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Hele-Shaw Cell Experiments of Viscous Fingering and Bubble Motion in Polymer Solutions

三重大工　川口正美（Masami Kawaguchi）

Faculty of Engineering, Mie University

Viscous fingering phenomena is a kind of far from equilibrium pattern formation and its pattern is developed by an instability during the displacement of a more viscous fluid by a much less viscous one in a narrow gap between two parallel rigid walls (Hele-Shaw cell). The dynamics of the viscous fingers observed in the flow of Newton fluids in the Hele-Shaw cell is now well understood.[1-3)]

The motion of bubbles in a Hele-Shaw cell has drawn much interest recently in conjunction with remarkable shapes and unexpected translational velocities at certain flow conditions.[4)] The basic transport equation for the gap averaged flow in the viscous fingering as well as in the bubble motion is given by Darcy's law.

Since non-Newtonian fluids, such as polymer solutions, suspensions, and emulsions produce branched, fractal, and fracture-like patterns in the viscous fingering due to the viscoelastic characteristics of theses fluids, understanding is far from complete.[5-13)] On the other hand, few works of the bubble motion in polymer solutions were reported.

Here, we investigate the viscous fingering in different geometry Hele-Shaw cells filled with aqueous solutions of hydroxypropyl methyl cellulose (HPMC) as functions of the molecular weight and concentration of HPMC. Moreover, we study the bubble motion in dilute HPMC solutions.

When the concentration of HPMC was less than its overlapping concentration, the observed fingering patterns in a radial cell were similar to the tip-splitting ones observed for Newtonian fluids. Above the overlapping concentration, the HPMC solutions showed a dense-branching pattern, suggesting that the dense-branching pattern is due to the viscoelastic properties resulting from the chain entanglements.

Addition of isopropyl alcohol (IPA) to the HPMC solution leads to a poor solvent quality, since IPA is a non-solvent for HPMC. With an increase in the IPA content it can be expected that a HPMC chain makes a more compact form and its elastic property should become weaker, leading to a morphological transition of the viscous fingering pattern from dense-branching pattern to tip-splitting one.[8)]

An increase in the molecular weight of HPMC can easily yield chain entanglements, which lead to a higher elastic modulus and a shear thinning onset at a lower shear rate. The highest molecular weight HPMC solutions showed stronger shear thinning behavior than the lower HPMC ones. They exhibited continuous changes in the morphology of the finger pattern from dense-branching to skewering pattern via tip-splitting with an increase in the injection pressure. On the other hand, the lower molecular weight HPMC solutions showed the dense-branching pattern, irrespective of the injection pressure.[10, 13)]

Anisotropy in the linear cell induced larger finger velocity and thinner finger width, irrespective of HPMC concentration, is due to predominant direction of the finger growth. For the weak chain entanglements at the intermediate HPMC concentration, the pattern morphology changes occurred near the specific shear rate, above which shear thinning is observed in the plot of steady-state shear viscosity against shear rate of the corresponding HPMC solution. On the other hand, at the highest concentration where strong chain entanglements are subjected, branched finger patterns were observed in the isotropic cell and appearance of the side branching pattern occurred in the anisotropic cell, irrespective of the injection pressure.[11,12]

The finger velocities were proportional with the ratio of the pressure gradient to the shear dependent viscosity of the more viscous fluid, irrespective of the pattern morphology and the cell.[14]

For the motion of an air bubble in HPMC solutions, the time evolution of shape and migration speed of the bubble were determined. The oblate and prolate drops were characterized by negative and positive values of the deformation parameter. An increase in the HPMC concentration led to changes in the drop shape from the oblate ellipsoid and the circle and to a decrease in the migration speed of the bubble. This indicates that adsorption of HPMC onto the surface of the air bubble renders the bubble a solid-like sphere. By adding IPA to the HPMC solution, the drop deformed into a oblate shape and its migration speed became larger since some parts of the adsorbed HPMC were desorbed from the bubble surface.

References

1. T. Vicsek, *Fractal Growth Phenomena*, World Scientific, Singapore 1992, p.302.
2. P. Meakin, *Fractals, Scaling, and Growth far from Equilibrium*, Cambridge University Press, Cambridge, 1998, p.44.
3. K. V. McCloud and J. V. Maher, *Phys. Rep.* **260**, 139 (1995).
4. *Drops and Bubbles in Interfacial Research*, D. Mobius and R. Miller (Eds.), Elsevier, Amsterdam, 1998.

5. H. Van Damme and E. Lamaie, in: *Disorder and Fracture*, J. C. Charnet, S. Roux, and E. Guyon (Eds.), Plenum, New York 1986, p.83.

6. H. Zhao and J. V. Maher, *Phys. Rev. A* **45**, R8328 (1992); *Phys. Rev. E* **47**, 4278 (1993).

7. D. Bonn, H. Kellay, M. Ben Amar, and J. Meunier, *Phys. Rev. Lett.* **75**, 2132 (1995); *Physica A* **220**, 60 (1995).

8. K. Makino, M. Kawaguchi, K. Aoyama, and T. Kato, *Phys Fluids* **7**, 455 (1995).

9. D. Bonn and J. Meunier, *Phys. Rev. Lett.* **79**, 2662 (1997).

10. M. Kawaguchi, K. Makino, and T. Kato, *Physica D* **109**, 325 (1997).

11. M. Kawaguchi, A. Shibata, K. Shimomoto, and T. Kato *Phys. Rev. E* **58**, 785 (1998).

12. M. Kawaguchi, S. Shimomoto, A. Shibata, and T. Kato, *Chaos* **9**, 323 (1999).

13. M. Kawaguchi, K. Makino, and T. Kato, *Kagaku Kogaku Ronbunshu* **25**, 516 (1999).

14. M. Kawaguchi, *Macromolecular Symposia,* in press.