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EFFECT OF THE NUMBER OF BLADES ON PARTICLE SUSPENSION WITH PITCHED-BLADE TURBINES

WPŁYW LICZBY ŁOPATEK MIESZADŁA PBT NA WYTWARZANIE SUSPENSJI

Abstract

In present paper the effect of blade number is discussed on the basis of electrochemical measurements of particle suspension in wide range of particle contents. Experiments were carried out in a Perspex vessel of inner diameter $D = 300$ mm equipped with four standard baffles. The turbines with four and six pitched blades of diameter $d = 100$ mm were used in measurements. The results have shown that six-blade turbine needs less speed for solid phase suspension than four-blade turbine and these speeds increase with increasing particle size and concentration. The six-blade turbine also needs less power needed to particle suspension than four-blade turbine.

Keywords: agitator power, blade number, Froude number, pitched blade turbine, particle suspension

Streszczenie

W pracy przedstawiono analizę wpływu liczby łopatek na wytwarzanie zawiesiny dla szerokiego zakresu zawartości cząstek ciała stałego. Badania prowadzono w naczyniu z tworzywa Perspex, o średnicy $D = 300$ mm, z czterema przegrodami. Powstawanie zawiesiny oceniano metodą elektrochemiczną, w badaniach stosowano mieszadła PBT o średnicy $d = 100$ mm z czterema lub sześcioma łopatkami. Wyniki wskazują, że sześciołopatkowa turbina wytwarza suspensję przy niższej częstości obrotów niż czterołopatkowa i prędkość ta wzrasta wraz ze wzrostem średnicy i stężenia cząstek ciała stałego. Zapotrzebowanie mocy do wytworzenia suspensji dla turbiny sześciołopatkowej jest również niższe.

Słowa kluczowe: moc mieszania, liczba łopatek, liczba Froude'a, mieszadło z pochylonymi łopatkami (PBT), suspensja

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1. Introduction

Pitched-blade turbines are widely used for mixing of suspensions. In an earlier paper [1], we concluded that the number of blades has no significant effect on the suspension efficiency of pitched-blade turbines in a vessel with a dished bottom. In a vessel with a flat bottom, the six-blade turbine was reported to be more efficient [2]. However, in the cited papers this conclusion was reached on the basis of visual observations with two solid particle contents (2,5 and 10%) only. In the present paper, the effect of the number of blades will be discussed on the basis of electrochemical measurements of particle suspension in a wide range of particle contents.

2. Theoretical basis

The following relation was recommended in [3] for evaluating critical agitator speed measurements for a given particle content and agitator type in the turbulent region

$$Fr' = f\left(\frac{d_p}{D}\right) \tag{1}$$

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

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

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

$$C = A \cdot \exp(B \cdot c_v) \tag{3}$$

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

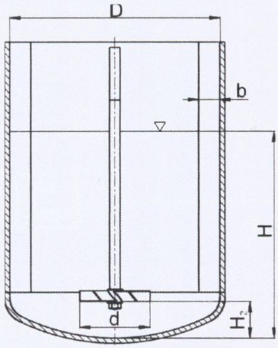
The dimensionless criterion

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

was proposed for a comparison of the agitator power consumption necessary for suspending solid particles in [5].

3. Experimental procedure

The experiments were carried out in a perspex vessel of inner diameter $D = 300$ mm equipped with four standard baffles, as shown in Fig. 1. Turbines with four and six pitched blades of diameter $d = 100$ mm were used in the measurements. The height of the impellers above the vessel bottom was equal to $0{,}5 \cdot d$. The impellers were operated to pump the liquid down towards the bottom of the vessel. 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 $H = D$.



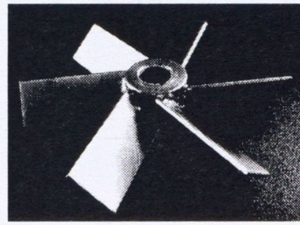


Fig. 1. Experimental vessel with a pitched six-blade turbine

Rys. 1. Eksperymentalny mieszalnik z turbiną PBT, sześciołopatkową

For the suspension measurements, we used an electrochemical method, so-called electrodiffusion diagnostics (EDD), to determine the just suspended impeller speed. For a description, see [6]. The method is based on determining the current level between two electrodes, one of which (the probe) is embedded in the bottom of the vessel. The basic condition for the functionality of this method is a conductive liquid phase and a dielectric solid phase. The presence of stagnant particles on the bottom of the vessel makes transport of current between the electrodes impossible. Conversely, the absence of particles from the vessel bottom makes current transfer possible, and this is the stage of just suspended particles. We used a 2.5% NaCl water solution as the liquid phase, and glass particles with four equivalent diameters between 0.18 and 0.89 mm as the solid phase, and their volumetric concentration changed 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 was recorded using the A/D converter to the PC, and was recalculated using the calibration function to the torque values.

