Anomalous Phenomena of Rod-Like Micelle Surfactant Solutions Passing through Small Orifices

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Introduction. Drag reduction by surfactant solutions is well-known. However, the characteristic length was relatively large. On the other hand, small-scales were easily made with MEMS. It was important for fluid mechanics but limited. Additionally, many previous studies have used pipes. Studies of flows through orifices were rare cases. In this study, pressure drops of rod-like micelle surfactant solutions were measured owing to investigating flow properties in abrupt contraction and expansion flows with diameters ranging from 100 μm to 1.0 mm.

Test Fluids. Deionized water (electric conductivity = 0.055 μS/cm; RFD240NC, ADVANTEC Co Ltd) and surfactant solution (Cocoyl Alkyltrimethyl ammonium chloride; Lipoquad C-50, MW = 320.0 g/mol, Lion Specialty Chemicals Co Ltd) with counter-ion (sodium salicylate; NaSal, MW = 160.1 g/mol, Wako Pure Chemical Industries Co Ltd). Molar concentration of Lipoquad is $C_s = 1.0 \times 10^{-1}$ mol/L. The molar concentration of NaSal is $C_c = 1.0 \times 10^{-1} \sim 1.0 \times 10^0$ mol/L because the molar concentration ratio ($\varphi = C_c/C_s$) was adjusted to range from 0.10 to 10. Moreover, viscosities ($\eta$) were measured by capillary-viscosimeter. A power-law relationship was assumed: $\eta = m(SR_w)^n$, where $SR_w$ is wall strain rate, $m$ is dilatant viscosity, and $n$ is power-law index. The detailed data is omitted. Water and all surfactant solutions exhibited Newtonian viscosity and non-Newtonian viscosity, respectively. Also, density is used as water value.

Experimental Apparatus. The experimental apparatus for measuring pressure drops is shown in Fig. 1. The test fluids were transported from a syringe pump (JP-H1, Furue Science Co. Ltd., Japan) to the acrylic channel (inner diameter; 25 mm, length; 180 mm) at a constant flow rate ($Q$). A small orifice (diameter $D = 100 \mu m \sim 1000 \mu m$) was attached to the channel. The pressure drop ($\Delta p$) was measured with a pressure transducer (SPX-D, SDP-12, Tsukasa Sokken Co Ltd).

Experimental Results. The experimental results of $D = 100 \mu m$ are shown in Fig. 2. The vertical axis is dimensionless pressure drop ($K$) and the horizontal axis is Reynolds number ($Re$) or generalized Reynolds number ($Re^*$, Eq. (1)).

$$Re^* = \frac{\rho V^{2-n} D^n}{m \left( \frac{3n+1}{4n} \right)^{n-1}}$$

Good agreement between the experimental results of water and the predictions is obtained. However, the experimental results of Lipoquad $\varphi = 1.0$ did not agree with the predictions. Moreover, Lipoquad of only $\varphi = 1.0$ exhibited these anomalous phenomena.

Discussion. For understanding the resultant pressure drops, we visualized and observed flow behaviors before small orifice. The unstable flow of only $\varphi = 1.0$ was investigated at upstream. We briefly concluded anomalous phenomena were caused by this behavior.

Concluding Remarks. We experimentally measured pressure drops of rod-like micelle surfactant solutions with constant flow rates. The molar concentration ratio of 1.0 exhibited a pressure drop increase. Furthermore, we discussed flow behavior at upstream before small orifice.

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