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The studies on mass transfer processes in a gas – liquid system agitated using two impellers on a common shaft

Introduction

Mechanically agitated aerated vessels are widely used to intensify the contact between gas and liquid phases in many industrial processes. Reactors equipped with the impeller are applied for such processes as oxygenation, fermentation, wastewater treatment. Because of better gas utilization and many other advantages the vessels with more than one impeller on the common shaft (double- [1–5] or triple- [4–6] impeller configuration) are more frequently chosen to conduct gas – liquid processes.

A multiple – impeller system provides more efficient two phases mixing and obtaining higher values of mass transfer coefficient. In the gas – liquid system the volumetric mass transfer coefficient k_La is affected by numerous factors: operating parameters (air flow rate, impeller speed, temperature, pressure), liquid phase characteristics (density, viscosity, surface tension), geometrical parameters of the vessel and geometry and number of the impellers used.

The aim of the experimental studies was to investigate the mass transfer process in a gas – liquid system agitated using two impellers on a common shaft. The volumetric gas – liquid mass transfer coefficients $k_{\mathrm{L}}a$ were measured for two configurations of the high – speed impellers operating in a tall vessel.

Experimental

The studies were carried out in the cylindrical, tall vessel of inner diameter $D = 0.288$ m, equipped with flat bottom and four planar baffles of width $B = 0.1D$. Geometrical parameters of the vessel used are shown in Fig.1. The vessel was filled with a liquid up to height $H = 2D$. Liquid volume V_L in the vessel was equal to 0.04 m^3. Two high-speed impellers of diameter $d = 0.33D$ were mounted on the common shaft in the vessel. Lower and upper impellers were located at the distance $h_1 = 0.17H$ and $h_2 = 0.67H$ from the bottom of the tank.

Smith (CD 6) disc turbine with $Z = 6$ blades and A 315 impeller ($Z = 4$) were used as lower impellers. Standard *Rushton* turbine was chosen as the upper impeller. Gas was dispersed in the liquid by means of the ring gas sparger of diameter $d_{\mathrm{d}} = 0.7d$. Off-bottom clearance of the sparger was equal to $e = 0.5d$.

Distilled water was used as a liquid phase. Gas phases were air and nitrogen. The measurements were carried out under different values of gas flow rate $\dot{V}_{\mathrm{g}}$, (where $\dot{V}_g \in \langle 0;\ 4.44 \cdot 10^{-4}$ m^3/s $\rangle$ and superficial gas velocity $w_{og} \in \langle 0;\ 6.82 \cdot 10^{-3}$ m/s $\rangle$). All the experiments were conducted within the turbulent regime of the fluid flow in the agitated vessel.

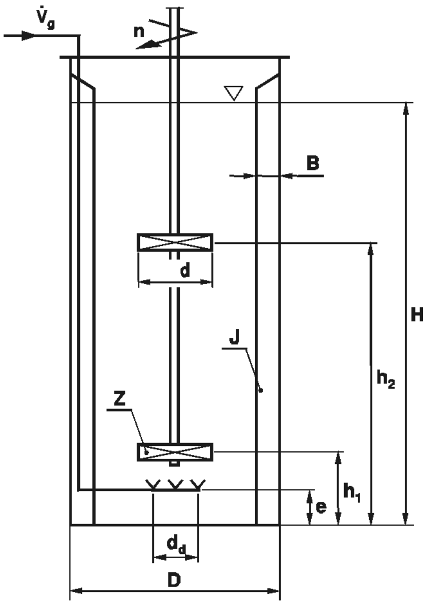

Fig. 1. Geometrical parameters of the agitated vessel

Volumetric gas – liquid mass transfer coefficients were measured using the dynamic method. The sensor used to measure the change of the oxygen concentration in liquid was immersed in the liquid. It was placed at half distance between the baffles and at half distance between impeller shaft and wall of the agitated vessel. The type of gas, which was introduced into the system, was changed by means of valve.

Results

On the basis of the experimental results the k_La coefficient values for both configurations of double-impellers working in the gas – liquid system were obtained.

The data, for various values of superficial gas velocity w_{og}, are presented in Fig. 2 for the vessel with A 315 – *Rushton* turbine system and in Fig. 3 for the vessel with *Smith* turbine – *Rushton* turbine system.

It follows from the results, that volumetric mass transfer coefficient is strongly affected by both impeller speed and superficial gas velocity. The differences in the k_La values between particular values of superficial gas velocity w_{og} are greater in the case of *Smith* turbine – *Rushton* turbine configuration. The effect of the impeller configuration on the volumetric

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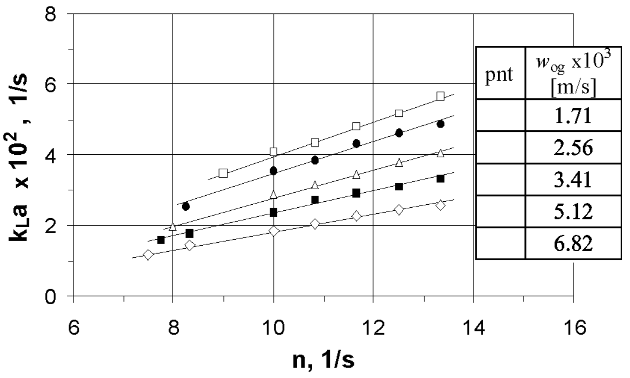