4. Experimental results

The primary experimental data was transformed into dimensionless criteria, and was plotted as suspension characteristics. The suspension characteristics for the turbulent region are the dependencies of modified Froude number Fr' on dimensionless particle size d_p/D at constant volumetric particle concentration c_v.

The regression of the suspension characteristics was evaluated in the power form according to Eq. (2). Typical dependences of modified Froude number Fr' on dimensionless particle size d_p/D for selected values of volumetric particle concentration c_v are shown in Fig. 2. This figure shows that the dependence Fr' on d_p/D is linear in logarithmic coordinates (in agreement with Eq. (2)), and the slope of this dependence is higher at higher particle concentration.

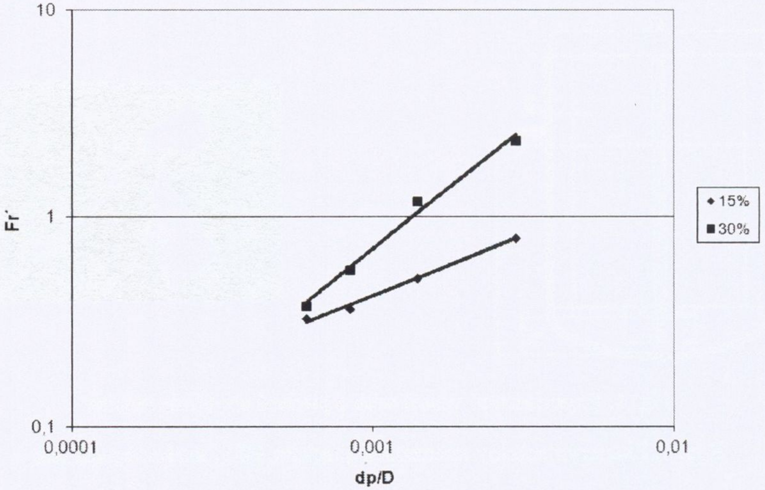


Fig. 2. Dependences of Fr' on the d_p/D ratio for selected concentrations, pitched four-blade turbine

Rys. 2. Zależność liczby Fr' od proporcji d_p/D, dla wybranych stężeń cząstek ciała stałego, turbina PBT, czterołopatkowa

The plot of exponent γ on particle volumetric concentration c_v for both numbers of blades is shown in Fig. 3. The figure shows that it rises linearly with increasing c_v. The dependence of coefficients C on particle concentration c_v is shown in Fig. 4, from which it is seen that the dependences can be approximated in semi-logarithmic coordinates by straight lines. This is in agreement with Eqs. (3) and (4).

