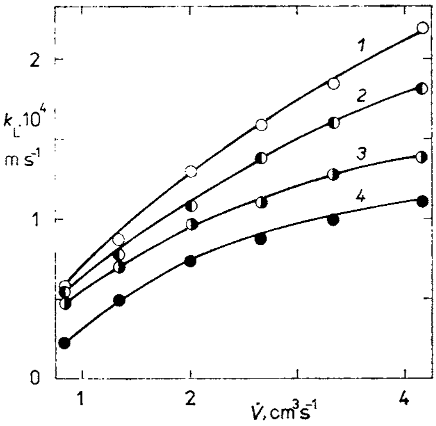

FIG. 2

Influence of the liquid flow rate on the liquid side mass transfer coefficient in column with spaced packing. Neuperm concentration (wt. %): *1* 0 (water); *2* 1·0; *3* 2·5; *4* 5·0 in which the menisci are formed between the spheres. The values of k_L for a 5 wt. % Neuperm solution at liquid flow rates of 0·83 and 1·33 cm^3 s^{-1} and for a 2·5 wt. % Neuperm solution at liquid flow rate 0·83 cm^3 s^{-1} are lower with unspaced packing than expected. It was observed that in these cases the liquid film flowed over packing elements without ripples. The experimental data have shown that the liquid side mass transfer coefficient can be correlated by equations in an absorber with unspaced packing

$$Sh = 8{\cdot}01\pi_1^{0.885}\pi_2^{0.221}\pi_3^{-0.306} \tag{6}$$

(correlation coefficient 0·950), and in an absorber with spaced packing

$$Sh = 10{\cdot}0\pi_1^{0.772}\pi_2^{0.193}\pi_3^{-0.230} \tag{7}$$

(correlation coefficient 0·981). The values of the dimensionless groups, π_1, π_2, and π_3, varied in ranges 3·98 – 128, 3·77 . 10^6 – 4·97 . 10^7, and 1·18 . 10^4 – 7·63 . 10^4, respectively.

In our previous work[2], the oxygen absorption in Neuperm solutions was studied in a laboratory model absorber with a wetted spherical body. It was shown that in the range of criterion π_1 from 0·705 to 23·4, the Sherwood number depends only on the criterion π_1 (in Eq. (*1*), $a_1 = 0{\cdot}329$, $a_2 = -0{\cdot}026$, $a_3 = -0{\cdot}011$). In addition, it can be seen from Eqs (*6*) and (*7*) that the power of the criterion π_1 for unspaced packing is somewhat greater than that for spaced packing. This agrees with results obtained in our preceding work[3], in which the values of the liquid side mass transfer coefficient were correlated by the power flow model. For unspaced packing the Reynolds number exponent had a value of 0·83, while for spaced packing it had a value of 0·73. It must be noted that the same Neuperm solutions were used in the present work and previously[3]. However, the different values of the Reynolds number exponent and exponent of criterion π_1 can be caused by the slightly differing flow curves data measured for Neuperm solutions which differed by their age in the cases quoted. It can be supposed that the power of hydrodynamic criteria (Re,π_1) depends on both flow curves data and the accuracy of their description by the given flow model. Similarly Norman and Sammak[5,6] have obtained the 0·61 power of the Reynolds number for unspaced packing and 0·47 power of the Reynolds number for spaced packing.

Although the tested polyacrylamide solutions showed pseudoplastic behaviour the greater influence of change of hydrodynamic conditions on intensity of mass transfer appeared for unspaced packing in comparison with spaced packing. The results obtained in present work are thus similar to those available for Newtonian fluids.

SYMBOLS

$a_0 - a_3$	regression coefficients
c	concentration of polymer in solution, wt. %
D	diffusivity of gas in liquid, $m^2 s^{-1}$
d	diameter of spherical particles, m, cm
k_L	liquid side mass transfer coefficient, $m s^{-1}$
$Sh = k_L d/D$	Sherwood number
$\dot{V}$	liquid flow rate, $m^3 s^{-1}$, $cm^3 s^{-1}$
α	parameter of Ellis flow model
$\dot{\gamma}$	shear rate, s^{-1}
π_1, π_2, π_3	modified criteria for Ellis flow model
ϱ	density of liquid, $kg m^{-3}$
τ	shear stress, $kg m^{-1} s^{-2}$
ϕ_0, ϕ_1	parameters of Ellis flow model, $kg^{-1} m s$, and $kg^{-\alpha} m^{\alpha} s^{2\alpha-1}$

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