MIXING CHARACTERISTICS OF A CONTINUOUS RIBBON MIXER

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INTRODUCTION

When mixer is designed or operational condition of a mixer is determined, it is necessary and important to make clear the mixing mechanism of solid particles in a mixer. From such viewpoint, the mixing mechanism has been studied using very simple mixer such as cylindrical vessel with a blade or with multiple blades, and those results were reported.[4,5] In the previous reports, the mixing mechanism of solid particles in such mixers could be illustrated by a mathematical model.

In this study, the results obtained in the previous paper have been applied to the ribbon mixer for a practical use. That is, it has been tried to illustrate mixing mechanism of solid particles in the mixer using "distribution side capacity model" as a mathematical model.

Though this method was very rough, but experimental results were fairly agreed with the results obtained by the model. The previous experimental results for a ribbon mixer could also be explained by this model.

1 EXPERIMENTAL

1-1 Apparatus

A schematic diagram of the experimental apparatus used is shown in **Fig. 1.**

Toyo-ura Standard Sand used as experimental materials is supplied into a ribbon mixer (⑤) passing through the hopper (①), head tanks (②) and tracer holder (③), successively. Both the feed rate and the discharge rate of materials to or from the mixer are controled by orifices (④) and (⑥).

Mixture discharged from the mixer is fallen down into a water tank (⑨) to measure concentration of tracer in the mixture. The tank is a stirrer vessel with two agitators and three baffle plates. A definite volume of water previously has been poured into the tank. Tracer (sodium carbonate) in the mixture is solved immediately in it and a change of electric conductivity of

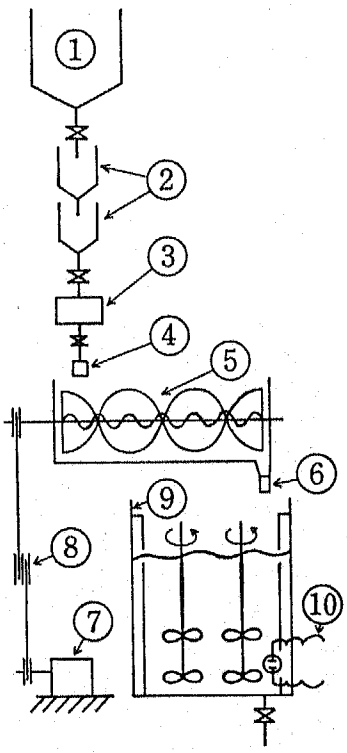

Fig. 1 Experimental apparatus

solution in a cell (⑩) is measured. According to this method, the total concentration of tracer can be measured.

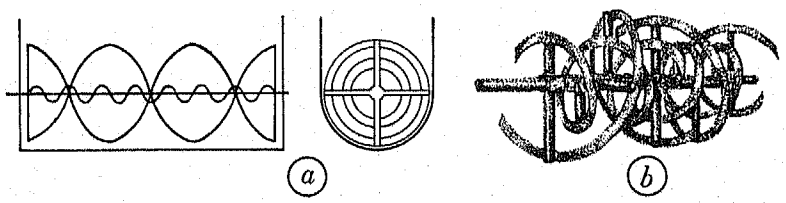

Fig. 2 Mixing vessel and ribbon

A mixing vessel and an agitating ribbon are shown in **Fig. 2.** The sizes of the mixing vessel (ⓐ) are 377mm in length, 90mm in width and 115mm in maximum depth. Total and effective volumes of the vessel are 3570 and 2730 cu.-cm, respectively. A ribbon (ⓑ) is double helical type with outer and inner ribbons and their major dimensions are shown in **Table 1.**

Table 1 Dimensions of the ribbon

No. of ribbon		diameter D (mm) outer	diameter D (mm) inner	width W (mm)	pitch P (mm)	P/D
1	outer	88	78	5	88	1.0
	inner	58	44	7	44	—
2	outer	88	78	5	105	1.2
	inner	58	44	7	35	—
3	outer	88	78	5	130	1.5
	inner	58	44	7	29	—

1-2 Materials

As experimental materials, Toyo-ura Standard Sand of 42 to 100 mesh was used. Sodium carbonate was adjusted to the same range of particle size as Sand. It was used as tracer of impulse response method. The properties of these materials are shown in **Table 2**.

Table 2 The properties of materials

		Toyo-ura Sand	Sodium carbonate
particle size (mesh)		−42/+100	−42/+100
density (g/cc)		2.67	2.61
bulk density (g/cc)	max.	1.50	0.97
	min.	1.34	0.82

1-3 Impulse Response Method

The impulse response method was adopted for observation of mixing mechanism of solid particles in the mixing vessel. Here, sodium carbonate of 25 grams was used as tracer.