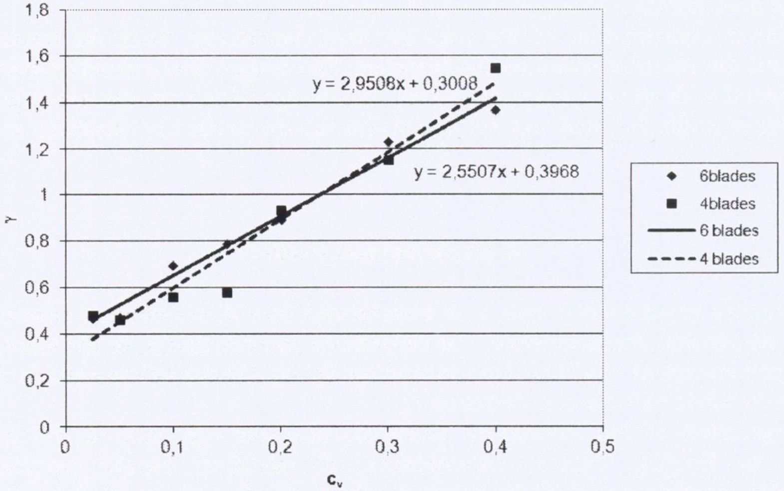


Fig. 3. Plot of exponents γ on particle concentration c_v

Rys. 3. Wykres zależności wykładnika γ od stężenia cząstek ciała stałego c_v

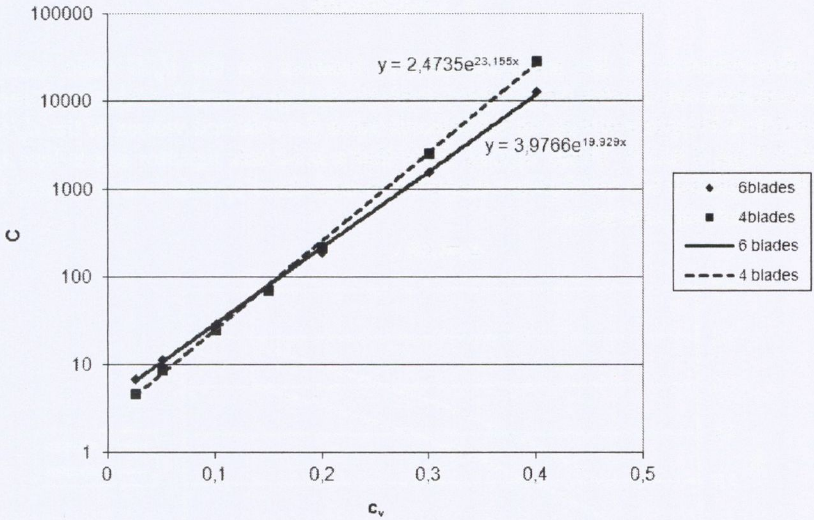


Fig. 4. Plot of coefficients C on particle concentration c_v

Rys. 4. Wykres zależności wykładnika C od stężenia cząstek ciała stałego c_v

Power measurements were carried out in order to calculate criterion (5). The results in the form power number on Reynolds number are depicted in Fig. 5. This figure shows that the power number is independent of the Reynolds number in the turbulent regime, and the power number for a six-blade turbine is greater than the corresponding number for a four-blade turbine.

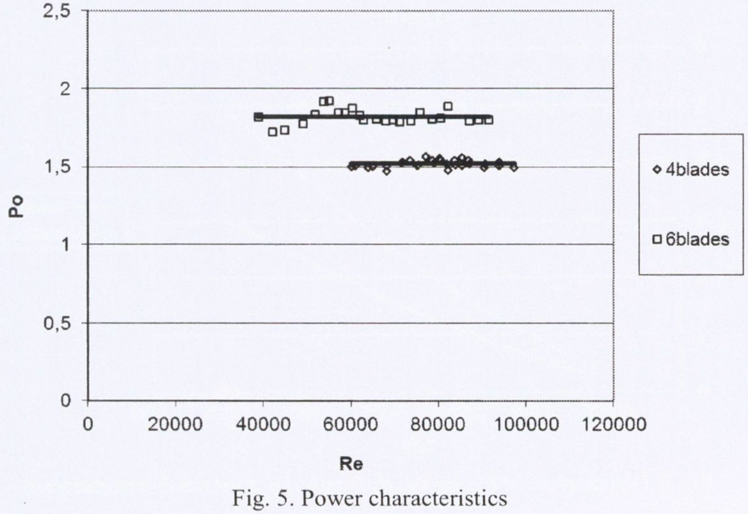


Fig. 5. Power characteristics

Rys. 5. Charakterystyka mocy

5. Conclusions

The dependences of the modified Froude number on the d_p/D ratio calculated for selected concentrations from Eqs. 2-4 are depicted in Figs. 6 and 7. Calculated dependences of the modified Froude number on the concentration for selected values of the d_p/D ratio are depicted in Figs. 8 and 9. These figures show that a six-blade agitator needs less speed than a four-blade agitator for solid phase suspension, and these speeds increase with increasing particle size and concentration.

