

DEVELOPMENT OF JET MIXER WITH ROTATING AND UP-AND-DOWN MOVING NOZZLES

SEUNG TAE KOH, SETSURO HIRAOKA, YUTAKA TADA,
TSUTOMU ARAGAKI, IKUHO YAMADA AND ISAMU MORIMOTO

Department of Applied Chemistry, Nagoya Institute of Technology, Nagoya 466

Key Words: Mixing, Jet Mixing Vessel, Mixing Time, Rotating Nozzle, Reciprocating Nozzle

Introduction

A liquid jet is often used to mix low-viscosity liquids in a large tank¹⁾. Shear and circulation flows resulting from injection of liquid at high velocity into slow-moving or stationary liquid mix the tank contents efficiently. The jet flow from a fixed jet nozzle, however, is liable to induce dead spaces because the shear and circulation flows are restricted to the vicinity of the jet nozzle. To eliminate dead spaces and to promote mixing efficiency it is useful to rotate the jet nozzle and/or move it up and down in reciprocating motion.

This paper deals with the development of a jet mixer with rotating and reciprocating nozzle, and with the measurement of mixing time in the vessel. Then the effects of jet flow rate, number of jet nozzles, nozzle rotation speed and reciprocation frequency on the mixing time are elucidated.

1. Experimental

A schematic diagram of a jet mixer with rotating and reciprocating nozzles is shown in **Fig. 1**. The aluminium cylinder ⑥ of the mixer, 12 cm in outer diameter, is rotated by a variable-speed motor and its rotation makes the cylinder move up and down with the help of a guide. The cylinder has two injection nozzle holes, 0.7 cm in inner diameter (I.D.). For single-nozzle experiments, one of the nozzle holes is plugged. Jet flow rate is controlled by the rotation speed of a suction impeller ② which is set in the lower part of the cylinder and is connected to another variable-speed drive motor.

An acrylic resin vessel ① in which the mixer is positioned is 30 cm I.D. and 30 cm in height, and is filled with liquid to a height of 20 cm. The bottom of the cylinder of the mixer is set 3.5 cm above the vessel bottom. In case of nozzle rotation without reciprocating motion the injection nozzles are set horizontally, 12.5 cm above the vessel bottom, and in case of nozzle rotation with reciprocating motion the nozzle height

* Received March 6, 1990. Correspondence concerning this article should be addressed to S. T. Koh. I. Morimoto is at Tokushu Kika Kogyo Co., Ltd. Osaka 553, Japan.

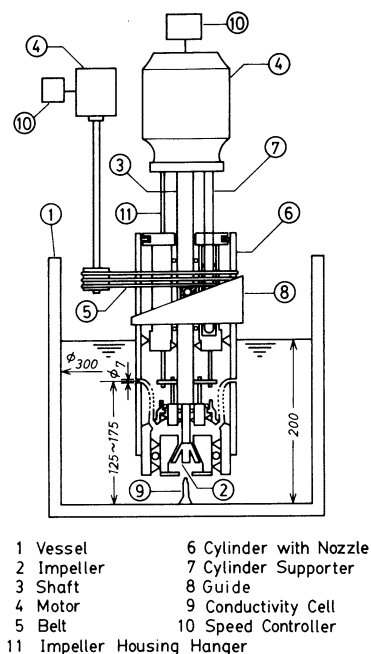


Fig. 1. Schematic diagram of mixer

is varied from 12.5 cm to 17.5 cm above the vessel bottom. An electric conductivity cell is set under the suction impeller.

For measurement of mixing time t_M , 50 cm³ of sodium chloride aqueous solution is poured into the mixing vessel in a very short pulse, and the fluctuation of electric conductivity of the liquid in the vessel is observed with a conductivity meter and a mV recorder. The mixing time is defined as the time in which the fluctuation of electric conductivity decays less than 1% of converged electric conductivity, in the same manner as in the previous report⁴⁾. The rotation speed of the cylinder is 8 to 80 min⁻¹ and the jet flow rate is 2.0 to 6.0 l/min. The frequency of reciprocating motion is equal to the rotation speed of the cylinder.

