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MIXING OF SUSPENSIONS IN TALL VESSELS WITH  
A DRAUGHT TUBE

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WYTWARZANIE ZAWIESINY  
W SMUKŁYCH MIESZALNIKACH  
Z RURĄ CYRKULACYJNĄ

**A b s t r a c t**

The paper deals with particle suspension measurements in tall vessel with axial flow agitator in a draught tube. The effect of particle size and content on agitator speed required for particle suspending is reported.

*Keywords: tall vessel, draught tube, suspension, pitched blade turbine*

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

W pracy przedstawiono wyniki badań nad wytwarzaniem suspensji w smukłych mieszalnikach z mieszadłem osiowym w rurze cyrkulacyjnej. Przedstawiono wpływ wielkości cząstek oraz udziału ciała stałego na częstość obrotów niezbędną do wytwarzania zawiesiny.

*Słowa kluczowe: mieszalnik smukły, rura cyrkulacyjna, zawiesina, mieszadło z łopatkami pochylonymi*

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## 1. Introduction

Large tall vessels with a draught tube are used for the mixing of suspensions especially where high homogeneity or heat transfer are desirable. Tall vessels are also advantageous for high pressure. For many years the traditional approach to this situation was to use air lift agitation, commonly known as Pacucha systems [1]. Pacucha systems require high energy input and for this reason air lift was substituted by the axial flow impeller in the upper part of the draught tube. Advantage of this arrangement over standard mixing equipment was established by comparison of the agitator power consumption needed for suspension of solid particles [2, 3]. The aim of this paper was to determine the effect of particle size and content on agitator speed required for particle suspending.

## 2. Theoretical background

The measurements of particle suspending were evaluated according to recommendation derived in [4] as a dimensionless dependence of modified Froude number

$$\text{Fr}' = \frac{n^2 \cdot d_p}{g \cdot \Delta\rho} \quad (1)$$

on the dimensionless particle size  $d_p/D$  and particle volumetric concentration  $c_v$ ,

$$\text{Fr}' = f\left(\frac{d_p}{D}, c_v\right) \quad (2)$$

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

$$\text{Fr}' = A \cdot \left(\frac{d_p}{D}\right)^a \quad (3)$$

The values of coefficients  $A$  and  $a$  depend on particle volumetric concentration. The mathematical description of these dependencies was proposed by Rieger [5] in the form

$$A = A_1 \cdot \exp(A_2 \cdot c_v) \quad (4)$$

$$a = a_1 + a_2 \cdot c_v \quad (5)$$

## 3. Experimental

The experiments were carried out in model mixing equipment with Perspex vessel shown in Fig. 1 with the dimensions presented in Table 1. The water suspensions of five fractions of glass balotine with mean volumetric diameters in the range from 0,15 to 1,28 mm were used in measurements up to mean volumetric content of 40%. The suspension speed  $n_k$  was determined visually by decreasing the agitator speed to the state at

which the solid particles began to settle. The speed of agitator required to initiate suspension  $n_p$  was also determined by increasing the agitator speed to the value at which all particles were suspended. The speed of the agitator was measured photoelectrically.

