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Mixing of suspensions with pitched six blade turbines

Introduction

Mixing of suspensions is very important hydraulic operation. It frequently appears at preparation of dispersions, their homogenisation, mass transfer operations between solid particles and liquid that is often accompanied by a chemical or biochemical reaction. It is estimated that about 60% of mixing is related to the heterogeneous system: particulate solid phase-liquid.

Number of papers on particle suspension in agitated vessels was published. Review of this knowledge was presented by *Rieger* and *Ditl* [1] and latterly by *Kasat* and *Pandit* [2]. From their conclusions it follows, that it is generally understood that axial-flow pattern impellers are the most suitable agitators in such cases. The pitched six blade turbine shown in Fig.1 is the one of most widespread axial-flow impellers.

Theoretical background

In order to design mixing apparatuses it is important to know the reference state of just off-bottom particle suspension that 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 balance of forces affecting the suspended particle *Rieger* and *Ditl* [1] proposed the following relationship among the modified Froude number Fr', the dimensionless particle diameter d_p/D and the mean volumetric concentration of solid phase c_v

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

This relation holds for geometrically similar mixing equipment and 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* [3, 4] in the form

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

and

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

Experimental

Two pitched six blade turbines were used in model measurements of just suspension impeller speed. The ratio of vessel to agitator diameter D/d were 3 and 4.5. The measurements were carried out in dish-bottomed vessels with diameter 200 and 300 mm. The height of impellers above the vessel bottom was equal to 0.5d. The impellers have been operated to pump the liquid downwards the vessel bottom. The vessels were equipped with four radial baffles of width $b = 0.1\ D$. The height of the liquid level was equal to the vessel diameter $H = D$. The experimental layout is shown in Fig. 1.

The two types of suspensions were used in measurements. Standard suspensions were represented by suspensions of glass ballotine, fine-grained suspensions were represented by suspensions of clay. Glass ballotine particle diameters changed in the range from 0.18 to 0.9 mm and

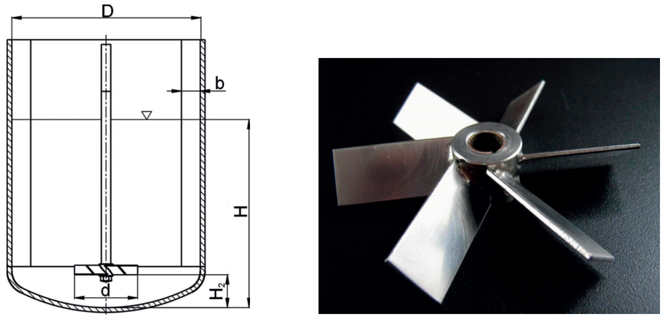

Fig. 1. Experimental layout with pitched six blade impeller

their volumetric concentration changed in the range from 0.025 to 0.4. The clay particles have mean diameter 6.5 μm, their volumetric concentration changed in the range from 0.05 to 0.2. The just suspension impeller speeds were measured by electrochemical method described e.g. in [5] and checked visually.

Experimental results

The primary experimental data obtained were transformed into dimensionless criteria and plotted as suspension characteristics. Suspension characteristics for the turbulent region are dependencies of modified *Froude* number Fr' on the 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). The plot of exponent γ on the particle volumetric concentration c_v for both values of D/d ratio is shown in Fig. 2. From this figure it can be seen that it rises linearly with increasing c_v. The dependence of coefficients C on particle concentration c_v is shown in Fig. 3 from which it is shown that the dependences can be approximated in semi-logarithmic coordinates by straight lines. It is in agreement with Eqs. (3) and (4).

To compare the agitator speed needed to particle suspension in the given vessel, the values of criterion $(Fr' \cdot D/d)^{1/2}$ were calculated from Eq. (2). The dependences of this criterion on d_p/D ratio for selected concentrations are depicted in Figs. 4 and 5. From these figures it can be seen that speeds of agitator for particle suspension are greater for smaller impeller and increase with increasing particle size.

It is also seen that the impeller speed increases with increasing amount of solids in suspension. This increase is much more outstanding for bigger particles. It is clearly seen in Figs. 6 and 7, where the dependences of the criterion $(Fr' \cdot D/d)^{1/2}$ on particle concentration c_v at both boundary values of ratio d_p/D are depicted. The growth of the dependences is more distinct for smaller impeller.

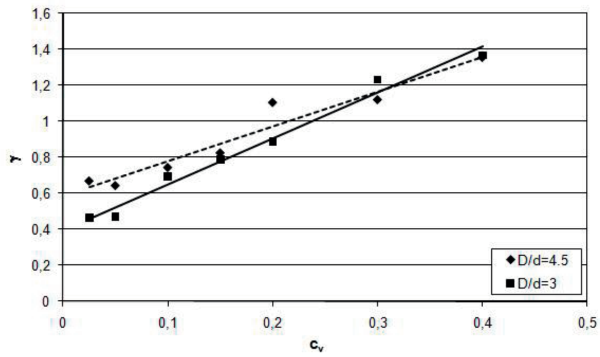

Fig. 2. Dependence of coefficient γ on particle concentration c_v

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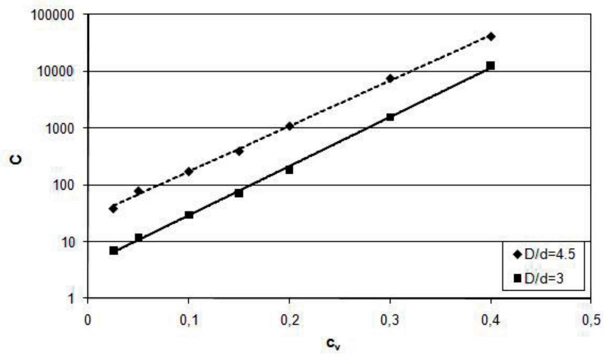

