Mixing Method for a Micro Mixer by Vibrating the Flow Channel

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Abstract- Mixing in micro channels has attracted growing interest in chemistry and medical analysis. This research aims to develop a micro mixer that can mix high viscosity fluids. A new mixing method for micro mixers is described in the paper. In addition, we prototype a small mixer and evaluate its mixing characteristics. The prototype mixes two flowing fluids by vibrating the wall of the flow channel using a pneumatic actuator operated by a compressor air. The mixing process was observed under an optical microscope fitted with a CCD camera. High viscosity fluids were prepared by adding thickening agents to water. We determined the optimal mixing state by mixing fluids of two colors (red and green). The best mixing was achieved at an actuator pressure and frequency of 0.09MPa and 2.5 Hz respectively.

Keywords – Micro Mixer, Micro Reactor, Fluid Control Device

I. INTRODUCTION

A micro mixer is a device that mixes different fluids in a micro channel [1]-[2]. Because the surface contact area is much smaller in a micro mixer than batch type mixer, the time required for mixing is reduced and high speed mixing becomes possible. The mixer is also able to controlled precise mixing temperature so that a heating and cooling rate are fast. Furthermore, the time of processes such as chemical reactions is easily controlled in a micro mixer. On account of these characteristics, micro mixers have become increasingly popular in the fields of chemistry and medical analysis [3].

Our research group has previously developed a micro mixer that stimulates mixing by vibrating the thin metal plate in the micro channel. Vibration occurs as the thin plate becomes magnetized under an external magnetic field [4]. However, the vibrations may be disturbed by air bubbles entering the flow channel. When the vibration stalls, the thin plate adheres to the channel wall. Moreover, when the thin plate flows into the outlet, the mixer does not operate. This phenomenon observes more noticeable for higher viscosity fluids. Thus, it is necessary to take special care developing a micro mixer for high viscosity fluids. High viscosity fluids are generally mixed in batch mixers. However, the batch mixer is large and much mixing fluid is required. Consequently, proper mixing is difficult to achieve within a short time period.

Mixing in a micro channel is therefore considered necessary for mixing high viscosity fluids. For example, there is the mixing of two-part adhesives during industrial production processes [5]. The adhesive can then be cured within a short time by mixing the resin and hardener. However, incomplete mixing suffers under the influence of the adhesion effect. Our developed micro mixer has been confirmed to operate at viscosities up to 205 mP. However, the viscosities of two-component adhesives reach at least several hundred centipoise exceeding the viscosities tested in experiments of the developed mixer by more than 10 times. Therefore, previous mixing method by an electromagnetic force is maybe difficult. We propose a new mixing method to combine the high viscosity fluids in this paper. Section II introduces our prototype of the small mixer, and Section III evaluates its mixing characteristics. The paper concludes with Section IV.

II. MIXING DEVICE

A. Design of the flow channel

The thin film in the electromagnetic micro mixer vibrates when magnetized by a magnetic force. However, as mentioned in Section I, the vibrator is subject to several serious problems that can disrupt the mixing process. Our newly proposed method prompts the mixture to vibrate the flow channel wall. The vibration of wall surface is generated using a pneumatic actuator. Figure 1 shows the structure of the mixing flow channel created by the SolidWorks 3D CAD software. The pressure engages the projections in both walls of the flow path, encouraging mixing by shearing the fluid flow. Because the Reynolds number of the fluid is low in the micro channel, the flow tends to be laminar. In laminar flow, fluid elements mix by molecular diffusion alone. Previous studies have proposed micro mixers with fine grooves on the channel walls [6]-[7]. As the fluid passes through the flow channel, the fine grooves impose a secondary flow that enables mass transfer by convection. We considered that the mixing ratio could be improved by placing projections in the flow path of the mixing device. However, turbulent flows with high a Reynolds number are difficult to achieve in high-viscosity fluids. Thus, grooves alone cannot be expected to provide adequate mixing of viscous fluids. Conversely, when the channel walls are vibrated in the proposed design, turbulent agitation is likely to occur. The inner and outer diameters of the tubular section are 3.25 mm and 5.25 mm, respectively. The wall projections are spaced 2.0 mm intervals.

