Flow Rate of He II Liquid-Vapor Phase Separator

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Experimental results are presented for superfluid (He II) flow through porous plug liquid-vapor phase separators. Tests have been performed on seven porous plugs with different thicknesses or different permeabilities. The temperature was measured from 1.5K to 1.9K. Two flow regions were observed in small and large pressure and temperature differences regions respectively. The experimental data are compared with theoretical predictions. The performance and applicability of the basic theory are discussed. Hysteresis of the flow rate is also observed and discussed.

Keywords: superfluid helium, liquid-vapor phase separators, flow rate.

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Introduction

A He II liquid-vapor phase separator, which separates helium vapor from the liquid of He II, is an indispensable device used to remain He II in cryostat and vent the vapor at microgravity. Based on the fundamentals of thermo-mechanical effect of He II in narrow channels, a porous plug has been used as a He II liquid-vapor phase separator, so it is important for the design of a He II cryostat to consider the basic characteristics of the mechanism for mass and heat transportation through the porous plug.

A number of research groups have investigated He II porous plug liquid-vapor phase separator\textsuperscript{1-6}. S. W. K. Yuan et al.\textsuperscript{[2]} analyzed experimental results with a theory of Gorter-Mellink turbulent flow. He summarized the experimental data of the porous plugs with different pore sizes and gave the experiential relation of Gorter-Mellink constant for the porous plug. DiPirro et al.\textsuperscript{[4]} and A. Nakano et al.\textsuperscript{[5, 6]} explored choked flow and offered a model on the assumption of laminar flow of He II in the porous plug.

This paper purposes to study flow characteristics of He II liquid-vapor phase separator. It summarizes data taken from tests of a series of porous plugs with different permeabilities or different thicknesses. The performances and applicability of basic theory of He II transport in these porous plugs are discussed.

Basic Theory

The fundamental of He II liquid-vapor phase separator

The schematic diagram of a vapor-liquid phase separator is shown in Fig. 1. The porous plug is in contact with He II on one side, and on the other side it is open to the vapor in the vent line, and \( v_s \) and \( v_n \) indicate the velocities of the super component and normal component of He II respectively. With the liquid being evaporated at the downstream, the latent heat of vaporization is taken away which results in a lower temperature on the downstream side. Based on the fundamentals of thermo-mechanical effect of He II in the porous plug, the super component and normal component flow in opposite directions as the temperature difference \( \Delta T \) and pressure difference \( \Delta p \) across the plug are existed, so the heat conduction of He II occurs in the porous plug as He II flows through it. The heat flux \( Q \) and net mass flow rate \( M \) can be connected by the latent heat of evaporation \( L \) at the steady state:

\[
Q = M \cdot L
\]  

(1)

where the heat conduction of the porous material has been neglected because of smallness compared to the
heat flux in the liquid. It is found that \( Q \) is linearly proportional to \( M \), and \( M \) was measured and discussed in the following sections. It is noted that \( M \) is jointly influenced by the mass and heat transportation in the porous plug.

\[ P \]

\[ M \]

\[ \rho, \eta \]

\[ \Delta P \]

\[ \Delta T \]

\[ \rho_v \]

\[ \eta_v \]

\[ \rho ST \Delta P_2 \]

\[ (L+ST)\eta_n \]

\[ \rho ST \Delta T_2 \]

\[ \rho S \]

\[ \rho_n \]

\[ K_{GM} \]

\[ \kappa_p \]

\[ \eta_n \]

\[ \rho_S \]

\[ \Delta \theta \]

\[ \Delta P \]

\[ \Delta T \]

\[ \rho \]

\[ S \]

\[ T \]

\[ \eta_n \]

\[ A \]

\[ \kappa_p \]

\[ \eta_n \]

\[ \rho \]

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