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SCALE-UP OF MIXING EQUIPMENT FOR SUSPENSIONS

POWIĘKSZANIE MIESZALNIKÓW ZAWIESIN

A b s t r a c t

The most of mixing experiments are carried out in laboratory scale with geometrically similar models. To be able to use the results for design of industrial mixing equipment, knowledge of scale-up rules is necessary. Therefore, this contribution is aiming to experimentally verify scale-up rules. The visual method of determination of just suspended impeller speed was used in order to determinate suspension measurements. This method is generally defined as the state at which no particle remains in contact with the vessel bottom for longer than a certain time (approximatelly 1 s). Glass particles with four equivalent diameters dp in range 0.16 and 1.19 mm and volumetric concentration c from 2.5% to 20% were used as solid phase.

Keywords: mixing of suspensions, scale-up rules, industrial mixing equipment, power consumption, impeller speed

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

Większość eksperymentów związanych z mieszaniem przeprowadza się w skali laboratoryjnej na modelach podobnych pod względem geometrycznym. Aby ich wyniki mogły być wykorzystywane do projektowania mieszalników przemysłowych, niezbędna jest znajomość zasad powiększania. Dlatego właśnie celem niniejszego artykułu jest weryfikacja tychże drogą eksperymentów. W celu dokonania pomiarów zawiesin zastosowano wizualną metodę określania szybkości wirnika napędzanego. Ogólnie rzecz biorąc, chodzi o stan, w którym żadna cząsteczka nie pozostaje w kontakcie z dnem naczynia dłużej niż przez określony czas (ok. 1 sek.). W fazie stałej wykorzystano cząsteczki szkła o czterech równoważnych średnicach d_p w przedziale 0,16–1,19 mm oraz stężenie objętościowe c w przedziale 2,5%–20%.

Słowa kluczowe: mieszanie zawiesin, zasady powiększania, mieszalnik przemysłowy, zużycie energii, szybkość wirnika napędzanego

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1. Introduction

Mixing of suspensions is very frequent operation in process industries. The most mixing experiments are carried out in laboratory scale on geometrically similar models. To be able to use the results for design of industrial mixing equipment, knowledge of scale-up rules is necessary. Power consumption per unit volume is often recommended as a scale-up rule for suspension mixing equipment. However a study of the relationship of power per unit volume by other authors presented by Einenkel [1] indicates that there are many conclusions reported by different investigators. Our first experimental results on this topic were presented in [2]. Results of our more systematic research on this topic were reported in [3]. Experiments presented in [3] were carried out with pitched six/blade turbine and volumetric glass balotine content up to 10%. Experimental verification of scale-up rule is also the main aim of present paper.

2. Theoretical basis

The following equation were recommended for evaluation of critical (just-suspension) agitator speed measurements for given particle content and agitator type in the turbulent region in reference [4]

$$Fr' = f(d_p / D) \tag{1}$$

For relatively small particles, the dependence between the modified Froude number and a dimensionless particle size can be formulated in power form

$$Fr' = C\left(\frac{d_p}{D}\right)^{\gamma} \tag{2}$$

The values of coefficients C and γ depend on particle volumetric concentration c_v. A mathematical description of these dependencies was proposed [5] in the form

$$C = A\exp(Bc_v) \tag{3}$$

$$\gamma = \alpha + \beta c_v \tag{4}$$

3. Experimental procedure

Experiments were carried out in three perspex vessels with flat bottom of inner diameters $D = 290$, 600 and 800 mm. The four pitched-blade turbines with standard slope 45° were used in measurements. The height of impellers above the vessel bottom was equal to $0.5{\cdot}d$. The impellers have been operated to pump the liquid downwards the vessel bottom. The ratio of vessel to impeller diameter $D/d = 3$. The vessels were equipped with four radial baffles of width $b = 0.1{\cdot}D$. The height of the liquid level was equal to the vessel diameter $H = D$.

For suspension measurements was used visual method of determination of just suspended impeller speed that is often defined as the state at which no particle remains in contact with the vessel bottom for longer than a certain time (approximately 1 s).

