NON-CONVENTIONAL SOLID - LIQUID SUSPENSION GENERATION IN A MIXER

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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 more widespread is the stirred reactor, in which the solid particles are suspended mechanically by agitator[1]. In literature the impellers are usually classified according to 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] 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 praxis 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. The generation of the suspension significantly depends on the agitator speed. In cylindrical tank, a deposit of solid particles, when the particle density is greater than 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: complete suspension, in which no particle remains on the tank base for longer than a given period (e.g. 1 s), and homogeneous suspension, in which the particle concentration and size distribution are uniform throughout the vessel[6]. In modern technologies, environment protection and biotechnology the situations are met when the density of solid phase is lower than liquid density, therefore density factor (1) is negative ($\Gamma < 0$) and a deposit 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 on the tank bottom when the agitator speed is low (Fig. 1, Pict. a-1). In the second case ($\Gamma < 0$) the solid phase is watched on liquid surface at the similar conditions (Fig. 1, Pict. b-1). In both cases the impeller speed n is lower of some first critical value n_1. Solid and liquid phases are separate. Solid particles are effectively suspended increasing the agitation rate (Fig. 1, Pict. a,b-2), when $n_1 < n < n_2$. Finally, the suspension generation reaches an optimum at higher agitator speeds (Fig. 1, Pict. a,b-3). The critical impeller speed n_2 at which all the solid particles are fluidized is important as a basis of agitation intensity determination in both conventional and non-conventional solid-liquid systems. Herewith the suspension forming depends meaningly on the pumping capacity for the impeller used. This important parameter varies with both: the size and the construction of an impeller. However, the constructional solutions are limited in special cases taking into account the particular conditions to be fulfilled for practical situations. Many types of mechanical agitator are used. One of the more important of them 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.

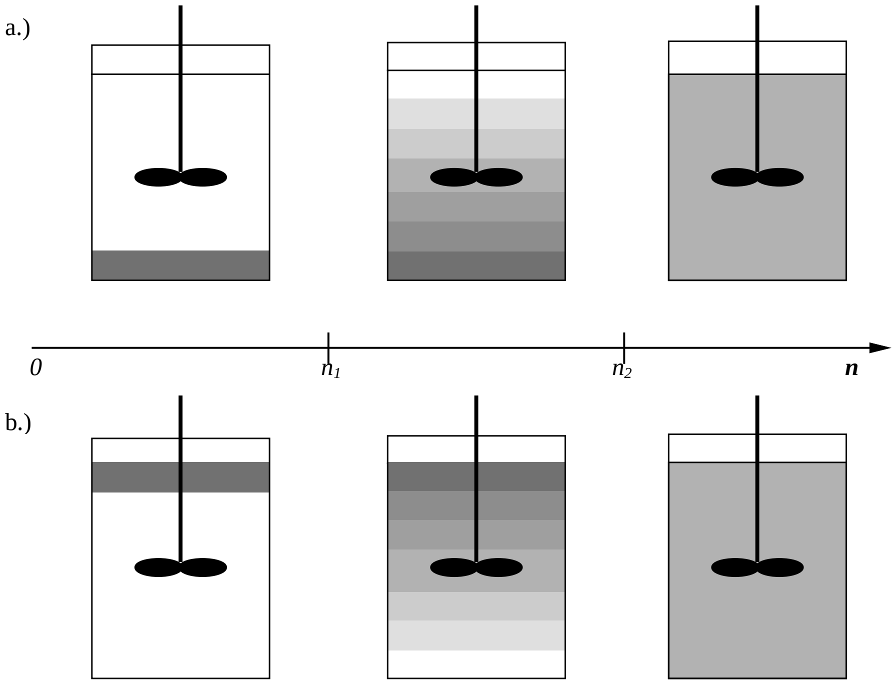

Fig. 1. Production of the solid-liquid suspension as a function of the impeller speed:
a.) conventional suspension, $\Gamma > 0$; b.) non-conventional suspension, $\Gamma < 0$

