Pitched Blade Turbine Efficiency at Particle Suspension

D. Ceres, T. Jirout, F. Rieger

Abstract

Mixing suspensions is a very important hydraulic operation. The pitched six-blade turbine is a widely-used axial-flow impeller. This paper deals with effect relative impeller size and particle content on the efficiency of a pitched six-blade turbine at particle suspension.

Two pitched six-blade turbines were used in model measurements of just suspension impeller speed. The ratios of the vessel to agitator diameter D/d were 3 and 4.5. The measurements were carried out in a dish-bottomed vessel 300 mm in diameter. The just suspension impeller speeds were measured using an electrochemical method, and were checked visually. A 2.5 % NaCl water solution was used as the liquid phase, and glass particles with four equivalent diameters between 0.18 and 0.89 mm and volumetric concentration from 2.5 % to 40 % were used as the solid phase.

The criterion values $\pi_s = Po\sqrt{Fr'^3(d/D)^7}$ were calculated from the particle suspension and power consumption measurements. The dependencies of π_s on particle content c_v show that larger agitators are more efficient for higher particle content.

Keywords: Pitched blade turbine, particle suspension, agitator efficiency.

1 Introduction

Mixing suspensions is a very important hydraulic operation. Suspensions are frequently mixed when dispersions are prepared or homogenised, and in mass transfer operations between solid particles and a liquid, often accompanied by a chemical or biochemical reaction. It is estimated that about 60 % of mixing involves heterogeneous particulate solid phase-liquid systems.
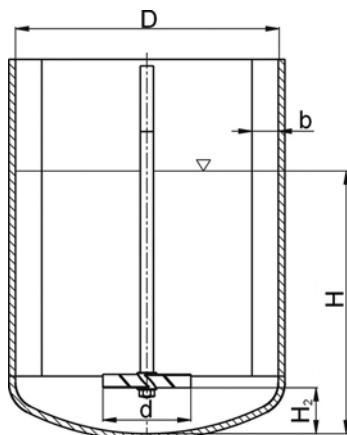

Fig. 1

Numerous papers on particle suspension in agitated vessels have been published. Reviews have been published by Rieger and Ditl [1] and more recently by Kasat and Pandit [2]. These authors show that axial-flow pattern impellers are generally considered the most suitable agitators in such cases. The pitched six-blade turbine shown in Fig. 1 is the one of most widely-used axial-flow impellers. The present paper deals with the effect of relative impeller size and particle content on the efficiency of a pitched six-blade turbine at particle suspension. This problem was also the topic of our earlier papers [3, 4], in which attention was focused on relative impeller size, and measurements were carried out for two particle contents only.

2 Theoretical background

In order to design mixing apparatuses, it is important to know the reference state of just off-bottom particle suspension, which is often defined as the state at which no particle remains in contact with the vessel bottom for longer than a certain time. The impeller speed corresponding to this state is referred to as the critical (just-suspended) impeller speed n_c.

On the basis of inspection analysis of the equation of continuity, the Navier-Stokes equation and the equation expressing the balance of forces affecting the suspended particle, Rieger and Ditl [1] proposed the following relationship linking the modified Froude number Fr', the dimensionless particle diameter d_p/D and the mean volumetric concentration of the solid phase c_v

$$Fr' = \frac{n_c^2 d\rho}{g\Delta\rho} = f\left(\frac{d_p}{D}, c_v\right). \tag{1}$$

This relation holds for geometrically similar mixing equipment and a turbulent regime.

The results of critical (just-suspended) impeller speed measurements for the given solid phase concentration c_v can be correlated in the 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 by Rieger [5, 6] in the form

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

and

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

The dimensionless criterion

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

was proposed in [7] for comparing the agitator power consumption necessary for suspension of solid particles.

3 Experimental

Two pitched six-blade turbines with pitch blade angle $45°$ and blade width $0.2 \cdot d$ were used in model measurements of just suspension impeller speed. The ratios of the vessel to the agitator diameter D/d were 3 and 4.5. The measurements were carried out in a dish-bottomed vessel 300 mm in diameter. The height of the impellers above the vessel bottom was $0.5d$. The impellers were operated to pump the liquid down toward bottom of the vessel. The vessels were equipped with four radial baffles $b = 0.1 \cdot D$ in width. The height of the liquid level was equal to the vessel diameter $H = D$.

The just suspension impeller speeds were measured by an electrochemical method described e.g. in [8], and were checked visually. A 2.5 % NaCl water solution was used as the liquid, and glass particles with four equivalent diameters between 0.18 and 0.89 mm and volumetric concentration from 2.5 % to 40 % were used as the solid phase.