For attachments by which the tracer is thrown in and concentration of the tracer is measured, and the experimental method in details, the previous paper[5] should be reffered to.

1-4 Methods

Supplying the materials at constant rate, the mixer was operated at a constant rotational speed which corresponded to the feed rate. When the equilibrium was achieved among feed rate of solid particles, transfer rate in a mixing vessel and discharge rate, the hold up became constant in mixing

vessel, that is, the free surface of the solid particles along the mixer axis became horizontal. We regarded this condition to be steady state. After the mixer was running for two or three times of an average residence time, the experiments of impulse response method were carried out. In this study as same as the previous paper,[5] even if tracer is added to the feed as impulse, its response is detected as total concentration of tracer in the mixer. That is, it is same to the curve (F-curve) obtained by step response method.

2 RESULTS

2-1 The Mixing State in Mixing Vessel

According to the observation of mixing state of solid particles in the continuous ribbon mixer and to some experimental results[2] investigated by sampling method, the flow pattern in the mixer vessel was obtained, and its outline is shown in **Fig. 3.**

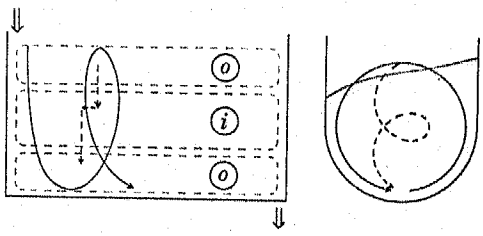

Fig. 3 Flow-pattern in a mixing vessel

In the mixing vessel with a double herical ribbon, the solid particles are transported along the axis in the mixer by rotation of outer ribbon, as shown by the solid line in **Fig. 3.** On the other hand, at a cross section of mixer, solid particles are moved toward the center of mixer by leakage out of the outer ribbon, and are transported slightly to the opposite direction to the bulk movement. Then the particles are moved again toward a outer ribbon, as shown by a dotted line. Therefore it can be considered that the solid particles may be mixed by repetition of the motions described above.

As mentioned above, the flow pattern in a mixing vessel may be divided to the two mixing zones. One of them is a zone in which the solid particles are mainly transported (shown with sign "ⓞ" in **Fig. 3**). The other is a zone in which the solid particles are mixed (shown with sign "ⓘ").

2-2 Results of Impulse Response Experiments

Two examples of the response curves obtained are shown in **Fig. 4.** In order to ascertain the reproducibility of the experiments, the several runs

were carried out under the same conditions, and those results are plotted in **Fig. 4**. **Fig. 4** shows they have the good reproducbiility. The solid line in the **Fig. 4** is calculated from the mathematical model as below.

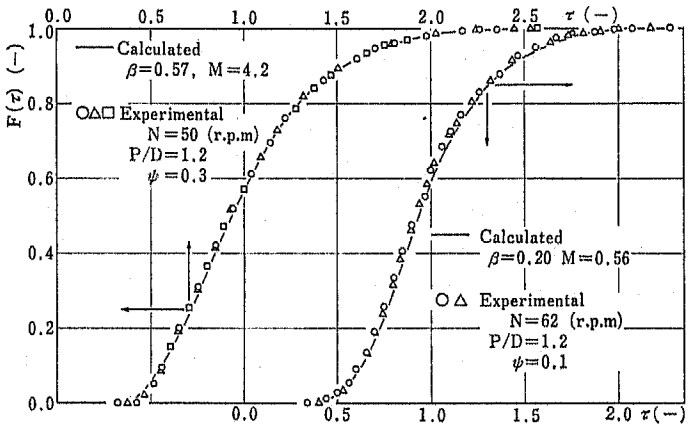

Fig. 4 Response curves
——reproducibility and comparsion of experimental results with calculated results

The experiments were carried out using three different types of ribbon, as shown in **Table 1**, under the various conditions of the hold up $\psi(-)$, the rotational speed of ribbon N (r. p. m.) and the ratio of ribbon pitch to its diameter P/D (—). As the results, it is clear that there is "time lag" which corresponds to about 40% of an average residence time of solid particles in the mixer. Moreover, for the lower rotational speed, the initial part of the response curve is linear, but "S" -type curve is obtained with increase of the rotational speed.

3 AN IDENTIFICATION OF THE RESPONSE CURVES BY THE MIXING MODEL AND DISCUSSION ON THE MIXING STATE

Because of the following considerations, "distribution side capacity model" was applied as the mixing model.