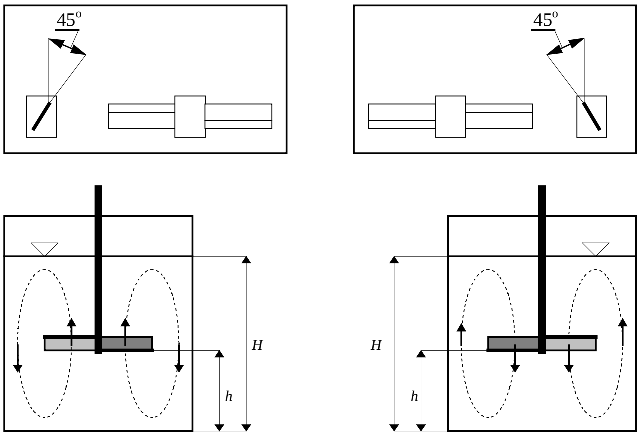

Fig. 2. Axial flow paddle impellers.

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° up and down, respectively, at the shaft working in the vessel. The experimental study using the above mentioned impellers as well as standard Rushton disc turbine was carried out in cylindrical tank of diameter D = 0.300m, at different distance between impeller and 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 solid phase suspended in the distillate water (ρ_L = 998 kg/m^3) at the temperature of 20 ± 0,5 °C was the granulate polyethylene particles (PET) of diameter d_S = 0.0042 m and of density ρ_S = 952 kg/m^3. Solid concentration was varied in the range $G_S/G_L \in (0.006;0.424)$ [kg S/kg L]. The effect of the both: the distance between impeller and 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 has been estimated.

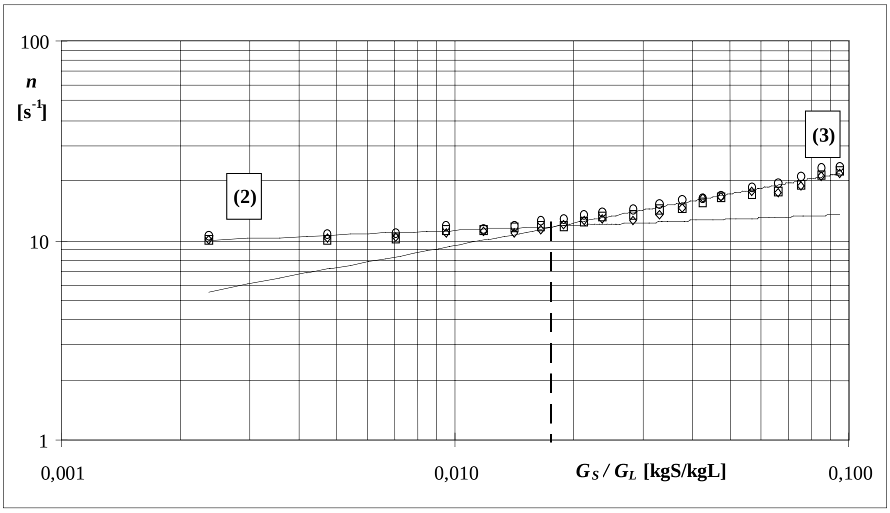

Fig. 3. The critical impeller speed versus solid concentration at constant distance between stirrer and tank bottom for pitched paddle - pumping down: o - h_1 = 1/3 H; m - h_2 = 1/2 H; ◊ - h_3 = 2/3 H.

