Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: Yu Yu Puzina *et al* 2020 *J. Phys.: Conf. Ser.* **1683** 022017

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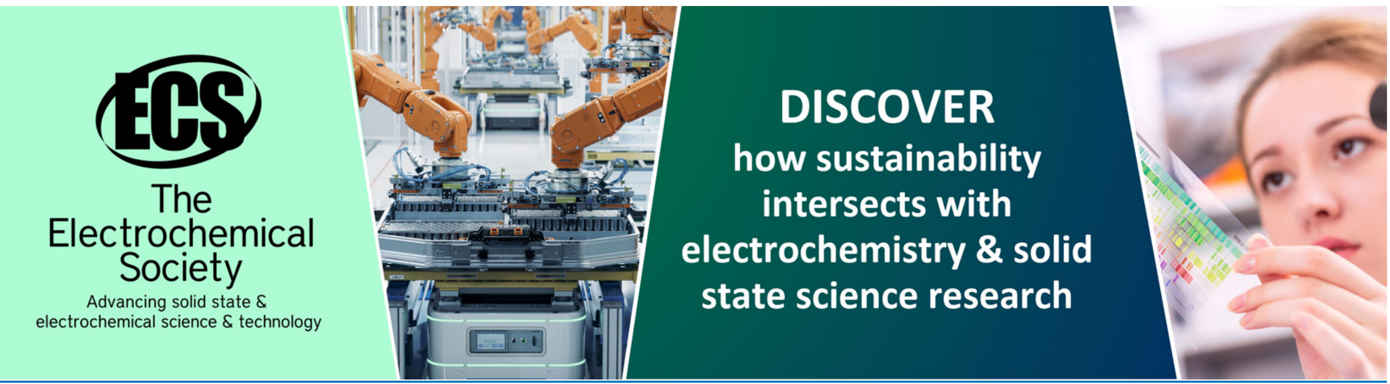

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Experiments of superfluid helium flow in a channel with a monodisperse backfill

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Abstract The experimental data on the superfluid helium flow in a U-shaped channel filled with a monodisperse backfill at a certain length is considered in this paper. The entire channel is immersed in a volume of superfluid helium. A flat heater is located in one end of the channel. When the heat load is applied, a vapor plug is formed in the channel. The column of superfluid helium begins to fluctuate in size with a constant amplitude and frequency. On the basis of the video recording of experiments, the dependence of the coordinate of the interfacial surface on time was plotted, and a qualitative analysis of heat and mass transfer processes is performed.

1. Introduction

Heat and mass transfer processes in superfluid helium differ from similar phenomena in non-quantum liquids, including cryogenic ones. This difference appears in two-phase systems also. The author's team has been investigating the behavior of superfluid helium in confined conditions for several years. The formation and dynamics of vapor films on the cylindrical and sphere heaters, flow of superfluid helium column in the channels with formation of vapor plug were investigated.

The dynamics of liquid in the channel with the heater in the one end was the problem under consideration. As the heat load is applied, the vapor plug appears at the heater surface. The ordinary liquid moves from the heater under any conditions and the velocity of the liquid movement depends on the thermophysical properties of the liquid [1].

The peculiarities of heat and mass transfer processes in the superfluid helium lead to changes in the liquid dynamics at the flow in the capillary. Helium-II column moves from the heater as the ordinary liquid when capillary length is less than a certain value (it was called by the authors as reversible). But when the capillary length is greater than reversible value, helium-II moves to the heater at the heat load applying [2]. It is obvious, that corresponding processes require the presence of a vapour area near the heater and separation of the liquid from the direct contact to the heater, so that there is space for the considered reverse flow. This reversible mode is not observed for ordinary liquids. Analysis of heat and mass transfer processes shows that reversible length depends on liquid properties and capillary diameter.

These types of flows were confirmed experimentally in a capillary with a diameter of 250 microns [3]. The reverse value of the length is about 3.5 m for this capillary at the considerable experimental conditions. It was shown that in a capillary 8 m long for bath temperatures of 1.3-2.0K, the helium-II column moves to the heater. In a capillary with a length of 8 cm under the same conditions, the helium-II column moves from the heater. Experiments with liquid nitrogen showed that liquid moves

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from heater for both lengths and vapour plug rises in the size. Thus, the behaviour of the helium-II column and corresponding heat mass transfer processes in liquid and vapour can be described by the mathematical model presented in [2]. It is interesting, that in some cases, the experiments show the oscillatory mode of meniscus dynamics in the capillary.

