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Gas – liquid mass transfer process in the presence of solids in an agitated vessel

Introduction

Mechanically agitated three phase systems are widely used in many industrial technologies. In such systems gas – liquid mass transfer processes in the presence of solids are carried out very often. Then the most important parameter is the volumetric mass transfer coefficient $k_L a$. Due to the fact that many industrial processes are conducted in the system with small quantity of solid particles, many investigations regarding gas – solid – liquid systems concentrate on these at low solid concentration [1–6].

The aim of the experimental studies was to investigate the effect of the presence and concentration of solid particles on the volumetric gas – liquid mass transfer coefficient in the agitated gas – solid – liquid system.

Experimental

The measurements were conducted in the cylindrical vessel with inner diameter of $D = 0.288$ m, equipped with flat bottom and four vertical planar baffles of $B = 0.1D$. Geometrical parameters of the vessel used are shown in Fig. 1. The agitated vessel was filled with the liquid up to the height $H = D$. The liquid volume was equal $V_L = 0.02$ m^3. Gas was supplied to liquid by means of the gas sparger in the shape of a ring of diameter $d_d = 0.7d$ and located at the height $e = 0.5d$ from the bottom of the vessel.
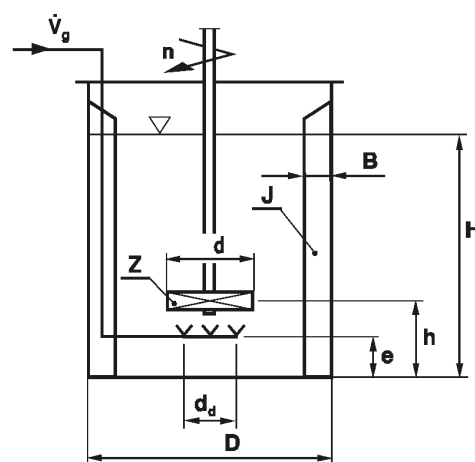

Fig. 1. Geometrical parameters of the agitated vessel

Three types of high-speed impellers were used for the agitation: *Rushton* turbine (RT), *Smith* turbine (CD 6) and A 315 impeller. All the impellers were of the diameter $d = 0.33D$. The impeller was located at the distance $h = 0.33D$ from the bottom of the vessel.

Coalescing and non-coalescing systems were tested. Three-phase systems consisted of distilled water or aqueous solutions of an electrolyte as continuous phases, and air and

particles of the sea sand as dispersed phases. Sodium chloride with concentration 0.4 and 0.8 kmol/m^3 was used as electrolyte ion. The measurements were conducted at various gas flow rates and concentration X of solid particles with mean diameter d_p = 335 μm. The concentration of solids was changed up to 5 % by weight. Gas flow rate values were varied within the following range: V_g <0; 5.56 · 10^{-3} m^3/s> (superficial gas velocity w_{og} <0; 8.53 · 10^{-3} m/s>). All the experiments were conducted within the turbulent regime of the fluid flow (Re < 6.7 · 10^5; 1.7 · 10^6>) in the agitated vessel. Impeller speeds higher than the critical impeller speeds n_{JSG} for three-phase system (the speed at which gas and solids are dispersed simultaneously) were maintained in the investigations. The n_{JSG} values were evaluated according to the *Zwietering* criterion [7], in which the particles do not stayed without moving on the vessel bottom longer than 1s.

Volumetric gas – liquid mass transfer coefficients were measured using dynamic method. The measurements of change of the oxygen concentration in liquid were carried out by means of the oxygen meter equipped with a sensor immersed in the liquid. The sensor was placed at half distance between the baffles.

Results

On the basis of the experimental studies the volumetric gas – liquid mass transfer coefficients $k_L a$ for gas – liquid and gas – solid – liquid systems were found.

The results of the measurements of volumetric mass transfer coefficients $k_L a$ in two phase gas – liquid and three phase gas – solid – liquid systems agitated by *Smith* turbine are compared in Figs. 2 and 3. In these Figs. filled points are ascribed to the two-phase system whilst empty points correspond to the three-phase system with the concentration of the solid particles 0.5 (Fig. 2) and 2.5% w/w (Fig. 3), respectively. It follows from the results that introducing solids to the system affects volumetric mass transfer coefficient $k_L a$. In the system with a half percent of solid particles inside, the values of the $k_L a$ are significantly higher than in the two-phase system (Fig. 2). In a coalescing system, it can be explained that solids in a small quantity during their movement in the system hit the gas bubbles, which are breaking into the smaller ones and in consequence, the interfacial area increa- ses.

