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EXPERIMENTAL ANALYSIS OF THE CHOSEN PARAMETERS EFFECTS ON A GAS HOLD UP FOR MECHANICALLY AGITATED TWO- OR THREE-PHASE SYSTEMS

EXPERYMENTALNA ANALIZA WPŁYWU WYBRANYCH PARAMETRÓW NA UDZIAŁ GAZU ZATRZYMANEGO W CIECZY DLA MIESZANYCH MECHANICZNIE UKŁADÓW DWU- LUB TRÓJFAZOWYCH

A b s t r a c t

In the paper, the analysis of the chosen parameters effects (gas flow rate, the impeller speed, type of impeller and concentration of the aqueous solutions of sucrose) on the gas hold-up for gas-liquid and gas-liquid-biophase systems mechanically agitated are presented. Experimental studies were conducted in a vessel of the diameter of 0.288 m. The agitated vessel was equipped with Rushton or A 315 impeller. The results were described mathematically. The study shows that gas hold-up strongly depends on the impeller speed and the gas flow rate.

Keywords: *mixing*, *hold-up*, *gas-liquid-biophase systems*

S t r e s z c z e n i e

Badania miały na celu określenie wpływu wybranych parametrów (natężenia przepływu gazu, częstości obrotów mieszadła, typu mieszadła oraz stężenia wodnych roztworów sacharozy) na udział gazu zatrzymanego w cieczy dla mieszanego mechanicznie układu ciecz-gaz lub ciecz-gaz-biofaza. Badania wykonano w mieszalniku o średnicy D = 0,288 m, w którym na wale zamontowane było mieszadło turbinowe Ruszona lub A 315. Wyniki badań opracowano w postaci równia (1). Na podstawie przeprowadzonych pomiarów stwierdzono, że udział gazu zatrzymanego w cieczy silnie zależy od częstości obrotów mieszadła oraz natężenia przepływu gazu.

Słowa kluczowe: *mieszanie*, *udział gazu zatrzymanego w cieczy*, *układ ciecz-gaz-biofaza*

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1. Introduction

To obtain the required gas dispersion in the system, the appropriate physical and operating parameters of the bioprocess have to be chosen. Achieving good gas dispersion in the system, as well as identifying the content of gas phase in a liquid depends on many factors, such as: the geometric parameters of the vessel, impellers and the gas sparger, the type and the impeller speed, the gas flow rate in the vessel and the physical parameters of the liquid [1–19]. In the case of the gas-liquid-biophase systems it is necessary to determine what impact on the biophase in the system (e.g. yeast cells) the impeller speed and the gas flow rate in the vessel will have. Excessive impeller speed and too high gas flow rate may adversely affect the yeast cell growth in the system [20–21].

Yeast is widely used in fermentation processes in the winemaking, brewing, distillery and baking industry, as well as in the biotechnological processes, including biomass production. The metabolic change speed of yeast Saccharomyces cerevisiae (e.g. baker's yeast) depends on the oxygenation conditions. The data from the relevant literature indicate that the appropriate system oxygenation significantly increases the biomass production as compared to the oxygen-free conditions. At the same time, the oxygen presence greatly impedes the alcoholic fermentation. In the oxygen conditions, it is also necessary to properly select the sucrose concentration in the medium (carbon source) to prevent partial inhibition of the yeast cell respiration (the Crabtree effect) [22–24].

In the paper, the analysis of the chosen parameters effects (gas flow rate V_g, the impeller speed n, concentration of the aqueous solutions of sucrose x and type of impeller) on the gas hold-up φ for gas-liquid and gas-liquid-biophase systems mechanically agitated are presented.

2. Experimental

Experimental studies were conducted in a vessel of the diameter of 0.288 m. The vessel was filled with a liquid up to the height $H = T$. The agitated vessel was equipped with Rushton ($Z = 6$) or A 315 impeller ($Z = 4$). The impeller was placed at the distance $h = 0.33H$ from the flat bottom of the vessel. Gas was introduced into the liquid through a ring-shaped sparger of diameter $d_d = 0.7d$. The sparger was located at a distance of $e = h/2$ from the bottom of the vessel. The liquid phase was aqueous solution of sucrose with mass concentration of 1, 2.5, 5 or 10%. Air was used as a gas phase. As a biophase was used the suspension of the yeast with concentration of 1%.