4 Results

The dependences of coefficient C and exponent γ on the particle volumetric concentration c_v for both D/d ratio values were presented in [9]. The plot of exponent γ on the particle volumetric concentration c_v

shown in Fig. 2 shows that it rises linearly with increasing c_v. The dependence of coefficient C on particle concentration c_v, see Fig. 3, shows that the dependences can be approximated in semi-logarithmic coordinates by straight lines. This is in agreement with Eqs. (3) and (4).
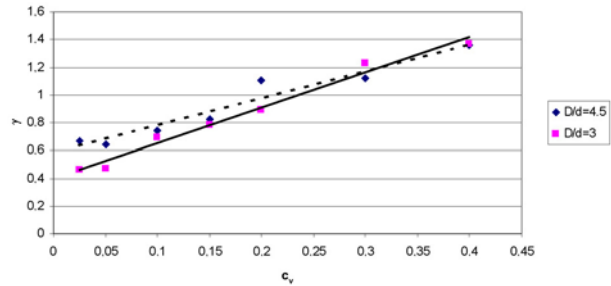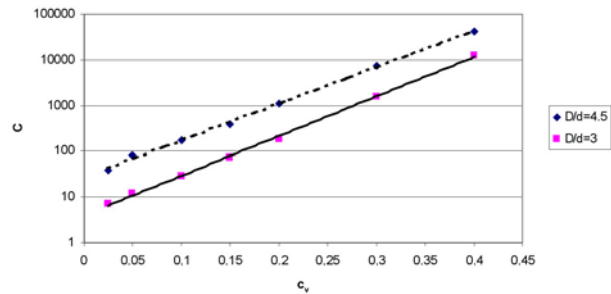

Fig. 2

Fig. 3

The values of criterion π_s were calculated from the results of particle suspension measurements (Eqs. (2–4)) and from the results of power consumption measurements presented in [7, 10, 11]. The results are presented in Figs. 4 and 5. Fig. 4 for smaller particles shows that at low particle content the smaller agitator needs less power for particle suspension, while the converse is true for higher particle content. Fig. 5 shows that for larger particles with low particle content, the two agitators need practically the same power for particle suspension. For higher particle content, the larger agitator is again more advantageous.
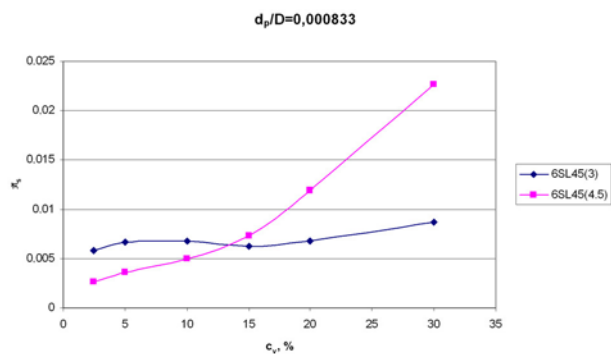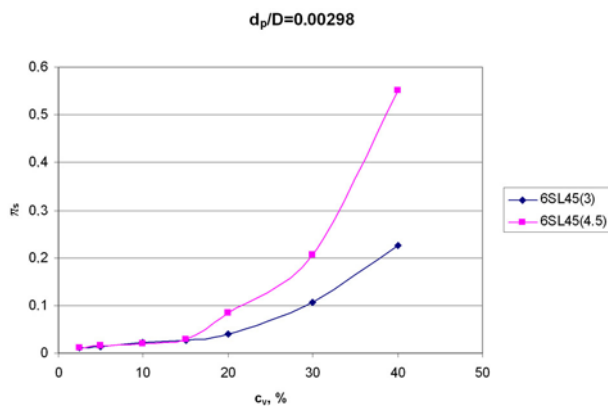

Fig. 4

Fig. 5

We can conclude that larger agitators are more efficient for higher particle content. This is in agreement with the conclusions presented earlier [3, 4].

5 Symbols

A, B	constants in Eq. (3)
c_v	volumetric concentration of particles
C	coefficient in Eq. (2)
d	agitator diameter
d_p	particle diameter
D	vessel diameter
Fr'	modified Froude number defined by Eq. (1)
g	gravity acceleration
n	agitator speed
n_c	critical agitator speed
Po	power number, $Po = \dfrac{P}{\rho n^3 d^5}$
α, β	constants in Eq. (4)
γ	exponent in Eq. (2)
π_s	dimensionless criterion defined by Eq. (5)
ρ	liquid density
$\Delta\rho$	solid-liquid density difference

Acknowledgement

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