Fig. 3. Dependence of coefficient C on particle concentration c_v

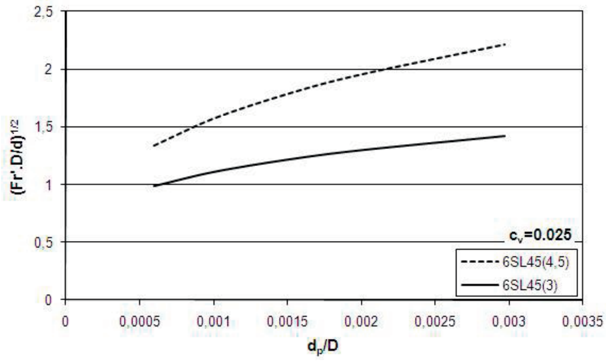

Fig. 4. Dependence of criterion $(Fr'D/d)^{1/2}$ on ratio d_p/D at low concentration of solids in suspension

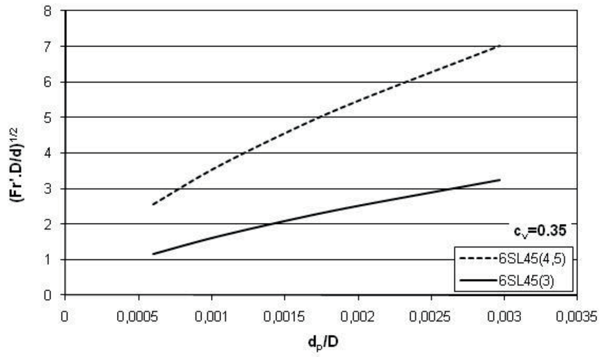

Fig. 5. Dependence of criterion $(Fr'D/d)^{1/2}$ on ratio d_p/D at high concentration of solids in suspension

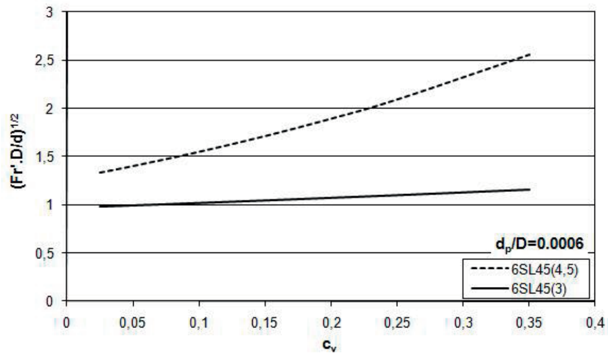

Fig. 6. Dependence of criterion $(Fr'D/d)^{1/2}$ on concentration c_v for smaller particles

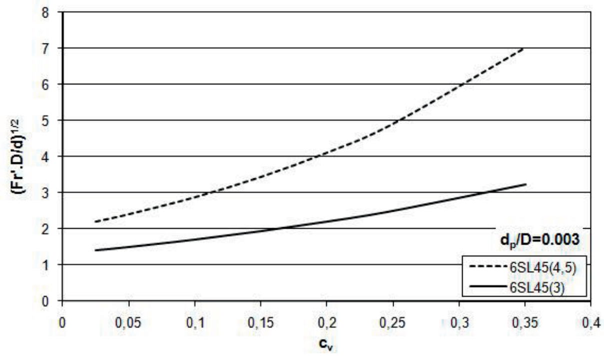

Fig. 7. Dependence of criterion $(Fr'D/d)^{1/2}$ on particle concentration c_v for bigger particles

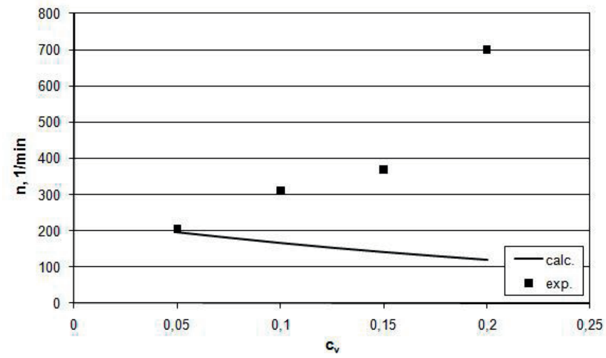

Fig. 8. Comparison of calculated and experimentally obtained impeller speeds for fine particles

The impeller speed calculated from equation (1) for fine clay suspensions were compared with experimental results as it is shown in Fig. 8. The relatively good agreement of experimental with calculated values were found only at low particle contents. At higher concentration the suspension characteristic can't be used for the impeller speed calculation. The concentrated fine suspensions exhibit non-Newtonian behaviour and the critical point for suspension mixing transfers from vessel bottom to the batch surface. The more research will be needed for mixing of such suspensions.

Conclusions

The results from suspension measurements proved that lower impeller speeds are needed for mixing with impeller of bigger diameter. The difference between speed of smaller and bigger impeller grows with increasing particles size and their concentration in suspension.

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_c – critical agitator speed
α, β – constants in Eq.(4)
γ – exponent in Eq.(2)
ρ – liquid density
$\Delta\rho$ – solid-liquid density difference

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