Glass particles with four equivalent diameters between 0.16 and 1.19 mm and volumetric concentration from 2.5% to 20% were used as solid phase.

4. Experimental results

Chosen experimental results in the form of Eq. (1) are depicted in Fig. 1 and 2.

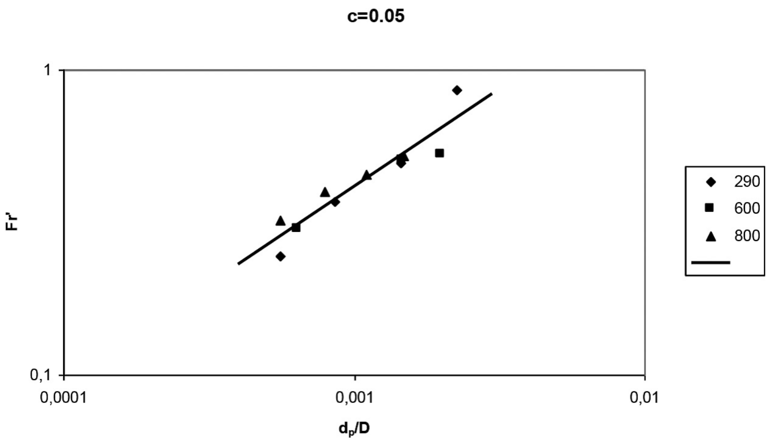

Fig. 1. Dependence of the form $Fr' = f(d_p/D)$ for volumetric concentration $c = 0.05$

Rys. 1. Zależność formy $Fr' = f(d_p/D)$ dla stężenia objętościowego $c = 0{,}05$

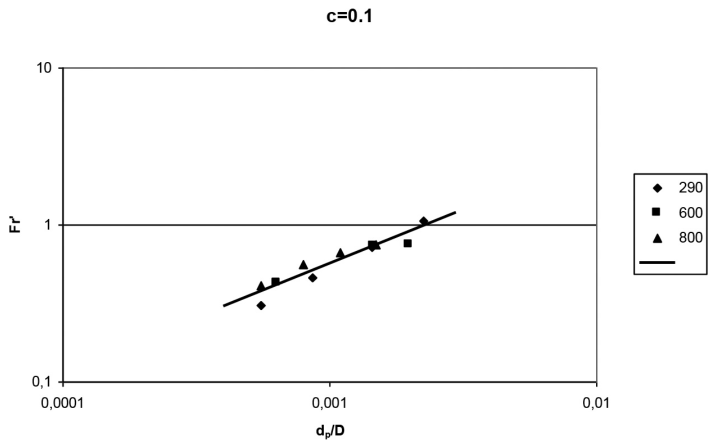

Fig. 2. Dependence of the form $Fr' = f(d_p/D)$ for volumetric concentration $c = 0.1$

Rys. 2. Zależność formy $Fr' = f(d_p/D)$ dla stężenia objętościowego $c = 0{,}1$

From both figures in logarithmic coordinates it is obvious that power form of data evaluation by Eq. (2) is acceptable. It is also seen that there is no significant difference between results obtained in vessels of different size. It means that experimental results obtained on smaller size models evaluated in the form of dimensionless eq. (1) can be used for calculation of impeller just-suspension speed in equipment of industrial size.

The plot of exponent γ on the particle volumetric concentration c is shown in Fig. 3. From this figure it can be seen that it rises linearly with increasing c. The dependence of coefficient C on particle concentration c is shown in Fig. 4 from which it is seen that the dependences can be approximated in semi-logarithmic coordinates by straight lines. It is in agreement with Eqs. (3) and (4), their parameters are also presented in corresponding above mentioned figures.