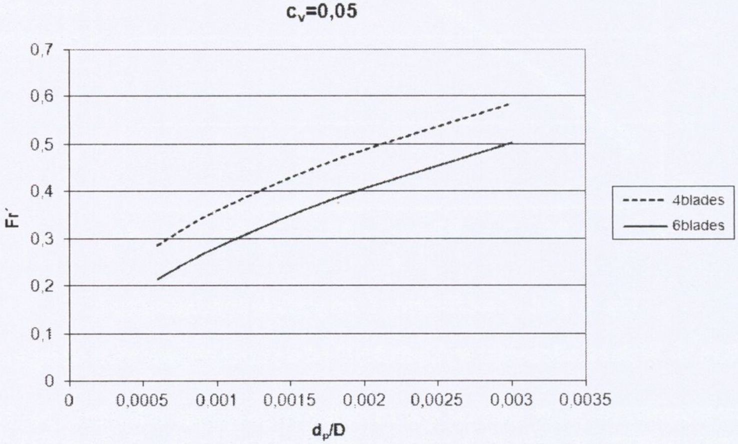


Fig. 6. Dependence of Fr' on the d_p/D ratio for a selected concentration

Rys. 6. Zależność liczby Fr' od proporcji d_p/D, dla wybranych stężeń cząstek ciała stałego

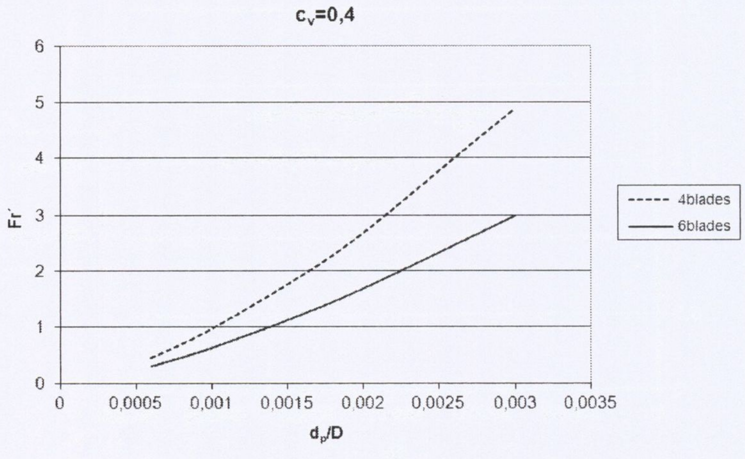


Fig.7. Dependence of Fr' on the d_p/D ratio for a selected concentration

Rys. 7. Zależność liczby Fr' od proporcji d_p/D, dla wybranych stężeń cząstek ciała stałego

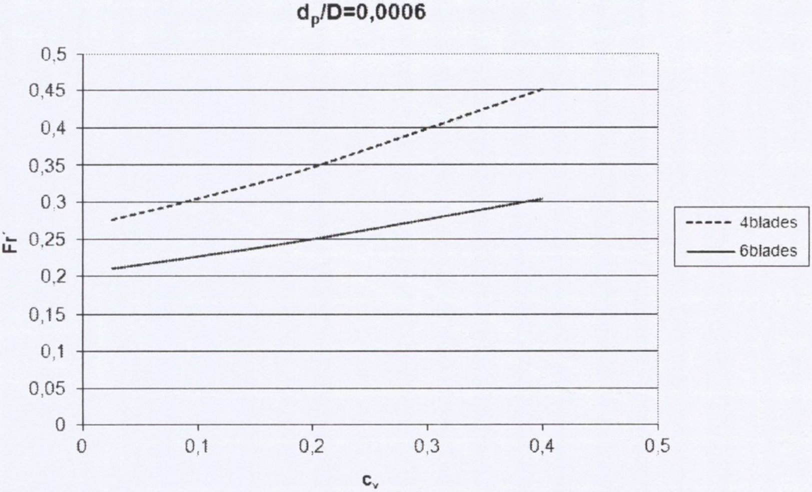


Fig. 8. Dependence of Fr' on concentration for a selected d_p/D ratio value

Rys. 8. Zależność liczby Fr' od stężenia cząstek ciała stałego dla wybranych proporcji d_p/D

