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exist for the publication of theoretical and experimental investigations of all aspects of the mechanics and thermodynamics of fluid-flow with special reference to fluid-flow machines

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poświęcone są publikacjom naukowym z zakresu teorii i badań doświadczalnych w dziedzinie mechaniki i termodynamiki przepływów, ze szczególnym uwzględnieniem problematyki maszyn przepływowych

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Generation of non-conventional suspensions in agitated multiphase system[2]

This paper presents the results of experimental study of non-conventional solid-liquid system when density factor is negative. The effect of both the distance between the impeller and the tank bottom, and the solid concentration on minimal value of rotating speed necessary to produce suspension has been estimated. The results for studied stirrers were compared with experimental data for standard Rushton disc turbine.

Nomenclature

d – impeller diameter,
h – distance between impeller and tank bottom,
n – impeller speed,
B – baffle size,
D – tank diameter,
G – mass,
H – liquid level,
ρ – density,
Γ – density factor

Subscripts

1 – first critical value of the impeller speed,
2 – second critical value of the impeller speed,
PET – polyethylene.
L – liquid phase,
S – solid phase,

1. Introduction

Many chemical and biochemical processes involve the dispersion of solid phase in a liquid phase. There are various types of solid-liquid contactors. One of the

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more widespread is the stirred reactor, where solid particles are suspended mechanically by the agitator [6]. In literature the impellers are usually classified according to the flow types in mixer. There are two main types of flow: the radial one, when the impellers used are flat blade paddle or flat blade turbine, and the axial one (propeller, special pitched turbine or pitched blade paddle). The axial flow impellers are recommended for agitation of conventional solid-liquid systems [2] in cases when the density of solid phase ρ_S is greater than the density of liquid phase ρ_L and the density factor Γ:

$$\Gamma = \frac{\rho_S - \rho_L}{\rho_L} \tag{1}$$

has positive values ($\Gamma > 0$). In review paper [1] the various impellers used in a practice have been tabulated. In study [7] the critical review of existing theories for suspension of solid particles and experimental methods used to determine the critical impeller speed required to lift particles from the vessel bottom has been presented.

Generation of suspension significantly depends on the agitator speed. In a cylindrical tank, a deposit of solid particles, when the particle density is greater than the liquid phase density, is observed on its bottom when the agitator speed is low. The solid phase is effectively suspended with increasing the agitation rate. Finally, the suspension reaches an optimum at higher agitator speeds. Two idealized states are defined when referring to the conventional suspension of particles in an agitated tank, namely: the complete suspension, where which no particle remains on the tank base for longer than a given period of time (e.g. 1 s), and the homogeneous suspension, where the particle concentration and size distribution are uniform throughout the vessel [6].

In modern technologies, particulary in environment protection and biotechnology, situations are met when the density of solid phase is lower than liquid density, therefore the density factor (1) is negative ($\Gamma < 0$) and a deposition of solid particles is observed in upper part of the vessel near the gas/liquid/solid interface. This type of two-phase solid-liquid systems can be called as a non-conventional or "light" suspension [8, 9]. The practical example of the light solid-liquid suspension is a graphite – liquid aluminium composite used in founding industry [4, 5]. Uniform suspension of solid particles in liquid is the main problem of mechanical agitation in both conventional and non-conventional solid-liquid systems. Three fundamental stages of the solid-liquid system observed in stirred reactors are schematically presented in Fig. 1. In the first case ($\Gamma > 0$) a deposit of solid particles is observed at the bottom of the tank when the agitator speed is low. In the second case ($\Gamma < 0$), the solid phase can be found on liquid surface at similar conditions. In both cases, the impeller speed n is lower than the first critical value n_1. Solid and liquid phases are separate. Solid particles are effectively suspended increasing the agitation rate, when $n_1 < n < n_2$.

Finally, the suspension generation reaches an optimum at higher agitator speeds. The critical impeller speed n_2, at which all the solid particles are fluidized, is important as a basis for determination of agitation intensity in both conventional and non-conventional solid-liquid systems. Herewith the way in which the suspension is formed depends significantly on the pumping capacity of the impeller used.