The physical parameters in the system (liquid phase or liquid-biophase system) changed in the following ranges: dynamic viscosity η [Pas] $\in <1 \times 10^{-3}; 3.3 \times 10^{-3}>$, density ρ [kg/m^3] $\in <1000; 1041>$, surface tension σ [N/m^2] $\in <0.072; 0.08>$. The measurements were performed within the turbulent liquid flow in the vessel (Re $\in <20000; 115000>$) for five values of the gas flow rate V_g (V_g [m^3/s] $\in <2.67 \times 10^{-4}; 5 \times 10^{-4}>$, (superficial gas velocity w_{og} [m/s] $\in <2.67 \times 10^{-4}; 7.7 \times 10^{-4}>$, where $w_{og} = 4V_g/(\pi D^2)$)).

The averaged value of gas hold-up φ was determined from 10 readings of the height H_g of a gas-liquid mixture in the agitated vessel.

3. Results

The effects of the gas flow rate V_g (expressed by superficial gas velocity w_{og}), the impeller speed n, the sucrose concentration x and type of impeller on the gas hold-up φ were analysed on the basis of approximately 1300 measurement points obtained in the study.

The impact of the impeller speed n on the gas hold-up φ for both Rushton turbine and A315 impeller is presented in Fig 1 for different values of superficial gas velocity w_{og} and both gas-liquid and gas-liquid-biophase systems by means of the function $\varphi = f(n)$. If the impeller speeds are increasing in the whole measurement range, the gas hold-up is from two to three times higher. It has been proven that the impact of the impeller speed on the gas hold-up is higher for the vessel with the Rushton turbine.

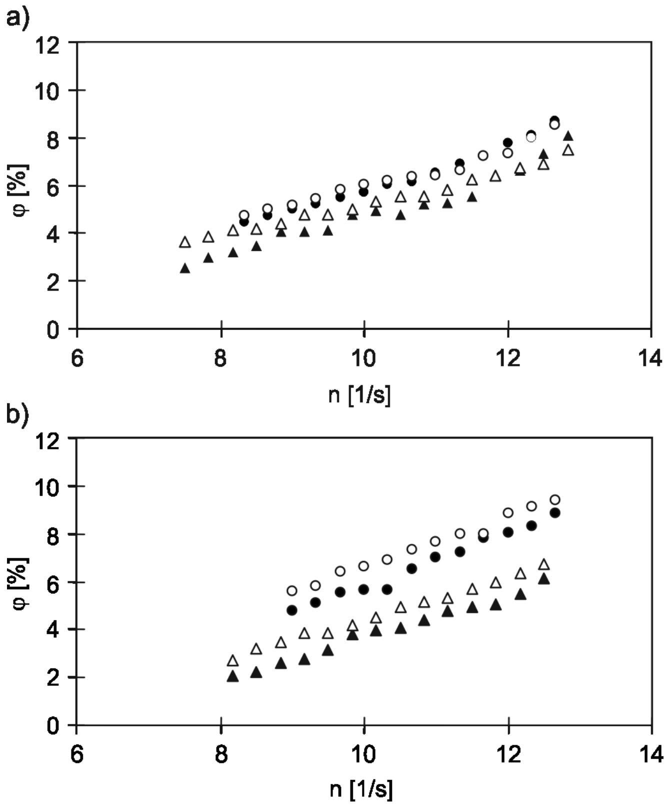

Fig. 1. The dependence $\varphi = f(n)$ for the systems: ▲, ● – 5% aqueous solution of sucrose – air; Δ, ○ – 5% aqueous solution of sucrose – air – 1% suspension of the yeast; ▲, Δ – $w_{og} = 1.67 \times 10^{-4}$ m/s; ●, ○ – $w_{og} = 5 \times 10^{-4}$ m/s; a) RT; b) A 315

In the case of a vessel with the A315 impeller, the increase in the superficial gas velocity w_{og} from 1.67×10^{-4} to 5×10^{-4} m/s, results in the 2-times growth in the gas hold-up (Fig. 1b). It has been observed that in the case of the Rushton turbine, the superficial gas velocity has a significantly smaller effect on the gas hold-up. On the other hand, assuming that the value of the impeller speed is constant, in most cases a conclusion could be drawn that adding yeast to the system results in small growth in the gas hold-up.

