§ 6. Heat and Mass Transfer of He II in Porous Media

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Since the superfluid helium (He II) has peculiar properties such as thermo-mechanical effects, very low viscosity and extremely high heat transport capability, there are considerable interests as a coolant for space application and superconducting magnets. One particular application utilizes thermo-mechanical effects to transfer heat and/or He II through porous media. He II consists of two interpenetrating fluids, normal fluid and superfluid. According to the equation of motion for both normal and superfluid components,

$$\rho_n \frac{d\vec{v}_n}{dt} = -\frac{\rho_n}{\rho_s}\nabla P - \rho_s S \nabla T - \eta_n \nabla \times \nabla \times \vec{v}_n \qquad (1)$$

$$\rho_s \frac{d\vec{v}_s}{dt} = -\frac{\rho_s}{\rho}\nabla P - \rho_s S \nabla T \qquad (2)$$

where ρ is density, v is velocity, P is pressure, S is entropy, T is He II temperature of heated section and η is viscosity of normal fluid component. A subscript n and s denote normal and superfluid components, respectively.

Using equations (1) and (2), London relation can be obtained as:

$$\nabla P = \rho S \nabla T \qquad (3)$$

So, the one can see that the He II pressure will be increased with its temperature. This effect is significantly affected by the permeability κ of porous media. If two rectangular channels filled with He II were connected by the porous media, applied heat Q would induce pure superflow with zero entropy:

$$Q = \dot{m}_s S_H T_H \qquad (4)$$

where H denotes heated section. At the same time, the laminar flow of normal component is generated through the porous media as:

$$m_L = \frac{\kappa \varepsilon A_F \rho \Delta P}{\eta L} \qquad (5)$$

finally,

$$Q = \frac{\kappa \varepsilon A_F}{L} \int_{T_b}^{T_H} \frac{\rho^2 S^2 T}{\eta} dT \qquad (6)$$

The collaboration between NIFS and CEA-Saclay has been conducted as a part of Nb_3Sn superconducting magnet development program. Heat transport mechanism of porous media has been studied experimentally at CEA last year.

To study the characteristics of porous media, Al_2O_3, ceramic type sample was chosen. The specification of samples is following: the pore diameter is 2 micro meter, the porosity is 32 % and three thicknesses, 2, 3 and 4 mm.

Fig. 1 shows the test section of the apparatus to measure heat transport of He II. The porous media was glued on the support flange to mount on the test cell. The flange was placed with 12 stainless steel bolts with 2mm indium o-ring seal to prevent heat leak through gaps between the flange and the can. The test cell was also mounted on the outer vacuum can for thermal isolation from the He II bath.

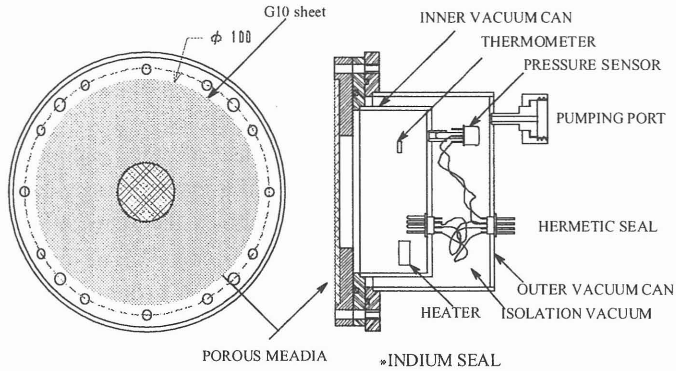

Fig. 1. Schematic of experimental apparatus.

Fig. 2 shows the data for 2mm sample with He II temperature range from 1.4 K to 2.1 K. Non-linearity is apparent as heat flux increase, which caused by the interaction of superfluid component with porous media as well as normal component viscosity.

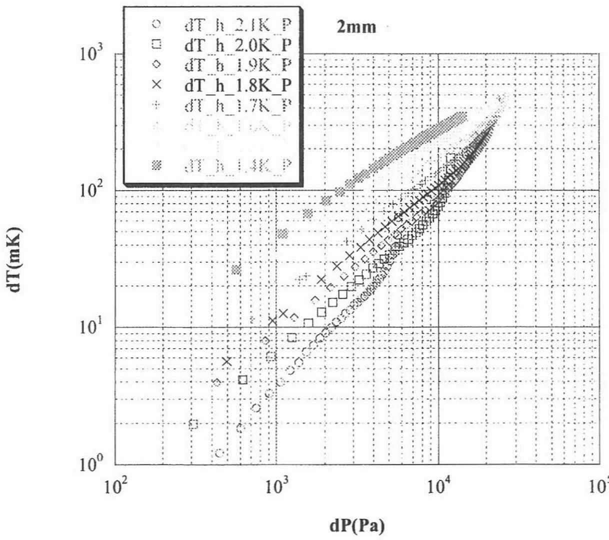

Fig. 2 dP vs dT for the 2mm sample.

Permeability of each sample were calculated and comparable with different thicknesses. Further study is required to evaluate the heat transport characteristics of porous media as a function of porosity and pore diameter.