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Flow of a Liquid Crystal Mixture in a Mini-Cylinder under Rotating Electric Fields

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ABSTRACT

Flow visualization of a liquid crystal mixture in mini cylinders is conducted under application of the rotating electric fields. The mini cylinder with the electrodes on some parts of the inner surface of the cylinders is used. The cylinder is 1.0mm or 2.0mm in length and 1.1mm in diameter. The three-phase alternating currents and the rectangular wave voltages are used as the rotating electric fields. The frequency and the amplitude of the voltages are changed to investigate the effect of the unsteady electric fields on the flow phenomenon of the liquid crystal mixture. When the frequency and the voltage of the three-phase voltages are 60Hz and 260V the rotation speed of the liquid crystal is 14.3 r.p.m. On the other hand, when the frequency and the voltage of a rectangular wave voltage are 600Hz and 200V the rotation speed is 2.7 r.p.m.

KEY WORDS

Functional fluid, Liquid crystal, Rotating electric fields, Flow visualization

INTRODUCTION

Fluids whose rheological properties like an apparent viscosity can be controlled using electric or magnetic fields from outside are known as one of the functional fluids nowadays. Especially fluid whose properties can be controlled using the electric fields is said to be ER (Electro-rheological) fluids. Many research works about the welfare devices, the micro machine etc, as the application of the ER fluids have been performed. Liquid crystal is one of the homogeneous ER fluids without precipitation and therefore has high reliability. The area for the application using the liquid crystal is expanding and many applications are expected in the future.

The authors examined the influence of the electric fields on the flow of the liquid crystal mixture in the circular tube with the electrodes on some parts of the inner surface of the tube [1]-[3]. As a result, the influence of

the electric fields on the characteristics between the pressure drop and the flow rate of the liquid crystal mixture became clear when it flowed in the circular tube electrode. Furthermore, we found that the liquid crystal mixture flows in the peripheral direction in a mini-cylinder with three sets of electrodes on the inner wall under application of three-phase alternating currents as the rotating electric fields [4]. The facing electrodes have an equal electrical current potential. Namely the liquid crystal mixture in itself causes the flow under application of the unsteady electric fields. Development of a micro-motor is expected using the mechanism mentioned above, but the mechanism of the liquid crystal mixture generating a flow is unclear in the present stage.
In this study, the influence of the rotating electric fields on the flow of the liquid crystal mixture is examined in detail using two different cylinder electrodes. The inside diameter is smaller than the cylinder electrode made in a previous report [4]. The depths of the present mini-cylinder electrodes are 1 and 2mm. Especially the velocity distribution of the liquid crystal is investigated using PIV(Particle Image Velocimetry) processing. And we found that the liquid crystal mixture flows in the peripheral direction when the rectangular wave voltages are used as the rotating electric fields.

EXPERIMENTAL SETUP AND METHODS

In the present experiments, the liquid crystal mixture is used as one of the homogeneous ER fluid. This is the material that is mixed with some kinds of the nematic liquid crystals, and its viscosity is higher than the nematic liquid crystal. The liquid crystal mixture was supplied by MERCK Japan Co., Ltd. The isotropic nematic transition is 90.0 ℃ and smectic-nematic transition is − 44.0℃. The physical properties of the liquid crystal mixture used in the present study are shown in Table.1. Moreover those of the nematic liquid crystal are also shown in the same table.
Figure 1 shows a mini-cylinder of 1.1mm in inner diameter with the electrodes on the inner wall used in this experiment. Six electrodes are insulated every 0.2mm interval on the inner wall.
Figure 2 shows the experimental apparatus using three-phase alternating currents as the rotating electric fields to observe the flow of the liquid crystal mixture under the application of the electric fields. In this experiment, the electrodes facing each other have an equal electrical current potential. For example, the electrodes 1 and 4 have a same potential. The depth *d* is 1mm or 2mm.Three-phase alternating current shown in Figure 3 is applied on the electrodes in this cylinder electrode. The voltage curves ①, ② and ③ or ④, ⑤ and ⑥ come in that order. The voltage is applied in the clockwise direction from top view. Flow of a liquid crystal mixture in the cylinder is visualized in the axial direction using a commercially available digital video camera. In addition, the effective value of the voltage to add on the electrodes of 1mm or 2mm in depth is changed between 0 and 260V and the frequency is also changed between 0 and 60Hz according to the change of the effective value in this experiment. Based on the present restriction of our device to generate the electric fields, the frequency and the effective value can not be changed independently. In this study, the frequency means the frequency of one-phase alternating current and the voltage means the effective value.

