EFFECT OF SCALE ON PARTICLE-IMPELLER IMPACT IN AN AGITATED VESSEL EQUIPPED WITH A RUSHTON TURBINE

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Introduction

Information relating particle impacts to mixer geometries is useful to an understanding of the secondary nucleation in crystallization, the breakdown of friable catalysts and so on, but has rarely been investi-

gated due to the difficulty of measurement^{1, 2)}. In the previous paper²⁾, the crayon method was developed to measure the rate and position of particle-impeller impact in an agitated vessel, and the effects of impeller speed and physical properties of particles were studied for a vessel of 0.144 m diameter. In this work, the

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Fig. 1 Relationship between N_{JS} , N_{SA} or N_{NI} and D

number of impacts was measured for larger vessels and the effect of scale on particle-impeller impact was studied.

1. Experimental

1.1 Experimental set-up

The vessels were open-top transparent acrylic resin cylinders of 0.200 and 0.290 m inner diameter and with a flat bottom. Four baffles having a width of one-tenth of the vessel diameter were fitted in each vessel. The impellers were six-bladed Rushton disc turbines with an impeller-to-vessel diameter ratio of 0.5. The clearance of the impeller above the vessel was one-quarter of the vessel diameter. These systems are geometrically similar to the vessel of 0.144 m diameter used in the previously reported study².

1.2 Crayon method

The crayon method described in the previous paper² was used to determine the number of particle-impeller impacts.

1.3 Particle and liquid

The particles used in this work were closely sieved spherical soda glass ballotini. Their mean volume-surface diameter as determined photographically was 1.38 mm. The solid concentration was fixed at 0.1% by weight of particles in the suspension. Deionized water was used in all experiments.

1.4 Definition of impactation rate

The rate of impactation was defined as the number of impacts per second, R_I , in the previous paper².

$$R_I = \frac{n_I - n_I|_{30}}{t - 30} \quad (1)$$

where n_I or $n_I|_{30}$ is the number of impact marks on six blades for t (> 30) s or for 30 s from the start of an experiment to eliminate the data for the unsteady state at the beginning of the experiment. In addition, another definition of the rate of impactation was defined as the number of impacts per second for a particle, R_P , in this

Fig. 2 Effect of impeller speed on R_I for vessels of different scale

Fig. 3 Impeller speed and β to give the same R_I for each vessel

work; that is, R_I divided by the total number of particles supplied into a vessel. In crystallization, the total number of product crystals may depend strongly on the total number of impacts represented by R_I and the product crystal size distribution on the number of impacts experienced by a particle implied by R_P .

2. Results and Discussion

The desirable working range of impeller speed may be $N_{JS} < N < N_{SA}$, where N_{JS} and N_{SA} are the complete suspension and surface aeration speeds respectively. The relationships between these speeds and the impeller diameter are shown in Fig. 1. The maximum speeds where no particle impactation occurs, N_{NI} , are also shown in this figure. As can be seen, every speed decreases with increase in scale, and the following relationships were obtained.

$$N_{JS} \propto N_{SA} \propto N_{NI} \propto D^{-1} \quad (2)$$

$$N_{SA} = 1.67 N_{JS} \quad (3)$$

$$N_{NI} = 1.25 N_{JS} \quad (4)$$

The exponent of D for N_{JS} in Eq. (2) is similar to the value of -0.85 reported by Zwietering³.

In general, the scale-up rule is described by the following equation.

Fig. 4 Effect of impeller speed on R_p for vessels of different scale

$$N_M D_M^\beta = N_L D_L^\beta \quad (5)$$

where the subscripts M and L mean model and larger vessel, and the exponent β is a parameter varying according to the scale-up condition. If $\beta = 0$ the scale-up rule is constant impeller speed, if $\beta = 2/3$ is constant mean energy dissipation rate throughout the vessel, if $\beta = 1$ is constant impeller tip speed and if $\beta = 2$ is constant Reynolds number.