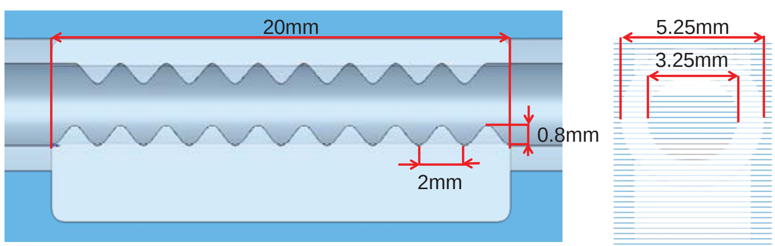


Figure 1. Mixing flow channel

B. Mixing equipment

As shown in Figure 2, the prototype consists of a mixing channel, an actuator for vibrating the flow channel, and a tool to fix them in place. This subsection describes the fabrication of the actuator and the flow channel.

The flow channel is made from silicone rubber which is sufficiently soft to be deformed by the external force. To accommodate two liquids, the channel of the electromagnetic micro mixers was built in a Y-shaped configuration in previous study. The same configuration was adopted in the new design. Because the silicone rubber must be poured into a mold, constructing a Y-shaped flow path from silicone rubber is a difficult task. Thus, once the mixing device was realized, a Y-shaped flow channel was constructed by connecting commercially available Y-fittings.

In this research, the flow channel was vibrated by a pneumatic actuator. The inner diameter of the flow channel with its 0.8 mm protrusions is approximately 3.25 mm. Thus, the required displacement of the actuator is approximately 2.45 mm. We fabricated the pneumatic actuator with a bellows which is made of low-density polyethylene. The bellows is cylindrical with a maximum diameter of 20 mm. We confirmed that when applied pressure in the bellows is increased, the bellows moves approximately 10 mm.

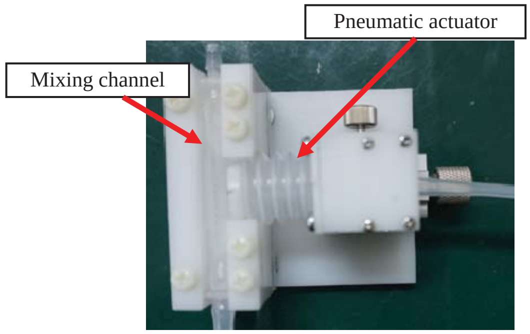


Figure 2. Mixing device with pneumatic actuator

III. EVALUATION OF THE MIXING METHOD

A. Experimental method

Figure 3 shows the configuration of the experiment. Compressed air sent to the actuator is controlled by air solenoid valve using a personal computer. We evaluated the mixing characteristics of the device. The behavior in the flow channel was captured under the USB microscope by a video camera and assessed by visual analysis. The flow was imaged near the outlet where no external force was applied. A high viscosity liquid was obtained by mixing sodium alginate and water. The viscosity of the liquid was 502 cP, which is close to the viscosity of some two-component adhesives [8]. In this experiment, the viscous liquid was colored red and green to observe the mixing behavior visually.

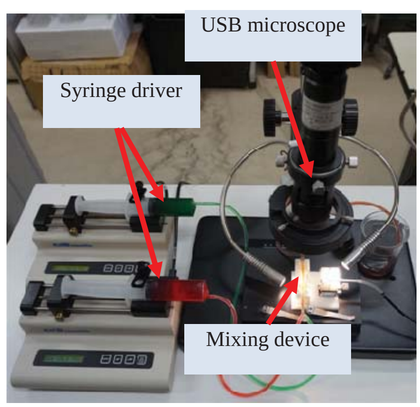


Figure 3. Configuration of the evaluation experiment

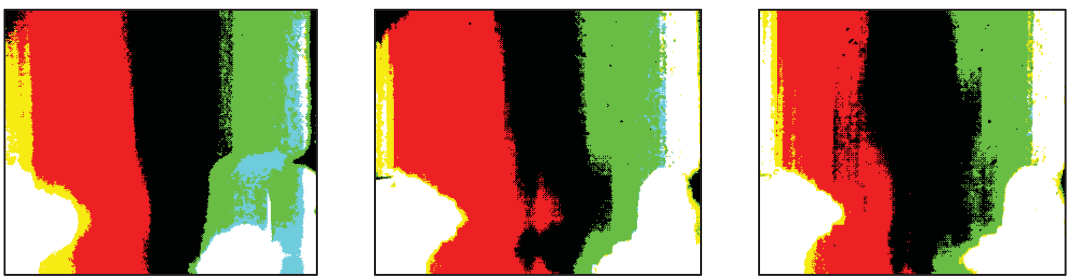
B. Evaluation of mixing characteristics

The mixing was evaluated under varying flow rate, air pressure and vibrational frequency. Measurements were taken in the outlet section of the mixing channel. The mixing state was visually observed, and the optimal mixing conditions were determined. The experimental results enhance contrast by performing image processing. Black Area indicates filled mixing zone and other area such as red and green indicates failed mixing zone too.

