RHEOLOGICAL PROPERTIES OF A LIQUID EFFECT ON SUSPENSION AGITATION

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Fluid mixing is of central importance in many production systems in chemical and process industries, and solid suspending is probably the most common mixing operation. The stirrer applied has to prevent the particles from settling at the bottom of the vessel[1]. A very important state for the designing of mixing apparatuses is the state of full particle suspension, at which no particle remains in contact with the vessel bottom for larger than a certain period, e.g. 1 s. Considerable attention has been paid to determining the critical impeller speed required to reach this state. The paper[2] contains the critical review of existing theories and experimental methods used to determine the critical speed required to lift particles from the vessel bottom. The Newtonian suspension theories can be divided into seven groups:

1° based on the balance between the energy dissipated by the settling particles and the energy dissipated in the fluid by the agitator[3-4];
2° based on the presumption that the energy needed to suspend the particle from the bottom is proportional to that of turbulent vortices[5];
3° based on a balance between the upward fluid velocity and the particle's settling velocity[6-8];
4° concerning on the balance between the force of a fluid affecting the particles and the gravity force reduced in buoyancy (for fine particles, $Ar < 40$)[9];
5° based on the presumption that the agitator must overcome the pressure difference caused by the differences in particle concentrations in upward and downward flow (for large particles, $Ar > 40$)[10-11];
6° concerning on the balance between the potential energy necessary to achieve suspension and the kinetic energy of fluid flow being discharged from the agitator[7];
7° based on the assumption of proportionality of kinetic energy of turbulent eddies and potential energy gained by the particles - the arising of suspension is due to turbulent eddies whose sizes are comparable with particle diameters and energy transferred to the particles from these eddies lifting them off the base[12].

Resulted from above theories proportions between the impeller speed required for particle suspension and other variables can been described as follows:

$$n_o \sim (\Delta\rho)^a \cdot \rho_l^b \cdot \eta_l^c \cdot d_p^e \cdot D^f \tag{1}$$

The experimental methods of determining suspension speed can be divided into two groups: direct and indirect measurements. The direct methods are visual, contact, radiation and based on observing the interface between sediment and transparent liquid[2]. The visual direct method for determining the critical impeller speed was firstly used by Zwietering[13]. The method is based on continuous measuring of the relationship between the height or radius of nonsuspended particle layer and the agitator speed. The other direct methods are useful in industrial vessels where visual methods cannot be applied[2]. There are various types of solid - Newtonian liquid suspension forming which are reviewed[14-16]. A number of fluids in common industrial use show highly non-Newtonian behaviour. In biotechnological processes liquids have pronounced even viscoelastic properties[17]. In available literature the studies on fundamental nature of the factors which affect the performance of

agitation equipment for the suspension of solid particles in non-Newtonian liquids have not yet been found. The purpose of this study is to determine the suspension speed for power-law liquids.
The measurements were carried out in flat-bottom plexi-glass vessel with inside diameter of D = 0.225 m with four baffles of width b = 0.1D. The tested agitator was standard Rushton turbine of diameter d = 0.075 m with six blades. The impeller was placed centrically in the axis of the tank. The ratio of vessel diameter to agitator diameter was D/d = 3 and ratios of h/d were equal to 1 and 3/2. The solid phase was made up of high-silica sand particles with the denisty of ρ = 2549 [kg/m^3] and mean diameter of d_p = 0.008-0.0010 m. The Newtonian liquid was water with viscosity of η = 10^{-3} [Pa.s] and density of ρ = 998 [kg/m^3]. The power-law fluids were aqueous CMC solutions and the CMC solutions with NaCl additives of various concentrations. The concentration of CMC in water was equal to $u_{CMC} \in (0.003;0.015)$ [kg CMC/kg]. The high-molecular CMC aqueous solutions as Tomsian fluids can undergo a mechanical degradation. In the experiments the mass ratio of particles to liquid were equal to U_{NaCl} = 0.010; 0.041; 0.076; 0.120 and 0.150 [kg NaCl/kg l]. In the present report the effect of sodium chloride on critical speed was studied for the CMC/water solution with concentration of u_{CMC} = 0.006 [kg CMC/kg]. Additionally the effect of NaCl concentration on consistency index has been evaluated. The preliminary measurements performed in water showed that the critical agitator speed obtained for h/d = 1 is lower than this one for h/d = 3/2. This regularity for all studied systems has been observed.