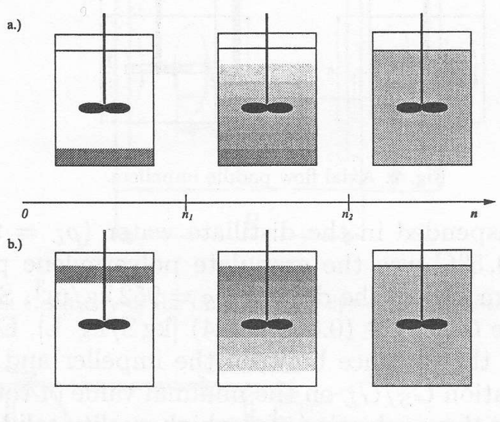

Fig. 1. Production of the solid-liquid suspension as a function of the impeller speed: a) conventional suspension, $\Gamma > 0$; b) non-conventional suspension, $\Gamma < 0$.

This important parameter varies with both the size and the construction of an impeller. However, the constructional solutions are limited. In some special cases they have to take into account particular conditions to be fulfilled for practical situations. Many types of mechanical agitators are used. One of the more important is the Rushton disc turbine. Disc turbine type impeller is often modified. Some types of those agitators (six-blade disc turbine), viz. with ring stabilizer, inclined blade, divided blade or curved, scaba blade correspond to the standard Rushton disc turbine geometry. In this paper the results of experimental modelling study performed for non-conventional solid-liquid system are presented.

2. Experimental setup and procedure

The experimental study was performed for two types of pitched paddle impellers shown in Fig. 2. Both investigated stirrers: pumping up (Fig. 2a) and pumping down (Fig. 2b) were of identical standard geometry ($D/d = 3$), but various construction – their blades were differently inclined 45^o up and down, respectively, at the shaft working in the vessel. The experimental study using the above mentioned impellers as well as the standard Rushton disc turbine (Fig. 3) was carried out in a cylindrical tank of diameter $D = 0.300$ m, at different distance between the impeller and a tank bottom: $h/H = 1/3; 1/2; 2/3$. Four standard baffles ($B/D = 0.1$) were mounted into the tank with flat bottom. The universal installation for experimental studies of mixing usable for both: gas-liquid and solid-liquid systems is presented in Fig. 4.

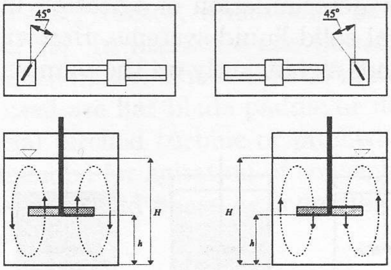

Fig. 2. Axial flow paddle impellers.

The solid phase suspended in the distillate water ($\rho_L = 998\,\mathrm{kg/m^3}$) at the temperature of $20 \pm 0,5^oC$ was the granulate polyethylene particles (PET) of diameter $d_S = 0.0042$ m and of the density $\rho_S = 952\,\mathrm{kg/m^3}$. Solid concentration was varied in the range $G_S/G_L \in (0.006; 0.424)$ [kg S/kg L]. Estimated has been the effect of the both: the distance between the impeller and a tank bottom h, and the solid concentration G_S/G_L on the minimal value of rotating speed of the impeller n necessary for the production of the high quality solid-liquid suspension.

3. Results of measurements

The critical values of the impeller speed obtained experimentally for both types of pitched paddle impellers as a function of the solid concentration at constant distance between impeller and tank bottom are presented in Table 1. The effect of the solid concentration at a constant distance between the impeller and a tank bottom on the critical values of impeller's speed for both pumping up and down stirrers are presented in Fig. 5 and Fig. 6, respectively.