The mathematical model of stationary processes of heat and mass transfer during the flow of helium-II in the channel was considered later [4]. In this case, a porous structure is used to create confined conditions instead of capillary channel. In this case liquid column flow to the heater is also possible. But the reverse length of the channel is the length of part filled with a porous material. The reversible length of the porous insert does not depend on the heat flux at laminar flow of the normal component. It depends on porosity and permeability of porous material and thermophysical properties of liquid. For turbulent movement of a normal component, the results of paper [5] are used. It was found that in this case reversible length of the porous insert depends on the heat flux due to the counterflow of superfluid components. The reversible length for porous plug is significantly less than the similar value for capillaries (several millimetres instead of several metres). The porous structure in the form of a monodisperse balls was analysed [4]. The diameter of monodisperse sphere was several tens of microns.

However, we can choose any size of channel in the experiment, since the reversible length for a porous structure does not depend on the diameter of the channel [4]. In connection with the above, a monodisperse backfill located inside the channel was selected for experimental studies of heat and mass transfer processes during the flow of superfluid helium in confined conditions.

It should be noted that in addition to the mentioned work [5], there are also studies devoted to determining the recovery heat flux for a wire located inside a porous shell, both with and without a gap [6]. Mathematical description for this case can be formulated based of the model [7] with taking into account heat mass transfer processes inside the pores as in paper [8].

In addition, the authors of this paper study the boiling process of helium-II inside a porous body [9], which also led to the appearance of new experimental results.

2. Scheme of the experimental cell

The general scheme of the experimental installation for the study of heat and mass transfer processes in superfluid helium, preparation and methods of research are presented in detail in [3, 9]. At the present stage of research, the installation was upgraded with new auxiliary devices and the power supply was replaced. The automatic system for data acquisition and processing allows information to be analyzed directly during the experiment. The pressure of helium in the inner vessel is monitored with a mercury cup manometer and automatically using Barathron (model 235) capasive pressure sensor.

The following problem statement of the superfluid helium flow in the channel filled by a porous backfill is considered .The experimental section is a U-shaped chlorocalcium tube TX-U-1-100.The lower part of tube is filled with a free filling of monodisperse balls for a height of 2 cm. The balls made of Pb96%Sb4% alloy according to the technology [10] and have a diameter (280 ± 5) microns. The heater is spiral made of nichrome wire with a diameter of 50 microns. This spiral is placed on the surface of copper disk with a diameter of 5 mm. This disk is pressed into a penoplex plug and this plug is inserted into the upper branch of the one end of U-shaped tube. The sealing adhesive is used to prevent leaks of superfluid helium. The scheme of the experimental site is shown in Fig. 1.

The experimental section is immersed in the volume of superfluid helium completely. When the heat load is applied, a vapour cavity is formed in the channel near heater and helium-II flows through the porous plug. The operating temperature of the superfluid helium bath in the Dewar vessel is achieved by continuous vapor pumping. Communication with the pumping line leading to the mechanical vacuum pump is carried out through a tube. Video recording is performed with simultaneous data acquisition. After termination of the heat load supply, liquid helium again fills the cavity in the channel, the vapor plug gradually collapses, and the liquid comes into contact with the heater.

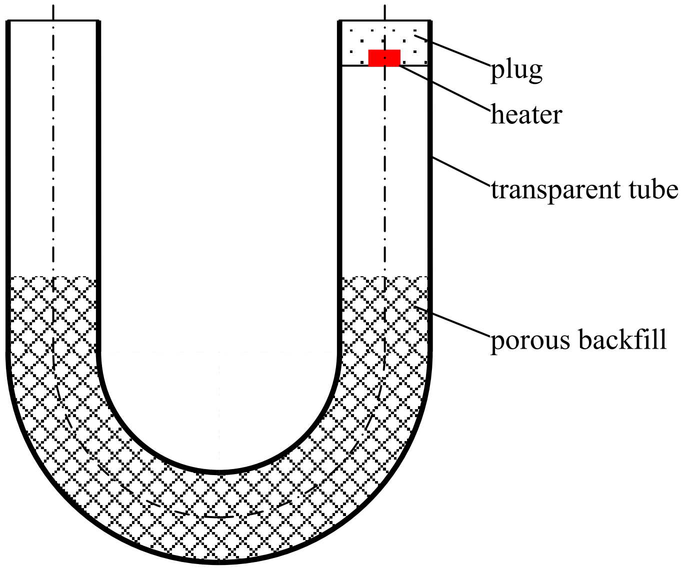


Figure 1. Scheme of the experimental cell

3. Experimental results

The vapour cavity appears in the channel when heat load is applied. After passing some distance from the heater, the interfacial surface stops and begins to move towards the heater. Before reaching it, the interfacial surface stops again and starts moving from the heater. Thus, a constant oscillatory motion of superfluid helium is realized in a channel with a monodisperse fill. The corresponding video frames for rising of vapour cavity are presented in fig.2. The pressure during this series remains at the level of 2110Pa, average heat flux is 39.5kW/m^2.

