RHEOLOGICAL ANALYSIS OF CAPSULE SUSPENSIONS CONTAINING DIFFERENT SIZE CAPSULES

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A particle that has an inner fluid enclosed by a thin elastic membrane is called a capsule. This structure is found in red blood cells and polymer coated medicines. Many studies have been conducted to reveal the rheology of capsule suspensions for industrial and biomedical applications. In a real system, there is a size distribution of capsules with a capsule suspension. However, few studies have focused on the effect of such a size difference on the rheology of capsule suspensions. In this study, we numerically investigate suspensions containing capsules of two different sizes under simple shear flow.

We consider a capsule suspension under Stokes flow. We use a method developed by Matsunaga et al.[1], which applies GPU computing to a method coupling of the finite element method and boundary element method proposed by Walter et al.[2]. The membrane obeys the Skalak constitutive law, and bending moments in the membrane ignored. The capillary number $Ca = \mu_f \dot{\gamma} a/G_s$ is a non-dimensional number which escribes the ratio between the viscous, and elastic forces where $\mu_f$ is the viscosity of the fluid, $\dot{\gamma}$ is the shear rate and $G_s$ is the shear elastic modulus of the membrane. We fix $Ca$ of large and small capsules as $Ca_l = Ca_s = 1.0$. Under a given volume fraction of capsules $\phi$, we change the ratio of small capsules to total capsules $R_\phi = \phi_s/\phi$ or the radius ratio of a small capsule to a large capsule $Ra = a_s/a_l$. We show examples of the simulation in Figure 1. The apparent shear viscosity $\eta$ can be described by $\eta = \mu_f + \mu_p$, where $\mu_p = \Sigma_{ij}^p/\dot{\gamma}$ is the increased viscosity due to the existence of capsules. Here, $\Sigma_{ij}^p$ is the particle stress tensor, and can be expressed by

$$\Sigma_{ij}^p = \frac{1}{V} \sum_{n=1}^{N} \int_{A_n} \left\{ \frac{1}{2} (x_i q_j + q_i x_j) \right\} dA_n,$$

(1)
where $V$ is the volume of the computational domain, $x_i$ is a position coordinate, $q_i$ is a point force, $N$ is the number of capsules in the domain and $A_n$ is the surface area of a capsule membrane.

Figure 2 shows $\mu_p$ for $Ra = 0.5$ as a function of $R_\phi$, where $\mu_p^{\text{ref}}$ is the value at $R_\phi = 0.0$ and angle brackets denote the time-averaged value. Because $Ca$ is the same for both large and small capsules, monomodal cases ($R_\phi = 0.0, 1.0$) show the same value. On the other hand, in bimodal suspensions, $\mu_p$ drops by a few percent, and this tendency becomes stronger at higher values of $\phi$. Figure 3 shows $\mu_p$ as a function of $Ra$ for $R_\phi = 0.5$. We found that the reduction of $\mu_p$ in bimodal suspensions becomes larger when $Ra$ is smaller; for example, it decreases by approximately 10% at $Ra = 0.3$.

Figure 1: The snapshots of the numerical result for $\phi = 0.4$. (a)$R_\phi = 0.0$. (b)$R_\phi = 0.25$. (c)$R_\phi = 0.5$. The bright zone is the original computational domain.

Figure 2: The fluctuation component of the shear viscosity $\mu_p$ as a function of $R_\phi$. Each value is normalized by the value at $R_\phi = 0.0$, and $Ra$ is fixed at 0.5.

Figure 3: The fluctuation component of the shear viscosity $\mu_p$ as a function of $Ra$. Each value is normalized by the value at $Ra = 0.0$, and $R_\phi$ is fixed at 0.5.

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