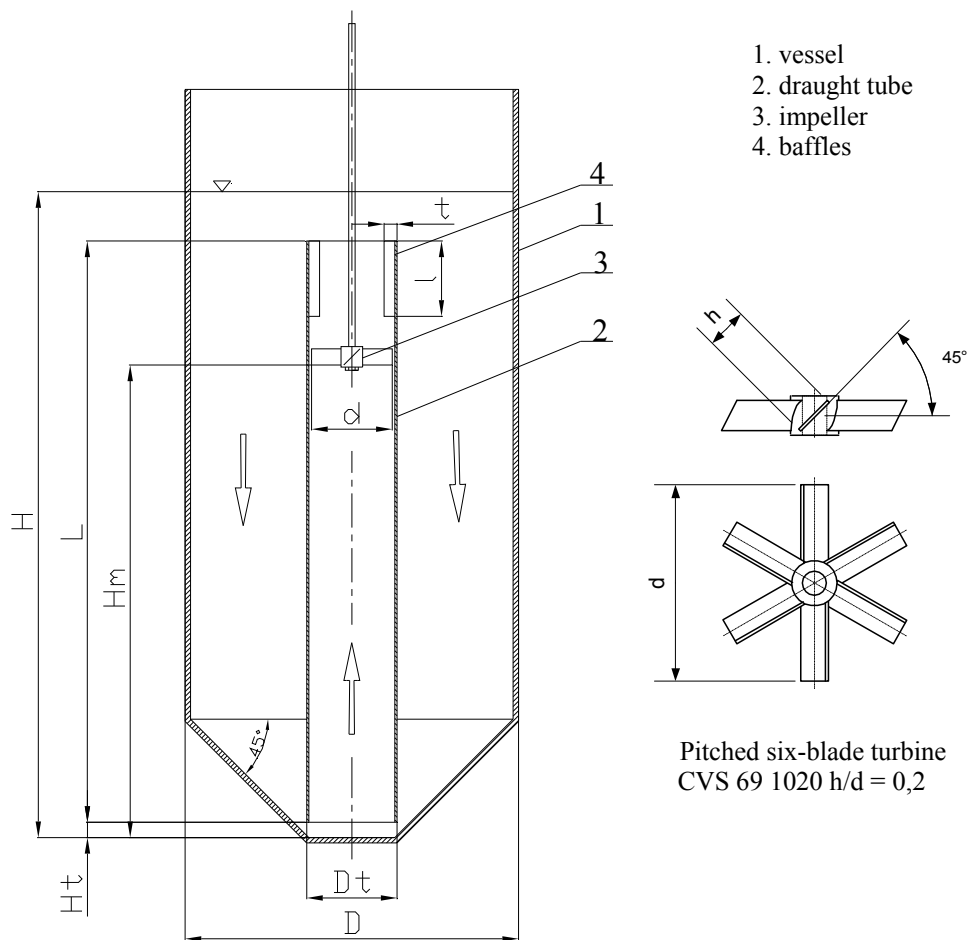


Fig. 1. Vessel with a draught tube

Rys. 1. Mieszalnik z rurą cyrkulacyjną

Table 1

Dimensions of experimental mixing equipment

$D$ [mm]	$D_t$ [mm]	$d$ [mm]	$H$ [mm]	$H_m$ [mm]	$H_t$ [mm]	$t$ [mm]	$L$ [mm]	$l$ [mm]
300	80	65	600	444	14	8	540	54

#### 4. Results

The results of suspension speed measurements are depicted in Fig. 2.

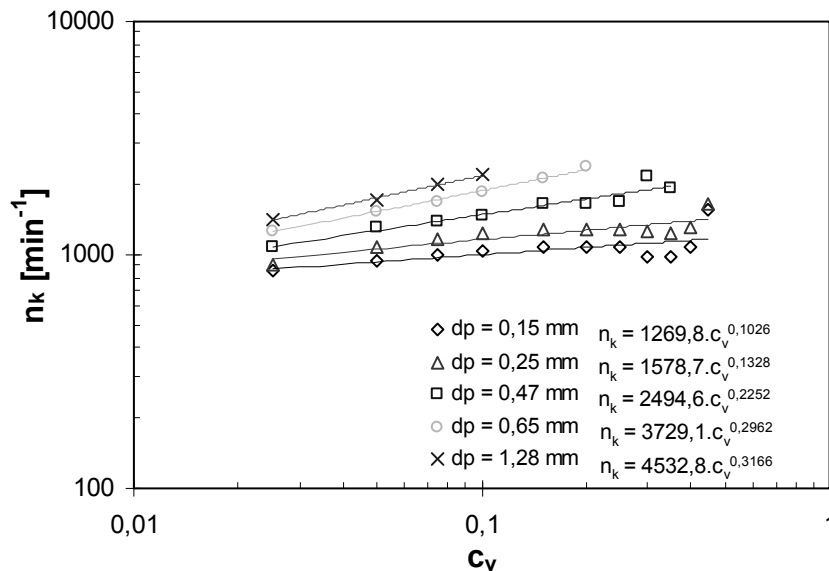


Fig. 2. Dependence of critical speed  $n_k$  on volumetric particle content  $c_v$  and particle diameter  $d_p$

Rys. 2. Zależność prędkości krytycznej  $n_k$  od zawartości objętościowej cząstek  $c_v$  i ich średnicy  $d_p$

The results of agitator speed required to initiate suspension  $n_p$  are shown in Fig. 3. From both figures it can be seen that suspension speed increases with increasing particle size and content.

From the comparison of both speeds presented in Fig. 4 it can be seen that for small particles the speed to initiate suspension are significantly greater than speed necessary to keep particle in suspension. It is caused by more compact sediment of small particles.

For generalization, the experimental results were recalculated to the dimensionless form of the modified Froude number dependence on the relative particle size according to Eq. (2). This dependence for a few selected concentrations is shown in Fig. 5. From this figure it can be seen that the results can be expressed in the power form of Eq. (3).