The effect of the superficial gas velocity w_{og}, the impeller type and the sucrose concentration x on the gas hold-up is illustrated in Figs. 2 and 3 by means of the dependence $\varphi = f(Kg)$ for both gas-liquid and gas-liquid-biophase systems. The higher the superficial gas velocity, the lesser the impact of the gas flow number Kg on the gas hold-up. Assuming a constant value of Kg, the increase of the superficial gas velocity w_{og} results in the approximately 50% increase in the gas hold-up φ. In the case of the lower value of the gas flow rate, the highest φ values were obtained for the vessel with Rushton turbine impeller.

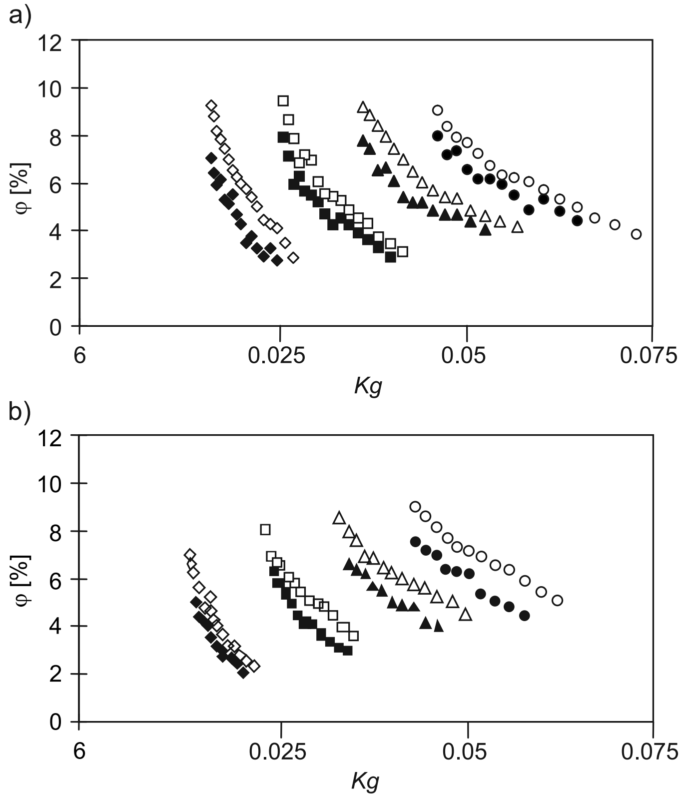

Fig. 2. The dependence $\varphi = f(Kg)$ for the systems: ♦, ■, ▲, ● – 1% aqueous solution of sucrose – air; ◊, □, Δ, ○, – 10% aqueous solution of sucrose – air; ♦, ◊ – w_{og} = = 1.67×10^{-4} m/s; ■, □ – w_{og} = 2.78×10^{-4} m/s; ▲, Δ – w_{og} = $3{,}89 \times 10^{-4}$ m/s; ●, ○ – w_{og} = 5×10^{-4} m/s; a) RT; b) A 315

The impact of the impeller type on the gas hold-up decreases with the increase of the gas flow rate in the system. From the comparison of the values related to the gas hold-up for the 1% sucrose-air system and 10% sucrose – air system, it can be concluded that the increase in the sucrose concentration from 1 to 10% results in the increase of the gas hold--up by about 20%. In the case of the gas-liquid system, it has been observed that sucrose concentration has a greater impact on the gas hold-up for the vessel with the A 315 impeller. The opposite situation occurs when the yeast have been added to the system. In such a case, the greater impact of the sucrose concentration on φ corresponds to the vessel with the Rushton turbine impeller. For the constant value of the superficial gas velocity, this impact increases along with the increase of the gas flow number *Kg*.

