§19. Study of Heat Transfer across the Interface of Phase transition (He II/He I)

Kimura, N. (Cryogenic Science Center, High Energy Accelerator Research Organization),
Iwamoto, A., Takada, S.

For fusion reactors, superconducting magnet systems of high stability and high performance have been strictly required. Thus the high performance coolant loop is also required for this purpose. The cooling system using superfluid helium is one of candidates for the superconducting magnet system of high stability.

Superfluid helium has extremely high ability of heat transport. However, its low viscosity causes the difficulty to be used in a commercial cooling system so that there is no available circulation pump for superfluid helium[1]. In other words, the study of development of a circulation pump for He II cooling system is an important issue for fusion.

In 1980's and 1990s, many researchers try to apply the thermo-mechanical effect in He II to circulation pump using porous plug called fountain effect pump (FEP) [1)-4)]. The circulation system is shown schematically in Fig.1. FEP is based on the thermo-mechanical effect in He II. The thermo-mechanical effect is expressed by London's formula,

$$\Delta p = \rho s \Delta T \quad \text{(Eq.1)}$$

, where ΔT is the difference of temperature across porous plug. For ideal FEP the corresponding mass flow rate is given by the following equation

$$Q = \dot{m} S_o T_o \quad \text{(Eq.2)}$$

, where the subscript o applies to the conditions at the pump outlet. However the pressure difference between FEP has not high and the efficiency is not sufficient though the ability of heat transportation is very large. Therefore the cooling loops using FEP were not conventional choice for magnet cooling yet.

Prof. H. Kobayashi in Nihon Univ. suggested another concept that the cooling loop is used forced flow of normal liquid helium through the sub-cooler with saturated He II exchanger as shown in Fig.2[5]. This type of cooling loop may be composed with conventional pumps for cryogenic liquid. However the design of heat exchanger for He II-He I transition is difficult because He II- He I interface always propagate to He I side in 1D channel.

The stable conditions of the two phase coexistence have to understand. The past research indicated that distribution of heat current may stabilize He II-He I interface[6]. Therefore we made the optical 2D channels which can create several distribution pattern of heat flux were made to understand the stabilization mechanisms of the interface between He II and He I shown in Fig.3. For simple experiment, the interface will be observed under heat generation condition assuming reversible process. The visualization of He II-He I inter face can be observed using by the shadowgraph method[7]. This 2-D channel is consist of GFRP duct and transparent glass glued on the epoxy resin (DP-190) which can seal superleak. In 2013, the optical channel have been prepared successfully.

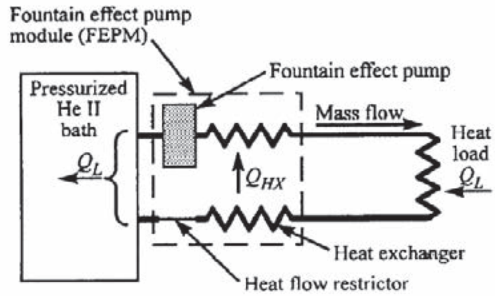

Fig.1 the concept of Self driven loop with FEP (cited from Ref.2)

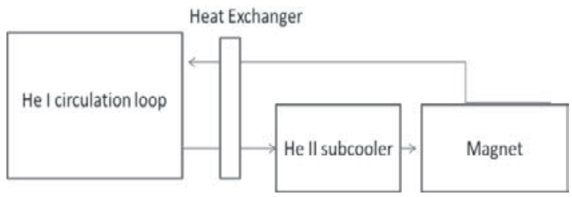

Fig. 2. Flow Diagram of He II forced flow loop with He I loop

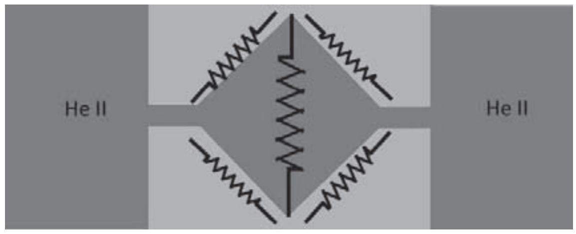

Fig.3 Sketch of optical 2D channel

1) Van Sciver, S. W., Cryogenics 38(1998)503
2) Mord, A. J., Snyder H.A., Cryogenics36(1996)209
3)Kasthurirengan,S.,Hofmann,A.,Cryogenics33(1993)11225
4) Srinivasan, R., Hofmann, A.,Cryogenics 25(1985)641
5) Kobayashi, H. private communication
6) Kobayshi, H., et al., Cryogenics 49(2009)700
7) Takada, S., Murakami, M., Kimura, N., Kobayshi, H., Cryogenics 49 (2009)576