§27. Visualization Study of Stephan Problem in Superfluid Helium under Microgravity Condition

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Superfluid Helium (He II) can be a candidate of excellent coolant to large scale magnet for future fusion experiment. He II cooling had been succeeded in Tore Supra[1]. He II has extremely high ability of heat transport. When superconducting magnet quench occurs, boiling phenomena may occur. For the design of more high efficiency cooling channel, a fundamental study of heat transfer in He II had been carried out.

The problem of bubble growth has been investigated in ordinary fluid since more than 100 years ago[2], called as a Stefan problem across liquid-vapor phase change. In He II, the characteristic condition is realized because of high effective thermal conductivity, low surface tension and no viscosity. In He II, heat transports with zero net mass flow so that the heat transfer is similar to conductive heat transfer. Thus when the normal convection in vapor bubble is negligible small, the condition without convection heat flow on moving surface can be realized. In the boiling experiment under microgravity condition, the special condition mentioned above can be realized.

However, there are little superfluid helium experiments under microgravity condition [3), 4)] because the microgravity environment using parabolic flight is difficult to conduct. Our group has tried another approach to microgravity experiments such as free fall experiment using a 10 m height drop tower. The small cryostat equipped with optical windows [5)] was experienced microgravity condition when free-fall for about 1.3 sec. To generate a single spherical bubble in He II, a micro heater unit was installed in the cryostat consisting of a manganin wire, φ0.05 mm in outer diameter and 2.8 mm in length, and two NbTi superconducting wires consisting of cooper-stabilized mono filament as shown in Fig.1. The heat generation rate of this heater unit was measured by four terminals method. Most of heat was generated by the manganin part even when the superconducting wire parts were in bubble. The constant current was applied from just after free fall starting through the end of time duration in microgravity.

The visualized images taken by a high-speed camera were analyzed to obtain the time variation of large vapor bubble in the order of 10 mm. Fig.2 shows typical time variation of single bubble volume. It was seen that the sizes of single bubble is not estimated only the latent heat and the density of Helium vapor in saturated condition. On the other hand, in the case of He I (normal liquid Helium), the growth of single bubble could be predicted using only the latent heat and the vapor density on saturated vapor line. For the case of He I, it can be said that most of applied energy expended on vaporization. In other words, vapor volume for film boiling state in 4.2 K can be predicted easily in 90 % because the product of the gas density and the latent heat at 4.2 K is rather large. And some of applied heat must be transported to liquid phase in addition to the vaporization of He II. Furthermore, the heat transfer across liquid-vapor interphase has to be considered in He II.

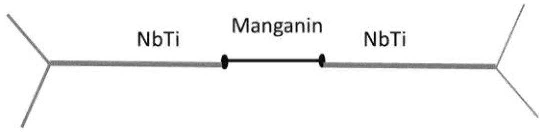

Fig.1 a schematic illustration of heater wire configuration

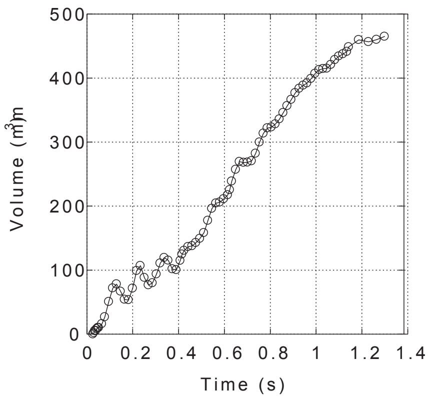

Fig. 2 Time variation of bubble size for 14.02 mW at 1.9 K

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1) G. Claudet, G. Bon Mardion, B. Jager, G. Gistau, Cryogenic, Volume 26, Issue 8, August–September 1986, pp. 443–449
2) S.G. Bancoff, Adv. Chem. Eng 5, 1964, pp. 75-150
3) Lipa J.A. Swanson D.R., Nissen J.A., Chui T.C.P., 1994. , Cryogenics, 34, 341-347
4) Gradt T., Szücs Z. Denne H. D. Klipping G., 1986., Advances in Cryogenics Engineering, 31, 499-504
5) N. Kimura, S. Takada, S. Gotoh, H. Kawamata, M. Iida, M. Murakami, H. Nagai and M. Mamiya, Cryogenics, v. 51, 2011, pp. 74-78.