Experimental investigation on He II porous plug liquid-vapor phase separator

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In this paper, the tests of a series of He II porous plug liquid-vapor phase separators for bath temperature at 1.5-1.9K are presented. For one separator, two regions (initial region and hysteresis loop) are observed in the relationship between mass flow rate and temperature (or pressure) difference. For two separators with similar parameters, the repeatability of experimental data could be observed. Furthermore, in order to prepare theoretical analysis of the separator, the data of cold vapor flow rate is obtained when the He II liquid level was below the porous plug.

INTRODUCTION

At zero gravity, superfluid helium (He II) liquid-vapor phase separator (LVPS) is a key device that keeps the liquid phase separated from the vapor for He II cryostat, which is used to cool space superconducting component and far infrared detectors of astronomical observation instruments. Based on a fundamental of thermo mechanical (fountain) effect in restricted geometries, helium II is retained in the tank by LVPS. Boil-off helium gas flows through LVPS and cools the He II tank.

Porous plug type LVPS have been investigated by a number research groups [1-5] and have been successfully operated in some space flight missions. This paper summarizes data taken from tests of several different porous plugs, which are made of sintered stainless steel and fabricated in disc form. The diameter, d, is 25.4 mm and the thickness, l, is 6.0 mm. Table 1 is summarizes the characteristics of these plugs. The radius, r, is calculated from the Blake-Kozeny equation [5] and pore size is measured by bubble method.

Table 1 Characteristics of porous plugs

Plug	Porosity (%)	r (μm)	Permeability (m^2)	Pore size(μm)		
				R_{max}	R_{ave}	R_{min}
1	39.6	1.37	5.01×10^{-14}	7.03	2.99	2.80
2	39.2	1.40	5.05×10^{-14}	8.25	3.05	2.90
3	40.7	1.85	1.03×10^{-13}	8.59	3.10	2.95
4	40.3	1.86	1.00×10^{-13}	8.64	3.08	2.99

The porous plugs are attached to their mount by electric capacity percussion seam welding, the effective cross-sectional area, A, is $5.07\times10^{-4}\,m^2$.

EXPERIMENTAL SET-UP

The schematic diagram of experimental apparatus is shown in Figure 1. The apparatus comprises the porous plug, helium dewar and two evacuation systems. The helium dewar is made of stainless steel. A vacuum jacket thermally insulates the He II bath from the helium dewar. The porous plug is fixed at the bottom of the evacuation tube. The inner-vented helium vapor is also thermally insulated from the He II bath by a vacuum jacket. A heater is installed in the He II bath to simulated heat input from a space instrument. The evacuation system for the He II bath and the porous plug is composed of three parts: the mechanical vacuum pump, the gate valve and the regulating valve. The vacuum pump (Pump 1) in the porous plug evacuation system is a lubrication free pump. The temperatures of the He II bath and of the downstream side of porous plug are measured by two germanium resistance thermometers (GRTs1-2). A