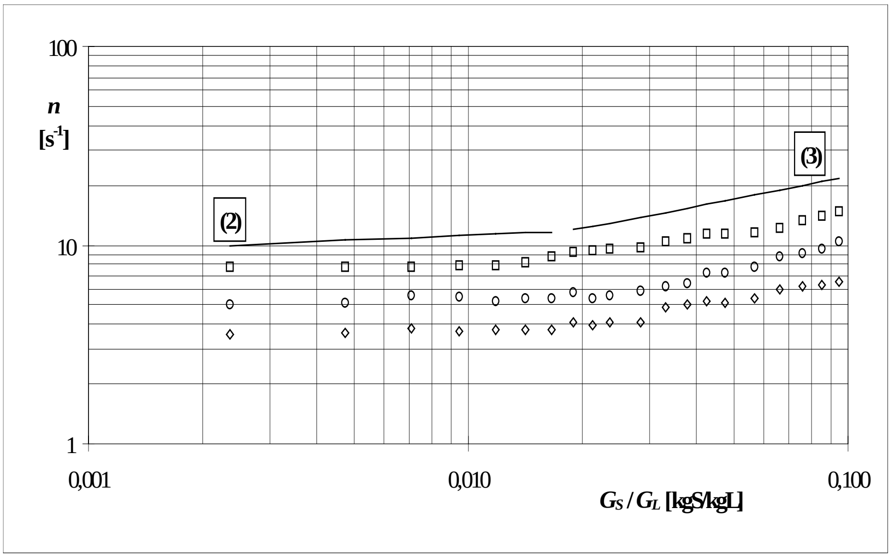

Fig. 4. The critical impeller speed versus solid concentration at constant distance between stirrer and tank bottom for pitched paddle - pumping up:o - h_1 = 1/3 H; m - h_2 = 1/2 H; ◊ - h_3 = 2/3 H

The effects of solid concentration at constant distance between impeller and tank bottom on the critical values of impellers speed for both pumping up and down stirrers are presented in Fig. 3 and Fig. 4, respectively. The experimental data for pitched paddle impeller - pumping down (Fig. 3) shows that the critical impeller speed increases when solid concentration increases but distance between stirrer and tank bottom is insignificant. Lines plotted in Fig. 3 represent the trends of the all experimental points obtained in this case. The trend lines describe the correlation relations as follows:

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

and

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

Influence of solid concentration is very similar when suspension production is realised by pitched paddle impeller - pumping up (Fig. 4). However critical impeller speed decreases when the distance between impeller and tank bottom increases.

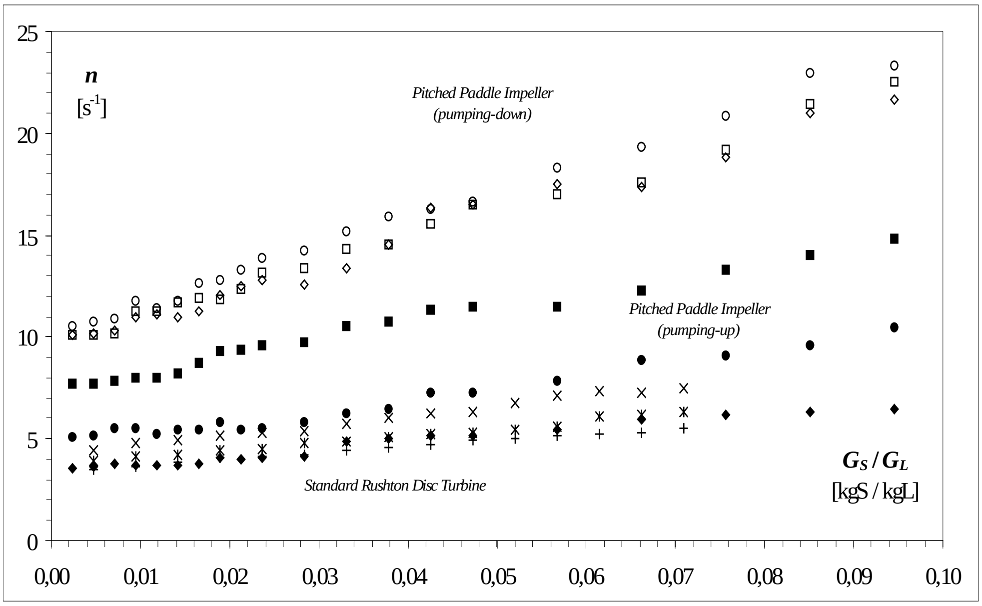

Fig. 5. The critical impeller speed versus solid concentration at various distance between stirrer and tank bottom for standard Rushton disc turbine and pitched paddle impellers:

Impeller	$h_1 = 1/3\ H$	$h_2 = 1/2\ H$	$h_3 = 2/3\ H$
pitched paddle, pumping - down	o	m	◊
pitched paddle, pumping - up	n	l	t
Rushton disc turbine	x	*	+

In Table 1 the values of constant and exponent of correlation relationship:

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

has been presented. The impeller speed has minimal values when the impeller working near liquid surface. The distance *h/H* = 2/3 is recommended for suspension production by this type of the axial flow paddle impeller. In this case the critical values of the impeller speed were compared with previous data[2] obtained for standard Rushton disc turbine (Fig. 5).

Table 1. The correlation values of the constant and exponent of Eq. (4) for pitched paddle impellers - pumping up.

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

The numerical results for minimal rotation speed for 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 should be preferred.

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