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Mixing of suspensions with curved blade turbine

Introduction

Curved blade turbines are often used for mixing of suspensions in food industry, reactors and bioreactors. For designing, construction and operating of mixing apparatus or for restoration of existing mixing apparatus is necessary to know the critical impeller speed and energy consumption necessary for off-bottom particle suspension state (that is the state when all particles are dissipated in liquid and no one stay immovable on the vessel bottom). The aim of this paper is to compare results of previous visual measurements of critical agitator speed [1] with a new measurements using electrochemical method described in [2] and to compare values of power consumption necessary for suspension of solid particles with the corresponding values for standard pitch six-blade turbine.

Theoretical basis

The following equation were recommended for evaluation of critical agitator speed measurements for given particle content and agitator type in the turbulent region in reference [3]

$$Fr' = f(d_p/D) \qquad (1)$$

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

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

The values of coefficients C and γ depend on particle volumetric concentration c_v. A mathematical description of these dependencies was proposed [4] in the form

$$C = A\exp(Bc_v) \qquad (3)$$

$$\gamma = \alpha + \beta c_v \qquad (4)$$

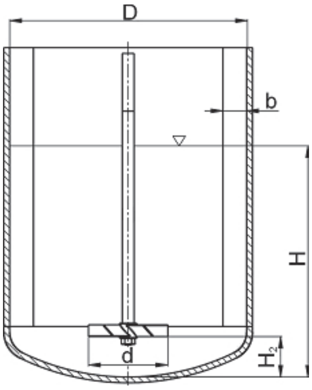
The dimensionless criterion

$$\pi_s = Po\sqrt{Fr'^3 (d/D)^7} \qquad (5)$$

was proposed for comparison of agitator power consumption necessary for suspension of solid particles in reference [5].

Experimental procedure

Experiments were carried out in a perspex vessel of inner diameter D = 300 mm equipped with four standard baffles shown in Fig. 1. The turbines with three curved blades of width 15 mm (Pf0.1) and 22.5 mm (Pf0.15) and diameter d = 150 mm in distance 15 mm from the vessel bottom were used in measurements.



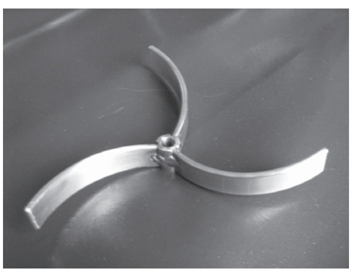


Fig. 1. Experimental layout with curved blade turbine

For suspension measurements was used electrochemical method of determination of just suspended impeller speed, the so called electrodiffusion diagnostics (EDD), which is based on determination of current level between two electrodes from which one (the probe) is embedded in vessel bottom. The basic condition of functionality of this method is conductive liquid phase and dielectric solid phase. Presence of stagnant particles on vessel bottom makes impossible transport of current between electrodes. Vice-versa, absence of particles from the vessel bottom makes possible the current transfer and this is the stage of just suspended particles. As liquid phase was used the 2,5% NaCl water solution, as solid phase were used glass particles with four equivalent diameters between 0.18 and 0.89 mm and volumetric concentration from 2.5% to 40%.

The power consumption of the impeller was determined from the torsion moment (torque) and the rotation speed of the impeller. The torque was measured using a rotary table equipped with strain gauges connected to a bridge. The data were recorded using the A/D converter to the PC and recalculated using the calibration function to the torque values.

Experimental results

From experimental data of the critical agitator speed, values of the modified *Froude* number Fr' were calculated. Typical dependencies of Fr' on the ratio d_p/D for c_v = 10% are shown in Fig. 2. In this figure the values presented in [1] for agitator with blade width 12 mm in vessel equipped with 2 baffles (Pf0.12) obtained by visual method are also depicted. From the figure it can be seen that the course of dependence is the same but values determined by visual method are greater than values obtained by electrochemical method. The same is valid also for measurements at other solid particles contents. It is caused by the fact, that critical impeller speed for suspension was determined visually according *Zwietering's* definition – no particle remains longer than 1 s on the vessel bottom. On the contrary the EDD method identifies critical speed as a speed at which intensive motion of particles on the bottom occurs.