The experimental data for pitched paddle impeller – pumping down (Fig. 5) show that the critical impeller speed increases whith increasing solid concentration, but the distance between the stirrer and a tank bottom is insignificant. Lines plotted in Fig. 5 represent the trends of all experimental points obtained in this case. The trend lines are described by the correlation relations as follows:

$$n = 16.2 \left(\frac{G_S}{G_L}\right)^{0.08} \quad \text{for} \quad \frac{G_S}{G_L} \in (0.0024; 0.0183) \tag{2}$$

and

$$n = 51.7 \left(\frac{G_S}{G_L}\right)^{0.37} \quad \text{for} \quad \frac{G_S}{G_L} \in (0.0183; 0.0945). \tag{3}$$

Influence of the solid concentration is very similar when suspension production is realised by pitched paddle impeller – pumping up (Fig. 6). However critical impeller speed decreases when the distance between the impeller and a tank bottom increases. In Tab. 2 values of constants and exponents of correlation

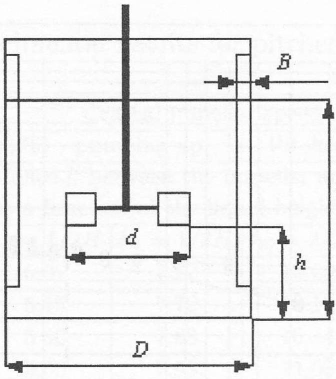

Fig. 3. Geometry of the tank-impeller system for Rushton turbine.

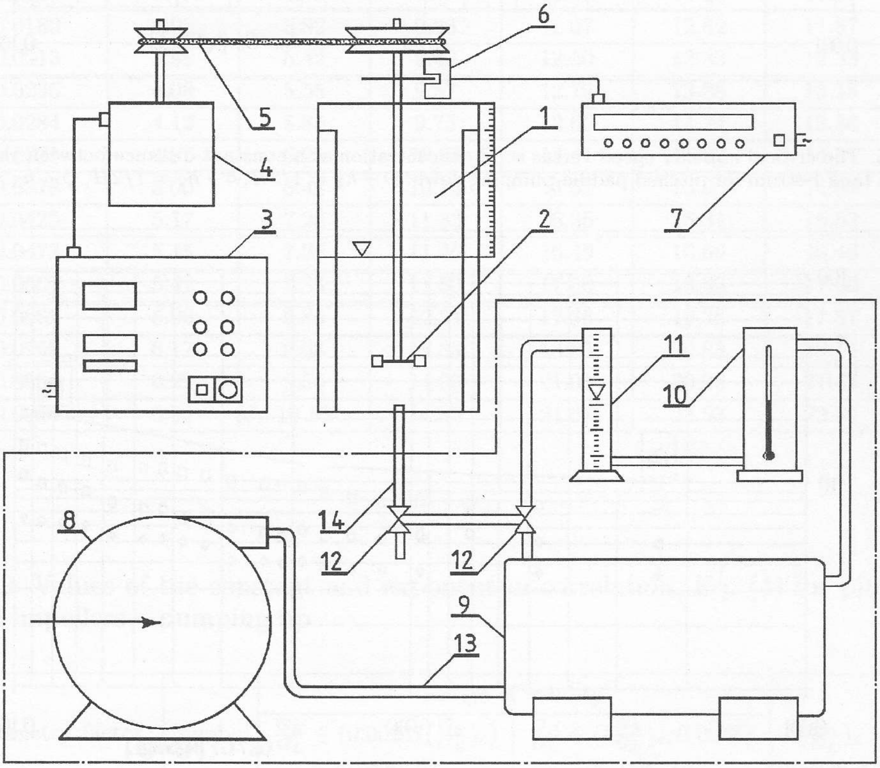

Fig. 4. Experimental installation (system encompassed by the dot-dash line shows part of the installation usuable for gas-liquid systems only). 1 – tank; 2 – impeller; 3 – MIN-102 system; 4 – motor PZB-b; 5 – belt; 6 – photo-cell; 7 – mechanical measure system; 8 – compressor; 9 – tank of gas; 10 – thermometer; 11 – rotameter; 12 – valve; 13 – gas tube; 14 – gas inlet.