Table 1 Comparison of physical properties

Physical properties	Liquid crystal mixture (MLC6650)	Nematic liquid crystal (K15)
Operating temperature region	-44～90℃	23.1～35.5℃
Kinetic viscosity	76mm^2/s	20mm^2/s (20℃)
Anisotropy of dielectric constant	52.6	14.3
Double refraction index	0.1498	0.1952

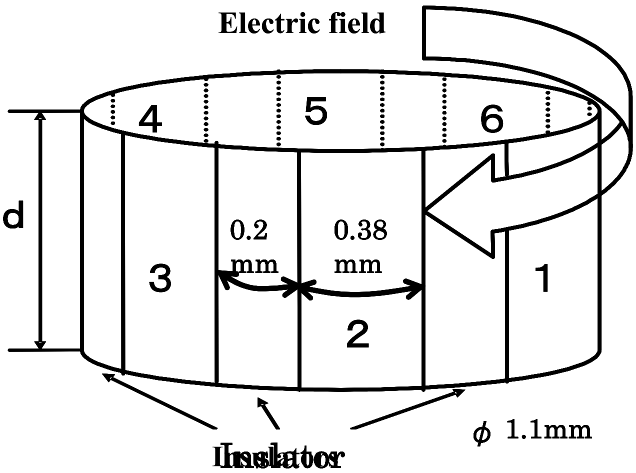

Figure 1 Mini-cylinder

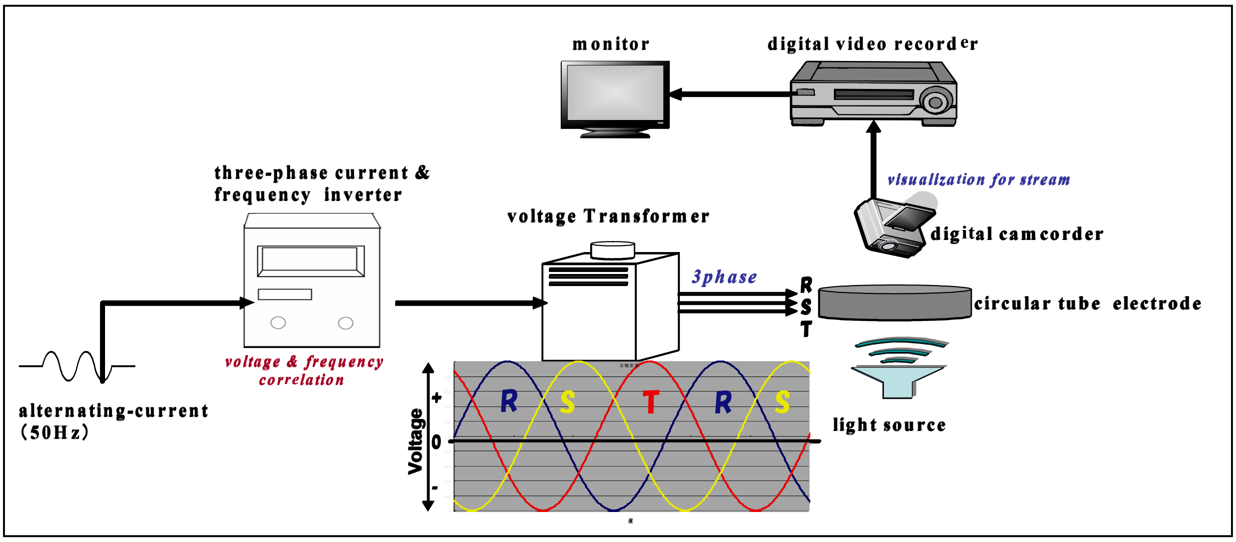

Figure 2 Experimental apparatus using three-phase alternating current

Figure 4 shows the experimental apparatus using the rectangular wave voltage as the rotating electric fields to observe the flow under the application of the electric fields. The electric field with 200V of maximum voltage rotates in the clockwise direction from a top view. For example, after the voltage is added between 1 and 2, it is added between 2 and 3, and so on. The frequency of 6Hz using a rectangular wave voltage means that the electric field rotates one round per a second. The frequency is changed between 0 and 1200Hz.