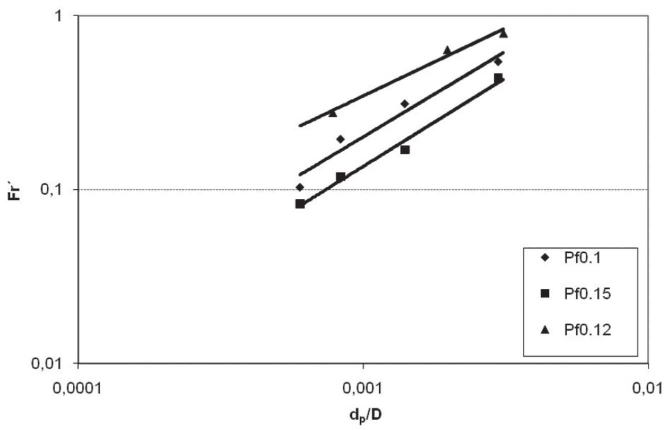


Fig. 2. Dependence of Fr' on d_p/D for c_v = 0,1

From Fig. 2 it can be also seen that the logarithmic plot of experimental data is linear and Eq.(2) can be used for their evaluation. Dependence of coefficient C and exponent c on c_v for both agitators are shown in Figs. 3 and 4. From these figures it can be seen that trends of dependencies are different at smaller and higher concentrations. It is in agreement with results presented in [1].

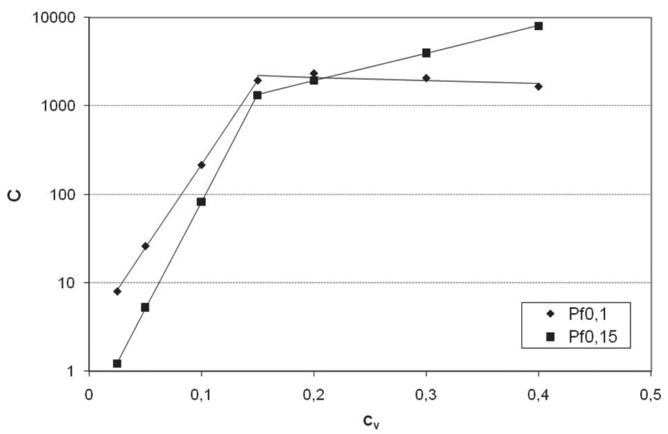


Fig. 3. Dependence of C on c_v

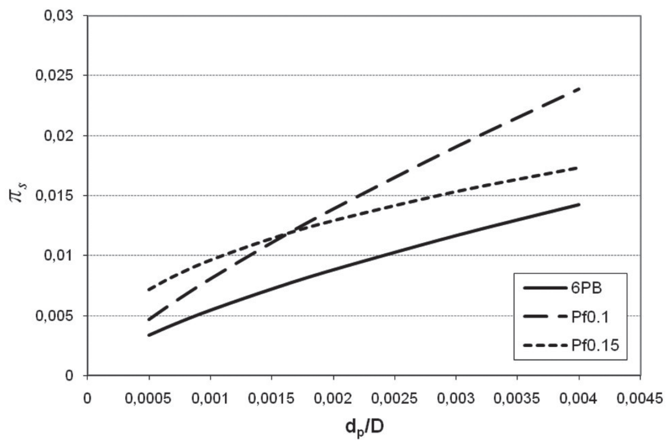


Fig. 6. Comparison of π_s values for curved and pitched blade turbines, $c_v = 0{,}025$