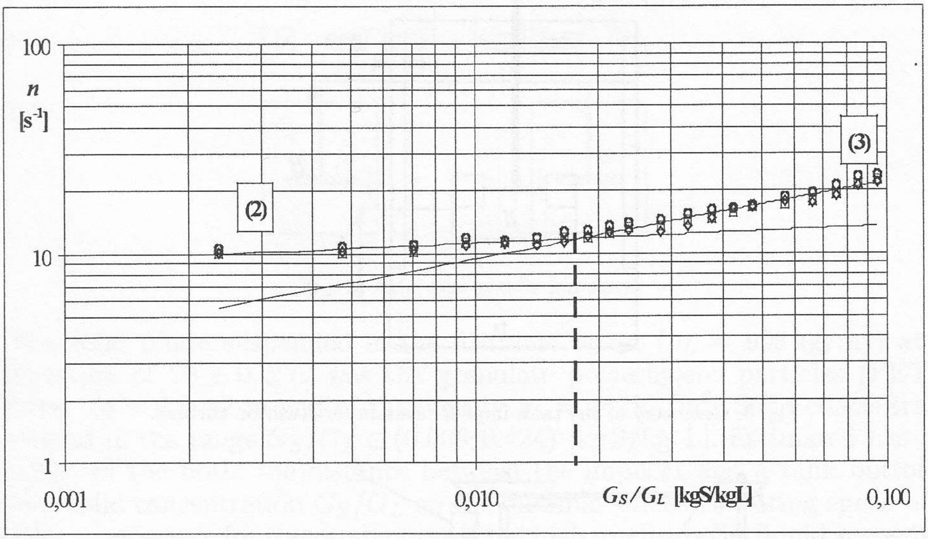

Fig. 5. The critical impeller speed versus solid concentration at a constant distance between the stirrer and a tank bottom for pitched paddle-pumping down. □ – $h_1 = 1/3H$, ○ – $h_2 = 1/2H$, ◇ – $h_3 = 2/3H$.

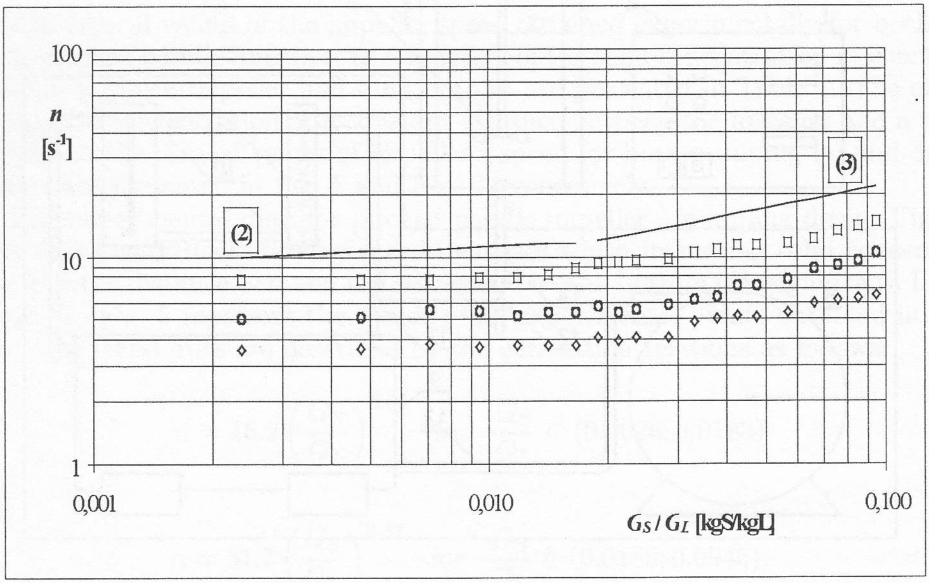

Fig. 6. The critical impeller speed versus solid concentration at a constant distance between the stirrer and a tank bottom for pitched paddle-pumping up. □ – $h_1 = 1/3H$, ○ – $h_2 = 1/2H$, ◇ – $h_3 = 2/3H$.