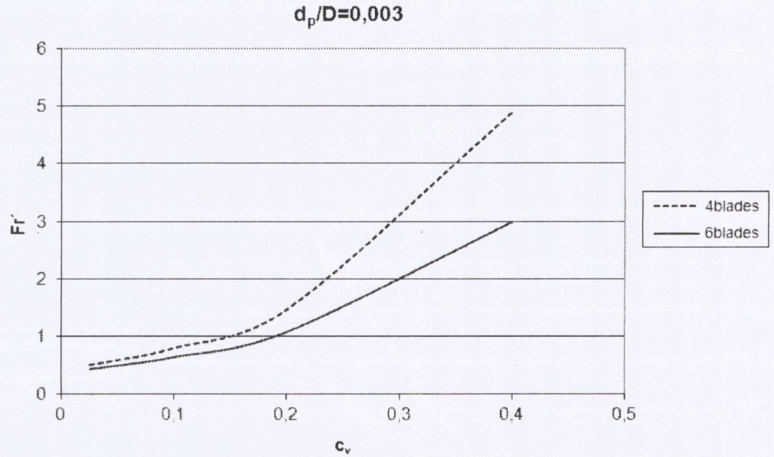


Fig. 9. Dependence of Fr' on concentration for a selected d_p/D ratio value

Rys. 9. Zależność liczby Fr' od stężenia cząstek ciała stałego dla wybranych proporcji d_p/D

To compare the agitator power needed to suspend particles in a given vessel, the values of criterion π_s were calculated from Eq. (5). The dependences of this criterion on the d_p/D ratio for selected concentrations are depicted in Figs. 10 and 11. The dependences of criterion π_s on concentration for selected values of the d_p/D ratio are depicted in Figs. 12 and 13. These figures show that a six-blade agitator is more efficient than a four-blade agitator, except in the case of a less concentrated suspension with relatively large particles, where the efficiency of the two agitators is comparable (see Fig. 13). This probably provides an explanation for the conclusions presented in [1].

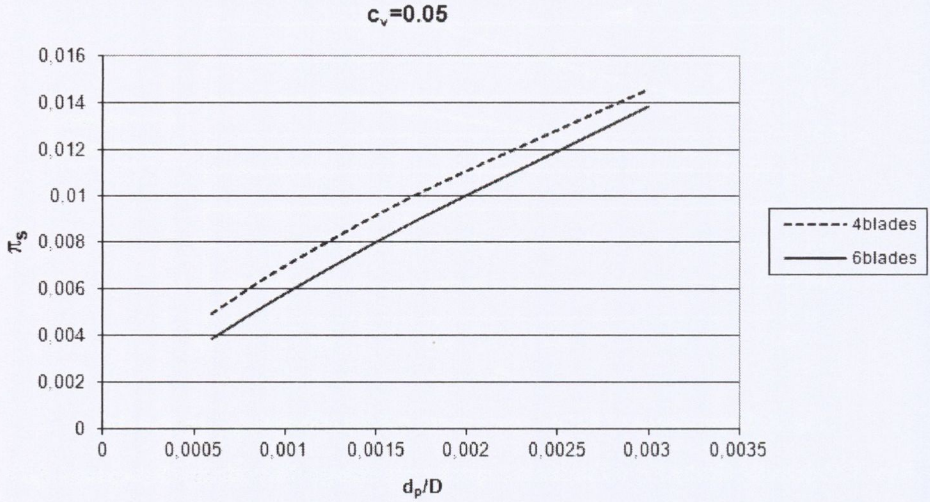


Fig. 10. Dependence of criterion π_s on the d_p/D ratio for a selected concentration

Rys. 10. Zależność kryterium π_s od proporcji d_p/D, dla wybranych stężeń cząstek ciała stałego

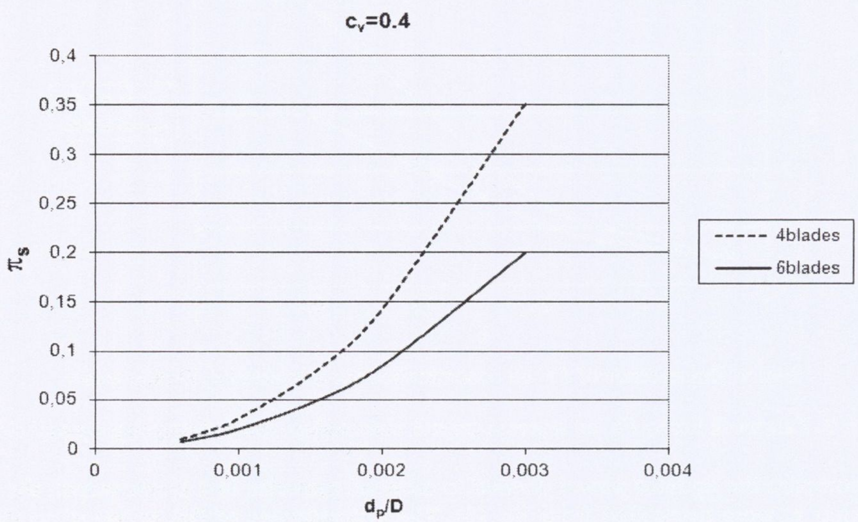


Fig. 11. Dependence of criterion π_s on the d_p/D ratio for a selected concentration