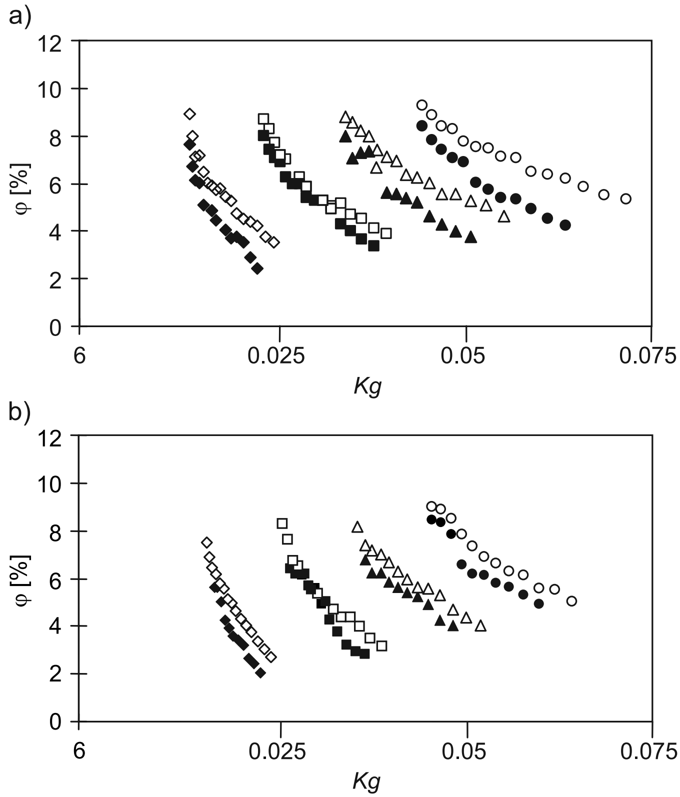

Fig 3. The dependence $\varphi = f(Kg)$ for the systems: ♦, ■, ▲, ● – 1% aqueous solution of sucrose – air – 1% suspension of the yeast; ◊, □, Δ, ○, – 10% aqueous solution of sucrose – air – 1% suspension of the yeast; ♦, ◊ – $w_{og} = 1.67 \times 10^{-4}$ m/s; ■, □ – $w_{og} = 2.78 \times 10^{-4}$ m/s; ▲, Δ – $w_{og} = 3{,}89 \times 10^{-4}$ m/s; ●, ○ – $w_{og} = 5 \times 10^{-4}$ m/s; a) RT; b) A 315

The effect of the yeast suspension concentration on the gas hold-up is presented in the Fig. 4. For a constant value of gas flow number *Kg*, it has been concluded from the data in Fig. 4 that the adding 1% yeast suspension to the gas-liquid system, slightly affects the value related to the gas hold-up. This effect depends additionally on the type of the impeller used.

