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Development of the horizontal swirl mixer with a fillet shape

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ABSTRACT

In this study, a new shaped continuous mixer with simple mixing structure is proposed, aiming to suppress the short pass phenomenon to gain high mixing performance. Therefore, fluid motion of secondary flow by centrifugal force and swirling flow is focused. Furthermore, validity was examined by numerical analysis.

Flow visualization was performed, and the mixing performance was verified using the electric conductivity method and transmission luminance measurement.

As a result, a horizontal disc mixing tank with a fillet shape as the shape of the mixer was proposed. In the radial direction, it is predicted that forced vortex occurs near the center and Quasi-free vortices occurs at the opposite edge. Moreover, at opposite edge in the vertical direction, a pair of upper and lower vortices was observed. It was confirmed that a secondary flow was generated at the opposite edge.

Concentration dispersion rapidly progresses in the vicinity of the side opposite edge of the mixing tank. It is confirmed that dispersion in the vicinity of the outlet part is small and uniformly mixed in the mixing tank regardless of the angle. It is regard as the consequence of the shear effect caused by the swirl flow generated near the outlet portion and the cross-sectional mixing due to the secondary flow generated at the opposite edge. It was found that it has mixing performance of about N = 9–14, comparing to the complete mixing tank train model.

1. Introduction

Currently, Mixing is an essential process as part of the chemical, food, and biological industry. In the conventional mixer, a batch method is used in which the fluid put into the tank is mixed by applying an external force such as a stirring blade or a vibration device. Batch method has the advantage that it can be used for low viscosity to high viscosity fluid due to various shapes of stirring blades. On the other hand, there are the following disadvantages, the equipment is large because it has a stirring mechanism, not suitable for mass production in order to carry out the mixing in each tank, environmental burden such as cleaning is large. By contrast, there is a continuous mixer that does not have a stirring mechanism, such as a static mixer [1]. The fluid in the mixer is divided and converted and inverted by the elements and the baffle plate to be effectively mixed [2]. The continuous mixer basically does not have a driving part, it has the feature that it can save space and mix with energy saving. However, in order to fabricate elements and baffles, sophisticated processing and bonding technology are necessary. Also, there is a disadvantage that the entire line must be stopped when the flow path is blocked or the element or the baffle plate breaks.

There is a swirl mixer [3–5] or a mixer that uses a secondary flow [6–8] generated in a bent pipe in a continuous type mixer not having an element or a baffle plate. The swirl mixer can efficiently mix by utilizing the shear force of the swirling flow generated helically in the cylindrical mixing part. In the mixer using the secondary flow generated in the pipe, the secondary flow shape is changed by altoring the flow velocity and angle, and mixed. Both have high mixing performance, it has a disadvantage that accuracy deteriorates due to "short pass"; discharge without mixing. From the above, the performance required for the mixer is that the energy is small, and the shape is simple and efficiently mixed uniformly, but it is not easy to achieve them at the same time.

In this study, focusing on fluid motion of the secondary flow by centrifugal force and swirling flow. A new shaped continuous mixer with simple mixing structure is proposed, aiming to suppress the short pass phenomenon to gain high mixing performance, resulting in the horizontal swirl mixer with a fillet shape. Performance prediction is performed using simulation, and also flow visualization was performed, and the mixing performance

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was verified using the electric conductivity method [9] and transmission luminance measurement.

2. Proposing shape

In mixing process, it is desirable to efficiently use the energy applied to the fluid. It is hoped that it is simple structure such as without having mixed mechanism and the obstructive board or element. Also, in order to mix uniformly, there is less dead space that does not contribute to mixing as much as possible, and a structure that can earn residence time is necessary. The appearance of the mixer proposed in this research is shown in Fig. 1. The inlet is arranged in the symmetrical direction on the tangent line of the end portion of the disk-shaped mixing tank. Also, an outlet for discharging the fluid mixed by vortex flow generated from the fluid flow was arranged at the center of the disk-shaped mixing tank. Two or more different fluids are supplied to the inner space of the mixing tank via a plurality of inlets. It is predicted to perform mixing by the cross-sectional diffusion effect of the secondary flow caused by the centrifugal force generated from the flow along the wall surface of the mixing tank and the shearing mixing effect by the swirling flow generated at the outlet portion. Although the number of inflows is not restricted, it is desirable that the mixing tank wall surface exists at least 30° among inlets in order to generate a sufficiently developed centrifugal secondary flow, so it is considered that the number of inlets should be 6 or less. There are two or more types of fluids to be mixed, and the number of inflows, the shape of the flow path, and the width of the flow path are appropriately set in order to obtain a target mixture. Also, mixing tank is shaped like flat disk and fillet processed at the end. It is predicted to reduce the dead space at the corner of the mixing tank by applying the fillet processing. Also, the flat mixing tank shape is predicted to extend the residence time and reducing the short pass phenomenon. Further, since the structure is simple, it is possible to easily clean the inside. The thickness of the mixing tank shall be equal to the diameter of the inlet. Fluids to be mixed are assumed to be fluids of different kinds, different components and heterogeneous.