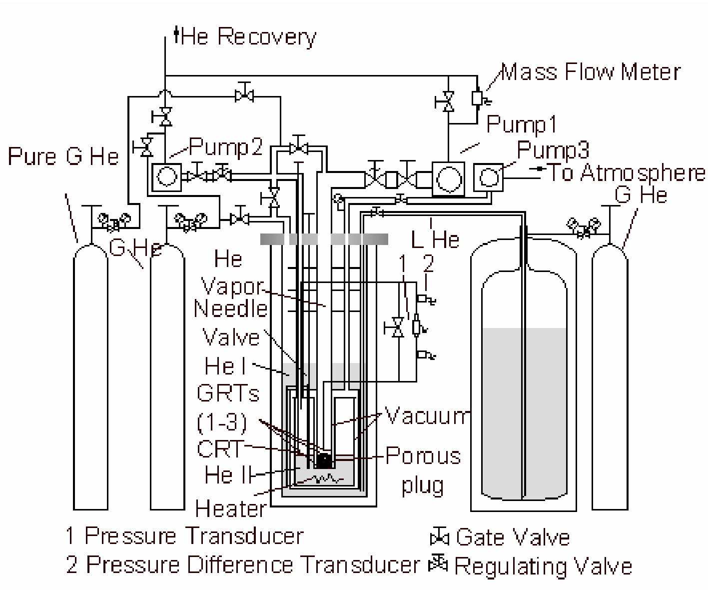

Figure 1 Schematic illustration of experimental apparatus

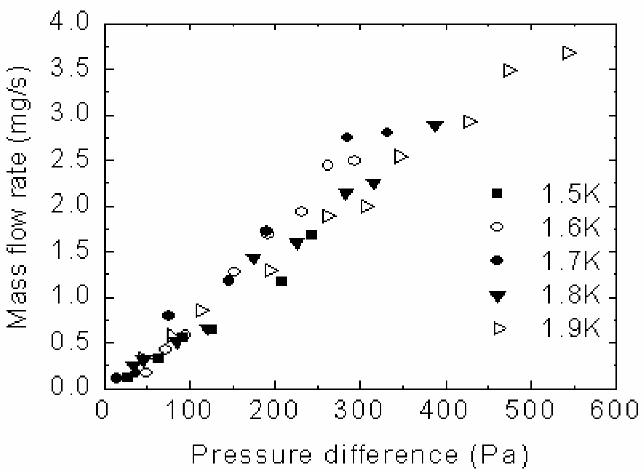

Figure 2 Variation of the mass flow rate of cold vapor with pressure difference

further GRT 3 is located 4 mm downstream from the upper surface of the porous plug to obtain the temperature of helium vapor. The temperature difference between the GRT 2 and the GRT 3 is used to detect liquid break through phenomena. Each GRT is excited by a 0.5μA DC current. The bath pressure and the downstream pressure are measured by resistance pressure transducers. The pressure difference is measured by a precision pressure difference transducer. The mass flow rate of helium vapor was measured by a mass flow rate meter located at the exhaust side of the evacuation pump. The liquid level in the helium dewar was measured by a liquid level sensor. A carbon resistance thermometer (CRT) is fixed at the bottom of thin pipe to monitor the He II liquid level, which is adjustable in the vertical direction. All data were recorded by a Keithley multi meter/data acquisition system and then stored on the hard disk of a personal computer.

EXPERIMENTAL RESULTS AND DISCUSSION

Cold vapor flow rate test

This experiment was performed when the He II liquid level in the inner bath was below the porous plug. The gas flow rate was controlled by liquid boil-off using the heater and the regulating valve. The experimental data of the gas flow rate $\dot{m}_v$ are plotted against the pressure difference between the upstream and the downstream side of the porous plug Δp for several gas temperatures in Figure 2. By fitting to data of figure 2, the linear equation below has been obtained.

$$\dot{m}_v = c_0 \cdot \kappa_p \, \Delta p / l_v \tag{1}$$

The coefficient c_0 of cold vapor was calculated from the fitting data. For the temperature of vapor at 1.5K, 1.6K, 1.7K, 1.8K and 1.9K, c_0 is 739.2, 1023.6, 1068.0, 880.8 and 840.0 $\mathrm{mg/(s \cdot m \cdot Pa)}$, respectively, which can be used in the further numerical analysis of the separators.

<u>General flow characteristics</u>

Figure 3 presents the variation of the mass flow rate with pressure difference and the temperature difference for bath temperatures 1.5-1.9 K. Figure 3(a) and (b) show the data obtained from the plug 1. On the other hand, Figure 3c and d show the data obtained from the plug 3. It is found that the mass flow