Table 1. The experimental results for pitched paddle impellers

Solid concentration G_S/G_L	Critical impeller speed n [s^{-1}]					
	Pitched paddle – pumping up			Pitched paddle – pumping down		
	Distance h between the impeller and a tank bottom as a function of the liquid height H in the tank					
[kg S/kg L]	$h_3 = 2/3H$	$h_2 = 1/2H$	$h_1 = 1/3H$	$h_3 = 2/3H$	$h_2 = 1/2H$	$h_1 = 1/3H$
0.0024	3.58	5.07	7.72	10.09	10.52	10.08
0.0047	3.61	5.15	7.72	10.19	10.77	10.11
0.0071	3.79	5.56	7.83	10.34	10.93	10.18
0.0095	3.69	5.50	7.98	11.00	11.76	11.24
0.0118	3.73	5.24	7.98	11.12	11.44	11.28
0.0142	3.73	5.43	8.20	10.97	11.75	11.73
0.0165	3.75	5.42	8.75	11.27	12.66	11.91
0.0189	4.05	5.82	9.28	12.07	12.82	11.87
0.0213	3.98	5.42	9.40	12.50	13.33	12.33
0.0236	4.08	5.55	9.57	12.79	13.88	13.18
0.0284	4.12	5.85	9.75	12.60	14.24	13.38
0.0331	4.87	6.25	10.51	13.41	15.22	14.34
0.0378	5.00	6.48	10.73	14.52	15.95	14.57
0.0425	5.17	7.28	11.33	16.35	16.31	15.52
0.0473	5.15	7.25	11.46	16.49	16.66	16.46
0.0567	5.42	7.83	11.50	17.50	18.33	17.00
0.0662	5.96	8.85	12.31	17.36	19.36	17.57
0.0756	6.17	9.08	13.33	18.83	20.83	19.17
0.0851	6.29	9.56	14.05	21.01	22.96	21.41
0.0945	6.50	10.50	14.83	21.67	23.33	22.50

Table 2. Values of the constant and exponent in correlation, Eq. (4) for pitched paddle impellers – pumping up

Geometry factor	Symbol	Range of validity				$(\frac{G_S}{G_L})_c$ [kgS/kgL]
		$\frac{G_S}{G_L} \in (0.0024; (\frac{G_S}{G_L})_c)$ [kgS/kgL]		$\frac{G_S}{G_L} \in ((\frac{G_S}{G_L})_c; 0.0945)$ [kgS/kgL]		
		C	A	C	A	
$h_1 = 1/3H$		10.22	0.050	27.4	0.28	0.0137
$h_2 = 1/2H$	○	6.29	0.034	25.8	0.41	0.0234
$h_3 = 2/3H$	◇	4.13	0.023	14.1	0.33	0.0183

relationship:

$$n = C \cdot (\frac{G_S}{G_L})^A \tag{4}$$

have been presented. The impeller speed has minimal values when the impeller is working near the liquid surface. In the case of this type of the axial flow paddle impeller the distance $h/H = 2/3$ is recommended for suspension production. Critical values of the impeller speed in this case were compared with previous data [2], obtained for standard Rushton disc turbine (Fig. 7). The selected points for standard Rushton disc turbine are presented in Table 3.

Table 3. The experimental data for standard Rushton disc turbine ($D = 0.300$ m)

Solid concentration G_S/G_L [kgS/kgL]	Distance between the impeller and a tank bottom		
	$h_1 = 2/3H$	$h_2 = 1/2H$	$h_3 = 1/3H$
0.0047	3.50	3.92	4.42
0.0095	3.67	4.17	4.79
0.0142	3.83	4.25	4.91
0.0189	4.08	4.42	5.17
0.0236	4.17	4.50	5.30
0.0284	4.25	4.80	5,36
0.0331	4.42	4.90	5.73
0.0378	4.58	5.08	6.03
0.0425	4.75	5.24	6.23
0.0473	4.92	5.28	6.31
0.0520	5.00	5.47	6.75
0.0567	5.17	5.57	7.15
0.0614	5.25	6.12	7.35
0.0662	5.33	6.16	7.24
0.0709	5.50	6.31	7.48

4. Conclusions

The studies on the production of solid-liquid suspension in the case of the system with the negative value of density modulus have been carried out.

