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Front Aggregation and Labyrinthine Pattern in the Drying Process of Water-Granule Systems

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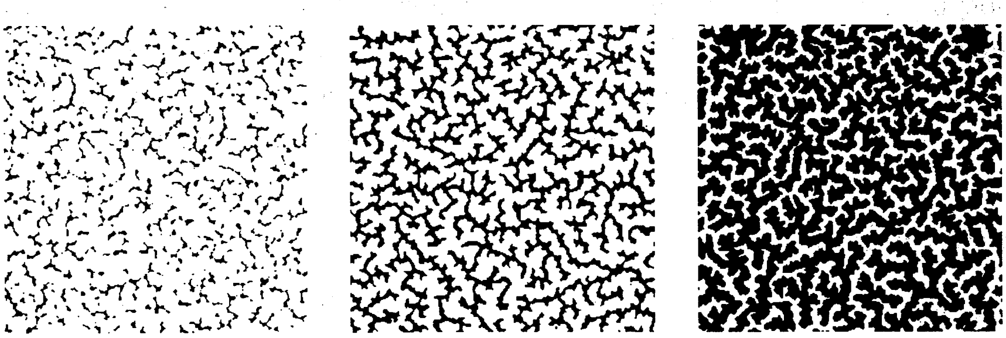
1. Introduction

In connection with the statistical approach to the macroscopic collective behavior of a group of microscopic movable (or motile) units, many studies concerning the behavior of granular materials have been carried out. Recently we found the interesting pattern formation in the drying process of water-granule mixture, and we have done some experiments by focusing our attention on the change of the pattern as a function of the granule content of the mixture [Y. Yamazaki and T. Mizuguchi, J. Phys. Soc. Jpn., **69** (2000), pp.2387-2390.]. In this conference we reported our experimental results and proposed the model to reproduce the dynamics of the pattern formation based on the phase field model.

2. Experiment

We prepared the experimental cell which consisted of a homogeneous mixture of water and granules (we use cornstarch), sandwiched between two glass slides. And the cell was set horizontally to dry. As a control parameter for this experiment, we defined the weight ratio of granules to water ϕ_g.

Figure 1 shows the typical pattern after the drying process. The black and white regions represent the compact granular region (C-region) and air region, respectively. The actual size of these figures is 12.7[mm]$\times$12.7[mm]. (a) $\sim$ (c) show the patterns for different ϕ_g. ((a)$\phi_g = 0.02$, (b)$\phi_g = 0.2$, (c)$\phi_g = 0.6$).



(a) $\phi_g = 0.02$ (b) $\phi_g = 0.2$ (c) $\phi_g = 0.6$

Fig.1 : The final patterns for different ϕ_g.

From the observation, the following features were clarified.

(i) By the water-air front advancing, granules are swept and gathered near the front in the water region. Therefore, the aggregation of granules occurs with the shift of the water-air fronts (Front Aggregation).

(ii) In low ϕ_g case, the rearrangement of water-air fronts brings about the disconnection of C-region.

(iii) As ϕ_g increases, the isolated compact granular regions tend to connect with each other. And C-region takes the form of the labyrinthine pattern.

3. Model

We proposed the following model for the front aggregation dynamics of granules:

$$\begin{aligned} \tau\dot{\phi} &= -\phi(\phi-1)(\phi-A(\psi)) + \epsilon\nabla\cdot(K(\psi)\nabla\phi) \ , \\ \dot{\psi} &= \nabla\cdot(D(\psi)\nabla\psi) - \nabla\cdot(C(\psi)\nabla\phi) \ . \end{aligned}$$

Here, ϕ is a phase field representing water ($\phi = 1$) and air ($\phi = 0$) regions. ψ denotes the density of granules. The coefficients $A(\psi)$, $K(\psi)$, $C(\psi)$, $D(\psi)$ are dependent on the granular density and should be determined by the physical properties of water-air surface (vapor pressure, surface tension) and the granular material (wettability, friction).

4. Results

By the numerical simulation of the above model, the disconnection of C-region was reproduced in low granular density case. We note that C-region is assumed to be a fluid obeying Darcy's law in this model. This assumption produces the diffusion field in C-region. The diffusion field, in addition to the prevention of the motion of water-air fronts due to the existence of granules, occurs the instability of a flat water-air front. This instability is considered to be the origin for the pattern formation.

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