2.1 Scale-up based on R_I

The relationships between R_I and impeller speed are shown in **Fig. 2**. In this figure, the line shows the data for $D = 0.072$ m reported in the previous paper²⁾. Impaction rate, R_I , increases drastically with increase in impeller speed for each vessel, but the dependency is slightly smaller for a bigger vessel because the data at high impeller speeds for $D = 0.145$ m might be affected by gas bubbles introduced by surface aeration. For each vessel the following relationships were obtained.

$$R_I = 2.35 \times 10^{-8} N^{13.1} \text{ for } D = 0.072 \text{ m} \quad (6)$$

$$R_I = 3.47 \times 10^{-6} N^{12.1} \text{ for } D = 0.100 \text{ m} \quad (7)$$

$$R_I = 2.71 \times 10^{-3} N^{9.26} \text{ for } D = 0.145 \text{ m} \quad (8)$$

The relationships between impeller speed to give the same R_I for each vessel calculated from Eqs. (6) to (8) are shown in **Fig. 3**. The speeds for impellers of larger size increase nearly proportionally to that for the model impeller. The value of β calculated by substituting Eqs. (6) to (8) into Eq. (5) is also shown in **Fig. 3**. This figure shows that the optimum value of β to get the same number of impacts per second, R_I , is about 1. Therefore, the constant impeller tip velocity may give the same R_I .

2.2 Scale-up based on R_p

The relationship between R_p and N for each vessel is shown in **Fig. 4**. In this figure, the line also indicates the value of impaction rate for $D = 0.072$ m obtained in the previous paper²⁾. As a matter of course, R_p for each vessel also could be expressed by the following equa-

Fig. 5 Impeller speed and β to give the same R_p for each vessel

tions.

$$R_p = 3.66 \times 10^{-11} N^{13.1} \text{ for } D = 0.072 \text{ m} \quad (9)$$

$$R_p = 1.93 \times 10^{-9} N^{12.1} \text{ for } D = 0.100 \text{ m} \quad (10)$$

$$R_p = 5.24 \times 10^{-7} N^{9.26} \text{ for } D = 0.145 \text{ m} \quad (11)$$

The relationships between impeller speed for each vessel to give the same R_p calculated from Eqs. (9) to (11) are shown in **Fig. 5**. The speeds for impellers of larger size increase proportionally with increase in that for the model impeller. The value of β calculated by substituting Eqs. (9) to (11) into Eq. (5) is also shown in **Fig. 5**. This figure shows that the optimum value of β to get the same number of impacts per second for a particle, R_p , is about 0.7 which is nearly $2/3$. Therefore, the constant mean energy dissipation rate throughout the vessel may give the same R_p . However, it should be noted that surface aeration will occur for a larger vessel to get the same R_p as that of a small one.

Conclusion

The effect of scale on the rate of particle-impeller impactation was studied. For the vessels used in this work ($0.144 \text{ m} \leq T \leq 0.290 \text{ m}$) it was found that the same number of impacts per second is given at a constant impeller tip speed and that for a particle at a constant mean energy dissipation rate throughout the vessel.

Nomenclature

D	= impeller diameter	[m]
N	= impeller speed	[s ⁻¹]
N_{JS}, N_{SA}	= complete suspension or surface aeration speed	[s ⁻¹]
N_{NI}	= impeller speed where no particle-impeller impact occurs	[s ⁻¹]
$n_I, n_I _{30}$	= number of impact marks for t (> 30) seconds or for 30 seconds from start of experiment	[-]
R_I, R_p	= impaction rate defined as number of impacts per second or that for a particle	[s ⁻¹]
T	= vessel diameter	[m]
t	= time	[s]

β = parameter for scale-up rule

<Subscripts>

72,100,145 = for 0.072 m, 0.100 m or 0.145 m
diameter impeller

M, L = model or large vessel

[-]

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