Finger Growth in Surfactant Solution in Hele-Shaw Cells

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1 Introduction

We studied the viscous fingering in surfactant solutions in a square and a rectangular Hele-Shaw cells. The test fluids are aqueous solutions of CTAB with excess of NaSal as a counter ion. When excess of counter ion is added into a solution of CTAB, worm-like micelles form network structures and the solution shows interesting flow behaviors, e.g. existence of bending points in flow curves [1]. Various growth patterns were observed in radial growth. We observed also a sudden finger protrusion from a cuspidate shaped finger tip and investigated the relation between characteristics of the CTAB/NaSal solution and this finger tip motion.

2 Experimental Methods and Test Fluids

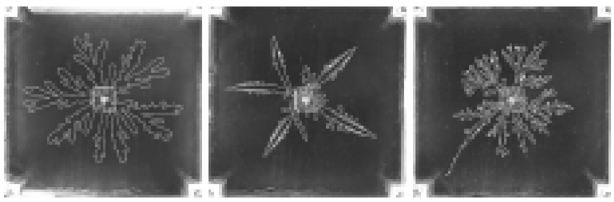
The cell is filled with a CTAB/NaSal solution, air is injected into the cell at a constant pressure p_{in}, and the growth of fingers are recorded with digital video cameras. We used several cells different in the cell thickness H. Two test fluids were employed: The ratio of mol concentration of CTAB (C_d) to that of NaSal (C_s) is kept to 1 to 7.7 and C_d is different for each fluid, i.e. C_s = 0.05, 0.04 and 0.03 mol/l for Fluids A, B, and C, respectively.

3 Results and Discussion

Figure 1 shows fingering patterns of the radial growth for Fluid B in the square cell of H=0.2 mm. The patterns are classified into three types, which correspond to Figs. 1(a), (b), and (c). Fingers of type a have round tip shapes and form high density structures. In the case of type b, fingers grow linearly and surface instability appears on the side face of fingers. For type c, fingers repeat splitting and form a highly branched structure.

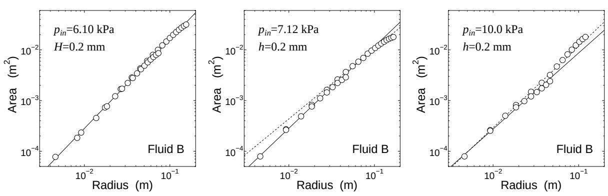
We dimensionally analyzed the patterns as shown in Fig. 2. The relation between the area of air A within a circle with a radius r centered on the inlet is described as $A \sim r^D$. The value of D lies between 1 and 2 and is large for high density structure and small for linear one: D is estimated as 1.75 for Fig. 2(a), 1.38 to 1.61 for Fig. 2(b), and 1.50 to 1.60 for Fig. 2(c). D is constant for type a, while in the cases of types b and c, the dimension changes during the finger growth: D increases in process of finger growth for type c, which means the structure changes from less branched pattern to more branched one. In the case of type b, no tendency was found in the change in D. The fingering pattern changes from high density structures to linear growth or from linear growth to highly branched structures with increasing the pressure gradient.

In Fig. 1(c), sudden protrusions from a cuspidate shaped finger tip were observed. We carried out experiments using a rectangular cell to clarify the relation of this phenomenon to characteristics of the CTAB/NaSal system. The experimental results indicate that the shear rates at which the sudden protrusion occurs are similar to that at bending points in flow curves [1].



(a) (b) (c)

Figure 1: Fingering patterns for Fluid B at H=0.2 mm: p_{in} = (a) 6.10, (b) 7.12, and (c) 10.0 kPa



(a) (b) (c)

Figure 2: Dimensional analysis for Fluid B at H=0.2 mm: p_{in} = (a) 6.10, (b) 7.12, and (c) 10.0 kPa

References

[1] T. Hashimoto et al., Nihon Reoroji Gakkaishi **33** (2005) 1.