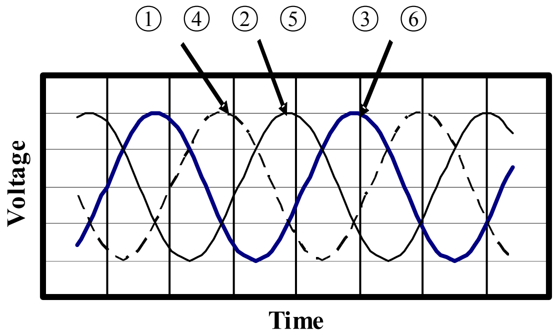

Figure 3 Three-phase alternating current

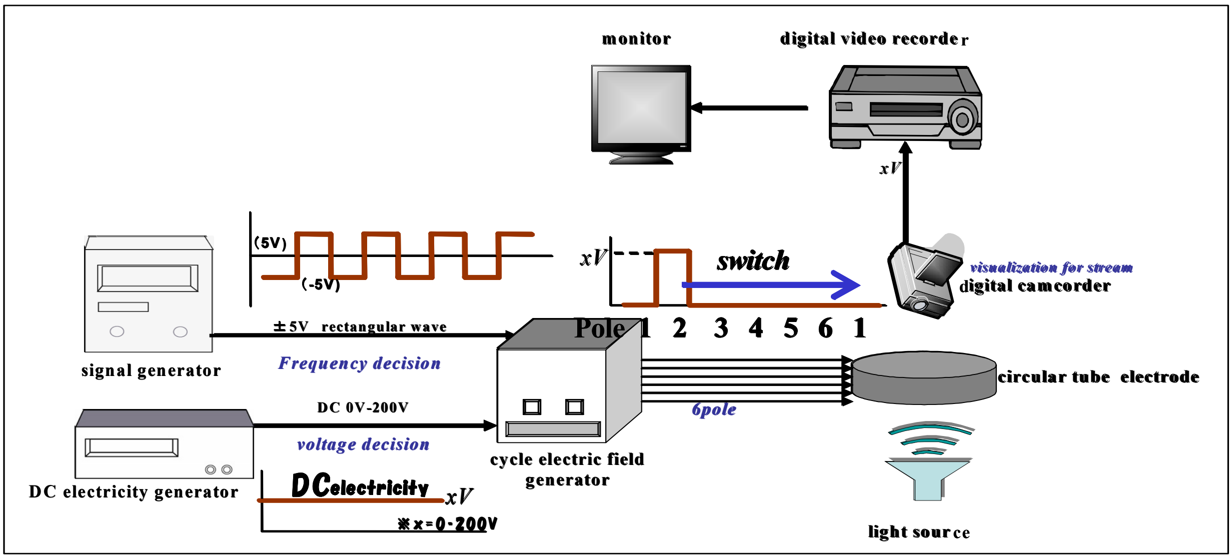

Figure 4 Experimental apparatus using rectangular wave voltage

EXPERIMENTAL RESULTS

Table 2 shows the flow states of the liquid crystal mixture when three-phase alternating currents are added on the electrodes in the cylinder with 1mm or 2mm in depth. The voltage is increased from 0 to 260V and the frequency is also increased from 0Hz to 60Hz according to the change of the voltage. In both the cylinder electrodes, the liquid crystal mixture does not flow without the electric field and it begins to flow when the electric field is applied on the electrodes. Furthermore, the frequencies of the voltage are about the same for two cases when the liquid crystal begins to rotate.

In addition, the flow visualizations under the application of the rectangular wave voltages in the circumference direction as a rotating electric field were conducted. Tables 3 and 4 show the results for *d* =1mm and 2mm. The rotating flow occurred for the rectangular wave voltage, but the rotational speed of the liquid crystal mixture for *d* =2mm is about 3 r.p.m. and is small compared with the case of three-phase alternating current.

We measured the rotational speed of the liquid crystal by observing a small air bubble moving in the circumference direction at 0.25mm of the radius from the visualized results using a commercially available digital video camera. The averages of the rotational speeds are shown in Figures 5 and 6. As a result, for both cases of *d* =1mm and 2mm, the rotational speed under the application of the three-phase alternating currents increased greatly from 51Hz as shown in Figure 5. And for *d* =2mm, the rotational speed under the application of the rectangular wave voltage increased greatly from 200Hz to 600Hz as shown in Figure 6. On the other hand, it is almost constant from 600Hz. And for *d* =1mm, the rotational speed under the application of the rectangular wave voltage did not change in the range of the present experiments. In addition, the liquid crystal mixture did not rotate from 1Hz to 800Hz in the case of *d* =1mm. So there is no experimental date of the rotation between 200Hz and 800Hz for d =1mm in Figure.6. The rotation speed for *d* =2mm is about twice as fast as for *d* =1mm between 800Hz and 1200Hz.

