EFFECT OF SIZE OF SPHERICAL PARTICLE ON COMPLETE SUSPENSION SPEED IN AGITATED VESSELS OF DIFFERENT SCALE

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Introduction

The making of solid suspensions in agitated vessels is common to many operations in the process industries, such as crystallization, hydrogenation, leaching and coal liquefaction. The main purposes of such suspensions are solid-liquid mass transfer and chemical reaction. In such operations, knowledge of the impeller speed at which particulate solids just become completely suspended is important to achieving the maximum surface area available. Many investigators have proposed correlations for the complete suspension speed^{1, 2, 3, 7)}. Generally, all are different but the correlation of Zwietering⁷⁾ covers the widest range of variables and is therefore recommended by several workers^{2, 3)}. However, experimental results which show no effect of particle size on complete suspension speed were reported recently for larger particles^{5, 6)}.

Thus the main aim of the work reported in this paper is to verify the effect of particle size on the complete suspension speed.

1. Experimental

A six-bladed Rushton disc turbine impeller was

adopted since the making of solid suspensions by such impeller has been studied extensively. Open-topped 0.100, 0.144, 0.200, 0.290, and 0.580 m diameter cylindrical vessels with four baffles having a width of one-tenth of the vessel diameter were used. The liquid height was equal to the vessel diameter and the impeller-to-vessel diameter ratio was 0.5. The clearance of the impeller above the bottom of the vessel was chosen as 25% of the vessel diameter.

Table 1 presents details of the spherical particles used in this work. Polystyrene, soda glass ballotini and alumina particles of spherical shape were sieved closely and their surface-to-volume mean diameter were determined photographically. It was found that the existence of distorted particles increased the complete suspension speed by about 10% in a preliminary experiment. The distorted particles were therefore removed and nearly perfect spherical particles were used for the experiments.

Deionized water was used in most experiments. Chloroform was also used, in investigating the effect of kinematic viscosity.

The complete suspension speed, N_{JS} , was taken as the speed at which no particle is visually observed to

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Table 1. Properties of spherical particles

Particle	d_p [μm]	mesh range	ρ [kg m^{-3}]
Polystyrene	292	48-60	1049
	377	35-42	
	565	28-32	
	894	16-20	
	2127	8-9	
	2539	7-8	
Soda glass ballotini	54	250-270	2400
	134	100-120	
	209	65-80	
	336	40-45	
	376	35-42	
	1380	12-14	
	2280	8-9	
	2860	7-8	
	3965	5-6	
	4920	3 $\frac{1}{2}$ -4	
Alumina	996	16-20	3720
	1940	9-10	

remain at rest on the tank base for more than one or two seconds⁷). As indicated by Nienow⁴), between 3 to 5% reproducibility can be achieved.

2. Results and Discussion

The work of Zwietering in 1958⁷) still represents the most complete investigation of N_{JS} . He analyzed the results using dimensional analysis to yield a purely empirical expression for N_{JS} .

$$N_{JS} = S v^{0.1} d_p^{0.2} (g \Delta \rho / \rho_L)^{0.45} X^{0.13} D^{-0.85} \quad (1)$$

The exponents of v , d_p , $(g \Delta \rho / \rho_L)$ and X were found to be independent of impeller type, vessel size and system configuration. S is the dimensionless constant accounting for these variations in system geometry. From the graph of S against T/D with T/C for disc turbine given by Nienow³), the value of S for the systems used in this work was given as 4.2. The calculated values of N_{JS} from the correlation developed by Zwietering were more than twice as large as the experimental ones.

By a multiple nonlinear regression using all experimental data obtained in this work, the values of the exponents and the constant S were determined again. As a result, the following correlation was obtained.

$$N_{JS} = 2.0 v^{0.10} d_p^{0.023} (g \Delta \rho / \rho_L)^{0.34} X^{0.22} D^{-0.54} \quad (2)$$

The number of data correlated was 390. The average deviation is 0.297s^{-1} . The agreement is not satisfactory, especially for larger particles.