1) Change in pressure

Maintaining the flow rate at 10 ml/h, the pressure and frequency were varied in the ranges from 0.02 to 0.1 MPa and from 5 to 25 Hz, respectively. Under each set of conditions, twelve camera shots were obtained and the admixture was examined. At the lowest pressure as 0.02 MPa, the force is small and the flow path is insensitive to frequency.

The fluid behavior was essentially unaltered under this condition. The experimental results obtained at 5.0 Hz are shown in Figure 4. At this frequency, the amplitude of the wall vibrations of the channel increases, facilitating mixing as the fluid is pushed out from the raised portion. Under 0.1 MPa pressure, the amplitude of the pneumatic actuator is sufficiently large that strong mixing is obtained at reduced frequency. In contrast, little mixing was observed at 0.05 MPa, probably because the small force exerted insufficient pressure on the flow channel. At the intermediate pressure of 0.075 MPa, the fluids were more blended than at 0.05 MPa, but less mixed than at 0.1 MPa. The results suggest that increasing the frequency encourages mixing by increasing the amplitude of the vibrating channel. The best agitation is achieved at 0.1 MPa pressure. However, under 0.1 MPa, an extra piece was displaced to the exterior of the passage. Therefore, it is recommended that the pressure remains below 0.1 MPa. To determine the optimal pressure, the pressure was decreased from 0.1 MPa at 0.01MPa intervals, and the mixing state was examined. The mixing results were essentially unchanged at 0.09 MPa.

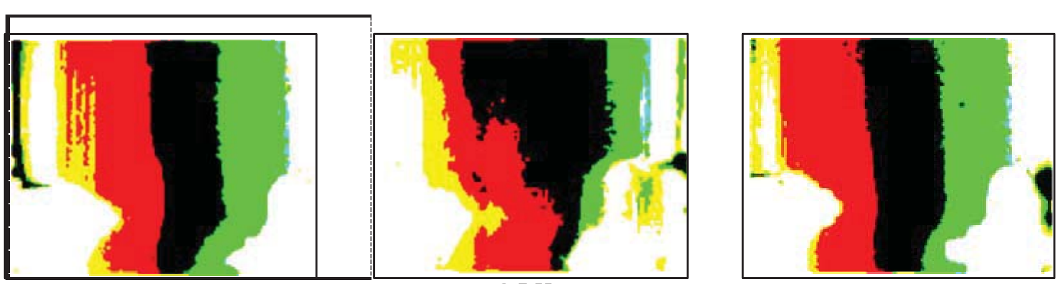


0.05 MPa　　0.075 MPa　　0.09 MPa

Figure 4. Observation of mixing under different pressures at 5.0Hz as applied frequency

2) Change in frequency

Next, the flow rate and air pressure was retained at 10 ml/h and 0.075 MPa, respectively, and the mixing state was evaluated at different vibration frequencies (3.5 Hz, 2.5 Hz, and 0.5 Hz). In the previous experiments, mixing was enhanced at small frequencies and was strongest at 5.0 Hz and 0.05 MPa. It is shown in Figure 4. The experimental results of the frequency experiment are shown in Figure 5. The best agitation state is observed at 2.5Hz, confirming that mixing is optimized at this frequency. The reduced mixing at 3.5 Hz is probably attributable to the smaller vibrational amplitude than at 2.5Hz. At 0.5 Hz, mixing is likely inhibited by the slow vibration.