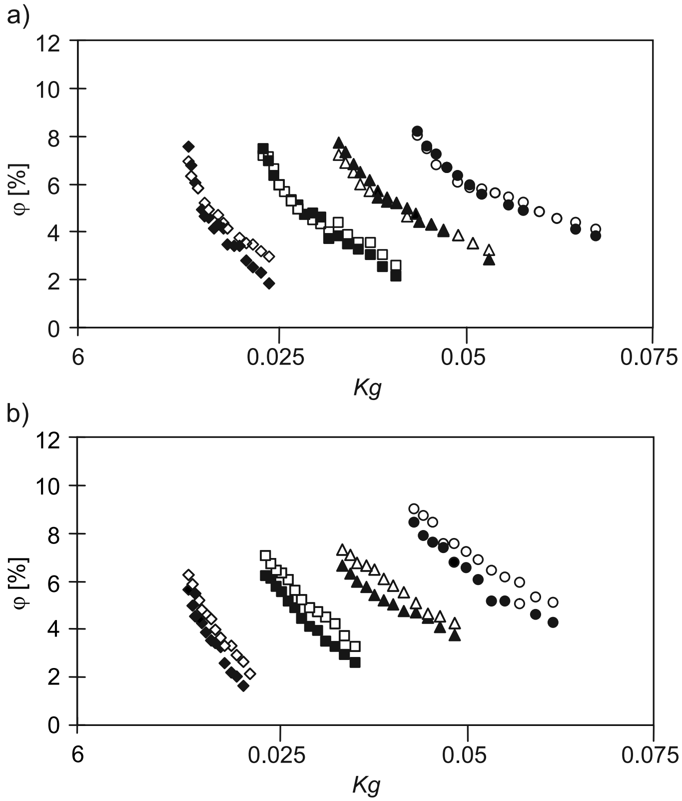

Fig. 4. The dependence $\varphi = f(Kg)$ for the systems: ♦, ■, ▲, ● – 5% aqueous solution of sucrose – air; ♦, □, Δ, ○, – 5% aqueous solution of sucrose – air – 1% suspension of the yeast; ♦, ◊ – $w_{og} = 1.67 \times 10^{-4}$ m/s; ■, □ – $w_{og} = 2.78 \times 10^{-4}$ m/s; ▲, Δ – $w_{og} = 3,89 \times 10^{-4}$ m/s; ●, ○ – $w_{og} = 5 \times 10^{-4}$ m/s; a) RT; b) A 315

Due to the small impact of the yeast suspension concentration in the system, the gas hold-up φ is described by means of the dependence including the gas flow number *Kg*, the Weber number We and the sucrose concentration *x* in the system

$$\varphi = a \cdot Kg^{b} \cdot \mathrm{We}^{c} \cdot (1+x)^{d} \qquad (1)$$

where:

- Kg – gas flow number $(= V_g/(nd^3))$,
- We – Weber number $(= n^2 d^3 \rho/\sigma)$,
- x – sucrose concentration [kg/kg].

The coefficient value *a* and the *b*, *c*, *d* exponents are shown in the Table 1.

Table 1

Values of coefficient *a* and exponents *b*, *c*, *d* in Eq. (1)

No.	Impeller	*a*	*b*	*c*	*d*	$\pm\Delta\%$
1-1	Rushton turbine	2.253×10^{-4}	0.13	0.82	2.16	8
1-2	A 315	1.203×10^{-4}	0.25	0.97	2.20	10

The equation (1) describes the results of the measurements within $Kg \in <0,01; 0,09>$; $We \in <800; 3800>$; $x \in <0.01; 0.1>$.

4. Conclusions

On the basis of the conducted research, it has been concluded that the impeller speeds *n* have the greatest (even 3-times) effect on the gas hold-up. The effect of gas flow rate V_g (or w_{og}) on the gas hold-up depends on the impeller type used. In the case of the vessel with the A 315 impeller, the increase of the gas flow rate V_g in the vessel results in the increase, even double, in the gas hold-up φ. The effect of sucrose concentration *x* in the system depends on whether or not the yeast suspension has been added to the system and it is significantly smaller than the impact of the impeller speed n and the gas flow rate V_g in the vessel. On the other hand, the effect of the yeast suspension concentration on the φ can be practically neglected within the range of the performed measurements.

References

[1] Stręk F., *Agitation and agitated vessels (in Polish)*, WNT, Warszawa 1981.

[2] Bouaifi M., Hebrard G., Bastoul D., Roustan M., *A comparative study of gas hold-up, bubble size, interfacial area and mass transfer coefficients in stirred gas–liquid reactors and bubble columns*, Chemical Engineering and Processing, 40, 2001, 97-111, DOI: 10.1016/S0255-2701(00)00129-x.

[3] Kamieński J., Niżnik J., *Gas hold-up for gas-liquid system agitated with dual impellers*, Inżynieria Chemiczna i Procesowa, 3C, 2001, 591-597.

[4] Kamieński J., Niżnik J., *The impact of the second impeller on the effects of gas dispersion in liquid*, Inżynieria i Aparatura Chemiczna, 41(33), 2002, 335-336.

[5] Alves S.S., Maia C.I., Vasconcelos J.M.T., *Experimental and modeling study of gas dispersion in a double turbine stirred tank*, Chemical Engineering Science, 57(3), 2002, 487-496, DOI: 10.1016/S0009-2509(01)00400-6.

[6] Moucha T., Linek V., Prokopowa E., *Gas hold-up, mixing time and gas-liquid volumetric mass transfer coefficient of various multiple configurations: Rushton turbine, pitched blade and techmix impeller and their combinations*, Chemical Engineering Science, 58(9), 2003, 1839-1846, DOI: 10.1016/S0009-2509(02)00682-6.