Experimentally estimated has been the effect of the both distance between

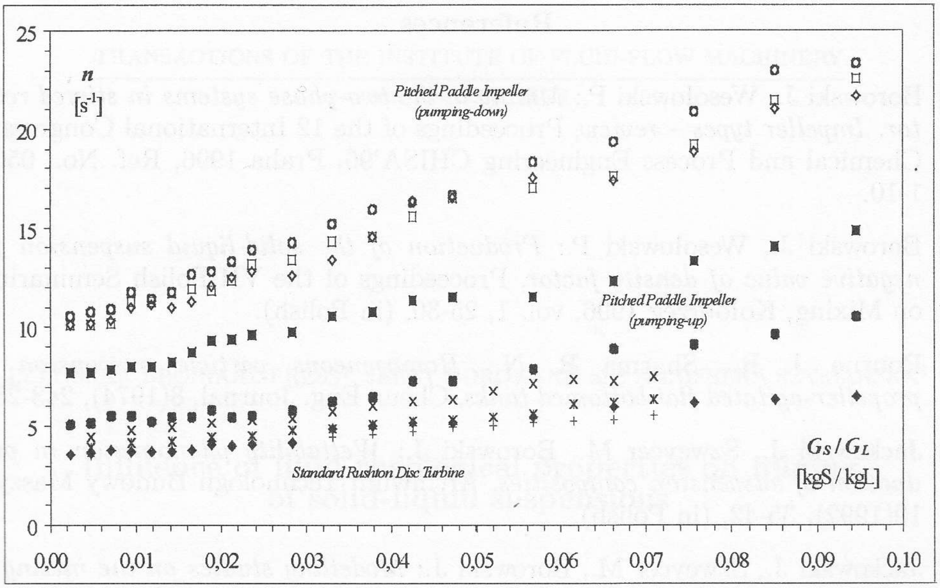

Fig. 7. The critical impeller speed versus solid concentration at various distance between the stirrer and a tank bottom for standard Rushton disc turbine and pitched paddle impellers:

Impeller	$h_1 = 1/3H$	$h_2 = 1/2H$	$h_3 = 2/3H$
pitched paddle, pumping-down	□	○	◊
pitched paddle, pumping-up	■	●	♦
Rushton disc turbine	×	*	+

the impeller and a tank bottom as well as concentration of solid on the minimal value of rotating speed.

The numerical results for minimal rotation speed of the paddle impeller pumping up were comparable with these obtained for standard Rushton disc turbine. Thus taking into account the similar construction, in comparison with the Rushton turbine, the paddle stirrer with two blades pumping up for problem solution should be preferred.

The investigations of the "light" suspension agitation will be continued. At the present stage of investigations, it is too early to attemp a more detailed analysis of the phenomenon.

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Wytwarzanie niekonwencjonalnych zawiesin w mieszalniku w układach wielofazowych

Streszczenie

W pracy przedstawiono wyniki badań eksperymentalnych dla układów ciecz – ciało stałe, dla których moduł gęstości jest ujemny. Określono wpływ odległości mieszadła od dna zbiornika oraz stężenia fazy stałej na minimalną liczbę obrotów niezbędną do wytworzenia zawiesiny. Wartości liczbowe minimalnej liczby obrotów uzyskane dla mieszadła łapowego pompującego w górę okazały się porównywalnymi z otrzymanymi dla standardowego mieszadła dyskowego turbinowego Rushtona. Biorąc pod uwagę podobieństwo konstrukcji do realizacji analizowanego układu należy rekomendować mieszadło łapowe pompujące w górę.