Layering phenomena driven by rotating magnetic field in ferrofluid

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ブラウン動力学シミュレーションを用いて、回転磁場の下で磁性流体の凝集過程を調べた。その結果、ある振動数と濃度の範囲で、シート構造を形成することを発見した。

1 Introduction

It is known that electro-rheological (ER) and the magneto-rheological (MR) fluid consist the sheet-like constructions when subjected to the rotation of electric or magnetic field in the current research [1][2]. As for ER and MR, the moment of each particle synchronizes with the external field because of the induced dipole and paramagnetic character. On the other hand, the ferromagnetic colloid, the moment of the particle synchronizes with the torque of the suspension, which causes phase shift between the particle and the external magnetic field. In this paper, we examined whether the magnetic fluid (MF) causes a sheet-like formation under the rotating field by using the computer simulation.

2 Model

A model ferrofluid system used here is supposed to consist of N interacting, uniformly sized magnetic particles, suspended in an incompressible Newtonian fluid of viscosity η. The model ferrofluid is embedded in a cubic of size $L_x \times L_y \times L_z$ Each particle is assumed to be an identical sphere of hydro dynamical radius a, involving coating layer by surfactants. Each particle has also a permanent magnetic dipole moment $m_0\vec{n_i}$, located at its center of mass position $\vec{r_i}(1 < i < N)$. A rotary magnetic field $\vec{H}(t) = H_0(\hat{\mathbf{x}} \sin \omega t + \hat{\mathbf{y}} \cos \omega t)$ is imposed. The equations of motion of $\vec{r_i} = x_i\hat{\mathbf{x}} + y_i\hat{\mathbf{y}} + z_i\hat{\mathbf{z}}$ (translational motion) and $\vec{n_i}$ (rotational motion) for interacting spherical magnetic particles can be described as [3]

$$\frac{d\vec{r_i}}{dt} = \dot{\gamma} z_i \hat{\mathbf{x}} + \frac{1}{\xi_t}[\sum_{j(\neq i)}^{N} (\vec{F}_{ij}^1 + \vec{F}_{ij}^2)], \tag{1}$$

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$$\frac{d\vec{n}_i}{dt} = [\frac{\dot{\gamma}}{2}\hat{\mathbf{y}} + \frac{1}{\xi_r}(\sum_{j(\neq i)}^{N} \vec{T}_{ij}^1 + \vec{T}_{ij}^2)] \times \vec{n}_i, \tag{2}$$

where $\vec{F}_{ij}^1$ is the force acting on the i-th particle due to the dipolar interaction interaction between particles i and j, $\vec{F}_{ij}^2$ is the short range repulsive force due to surface surfactants, and $\vec{T}_{ij}^1$ the torque due to the dipolar interaction, with the translational drag force coefficient $\xi_t \equiv 6\pi a\eta$ and the rotational drag force coefficient $\xi_r \equiv 8\pi a^3\eta$.

We introduce scale units of some physical quantities: the unit of length as a, the resulting equations have two dimensionless parameters: $\gamma_0 t_0$ and $\omega_0 t_0$. Using these dimensionless parameters is convenient to study the parametric properties of the model system.

3 Simulation Result

We have studied the microstructure formation in ferrofluid under certain range of ω and ϕ. The sheet formation can be observed with conditions $0.1 < \omega < 2$ and $0.01 < \phi < 0.1$ (Fig.1).

In the result of our simulation, a particle rotates respectively in the sheet though the experiment result shows that the sheet rotates as a whole after the particles aggregate.

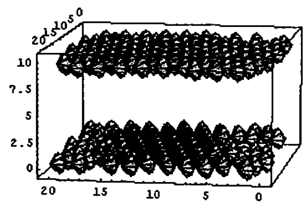

Figure 1: a snapshot of $\phi = 0.1$, $\omega = 0.1$ at 10,000stp

In our MF model, we obtained for the sheet-like structure in the rotating magnetic field same as in the ER fluid. For the extensive study, we propose to develop further study of focusing on the cluster dynamics model.

References

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