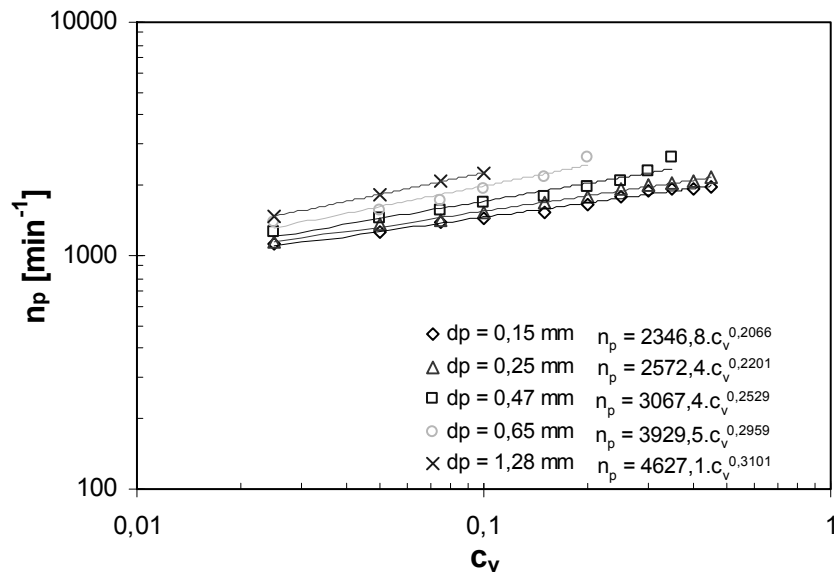


Fig. 3. Dependence of critical speed  $n_p$  on volumetric particle content  $c_v$  and particle diameter  $d_p$

Rys. 3. Zależność prędkości krytycznej  $n_k$  od zawartości objętościowej cząstek  $c_v$  i ich średnicy  $d_p$

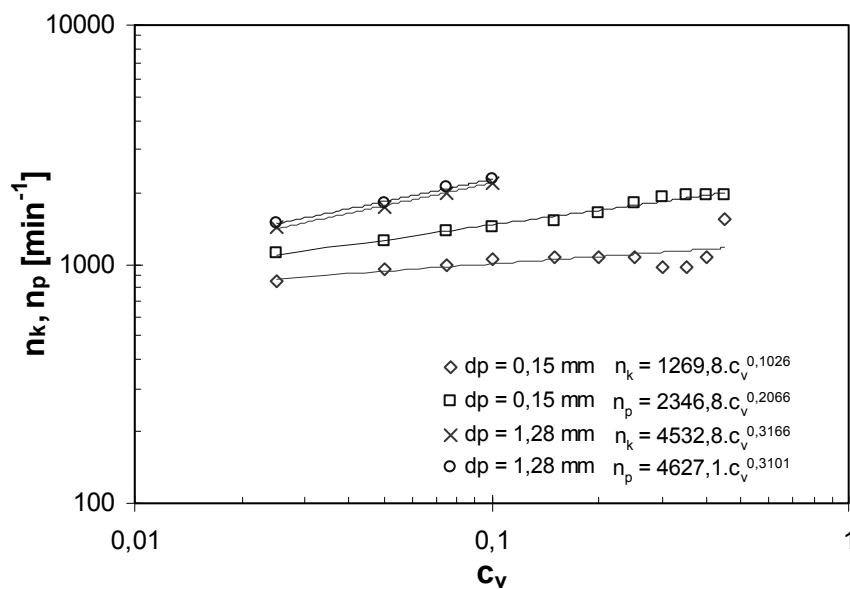


Fig. 4. Comparison of impeller speed  $n_{k,p}$  for particle diameters  $d_p = 1,28; 0,15$  mm

Rys. 4. Porównanie częstości obrotowej mieszadła  $n_{k,p}$  dla średnic cząstek  $d_p = 1,28; 0,15$  mm

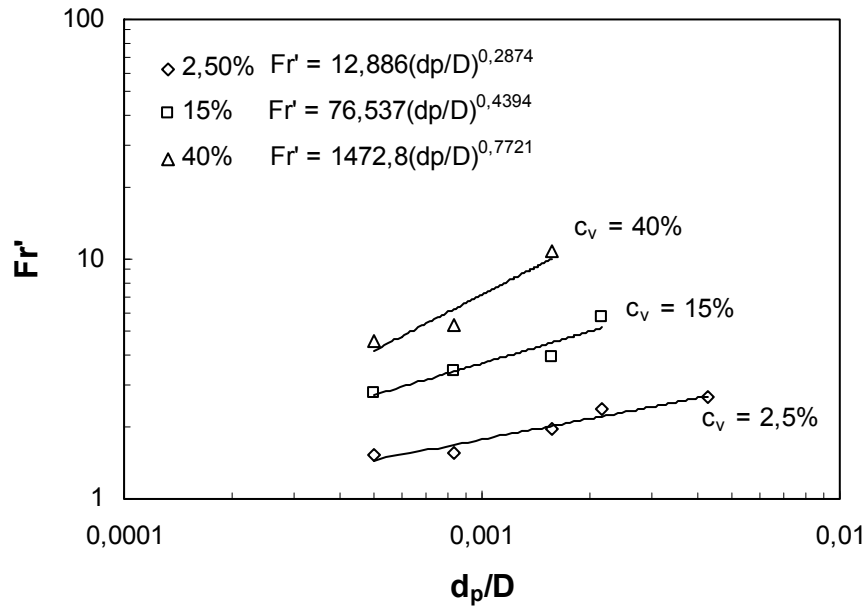


Fig. 5. Dependences of  $Fr'$  on the relative particle size  $d_p/D$  for selected volumetric particle contents  $c_v = 2,5; 15$  and  $40\%$