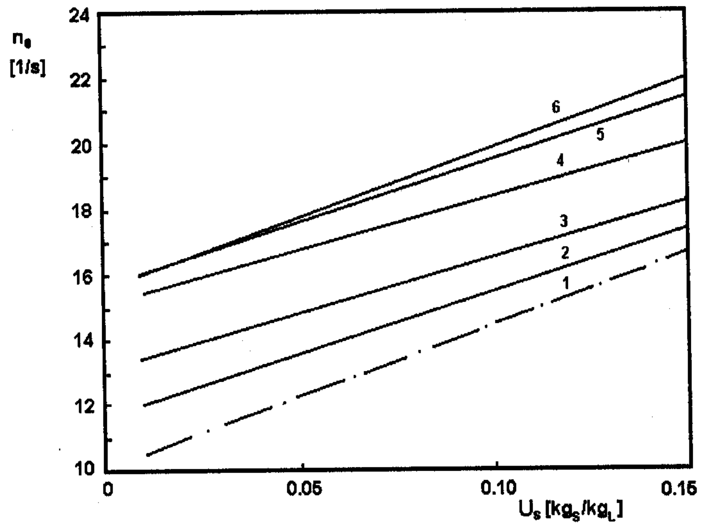

Fig. 1. Effect of concentration of CMC aqueous solutions on critical agitator speed:
1 - water; 2 - u_{CMC} = 0.003; 3 - u_{CMC} = 0.006; 4 - u_{CMC} = 0.009; 5 - u_{CMC} = 0.012;
6 - u_{CMC} = 0.015.

Thus the experimental data in fundamental part of the study for h/d = 1 have been analyzed. The function of the impeller speed required for particle suspension depending on CMC solution concentration u_{CMC} and solid mass ratio to liquid in a suspension U_s (Fig. 1) showed that the critical value of n_o increases with the both concentrations.The exemplary relationships $n_o = f(U_s, u_{NaCl})$ are presented in Fig. 2. Addition of the sodium chloride to CMC solution causes the decrease of the impeller speed required for suspension. This phenomenon can be explained by the electrolytic effect on the apparent viscosity values for aqueous solutions. The following phenomena have been observed, additionally. The holding in suspension in CMC solutions is more easy than in clear water. The pulling off the particles from the vessel bottom was more difficult because the settling velocity of the particles increases with the increase of shear-thinning properties of a liquid. The addition of the sodium chloride stabilized both the CMC solution and the suspension properties.

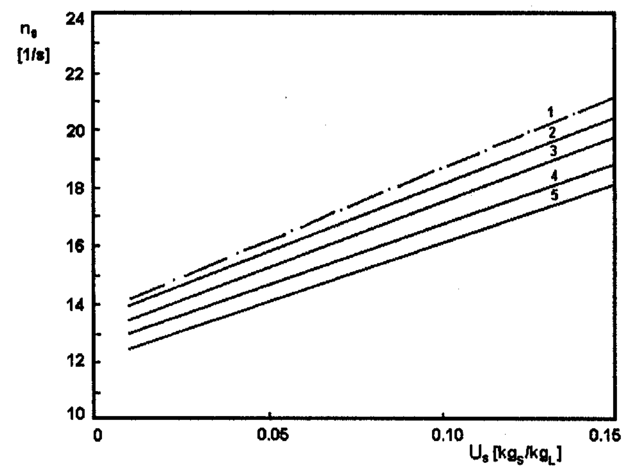

Fig. 2. Effect of concentration of NaCl on critical agitator speed for CMC/water solution of mass fraction u_{CMC} = 0.006 [kg CMC/kg]:
1 - u_{NaCl} = 0; 2 - u_{NaCl} = 0.03; 3 - u_{NaCl} = 0.06; 4 - u_{NaCl} = 0.15; 5 - u_{NaCl} = 0.18 [kg NaCl/kg].

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