However, adding more particles – 2.5 % w/w, causes the decrease of $k_L a$ values. For lower values of superficial velocity
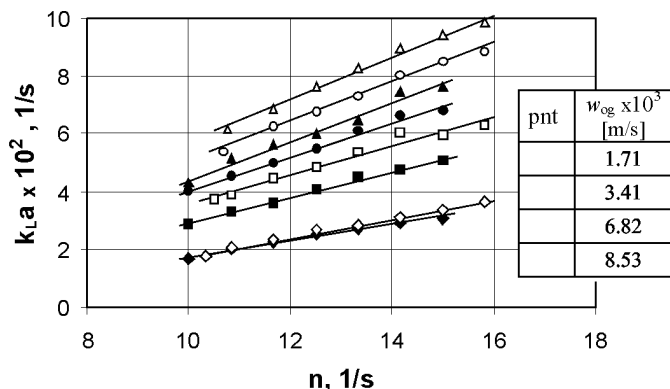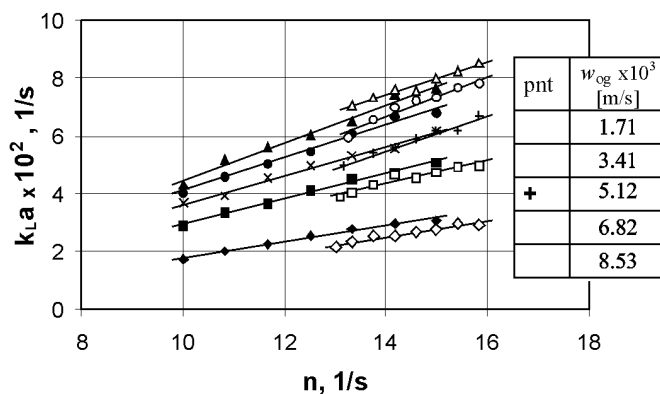

Fig. 3. The dependence $k_L a$ = f(n) for the *Smith* turbine and varied values of w_{og}; filled points: X = 0% w/w; empty points: X = 2.5% w/w; liquid phase: distilled water
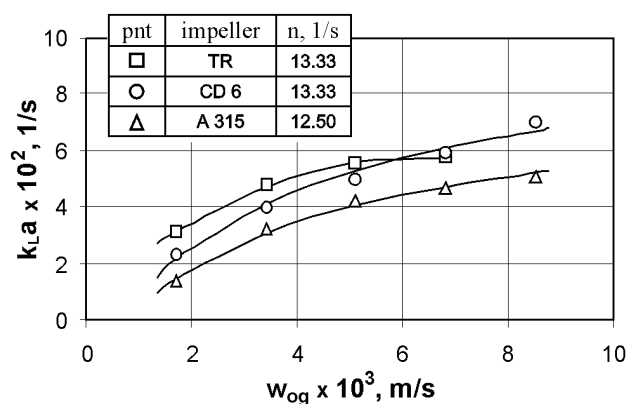

Fig. 4. Comparison of the $k_L a$ = f(w_{og}) for the three – phase system with solid concentration X = 2.5% w/w and different impellers; liquid phase: distilled water

w_{og}, the volumetric mass transfer coefficient values are even lower than those obtained in the gas – liquid system (Fig. 3).

The effect of the agitator type on the volumetric mass transfer coefficient $k_L a$ is presented in Fig. 4. Comparing the results obtained for each impeller it can be stated that in general the highest values of the $k_L a$ coefficient are characterized for *Rushton* turbine. However, at higher values of the superficial gas velocity w_{og} the better results of the volumetric mass transfer coefficient correspond to *Smith* turbine. The A 315 impeller, which differs in the generated profile of the liquid circulation from the turbines, is less effective for the mass transfer processes in the agitated vessel.