1) The behaviour of the solid particles in the mixing vessel can be divided to the two zones as shown in the previous section. The fact mentioned here is in agreement with the assumption of distribution side capacity model.

2) The results of mixing of solid particles in a mixer with multiple blades can be explained by this model.[5]

3-1 Distribution side Capacity Model

The mixing model is shown in **Fig. 5.** This model is based on the following assumptions.

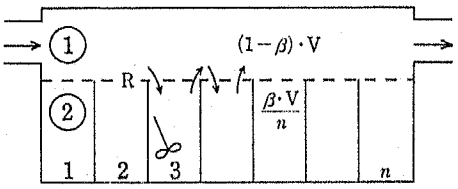

Fig. 5 Distribution side capacity model.

1) There are two mixing zones. One of them is "main mixing zone (①)" in which piston flow is assumed, and the other is "side mixing zone (②)" in which perfect mixing is assumed.

2) There is "mixing resistance R" between these two mixing zones. Thus, this model is the distributed type with the above assumption.

"Side capacity coefficient β" is defined as the volumetric ratio of side mixing zone to over-all mixing zone. In a continuous mixer, it is preferred to be small mixing resistance R, *i.e.*, the large mixing rate in the radial direction is desirable.

It may be considered that zones ⓞ and ⓘ shown in **Fig. 3** correspond to ① and ② in **Fig. 5**, respectively. The volumetric ratio of zone ⓘ to the mixer volume is expressed as side capacity coefficient β, and facility of mixing between zone ⓘ and ⓞ is inversely proportional to the mixing resistance R. Further, even if mixing resistance is large, chance of exchange of positions of solid particles between the two mixing zones increases with an increase in residence time. So, the ratio of average residence time to mixing resistance, that is the mixing coefficient, M is defined as

$$M=\bar{t}/R. \tag{1}$$

In order to mix up uniformly in the radial direction, a mixer should be operated under the condition which the both β and M become as large as possible.

From the mass balance equation, the transfer function of the model is described as

$$G(s)=\exp\{(\beta-1)s-\beta Ms/(\beta s+M)\}. \tag{2}$$

So the step response curve is given approximately as

$$F(\tau)=\frac{A_0}{2}+\frac{2}{\pi}\sum_{m=1,3,5\cdots\cdots}\frac{A_m}{m}\sin(m\omega_f\tau+\phi_m) \tag{3}$$

where $\tau=t/\bar{t}$, $A_0=|G(0)|$, $A_m=|G(jm\omega_f)|$ *and* $\phi_m=\underline{/G(jm\omega_f)}$[1].

3-2 An Identification between the Model and Experimental Results

Model parameters β and M can be calculated from moments of F-curves measured.[5] Substituting β and M into Eq. (2), and using Eq. (3), F-curve of the model can be calculated. The results are shown in **Fig. 4** as solid line. The **Fig. 4** shows that the experimental results fairly agree with the calculated values. Other experimental results also agree with the calculated values in the same extent.

3-3 Discussions on the Mixing State

3-3-1 Influence of Rotational speed : N (r. p. m.)

Experiments were carried out under the different conditions of rotational speed of ribbon (N), ratio of outer ribbon pitch to its diameter (P/D) and hold up (ϕ).

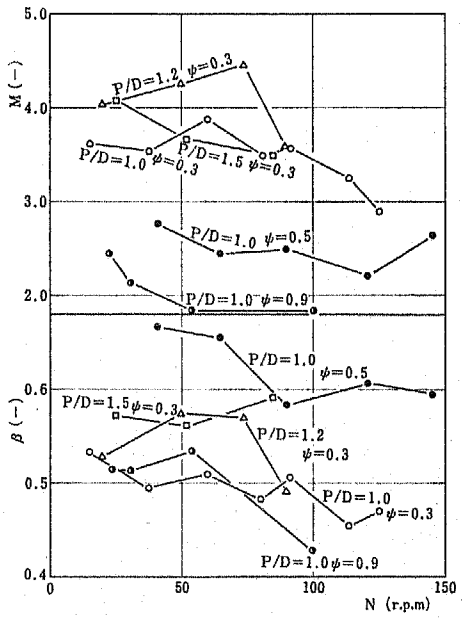

Fig. 6 Model parameters β and M vs. rotational speed N

Model parameters β and M are calculated from experimental results, and are plotted against rotational speed as shown in **Fig. 6**. Each point in the **Fig. 6** is average value of several experimental results obtained under the same conditions. In general, both β and M are slightly decreased with an increase in rotational speed, that is, the degree of mixing is lowered. It has been reported[2] that the treated amount of solid particles in the mixer is proportional to the 1.2 power of rotational speed. So, in order to treat a

large amount of solid particles, even if the degree of mixing may be decreased a little, large rotational speed should be required. On the other hand, if uniform mixing is desired, rotational speed must be small. However, although it is not so clear from **Fig. 6**, it has been known that the degree of mixing is lowered under the rotational speed of about 30 (r. p. m).[2] Therefore, the most preferable mixing operation must be carried out in the range of about 50 to 70 (r. p. m.).

