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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 μ_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 ϕ, 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 η can be described by $\eta = \mu_f + \mu_p$, where $\mu_p = \Sigma^p_{12}/\dot{\gamma}$ is the increased viscosity due to the existence of capsules. Here, Σ^p_{ij} is the particle stress tensor, and can be expressed by

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

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 μ_p for $Ra = 0.5$ as a function of R_ϕ, where μ_p^{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, μ_p drops by a few percent, and this tendency becomes stronger at higher values of ϕ. Figure 3 shows μ_p as a function of Ra for $R_\phi = 0.5$. We found that the reduction of μ_p in bimodal suspensions becomes larger when Ra is smaller; for example, it decreases by approximately 10% at $Ra = 0.3$.

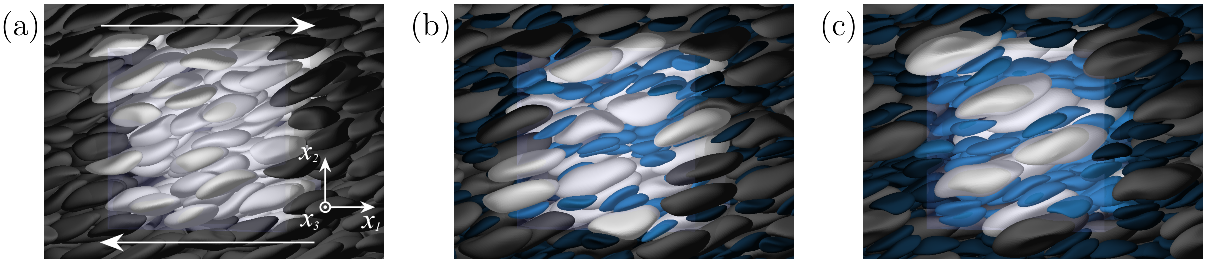

Figure 1: The snapshots of the numerical result for $\phi = 0.4$. (a)$R_\phi = 0.0$. (b)$R_\phi = 0.25$. (c)$R_\phi = 0.5$. The bright zone is the original computational domain.

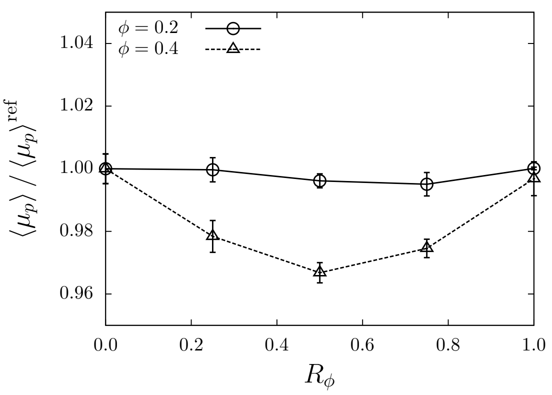

Figure 2: The fluctuation component of the shear viscosity μ_p as a function of R_ϕ. Each value is normalized by the value at $R_\phi = 0.0$, and Ra is fixed at 0.5.

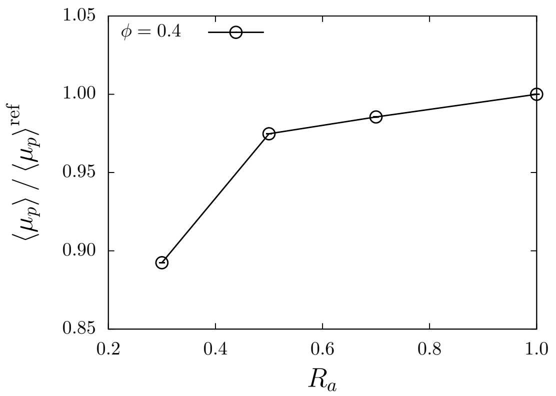

Figure 3: The fluctuation component of the shear viscosity μ_p as a function of Ra. Each value is normalized by the value at $Ra = 0.0$, and R_ϕ is fixed at 0.5.

REFERENCES

[1] D. Matsunaga, Y. Imai, T. Omori, T. Ishikawa and T. Yamaguchi. submmited.

[2] J. Walter, A.-V. Salsac, D. Barthès-Biesel and P. Le Tallec. Coupling of finite element and boundary integral methods for a capsule in a Stokes flow. *int. J. Numer. Meth. Eng.* **83**, 829-850, 2010.