A NEW MICROFLUIDIC DRIVE AND CONTROL METHOD BASED ON THE LIQUID CRYSTALLINE BACKFLOW

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Summary For the purpose of developing new micro fluidic drive and control method, the liquid crystalline backflow induced by electric field between two parallel plates was studied. The twist angle has an effect on the induced velocity profiles, and the magnitude of the shear stress acting on the plates depends on the applied voltage and the gap. The experimental results was consistent with the theoretical one.

INTRODUCTION

Along with the development of the micro fluidics system, especially the lap-on-chip technology, the micro fluidic drive and control technology in the micro or nano system has aroused the attention of researchers. More and more new ideas have been reported. In this study, we proposed a new method to drive and control the micro fluid based on liquid crystalline backflow effect. An attempt is made to investigate the mechanism and the influence factors of the backflow caused by the imposition of the electric field between two parallel plates, especially the coupling of the backflow and the director field. On the basis of the small molecule LC Leslie-Ericksen (L-E) theory and with the micro-fluid size and surface effect as reference, the micro-scale dynamic equations of LC can be established. As the actual measurement of liquid crystalline director inside the cell can not be achieved until now, the study method of numerical simulation supplemented by experimental verification is most appropriate.

NUMERICAL SIMULATION

Nematic liquid crystals have a microstructure where the positions of molecules are random like isotropic liquids but molecules are oriented in a certain direction. Hence, the nematic materials require an additional new variable, which indicates the local anisotropy. Theories which are accountable for the rheology of the nematic materials couple the molecular orientation and velocity fields. The L-E theory is the most elementary theory for nematic liquid crystals and in this theory, in order to express the long axes of neighbouring molecules, a unit vector **n** called director is introduced to represent the direction of preferred orientation. For the purpose to resolve the coupling of the backflow and the orientation field, the angular velocity of the director relative to surrounding rotation **N** has been used, which can be defined as

$$\mathbf{N} \equiv \frac{D\mathbf{n}}{Dt} - \mathbf{n} \cdot \frac{\nabla\mathbf{v} - \nabla\mathbf{v}^T}{2} \tag{1}$$

When a uniform electric field with intensity E(=constant) is applied in the y direction, as shown in Fig.1, no secondary flow is anticipated, and hence we set the y component of the velocity to 0. A no-slip condition for the velocity field was used at the plates. For the orientation field, when the polar coordinates of the director are expressed in terms of two angles $\theta(y)$ and $\phi(y)$, as shown in Fig.1, we define the tilt angle $\theta(0) = \theta(H)$ and the twist angle ϕ_w as $\phi(H) - \phi(0)$, where H is the gap between the upper and lower plates. In the simulation, we varied the twist angle form 0° to 180°and set the tilt angle to 5°. A finite difference method and the Crank-Nicolson method were used to discretize the governing equations. The basis of a preliminary computation, we selected $\Delta y = H/100$ and $\Delta t = 10^{-6}s$, in which Δy is the mesh size and Δt is the time step.

The computational parameters are the voltage V(=EH) applied to the liquid crystal and the gap H as well as the director boundary conditions. When we investigated the effect of a parameter, we fixed the other parameters to representative values of ϕ_w=0°,V=5V,and H=50 μm. A single-step change of the voltage form 0 to V was applied at t =0, then we kept the value of V constant. For initial values, we set V=0 in the entire computation domain and chose a one-dimensional equilibrium sulution without an electric field for the director orientation. In this computation, the material of 5CB was used, which is a low-molar-mass nematic liquid crystal[1].

RESULTS AND DISCUSSION

In the Fig.2-3 shows the angular velocity of the liquid crystal N_y and the profiles of the induced flow by the electric field in 0.24-0.36s, within this time the coupling of the director and the flow is the most dramatic. When ϕ_w= 0°(in Fig.2), in 0.2-0.30s, due to the anchoring effect of the plates, the value of N_y near the plates is smaller than the middle one, and the induced flow between the two plates is anti-S-shaped. As the flow rate increases, the coupling to the roattion of the liquid crystalline molecules becomes stronger, and due to a larger gradient of the velocity near the plates, the coupling is stronger. In addition, since the tilt angle in the middle of the plates becomes more than 45°, the effect of the electric field to the molecules turns to become weak, so from 0.3s, the value of N_y near the plates becomes more bigger than the middle one. The induced velocity continues to increase and reaches maximum of 30μm/s at 0.36s. Since the Z component of the director is 0 when ϕ_w= 0°, there is no velocity induced in the Z direction. When ϕ_w= 180°(in Fig.3), the anchoring effect and the coupling of the flow to the director changes, the N_y of the middle place increase for

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0.24-0.33s, so the induced flow velocity reaches a larger value of 65μm/s in the X direction and 33μm/s in the Z direction. So it can be say that the twist angle is the key factor of the coupling between the director rotation and the induced flow.

Fig.4 shows the effect of applied voltage and the gap to the shear stress acting on the upper plate, here we choose the twist angle as a common parameter. We can see that with the increasing of the voltage, the stress increases. On the contrary, when the gap becomes bigger, the stress decreases. The twist angle has little effect on the stress.