Fig. 2. The dependence k_La = f(n) for the impeller configuration A 315 (lower) – *Rushton* turbine (upper) and varied values of w_{og}

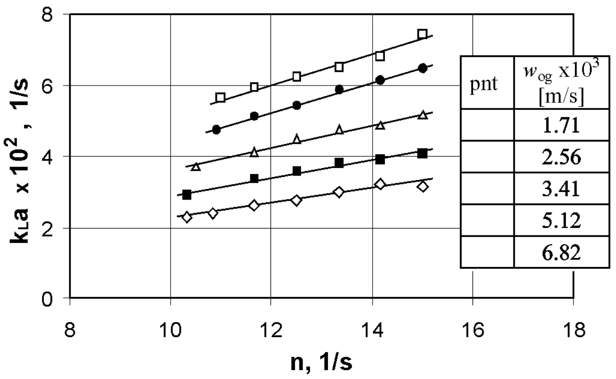

Fig. 3. The dependence k_La = *f*(n) for the impeller configuration CD 6 (lower) – *Rushton* turbine (upper) and varied values of w_{og}

mass transfer coefficient k_La value is presented in Fig. 4. Comparison of the results obtained for each double – impeller system shows that at a constant value of the impeller speed, the highest values of the k_La coefficient were obtained using *Smith* turbine – *Rushton* turbine configuration. At higher values of superficial gas velocity the differences between volumetric mass transfer coefficient values adequate to each configuration increased. The A 315 impeller, which differs in the generated profile of the fluid circulation from the turbine, is less effective as a lower impeller for the mass transfer processes in the agitated vessel comparing with CD 6 impeller.

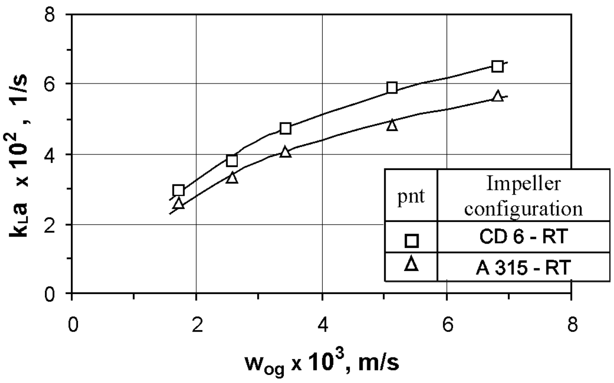

Fig. 4. The dependence k_La = *f*(w_{og}) for two agitator configurations; n = const = 13.33 s^{-1}

The results of the measurements of the volumetric mass transfer coefficient k_La were approximated using the function k_La = f($P_{G\text{-}L\text{-}S}/V_L$, w_{og}). On the basis of the experimental data the following equation was obtained

$$k_La = A\left(\frac{P_{G-L-S}}{V_L}\right)^B w_{og}^C \tag{1}$$

where k_La has dimension [1/s]. The coefficients in Eq. (1) for each impeller configuration are collected in Table 1.

Table 1

The values of the coefficients in Eq. 1

Impeller configuration		A	B	C	±Δ
Lower	Upper				
A 315	*Rushton* turbine	0.027	0.466	0.575	3.0
Smith turbine	*Rushton* turbine	0.092	0.334	0.6	2.6

This equation is applicable within the following range of the measurements: w_{og} [m/s] ⟨ 1.7 · 10^{-3} ÷ 6.8 · 10^{-3} ⟩; $P_{G\text{-}L\text{-}S}/V_L$ [W/m³] ⟨ 540 ÷ 4350 ⟩. Comparison of the experimental (k_La_{exp}) and calculated from the Eq. (1) (k_La_{exp}) data is shown in Fig. 5.

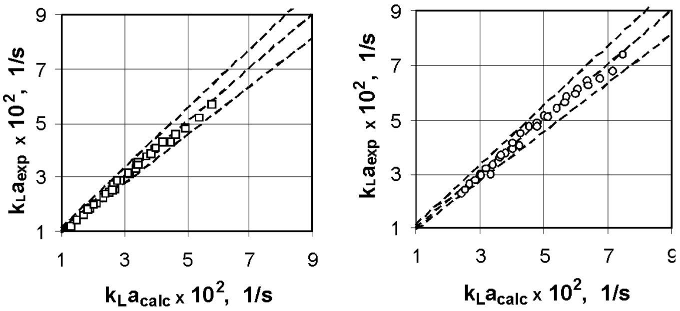

Fig. 5. Comparison of the experimental (k_La_{exp}) and calculated from the Eq. (1) (k_La_{calc}) data; a) A 315 – *Ruston* turbine, b) CD 6 – *Rushton* turbine

Conclusions

On the basis of the experimental measurements of the volumetric gas – liquid mass transfer coefficient conducted in the system agitated by two different configurations of high – speed impellers it can be stated that:

- Superficial gas velocity significantly affects the volumetric mass transfer coefficient. For both configurations of the impellers the k_La coefficient increases with the increase of w_{og}.
- Geometry of lower impeller has strong influence on the volumetric mass transfer coefficient values. From two configurations used in the study better results characterized *Smith* turbine – *Rushton* turbine system.

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