3. Evaluation method

3.1. Mixing characteristics

Mixing condition, residence time distribution function and mixing time were used for evaluation of mixing characteristics of mixer. In this study, the mixing time θ_g represents the time taken for the outlet concentration C_{out} to reach the target concentration C_g. Then, the mixing time θ_g was defined as the following equation using a dimensionless number D normalized by target concentration C_g.

$$\begin{aligned} &D = C_{out}(t)/C_g \\ &\theta_g = \{Elapsed\ time\ t\ when\ D\ converges\ to\ 1 \pm 0.05\} \end{aligned} \tag{1}$$

The mixing condition, was evaluated based on the standard deviation of the target concentration (Mixing degree) at a plurality of observation points set in the mixing tank defined the following expression. The mixing degree takes a value of 1 in a completely separated state and assumes a value of 0 in a state of complete mixing.

$$M = \frac{\sqrt{\sigma_t^2}}{\sqrt{\sigma_g^2}} \tag{2}$$

$$\sigma_t = \sqrt{\frac{\sum \{C(x,t) - C_g\}^2}{n}} \tag{3}$$

M: standard deviation, σ_t: deviation σ_g: Target deviation, C (x, t): concentration at position x, time t, target concentration.

Mixing characteristics in the device can be expressed by mean residence time and residence time distribution. Mixing performance was evaluated by comparing the obtained value with the complete mixing tank train model. The residence time function $E(t)$ is given by the following equation, assuming the outflow concentration function F(t) in the case of step inflow at a constant concentration C_0.

$$E(t) = \frac{1}{C_0}\frac{dF(t)}{dt} \tag{4}$$

Also, the residence time function in the impulse response $E(t)$ is expressed by the following equation using the average residence time t_m the normalized dimensionless time $\theta\left(=\frac{t}{t_m}\right)$, and the tracer concentration C:

$$t_m = \int_0^\infty tE(t)dt \tag{5}$$

$$E(\theta) = \frac{C(\theta)}{\int_0^\infty C(\theta)d\theta} \tag{6}$$

A complete mixing tank stages model which is a model of a continuous mixer is expressed by the following equation as a function of the number N of tanks to be divided.

$$E(\theta) = \frac{N^N}{(N-1)!}\theta^{N-1}\exp(-N\theta) \tag{7}$$

3.2. Pressure loss

The pressure loss in the mixer ΔPe is defined as the following equation using a difference between the mean total pressure at the inlet P_1 and the outlet P_2, respectively.

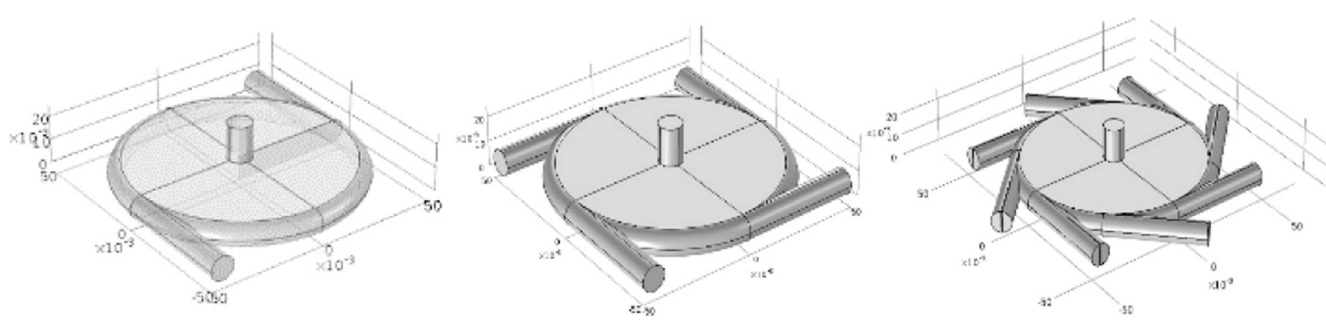

Fig. 1. Proposed mixer.