3-3-2 Influence of Hold up : ψ (−)

To investigate the influence of hold up to mixing state, the values of β and M in the region of rotational speed of 50 to 70 (r. p. m.) are plotted against the hold up. The results are shown in **Fig. 7**.

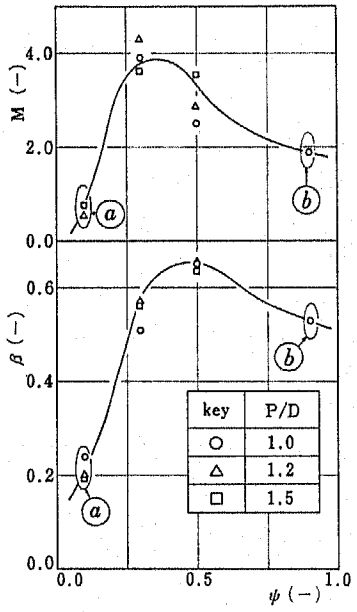

Fig. 7 Model parameters β and M vs. hold up ψ

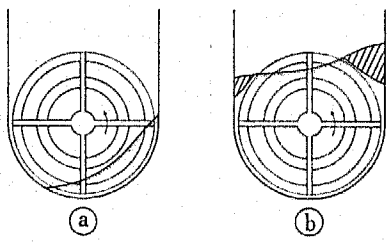

Fig. 8 Profiles in a mixing vessel
ⓐ : ψ=0.1, ⓑ : ψ=0.9

It is clear that both β and M are shown by convex curves against hold up, and they have maximum in the region of ψ=0.4 to 0.6. Uniform mixing can be expected in this range.

Previously it had been reported that the fluctuation of concentration in ribbon mixer was smallest at about ψ=0.4.[3] Also, the degree of mixing which calculated from the variation of consentration for definite time at the outlet of mixer was best in the same range.[3] The result in this study is

fairly agreed with these results in the previous report.

The outlines of profile of the mixer correspond to $\phi=0.1$ (ⓐ) and $\phi=0.9$ (ⓑ) in **Fig. 7**, are shown in **Fig. 8**. Considering the state of (ⓐ) in the **Fig. 8.** as regard to the model, side capacity part and mixing coefficient are both small (**Fig. 7**—ⓐ). On the other hand, at $\phi=0.9$, dead space, in which the solid particles are not mixed by ribbon, appears as shown by an oblique line in **Fig. 8**—ⓑ. So, volumetric ratio of side capacity to total volume of vessel is decreased. But solid particles in dead space are scarcely mixed, and they are moved toward outlet of mixer by the movement of the layer beneath of dead space.

In general, mixers are classified in rotary type as V-mixer and in fixed type as ribbon mixer mentioned in this report. In case of the later, mixing vessel is fixed and a agitator is rotated in it. By rotation of agitator such as a ribbon, solid particles are pushed toward the wall side of the vessel. Taking account of this fact, the appearance of the difference of concentration at any cross section of mixer is understood. Then the mixing mechanism in this mixer may be illustrated by the distribution side capacity model, in which difference of concentration can be assumed in direction of perpendicular to main flow only.

SUMMARY

In order to investigate the mixing mechanism and the influence of operational conditions to the mixing performance in a continuous mixer, some experiments have been carried out using a continuous ribbon mixer.

In this study, the mixing characteristics were investigated by impulse reponse method using Toyo-ura Standard Sand and sodium carbonate as tracer.

The results obtained are as follows.

1) "Distribution side capacity model" can be applied to the experimental response curves.

2) The results obtained using the model is fairly agreed with the results obtained from the previous experiments using the sampling method.

Acknowledgment

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Nomenclature

D=diameter of outer ribbon	(mm)
M=mixing coefficient of the model	(—)
N=rotational speed of a ribbon	(r. p. m.)
P=pitch of outer ribbon	(mm)
R=mixing resistance	(sec.)
t=mixing time	(sec.)
$\bar{t}$=average residence time	(sec.)
β=side capacity coefficient	(—)
ϕ=hold up	(—)
τ=dimensionless time	(—)

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