Rys. 11. Zależność kryterium π_s od proporcji d_p/D, dla wybranych stężeń cząstek ciała stałego

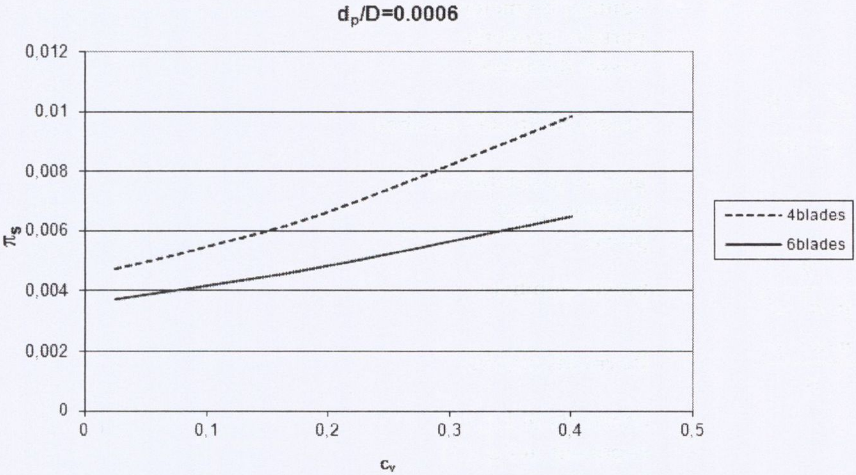


Fig. 12. Dependence of criterion π_s on concentration for a selected d_p/D ratio value

Rys. 12. Zależność kryterium π_s od stężenia cząstek ciała stałego dla wybranych proporcji d_p/D

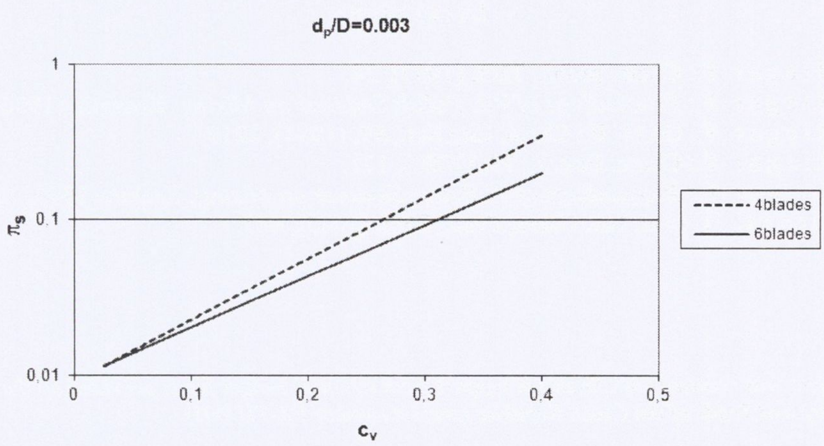


Fig. 13. Dependence of criterion π_s on concentration for a selected d_p/D ratio value

Rys.13. Zależność kryterium π_s od stężenia cząstek ciała stałego dla wybranych proporcji d_p/D

Symbols

A, B	–	constants in Eq. (3)	[–]
c_v	–	volumetric concentration of particles	[–]
C	–	coefficient in Eq. (2)	[–]

d	–	agitator diameter	[m]
d_p	–	particle diameter	[m]
D	–	vessel diameter	[m]
$Fr' = \frac{n^2 \cdot d \cdot \rho}{g \cdot \Delta\rho}$	–	modified Froude number	[–]
g	–	gravity acceleration	[m·s^{-2}]
n	–	agitator speed	[s^{-1}]
P	–	power	[W]
$Po = \frac{P}{\rho \cdot n^3 \cdot d^5}$	–	power number	[–]
$Re = \frac{n \cdot d^2 \cdot \rho}{\mu}$	–	Reynolds number	[–]
α, β	–	constants in Eq. (4)	[–]
γ	–	exponent in Eq. (2)	[–]
μ	–	viscosity	[Pa·s]
ρ	–	liquid density	[kg·m^{-3}]
$\Delta\rho$	–	solid-liquid density difference	[kg·m^{-3}]

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