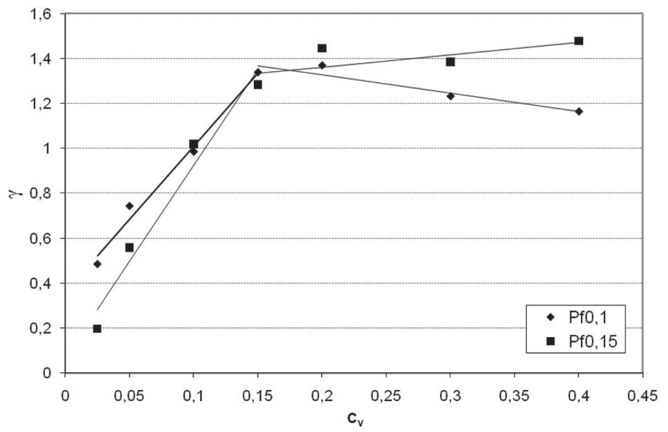


Fig. 4. Dependence of γ on c_v

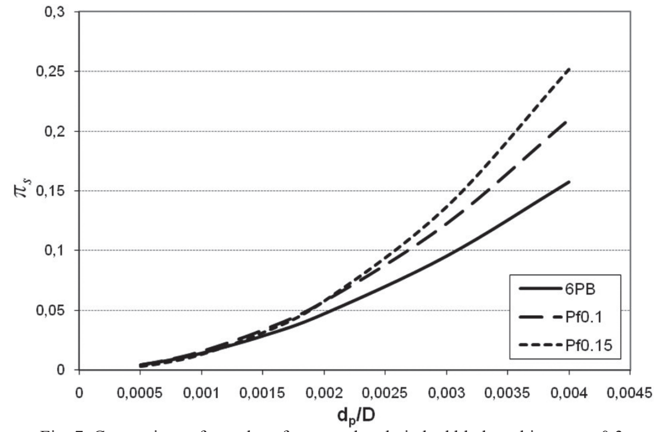


Fig. 7. Comparison of π_s values for curved and pitched blade turbines, $c_v = 0{,}3$

For calculation of criterion (5) the power measurements were carried out. Their results in the form power number on *Reynolds* number dependence are depicted in Fig.5.

Comparison of π_s values for curved blade turbines with values for pitched six-blade turbine ($D/d = 3$) [6] is depicted for selected particle contents c_v in Figs. 6 and 7.

From these figures it can be seen that curved blade turbines are comparable with standard turbine at mixing concentrated suspensions of relatively small particles.

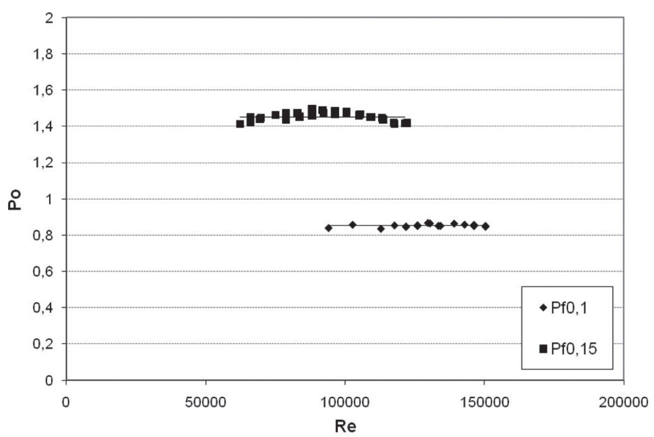


Fig. 5. Dependence of Po on Re

Conclusions

With increasing d_p/D ratio and volumetric concentration of particles c_v it is observed a better suspension efficiency of Pf0,1 turbine with respect to Pf0,15, and of 6PB turbine with respect to Pf0,1.

Symbols

A, B, C – coefficients in Eqs. (2) and (3), [l]
b – width of blade, [m]
c_v – mean volumetric concentration, [l]
d – agitator diameter, [m]
d_p – mean particle diameter, [m]
D – vessel diameter, [m]
Fr' – modified *Froude* number, $Fr' = n^2 d\rho / g\Delta\rho$
g – acceleration due to gravity, [m/s^2]
H_2 – impeller-bottom clearance, [m]
n – impeller speed, [*1*/s, rpm]
Po – power number, $Po = P/\rho_s n^3 d^5$
α, β, γ – coefficients in Eqs. (2) and (4), [l]
ρ – density, [kg/m^3]
$\Delta\rho$ – solid-liquid density difference, [kg/m^3]
ρ_s – density of suspension, [kg/m^3]
π_s – dimensionless power consumption for suspension of particles, Eq.(5)

LITERATURE

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