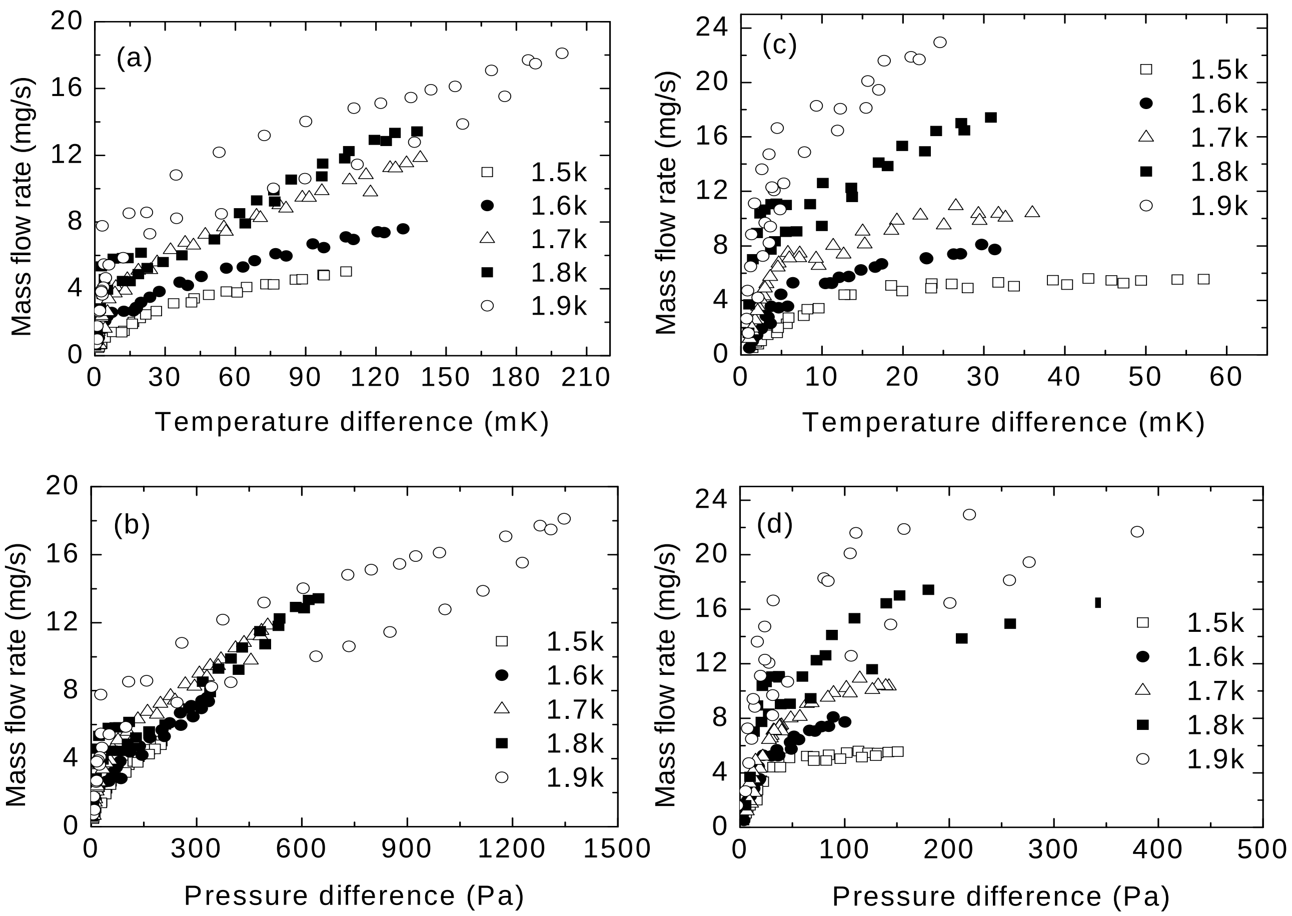

Figure 3 General flow characteristics through porous plug liquid-vapor phase separator
Obtained from Plug 1: (a); (b). Obtained from Plug 3: (c); (d)

rate rises as the bath temperature increases or the permeability of plug increases. Two different regions (initial region and hysteresis) exist in the increases and decreases of mass flow rate. This phenomenon is evident in the variation of the mass flow rate with pressure difference and the temperature difference for each bath temperature. The initial region corresponds to the small pressure and temperature differences. In this region, the mass flow rate dramatically increases as the temperature and pressure differences increase until the plug achieves a choked condition. The flow rate at this point is referred to as the critical flow rate. Above this point, a hysteresis loop is observed in the relationship between mass flow rate and pressure (or temperature) difference. In this loop, the upper branch corresponds to the increasing process and the lower branch corresponds to the decreasing process. For the upper branch, the data points seem unstable because the pressure and the temperature difference increase slightly with the change of time. Furthermore, it is found that the difference between the upper and lower branch becomes small as the bath temperature decreases.

Comparison of two plugs

A number of tests were performed with plug 1 and plug 2 to characterize the repeatability of the flow characteristic through similar porous plugs. Figure 4 shows the data taken for plug 1 and 2 at 1.7 K. The mass flow rate against the temperature difference is plotted in Figure 4a. The relationship between the

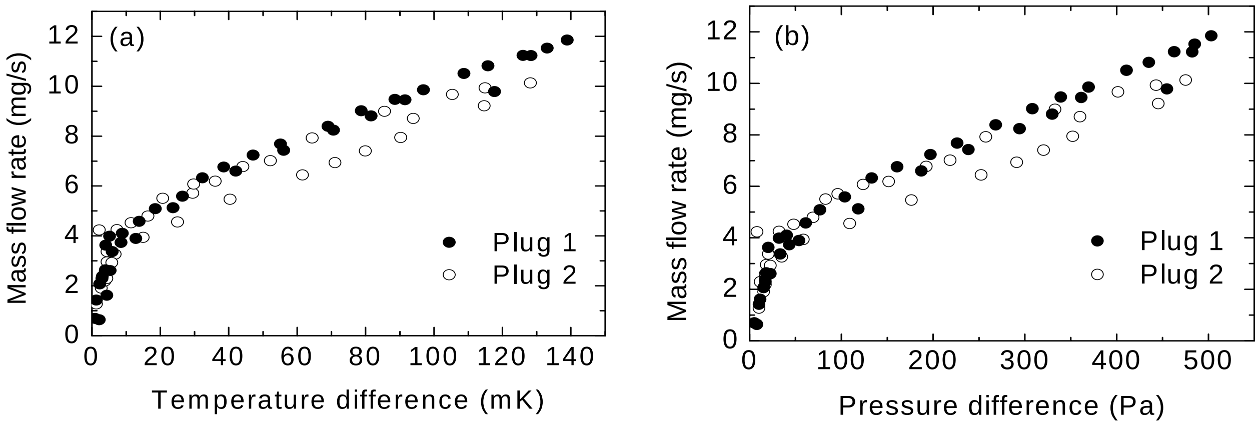

Figure 4 Comparison of the mass flow rates obtained from Plug 1 and Plug 2

mass flow rate and the pressure difference is plotted in Figure 4b. The data obtained from the plug 1 does agree with the data obtained from plug 2. The repeatability of the flow characteristic through the similar porous plugs could therefore be proven.

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