2. Results and Discussion

Figure 2 shows the correlation between the ratio of mixing time to mean residence time of circulating liquid, t_M/t_R , and the dimensionless angular velocity, Ω^* , in the same manner as in the previous papers^{4,5)}. The mean residence time t_R and Ω^* are defined as

$$t_R = V/(nQ) \quad (1)$$

$$\Omega^* = (\omega d/2)/(u \cdot \sqrt{n}) \quad (2)$$

where Q is the jet flow rate per nozzle and ω is the angular velocity of the cylinder. The correction factor \sqrt{n} for the ordinate in Fig. 2 was determined empirically such that the observed dimensionless mixing times for both one- and two-jet nozzle systems would coincide with each other, whereas the correction factor \sqrt{n} in Eq. (2) followed the correlation method in the previous paper.⁴⁾ t_M/t_R is well correlated with

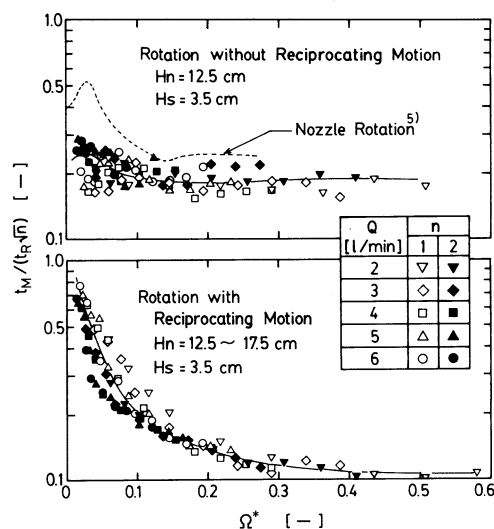


Fig. 2. Mixing time for nozzle rotation with and without reciprocating motion

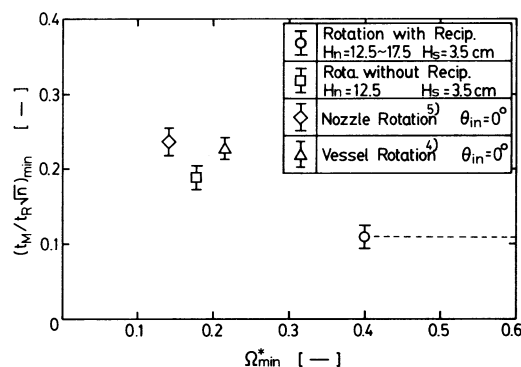


Fig. 3. Dimensionless minimum mixing time

Ω^* .

In the case of nozzle rotation without reciprocating motion the dimensionless mixing time t_M/t_R decreases slowly at the range of $\Omega^* < 0.15$, and approaches a constant value for larger Ω^* . The dotted line in the figure shows the result for the jet mixing experiments using a rotating nozzle around a vessel axis, where the jet flow was produced by a pump set outside the vessel.⁵⁾ The dotted line is located above the present data, but the tendency of the appearance of maximum and minimum value of t_M/t_R is very similar to that of the present results.

In the case of nozzle rotation with reciprocating motion, t_M/t_R decreases rapidly as Ω^* increases, and t_M/t_R is larger than in the case of nozzle rotation without reciprocating motion in the range of $\Omega^* < 0.15$, whereas t_M/t_R is smaller at larger values of Ω^* .

In Fig. 3 the minimum value of dimensionless mixing time, $(t_M/t_R)_{min}$, for each system is correlated with Ω^*_{min} at which $(t_M/t_R)_{min}$ appears. For the case of nozzle rotation with reciprocating motion, $(t_M/t_R)_{min}$ appears in the range of $\Omega^* > 0.4$ in Fig. 2, and the smallest

value 0.4 is selected as Ω_{min}^* in Fig. 3. The values of $(t_M/t_R\sqrt{n})_{min}$ for nozzle rotation with reciprocating motion is about 0.1, which is about half the value for the nozzle or vessel rotation without reciprocating motion⁵⁾, 0.18–0.23.