Recently, several investigators^{5, 6}) reported that the complete suspension speed for larger particles is independent of particle size. Therefore, the effect of particle size on complete suspension speed was investigated in detail. The relationships between N_{JS} and d_p for soda glass ballotini are shown in **Fig. 1**. It can be seen that with an increase in d_p the N_{JS} value first increases till it reaches a certain critical value, d_p^* , and then decreases

Fig. 1 Relation between complete suspension speed and particle size for soda glass ballotini (○: 0.1 wt%, ●: 0.2 wt%, △: 0.5 wt%, ▲: 1.0 wt%, □: 2.0 wt%)

Fig. 2 Relation between critical particle size and impeller diameter for each particle (○: Polystyrene, △: Soda glass ballotini, □: Alumina)

for low-solid concentrations or only changes slope for high-solid concentrations for all systems used in this work.

The critical particle size d_p^* was determined by the following procedure. The N_{JS} data at a low-solid concentration of 0.1 wt% were interpolated with the particle size by using a cubic polynomial spline. The point where the differential coefficient is zero was defined as d_p^* .

The relation between the critical particle size d_p^* for each particle and the impeller diameter is shown in **Fig. 2**. For polystyrene, several particles cohered in spite of the addition of some interfacial active agent into the liquid, and thus the apparent critical particle size should be larger than the real one shown in **Fig. 2**. This figure shows that d_p^* increases with increase in impeller diameter or decrease in particle density. The relationship between d_p^* and D was expressed as follows, using data for soda glass ballotini and alumina:

$$d_p^* = 18D^{0.63} \Delta\rho^{-1.0} \quad (3)$$

where the unit of d_p^* or D is [m] and that of $\Delta\rho$ is [kg m^{-3}]. The calculated results for soda glass ballotini and alumina are shown as solid lines in Fig. 2. Rieger and Dittl⁵⁾ reported that complete suspension was not dependent on particle size when the particle size was more than $0.0073T$ for glass ballotini in vessels agitated by a six-pitched blade turbine with a blade angle of 45° and an impeller-to-vessel diameter ratio of $1/3$. By substituting $\Delta\rho = 1400\text{kg/m}^3$ and $T/D = 3$ into Eq. (3), the following relationship was obtained:

$$d_p^* = 0.0064T^{0.63} \quad (4)$$

The exponent of T in Eq. (4) is smaller than that suggested by Rieger and Dittl⁵⁾.

Using the experimental data when $d_p < d_p^*$, the constant and exponents in Eq. (2) were redetermined by nonlinear regression. The number of data analyzed was 157. The correlation derived was

$$N_{JS} = 1.8v^{0.10} d_p^{0.050} (g\Delta\rho/\rho_L)^{0.38} X^{0.17} D^{-0.60} \quad (5)$$

$(d_p < d_p^*)$

The average deviation is 0.237s^{-1} . For particles smaller than d_p^* , Eq. (5) is suitable for calculating N_{JS} .

Conclusion

The effect of particle size on the complete suspension speed was investigated thoroughly. With increase in particle size, N_{JS} values first increase but start decreasing or changing slope above a certain critical

particle size. The critical particle size was correlated with the impeller diameter and the solid-liquid density difference.

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Nomenclature

C	= agitator clearance above base	[m]
D	= impeller diameter	[m]
d_p	= particle size	[m]
d_p^*	= critical particle size	[m]
g	= gravitational constant	[m s^{-2}]
N_{JS}	= agitator speed that just causes complete suspension	[s^{-1}]
S	= dimensionless constant in Equation (1)	[-]
T	= vessel diameter	[m]
X	= solids concentration	[-]
ν	= kinematic viscosity	[$\text{m}^2 \text{s}^{-1}$]
$\Delta\rho$	= solid-liquid density difference	[kg m^{-3}]
ρ_L	= liquid density	[kg m^{-3}]

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