Rys. 5. Zależność  $Fr'$  od względnej średnicy cząstek  $d_p/D$  dla wybranych zawartości objętościowych  $c_v = 2,5; 15$  i  $40\%$

The dependences of the coefficients of Equation (3) on concentration for both critical and initial agitator speeds were expressed in form of Eqs. (4) and (5) as it is shown in Fig. 6.

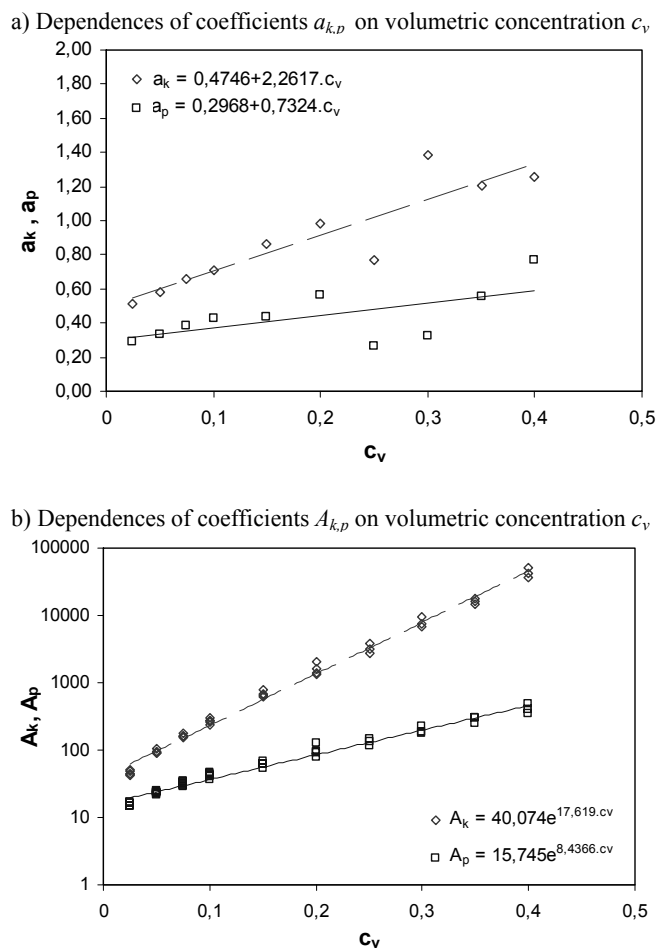


Fig. 6. Dependences of coefficients a)  $a_{k,p}$  and b)  $A_{k,p}$  on volumetric concentration  $c_v$

Rys. 6. Zależność współczynników a)  $a_{k,p}$  i b)  $A_{k,p}$  od zawartości objętościowej  $c_v$

## 5. Conclusions

From the results presented above it follows that the agitator speed required to initiate particle suspending can be calculated from Eq. (3) with coefficients described by the following equations

$$A_p = 15,74 \cdot \exp(8,44c_v) \quad (6)$$

$$a_p = 0,3 + 0,73 \cdot c_v \quad (7)$$

The critical agitator speed necessary to maintain particles in suspension can be also calculated from Eq. (3) with coefficients described by the following equations

$$A_k = 40,07 \cdot \exp(17,62 \cdot c_v) \quad (8)$$

$$a_k = 0,47 + 2,26 \cdot c_v \quad (9)$$

The agitator of industrial mixing equipment must be able not only to maintain particles in suspension but it must be also able to suspend particles after interruption of mixing.

### Symbols

$A_1, A_2$	– constants in Equation (4)	
$c_v$	– mean volumetric concentration of solid phase	
$A$	– coefficient in Equation (3)	
$d$	– impeller diameter	[m]
$d_p$	– mean volumetric particle diameter	[m]
$D$	– vessel diameter	[m]
$Fr'$	– modified Froude number	
$n$	– impeller speed	[1/s]
$a_1, a_2$	– constants in Equation (5)	
$a$	– coefficient in Equation (3)	
$\rho$	– liquid density	[kg/m <sup>3</sup> ]
$\Delta\rho$	– solid – liquid density difference	[kg/m <sup>3</sup> ]

### References

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