Influences of g-jitter on liquid diffusion experiments under microgravity

Satoshi Matsumoto[†], Misako Uchida[††], and Toshio Itami[†, †††]

† National Space Development Agency of Japan, Space Utilization Research Program
2-1-1, Sengen, Tsukuba, Ibaraki 305-8505, Japan
†† National Space Development Agency of Japan, Space Utilization Research Center
2-1-1, Sengen, Tsukuba, Ibaraki 305-8505, Japan
††† Hokkaido University, Graduate School of Science, Division of Chemistry
N10W8, Kita-ku, Sapporo, Hokkaido 060-0810, Japan

Abstract

We developed a numerical model to analyze the influences of the residual gravity and the g-jitter under microgravity conditions. A three-dimensional model was employed and calculations were performed by using numerical code named STAR-CD. It is found that the error in diffusion coefficients can be kept to be less than 1% when the 1mm diameter specimen is used. Hence, specimens with diameter less than 1 mm should be selected in order to avoid the effect of gravitational disturbances in the International Space Station.

1. Introduction

In spite of making efforts to suppress convection in melts, diffusion coefficient data have not yet been obtained accurately in terms of ground experiments compared with those obtained in microgravity experiments. Self- or impurity-diffusivity measurements should be performed under completely isothermal conditions. But, it is difficult to achieve such isothermal conditions in practice, especially at high temperature as high as 1800 K. According to numerical analysis, temperature differences less than 0.5 K across the sample at the vertical capillary configuration cause the flow and the convective transport rate becomes nearly equal to the diffusive transport [1]. In this case, concentration profiles seem to be achieved under pure diffusive transport at first sight. However, the numerical simulation tells us that the material transport is surely enhanced by convection. The measurement error of diffusion coefficient is still higher than 10-20% on the ground due to convection. In order to develop and verify the liquid diffusion model, we are aiming the accuracy of measured diffusion coefficients within 5% for self-diffusion and 4% for impurity diffusion. This requirement of accuracy comes from the necessity to verify our diffusion model. From several previous microgravity experiments, it was revealed that microgravity environment is efficient to measure this transport coefficient. We can attain the required accuracy by our modified experimental equipment.

Since even a weak convection affects the diffusion experiments, our experiment should be designed to minimize its effects. Convection in melts is induced by the residual gravity and the g-jitter which disturb concentration profiles, even under

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microgravity condition. The experimental condition has to be optimized to carry out highly precise diffusion experiments under microgravity conditions. Therefore, a numerical analysis of the effect of convection on diffusion measurements has been performed to evaluate the experimental error, and to optimize experimental conditions.

2. Numerical Simulation

A three-dimensional model of a liquid diffusion sample with a container, which was shown in Fig.1, was employed for this analysis. The convection was induced by both temperature and concentration gradients. The diameter of the specimen was varied from 0.5 mm to 2.0 mm. The magnitude of the residual gravity and the g-jitter used in the analysis was chosen based on the data estimated by NASA for the International Space Station (ISS). The residual gravity was 2 μg and its direction was inclined 45 degrees against the specimen axis (see Fig. 1). The g-jitters used in the numerical analysis were added to random directions and were artificially produced by the sum of sinusoidal vibrations ranging from 0.01 to 100 Hz following the ISS requirements. STAR-CD, which was the name of numerical code, was used to solve the velocity, temperature, and concentration fields.