Furthermore, Figures 7 and 8 show the results analyzed using PIV(Particle Image Velocimetry) processing to obtain the velocity distributions. The liquid crystal mixture flows both in the circumference direction and the axial direction in the cylinder for *d* =1mm. On the other hand, it flows only in the circumference direction for *d* =2mm. In these figures, the smoothing processing is done several times to obtain only the velocity direction in the flow field.

Table 2 States under three-phase alternating currents (*d* =1mm, 2mm)

State	Frequency [Hz]	Voltage [V]	Remarks
Stationary	0	0	Stationary
Random	1-44	0-195	Liquid crystal mixture flows under electric field added.
Slow rotation	44-55	195-245	Liquid crystal mixture rotates slowly.
Fast rotation	55-60	245-260	Rotational speed is 7.9-14.3r.p.m.

Table 3 States under rectangular wave voltages (*d* =1mm)

State	Frequency [Hz]	Voltage [V]	Remarks
Stationary	0	200	Stationary
Random	1-800	200	Liquid crystal mixture flows under electric field added.
Slow rotation	800-1200	200	Rotational speed is 1.3r.p.m.

Table 4 States under rectangular wave voltages (*d* =2mm)

State	Frequency [Hz]	Voltage [V]	Remarks
Stationary	0	0	Stationary
Random	1-250	200	Liquid crystal mixture flows under electric field added.
Slow rotation	250-600	200	Liquid crystal mixture rotates slowly.
Fast rotation	600-1200	200	Rotational speed is 2.7r.p.m.

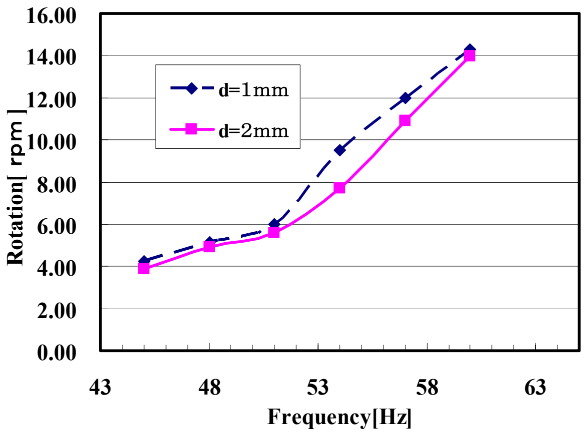

Figure 5 Rotational speeds per a minute (three-phase alternating currents)

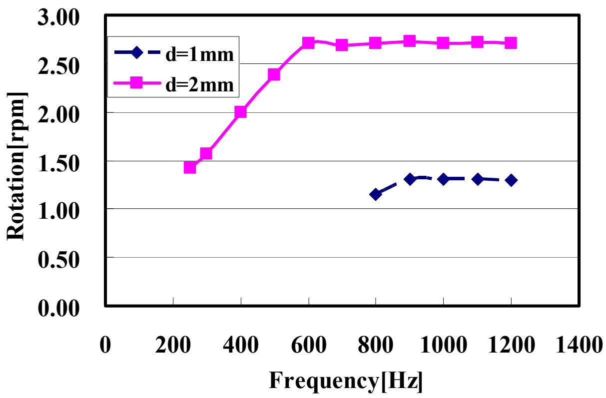

Figure 6 Rotational speeds per a minute (rectangular waves)