For correlation of mixing time in jet mixing and agitated vessels, the following dimensionless variables were derived in the previous report.⁵⁾

$$Y = (Nt_M)(N_{qd})(d/D)^3(D/H)^{0.5} = \frac{\pi}{4} \left(\frac{H}{D}\right)^{0.5} \frac{t_M}{t_R} \quad (3)$$

$$X = (D/d)(N_p/N_{qd}^3)^{1/4} = \frac{0.95}{\sqrt{n}} \left(\frac{D}{d_n}\right) \quad (4)$$

and the agitated vessels.⁵⁾ The product of Y and X is roughly a universal constant for both the jet mixing at the agitated vessels.⁵⁾ The product of Y and X is rearranged to the following form for jet mixing.

$$t_M = C \frac{D^{1.5} H^{0.5}}{\sqrt{n} u d_n} \quad (5)$$

The proportional constant C obtained from the minimum mixing time in Fig. 3 is 3.2 for nozzle rotation with reciprocating motion and is 5.6 for nozzle rotation without reciprocating motion, while it was 6.9 for the minimum mixing time in both vessel rotation and nozzle rotation in the previous papers^{4,5)}. The value of 5.6 is almost the same as the 5.5 obtained by Okita and Oyama⁶⁾. Some investigators expressed the correlation equation with D^2 instead of $D^{1.5}H^{0.5}$ in Eq. (5), where the proportional constants were 3.7 for Van de Vusse,⁸⁾ 4.5 for Fossett,²⁾ 3.2 for Hiby and Modigell³⁾ and 3.9 for Racz and Wassink⁷⁾. When the present data are correlated by using D^2 , the proportional constants C are corrected from 3.2 to 2.6 for nozzle rotation with reciprocating motion and 5.6 to 4.6 for nozzle rotation without reciprocating

motion. These values agree roughly with those of the other investigators.

Nomenclature

C	= proportional constant in Eq. (5)	[—]
D	= vessel diameter	[m]
d	= diameter of cylinder	[m]
d_n	= diameter of jet nozzle hole	[m]
H	= liquid height	[m]
H_n	= nozzle height from vessel bottom	[m]
H_s	= height of lower level of cylinder above vessel bottom	[m]
N	= rotating speed of cylinder	[s ⁻¹]
N_p	= power number of impeller, $P/(\rho N^3 d^5)$	[—]
N_{qd}	= discharge flow number, $nQ/(Nd^3)$	[—]
n	= number of jet nozzles	[—]
Q	= jet flow rate per nozzle	[m ³ /s]
t_M	= mixing time	[s]
$(t_M/t_R)_{min}$	= minimum dimensionless mixing time	[—]
t_R	= residence time	[s]
u	= mean velocity of liquid at jet nozzle	[m/s]
V	= liquid volume in vessel	[m ³]
θ_{in}	= jet nozzle angle to the radial direction	[°]
Ω^*	= dimensionless angular velocity defined by Eq. (2)	[—]
ω	= angular velocity	[rad/s]

Literature Cited

- 1) Bathija, P. R.: *Chem. Eng.*, **89** (25), 89 (1982).
- 2) Fossette, H.: *Trans. Inst. Chem. Engrs.*, **29**, 322 (1951).
- 3) Hiby, J. W. and M. Modigell: *Paper presented at 6th CHISA Conf.*, Prague. (1978).
- 4) Koh, S. T., S. Hiraoka, I. Yamada, Y. Tada, T. Aragaki and T. Takahashi: *J. Chem. Eng. Japan*, **22**, 611 (1989).
- 5) Koh, S. T., S. Hiraoka, Y. Tada, T. Takahashi, T. Aragaki and I. Yamada: *J. Chem. Eng. Japan*, **23**, 462 (1990).
- 6) Okita, N. and Y. Oyama: *Kagaku Kōgaku*, **27**, 252 (1963).
- 7) Racz, I. and J. G. Wissink: *Chem. Ing. Techn.*, **46**, 261 (1974).
- 8) Van de Vusse, J. G.: *Chem. Ing. Techn.*, **31**, 583 (1959).