The experimental verrification result of the velocity profile was shown in Fig.5, the vertical axis is the relative position of the particle, and the abscissa is the maximum measured velocity. Each point was measured for ten times, the range was given in dashes and the hollow ciecles showed the average values. In contrast, the theoretical curve was also shown. From the result, it can be say that the experimental value is entirely consisitent with the theoretical calculation.

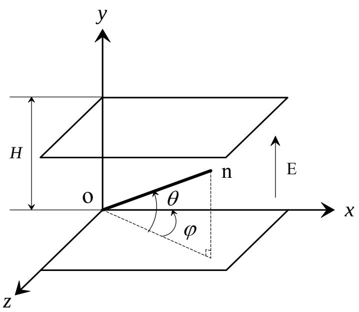

Fig.1 Flow geometry and coordinate of the director

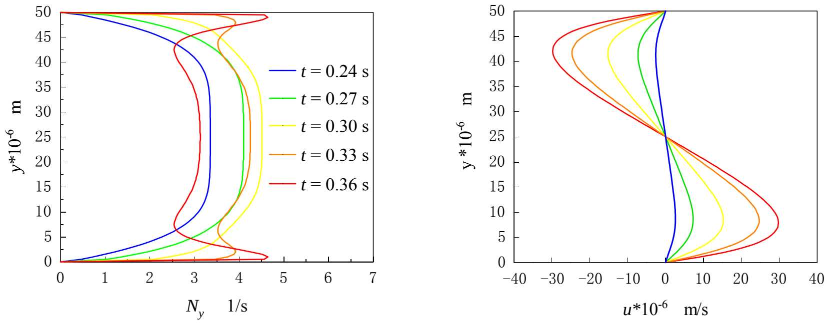

Fig. 2 The profiles of the director rotation rate N_y and induced flow velocity u ($\phi_w = 0°$)

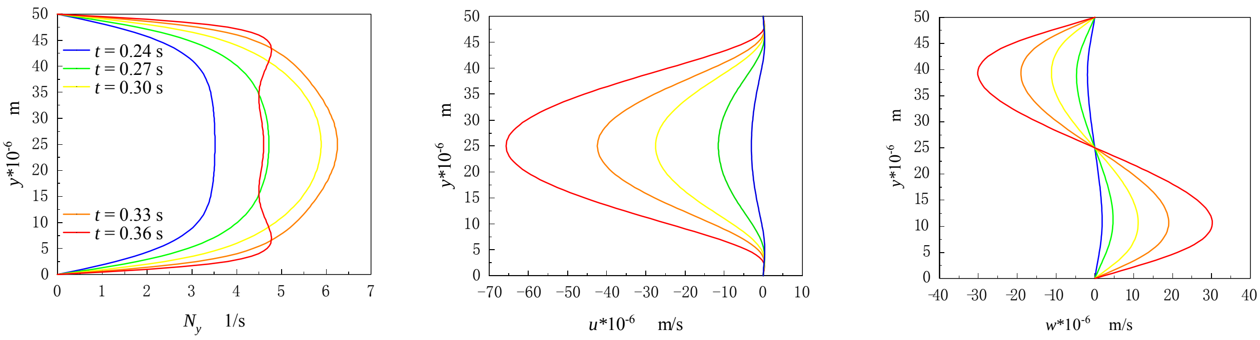

Fig. 3 The profiles of the director rotation rate N_y and induced flow velocity u ($\phi_w = 180°$)

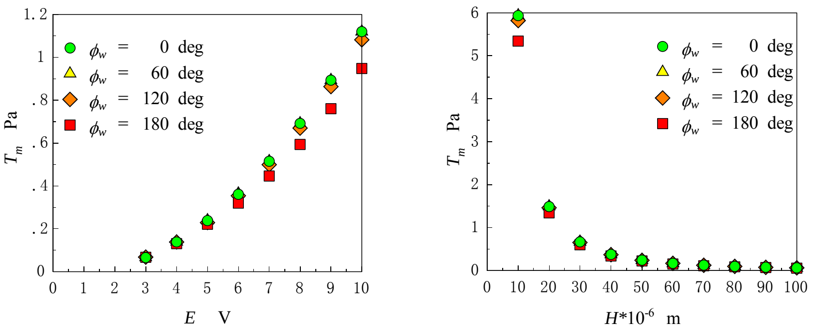

Fig. 4 The effect of the applied voltage and the gap

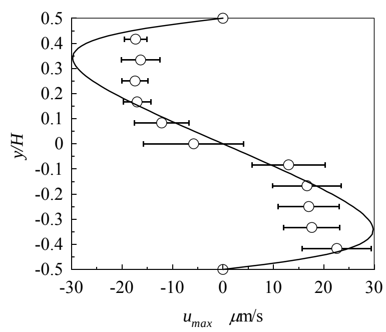

Fig. 5 Contrast with the experiment results

CONCLUSIONS

It is found that the liquid crystalline backflows induced by the electric field strongly depend on the twist angle and the applied voltage. An ideal flow can be obtained by selecting the proper parameters, so it can be used as a new method in micro fluidic field.

References

[1] De Gennes P.G., The physics of liquid crystals, 2nd, Oxford Clarendon Press, London.