FLOW PATTERN IN A DUAL MODE AGITATOR WITH SIMULTANEOUS UP-AND-DOWN AND ROTATIONAL MOTION OF IMPELLER

YASUHIRO MURAKAMI, TSUTOMU HIROSE, MASAHARU TAKAO, TSUTOMU YAMATO
AND HIDEYUKI FUJIWARA

Department of Chemical Engineering, Kyushu University, Fukuoka 812

MASAMITSU OHSHIMA

Nippon Dyeing Machine Mfg. Co., Ltd., Kanie-cho, Ama-gun, Aichi 497

Introduction

In the previous report²⁾, it was shown that a novel mechanics of dual mode (rotational and vertical) movement of an impeller reduces greatly mixing time without much increase in power consumption relative to the conventional single-mode (rotational) agitator. Up-and-down as well as circumferential circulation is necessary to distribute the fluid elements throughout the vessel for rapid mixing. The present work is a continuation of the previous paper²⁾ and deals with the flow pattern of liquid in the dual-mode agitator, based on a series of photographic observations in the vertical plane.

1. Experimental

The agitator investigated was the same as reported previously²⁾. The vessel was a 19 cm-diameter acrylic cylinder and the impeller used was a 17.6 cm-diameter cross paddle mounted at the middle of liquid depth, i.e. 95 mm from the bottom. The frequency ratio was 19:20, which means that the impeller experiences 19 vertical strokes during 20 revolutions in the whole cycle until it returns to the original height and orientation. The working fluid was corn syrup solution with the viscosity of 5 Pa·s and the impeller rotated counter-clockwise at 1 s⁻¹ with the corresponding Reynolds number of 8.3.

The streamlines in various vertical planes were visualized by the motion of tracer polystyrene spheres (1 mm dia.) illuminated with a vertical slit beam (8 mm wide) projected from a pair of mercury lamps (100 W). The impeller orientation, θ , which is defined as the angle of the illuminated plane ahead the impeller, was varied at 30° intervals by manual adjustment of a trigger mounted on the impeller shaft. The details of camera angle and the photographic procedure were reported elsewhere¹⁾.

2. Results and Discussion

The whole cycle of flow patterns was visualized by 120 pictures corresponding to 20 levels of height and 6 orientations. **Figure 1** shows typical flow patterns for some orientations at the moment when the impeller passes through the middle height of the vessel. Vertical circulation appears in any position of the impeller, as seen from the figure. The flow pattern changes not only with orientation but also with direction of the stroke or, more generally, with the impeller height. At $\theta=0^\circ$, for example, the fluid is forced to move upwards in the wall region in the upstroke while it moves downwards around the shaft in the downstroke. This pattern may be explained by the fact that the outer and inner blades of the cross paddle impeller, respectively, are so pitched as to face the fluid with larger projected area during the up- and downstrokes. At $\theta=60^\circ$ and 120° , the flow pattern is nearly upside-down between

Fig. 1 Typical flow patterns when a cross paddle impeller passes through middle height of vessel

Received March 3, 1981. Correspondence concerning this article should be addressed to Y. Murakami. T. Yamato is now with Daicel Chem. Ind., Ltd., Himeji 671-02

the up- and downstrokes. At $\theta=60^\circ$, a vortex appears partly only in the upper or lower portion of the vessel depending on the up- or downstroke while at $\theta=120^\circ$ a vortex develops more or less in the whole vessel. The systematic examination of 120 pictures reveals that the transition of flow pattern occurs more rapidly just after turning back of the impeller from up to downstroke and vice versa, and more gradually around the middle height of the impeller.

The velocity component projected to the vertical plane was measured from the path of a polystyrene tracer particle on the photograph. Typical results are shown in **Fig. 2** for six selected points in the vessel at three different impeller orientations. The direction of the local velocity varies over a wide angle during the whole cycle or 20 revolutions of the impeller, because of its up- and down motion. The velocity also fluctuates greatly in spite of the laminar flow. The velocity is large at 0° orientation since the impeller lies in this plane. Inward flow into the region enclosed by the six selected points is predominant at $\theta=60^\circ$, while outward flow is predominant at $\theta=120^\circ$.

The occurrence of various flow patterns and the frequent change in direction and magnitude of the local velocity corresponding to the impeller height are the most distinguishing features compared to conventional single-mode (rotational) agitation, in which only a single flow pattern and a single local velocity appear at a given orientation. When the flow is observed from stationary coordinates, the sequence of changes in flow patterns becomes too complicated to identify and follow by visual observation alone, because of the simultaneous changes in height and orientation of the impeller. Since any point in the vessel experiences various orientations, the direction of fluid velocity changes in almost all directions during the whole cycle or 20 revolutions. Such a frequent variation of flow

Fig. 2 Variation of local velocity during whole cycle at various orientations

pattern and local velocity increases the opportunity of replacement between fluid elements as well as the extent of deformation of fluid, which in turn results in improvement of mixing efficiency as stated previously²⁾.

Acknowledgments

The authors would like to express their hearty thanks to Nippon Dyeing Machine Mfg. Co., Ltd. for providing the test agitator and other support.

Nomenclature

θ = impeller orientation [deg]

Literature Cited

- 1) Murakami, Y., T. Hirose and M. Ohshima: Preprint of A.I.Ch.E. Joint Japan-North American Mixing Symposium, San Francisco, Nov. 1979 (reproduced in *Chem. Eng. Progr.*, p. 78, May 1980).
- 2) Murakami, Y., T. Hirose, T. Yamato, H. Fujiwara and M. Ohshima: *J. Chem. Eng. Japan*, **13**, 318 (1980).

(Presented at Oita Meeting of The Soc. of Chem. Engrs., Japan, at Oita, 1979.)

LETTER TO THE EDITOR

HETEROGENEITY OF THE REACTION SYSTEM OF ALKALINE HYDROLYSIS OF ETHYL ACETATE IN A BATCH STIRRED TANK

Dear Sir:

Alkaline hydrolysis of ethyl acetate has been frequently used to investigate the micromixing phenomenon in the continuous perfect macromixer. However, this reaction has been regarded as reaction controlling because the reaction rate is considerably slower than the rate of mixing for miscible liquids in

the usual batch operation^{2,3)}.

Here are presented some supplementary considerations as to heterogeneity due to the formation of droplets which has been observed for this particular reaction¹⁾.

Solid symbols in **Fig. 1** are the experimental data obtained in the system where pure ethyl acetate was poured into the sodium hydroxide solution without a viscosity-increasing reagent. The rate of reaction is depressed with increasing reaction time. Almost the same course of reaction was also observed in viscous