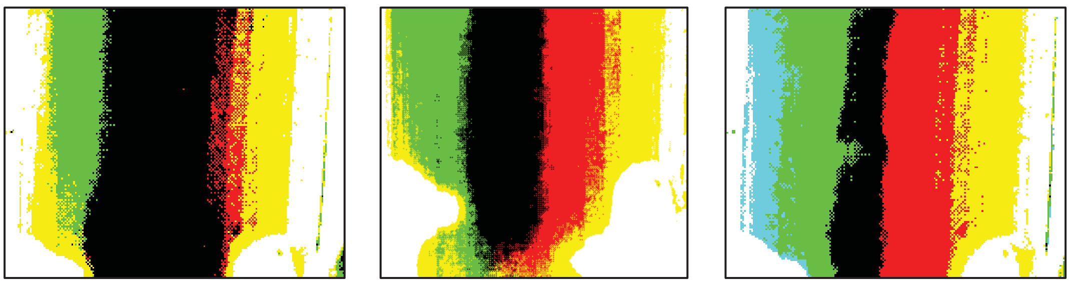


0.5 Hz　　2.5 Hz　　3.5 Hz

Figure 5. Observation of mixing at different applied frequencies

3) Change in flow rate

In this experiment, the mixing state was observed at different flow rates. The frequency and pressure were retained at the optimal mixing conditions (2.5 Hz and 0.09 MPa, respectively), and the flow rate was varied from 5 ml/h to 100 ml/h. The state of the fluid at the time of mixing was photographed by the video camera. The experimental results are shown in Figure 6. These results confirm that the external force largely affects the mixing at a low flow rate, but exerts a smaller effect as the flow rate increases. Low flow rates achieve stronger mixing than high flow rates. At a large flow rate, mixing is inhibited but may possibly be encouraged by increasing the frequency. However, the frequency investigation has already ruled out frequencies much higher than 2.5 Hz.



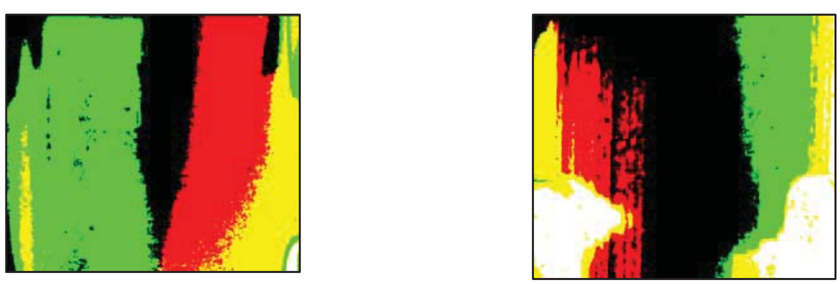
1 ml/h 10 ml/h 100 ml/h

Figure 6. Observation of mixing at various flow rates

4) Effect of projections in the flow channel

Finally, we investigated the effect of the protrusion formed in the flow channel. The flow channel is compared with commercial silicon tubing of inner and outer diameters 3.0 mm and 5.0 mm, respectively. The experimental conditions were as follows; the pressure is 0.09 MPa, the frequency is 2.5 Hz and the flow rate is 10 ml/h. The experimental results are shown in Figure 7. In the commercially available tube, the interface of the fluid did not substantially change even as the passage vibrated. In the fabricated flow path, vibration disturbed the flow and color mixing was confirmed. Subsection III (3) confirmed that a low flow rate facilitated mixing. Therefore, the tubing experiment was repeated at 0.09 MPa, 2.5 Hz and 1.0 ml/h.

In this experiment, mixing was achieved in both tube types, indicating that wall vibrations exert a mixing effect in the straight-walled tube. However, at the higher flow rate, mixing was small in the straight-walled tube. Therefore, the projections appear to improve the mixing efficiency in the flow passage.



Commercial tube Proposed tube

Figure 7. Comparison by the channel shape change

IV. CONCLUSION

We have developed a mixing device in which the flow channel walls are vibrated by a pneumatic actuator. The mixing characteristics were experimentally investigated. The requirement of mixing was optimized at a pressure of 0.09 MPa and vibrations of 2.5 Hz. Better mixing was obtained at a smaller flow rate. The shape of the flow path prioritizes the amplitude over the frequency of vibration, encouraging strong mixing. We confirmed that the churning effect of large-amplitude vibration was greater at low flow rates than at high flow rates. For the same reason, mixing is enhanced at low flow rates. Furthermore, when comparing the flow behavior in the straight-walled and bumpy-walled channels, the projections on the channel walls were found to improve the mixing. Although the air pressure-based mixing apparatus cannot completely mix two viscous fluids, the mixing can be improved by tuning the pressure, frequency, and flow rate, as confirmed in this study.

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