[7] Kamieński J., *Agitation of multiphase systems (in Polish)*, WNT, Warszawa 2004.

[8] Karcz J., Siciarz R., Bielka I., *Gas hold-up in a reactor with dual system of impellers*, Chemical Papers, 58, 2004, 404-409.

[9] Adamiak R., *Experimental studies of conditions for gas dispersion in liquid in the stirred tank on different scale (in Polish)*, Praca doktorska, Politechnika Szczecińska, Szczecin 2005.

[10] Shewale S.D, Pandit A.B., *Studies in multiple impeller agitated gas-liquid contactors*, Chemical Engineering Science, 61(2), 2006, 489-504, DOI: 10.1016/j.ces.2005.04.078.
[11] Montante G., Horn D., Paglianti A., *Gas-liquid flow and bubble size distribution in stirred tanks*, Chemical Engineering Science, 63, 2006, 2107-2118. DOI: 10.1016/j.ces.2008.01.005.
[12] Montante G., Paglianti A., Magelli F., *Experimental analysis and computational modeling of gas-liquid stirred vessels*, Chemical Engineering Research and Design, 85, 2007, 647-653, DOI: 10.1205/cherd06141.
[13] Martin M., Montes F.J., Galan M.A., *Bubbling process in stirred tank reactors I: Agitator effect on bubble size, formation and rising*, Chemical Engineering Science, 63, 2008, 3223-3234, DOI: 10.1016/j.ces.2008.03.028.
[14] Ahmed S.U., Ranganathan P., Pandey A., Sivaraman S., *Computational fluid dynamics modeling of gas dispersion in multi impeller bioreactor*, Journal of Bioscience and Bioengineering, 109(6), 2010, 588-597, DOI: 10.1016/j.jbiosc2009.11.014.
[15] Cudak M., *Process characteristics for the mechanically agitated gas-liquid systems in the turbulent fluid flow*, Przemysł Chemiczny, 90(9), 2011, 1628-1632.
[16] Fasano J.B., Myers K.J., Janz E.E., *Effect of geometric variations on the performance of gas dispersion impellers with semicircular blades*, The Canadian Journal of Chemical Engineering, 89, 2011, 961-968, DOI: 10.10.02/cjce.20459.
[17] Major-Godlewska M., Karcz J., *Gas hold-up in a tank equipped with the impeller and vertical tubular baffles*, Inżynieria i Aparatura Chemiczna, 4, 2011, 20-21.
[18] Major-Godlewska M., Karcz J., *Process characteristics for gas-liquid system agitated in a vessel equipped with a turbine impeller and tubular baffles*, Chemical Papers, 65, 2011, 132-138, DOI: 10.2478//S11696-010-0080-0.
[19] Major-Godlewska M., Karcz J., *Agitation of a gas-solid-liquid system in a vessel with high Speer impeller and vertical tubular coil*, Chemical Papers, 66(6), 2012, 566-573, DOI: 10.2478/s11696-012-0148-0.
[20] Yianatos J., Contreras F., Diaz F., *Gas hold-up and RTD measurement in an industrial flotation cell*, Minerals Engineering, 23, 2010, 125-130, DOI: 10.1016/j.mineng.2009.11.003.
[21] Vinnett Z., Contreras F., Yianatos J., *Gas dispersion pattern in mechanical flotation cells*, Minerals Engineering, 26, 2012, 80-85, DOI: 10.1016/j.mineng.2011.11.003.
[22] Libudzisz Z., Kowal K., Żakowska Z., *Technical microbiology (in Polish)*, PWN, Tom 2, Warszawa 2008.
[23] Garcia-Ochoa F., Gomez E., *Bioreactor scale-up and oxygen transfer rate in microbial processes: An overview*, Biotechnology Advances, 27, 2009, 153-176, DOI: 10.1016/j.biotechadv.2008.10.006.
[24] Gill N.K, Appleton M., Baganz F., Lye G.J., *Quantification of power consumption and oxygen transfer characteristics of a stirred miniature bioreactor for predictive fermentation scale-up*, Biotechnology and Bioengineering, 100, 2008, 1144-1155, DOI:10.1002/bit 21852.