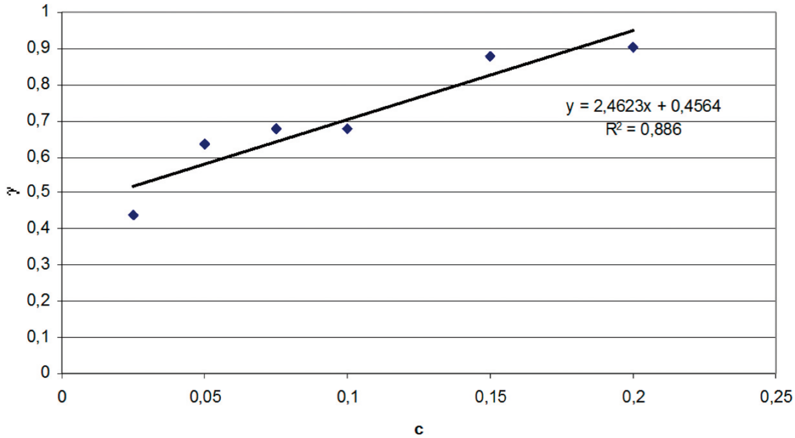

Fig. 3. The plot of exponent γ on the particle volumetric concentration c

Rys. 3. Wykres wykładnika γ przy stężeniu objętościowym c cząsteczki

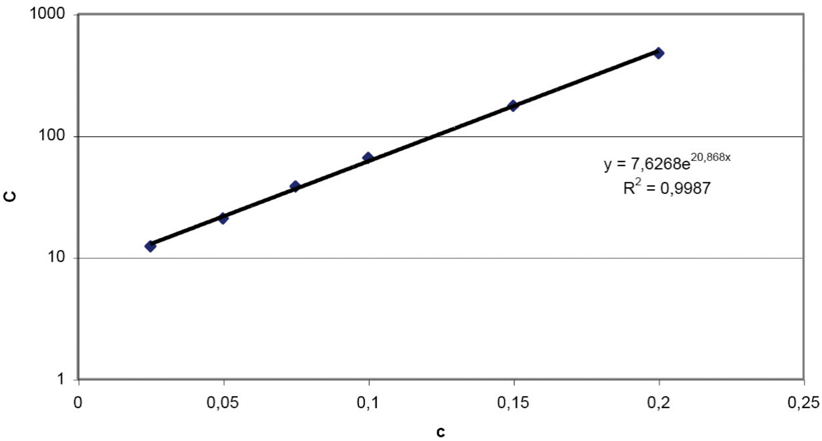

Fig. 4. The dependence of coefficient C on particle volumetric concentration c

Rys. 4. Zależność współczynnika C od stężenia objętościowego c cząsteczki

5. Conclusions

From the results presented it follows that just-suspension speed calculation of industrial agitator from dimensionless dependence of modified Froude number *Fr′* on relative particle size *dp*/*D* and volumetric particle content c measured on geometrically similar model of laboratory scale is acceptable. At geometrical similarity and given suspension we can express the dependence of critical impeller speed on equipment size in the form n~Dκ. From Eq. (2) it follows that

$$\kappa = -\frac{1+\gamma}{2} \tag{5}$$

From the above equation and equation presented in Fig. 3 it follows that exponent κ changes in the range from -0.73 to -0.97 when particle content c changes from 0 to 20%. It means that critical agitator speed decreases with increasing equipment s ize. For mixing equipment for suspensions the scale-up based on constant specific power consumption is frequently recommended, it corresponds to exponent κ = -2/3. From the range of exponent κ presented above it follows that scale-up on the basis constant specific power consumption is on the safe side. On the other hand scale-up on the basis of constant impeller tip speed that corresponds to κ = -1 can be recommended for highly concentrated suspensions only.

Symbols

A, B – constants in Eq. (3)
c – volumetric concentration of particles [1]
C – coefficient in Eq. (2)
d – agitator diameter [mm]
d_p – particle diameter [mm]
D – vessel diameter [mm]
Fr′ – modified Froude number, $Fr' = \frac{n^2 d\rho}{g\Delta\rho}$ [1]
g – gravity acceleration [m/s2]
n – agitator speed [s-1]
P – power [W]
Po – power number, $Po = \frac{P}{\rho n^3 d^5}$ [1]
Re – Reynolds number, $\mathrm{Re} = \frac{nd^2\rho}{\mu}$ [1]
α, β – constants in Eq. (4)
γ – exponent in Eq. (2)
κ – scale-up exponent

μ – viscosity [Pa·s]
ρ – liquid density [kg/m3]
Δρ – solid-liquid density difference [kg/m3]

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