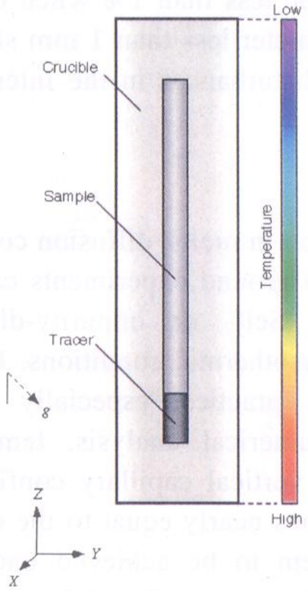

Fig.1 Numerical model

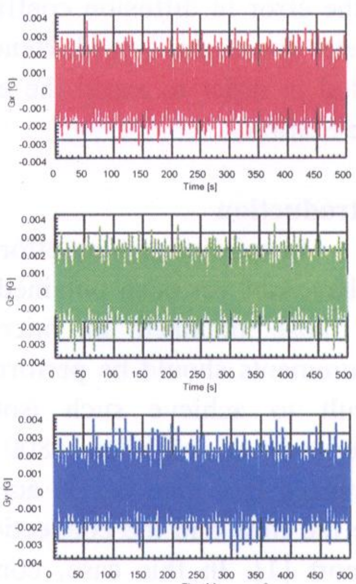

Fig. 2 Waveshapes of g-jitter

3. Results and discussion

Velocity vector, isotherms, and isoconcentration lines at 300s are shown in Fig.3. Convection occurs near the diffusion interface which indicated by horizontal line in Fig.3 (i). As a result, the convection significantly affects the results of diffusion measurement. When the 2 mm diameter specimen was used, the maximum velocity was 25 μm/s and the apparent diffusion coefficient became 3.6% higher than true diffusion coefficient. Such strong convection was found to spoil certainly the experimental data. In the case of the 1mm diameter specimen, the error in diffusion coefficient was less than 1%. Hence, specimens with diameter less than 1 mm should be adopted in order to avoid the effect of gravitational disturbances in the ISS.

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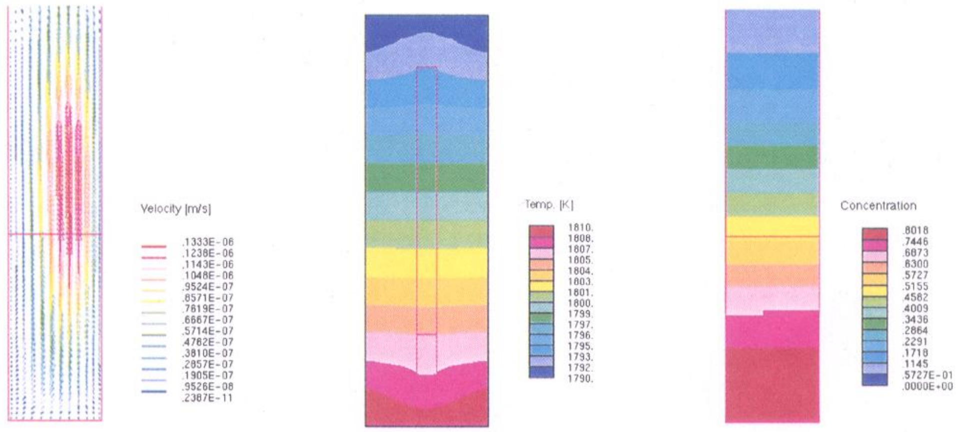
Recently, the application of strong magnetic fields to measure the diffusion coefficient was attempted to reduce convection on the ground [2]. However, the magnetic force acts essentially on moving charged particles, such as electrons and ions. Therefore, magnetic effects on the diffusion process are not fully understood and technological improvements are still needed.

The database on the diffusion coefficients is required for the development of the industrial processing. In order to get many accurate diffusion coefficients on the ground, technical developments, appropriate hardware and experimental procedures are needed. The highly precise data obtained in space will surely contribute to the improvement of the ground experiments as a reliable reference data.

By using the highly precise diffusion coefficient obtained under microgravity conditions, we can verify the diffusion model and develop the measurement procedure of the diffusion coefficient on the ground.



(i) velocity vectors (ii) isotherms (iii) isoconcentration lines

Fig. 3 Velocity vectors, isotherms, and isoconcentration lines (t = 300 s)

4. Summary

We developed a numerical model to analyze the influences of residual gravity and g-jitter under microgravity conditions. A three-dimensional model was employed and calculations were performed by using numerical code named STAR-CD. It is found that the error in diffusion coefficient can be kept to be less than 1% when the 1mm diameter specimen is used. Hence, specimens with diameter less than 1 mm should be selected in order to avoid the effect of gravitational disturbances in the International Space Station.

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