The measurements of $k_L a$ coefficients were conducted in the systems differing in capability of gas bubbles to coalescence. It follows from the results that this property of the system strongly affects the volumetric mass transfer coefficient value. In the whole range of the measurements, for constant value of solid concentration and superficial gas velocity, the highest value of $k_L a$ was obtained in the case of 0.4 kmol/m^3 NaCl solution used as a liquid phase, comparing with distilled water. However for greater concentration of electrolyte (0.8 kmol/m^3) $k_L a$ values are lower, although they are still higher than those for distilled water.

The experimental results of the measurements of the volumetric mass transfer coefficient $k_L a$ have been approximated using the function $k_L a$ = f(P_{G-L-S}/V_L, w_{og}, X). On the basis of the 910 experimental data for three impellers: *Rushton* turbi-

Fig. 2. The dependence $k_L a$ = f(n) for the *Smith* turbine and varied values of w_{og}; filled points: X = 0% w/w; empty points: X = 0.5% w/w; liquid phase: distilled water

Table 1

The values of the coefficients in Eq. 1

Impeller	Liquid phase	A	B	C	m_1	m_2	$\pm\Delta$	Exp. Points
Rushton turbine (RT)	Distilled water	0.031	0.43	0.515	-186.7	11.921	6.8	100
Smith turbine (CD 6)		0.038	0.563	0.67	-388.6	23.469	6.6	98
A 315		0.062	0.522	0.774	209.9	-11.038	10.3	108
Rushton turbine (RT)	Aqueous solution of NaCl with concentration 0.4 kmol/m^3	2.302	0.081	0.737	-246.8	19.018	9.8	91
Smith turbine (CD 6)		0.76	0.16	0.617	-137.1	14.57	7.6	92
A 315		0.124	0.36	0.599	-237.3	10.525	11.6	113
Rushton turbine (RT)	Aqueous solution of NaCl with concentration 0.8 kmol/m^3	0.287	0.2	0.578	-38,98	4.362	6.7	96
Smith turbine (CD 6)		0.345	0.23	0.628	49.87	6.1	7.4	93
A 315		0.2	0.309	0.618	-367.7	22.041	7.5	118

ne, *Smith* turbine and A 315, the following equation has been obtained

$$k_L a = A\left(\frac{P_{G-L-S}}{V_L}\right)^B w_{og}^C \left(\frac{1}{1 + m_1 X^2 + m_2 X}\right) \qquad (1)$$

where $k_L a$ is expressed in [1/s] unit. The coefficients in Eq. (1) for each impeller are collected in Table 1. This equation is applicable within the following range of the measurements:

$$X < 0.005 \div 0.05>; \qquad w_{og} \text{ [m/s]} < 1.71 \cdot 10^{-3} \div 8.53 \cdot 10^{-3}>;$$
$$P_{\text{G-L-S}}/V_L \text{ [W/m}^3] < 118 \div 5700>.$$

Lower values of the exponent B in Eq. (1) obtained for turbines working in the systems with electrolyte could be probably caused by particular hydrodynamic occurrence, which takes place there. In non coalescing systems at higher impeller speeds many gas bubbles generated by the turbine, due to the lack of capability of bubbles to coalescence are very small and probably too low to take a part in the mass transfer process, what result in the decrease of $k_L a$ coefficient values with the increase of impeller speed and P_{G-L-S}/V_L. However the values of $k_L a$ coefficient for turbines are still much higher than those for A 315 impeller.

Conclusions

The presence of the solids in the gas – liquid system affects the volumetric mass transfer coefficient $k_L a$. Within the range of the low values of the superficial gas velocity w_{og}, high agitator speeds n and low mean concentration X of the solids in the liquid, the value of the coefficient $k_L a$ increases even about 20% comparing to the data obtained for gas – liquid system. However, this trend decreases with the increase of both w_{og} and X values. For example, the increase of the $k_L a$ coefficient is equal to only 10% for the superficial gas velocity $w_{og} = 5.12 \cdot 10^{-3}$ m/s. Moreover, within the highest range of the agitator speeds n value of the $k_L a$ is even lower than that obtained for gas – liquid system.

Out of the agitators (*Rushton* or *Smith* turbine and A 315) which were used to agitate three phase system, better results for the $k_L a$ coefficient were obtained for the turbines.

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