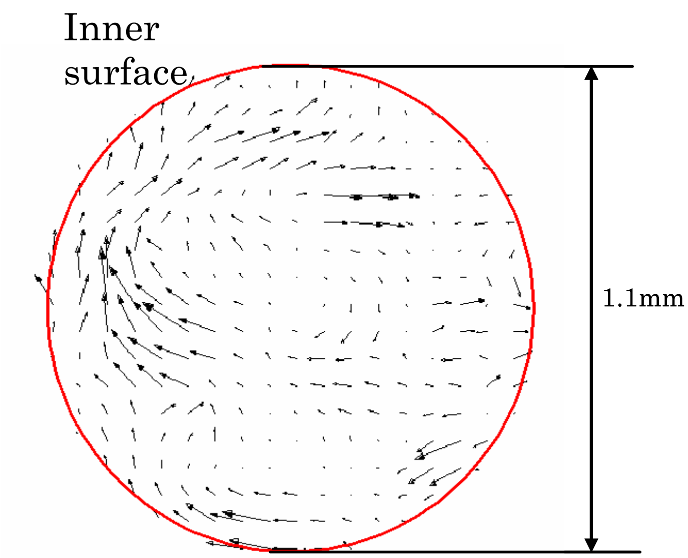

Figure 7 Results analyzed by PIV (*d* =1mm, three-phase alternating current)

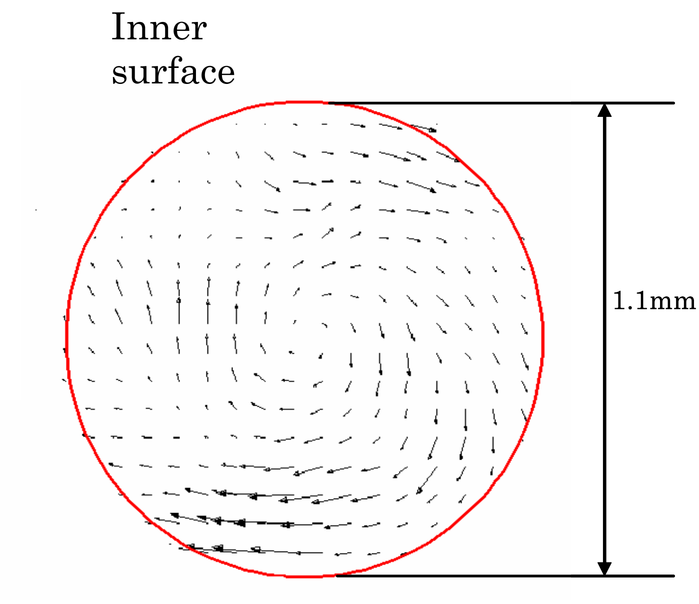

Figure 8 Results analyzed by PIV (*d* =2mm, three-phase alternating current)

CONCLUSIONS

In this study, we added the three-phase alternating currents and the rectangular wave voltages as the rotating electric fields on the liquid crystal mixture in the mini-cylinder with the electrodes to generate the flow in the circumference direction. Some main conclusions are shown below.

1. In both the cylinder electrodes for *d*=1mm and 2mm in depth under the application of the three-phase alternating currents, the liquid crystal mixture began to rotate when the frequency and the effective value of the voltage increased to 45Hz and 195V.
2. The liquid crystal mixture flows both in the circumference direction and the axial direction for *d* =1mm. On the other hand, it flows only in the circumference direction for *d* =2mm
3. Using the PIV processing, we analyzed the velocity distributions of the flow in the cylinder electrodes and can grasp the state of the liquid crystal mixture rotating.
4. The rotational speed of the liquid crystal mixture increases when the frequency and the effective value of the voltages increase in the range of the present experiments. The maximum rotational speed was about 14.3 r.p.m.
5. When the rectangular waves of the voltage were added as rotating electric fields on the liquid crystal, it rotates. However the rotational speed was smaller than that in the case of the three-phase alternating currents.

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REFERENCES

1. Tsukiji, T., Nakayama, K., Koyabu, E. and Mitani, T., Influence of electric fields on the flow of a liquid crystal mixture in a circular pipe with electrode surface, Preprint of the Japan Fluid Power System Society, 2003, autumn, pp.174-179. (in Japanese)
2. Tsukiji, T., Koyabu, E., Nakayama, K and Mitani, T., Influence of electric fields on the flow of a liquid crystal mixture in a circular pipe with electrode surface, Transactions of the Japan Fluid Power System Society, 2004, 35-5,pp.84-88.(in Japanese)
3. Tsukiji, T., Koyabu, E., Tsuji, T. and Chono, S., Flow characteristics of a liquid crystal mixture in the circular pipe electrodes, DVD Proceedings of First International Conference on Flow Dynamics, 2004.
4. Tsukiji, T., Ito, J. and Koyabu, E., Study on the flow of a liquid crystal mixture in a circular pipe electrode, Preprint of the Japan Fluid Power System Society, 2004, autumn, pp.38-40. (in Japanese)