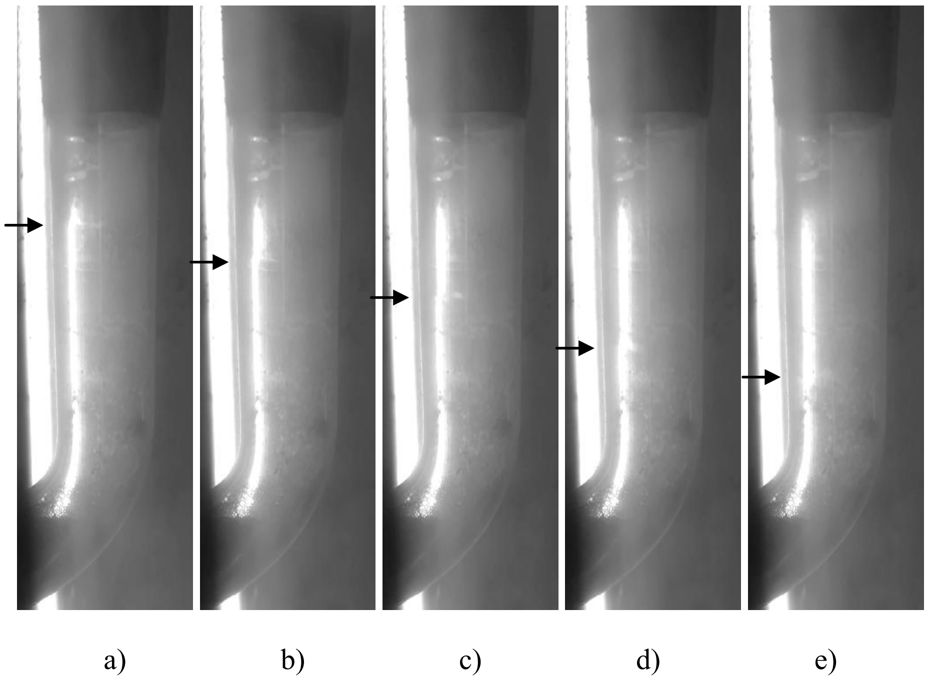
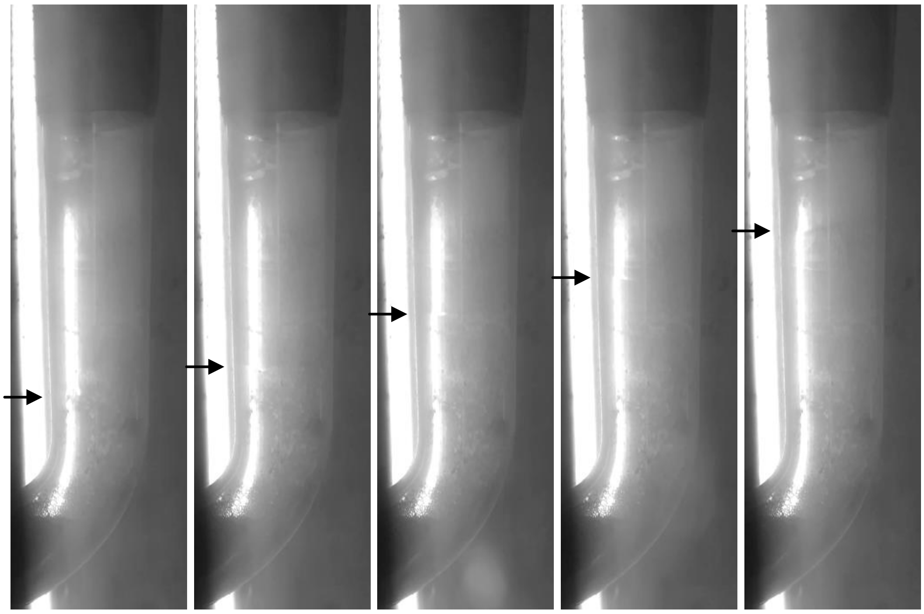


Figure 2. Experimental results of vapor plug rising

Minimum distance between the heater (black in the upper part of frames) and liquid-vapour interface is about 10 mm (fig. 2a), maximum distance is about 25 mm (fig. 2e). The interval between frames on fig. 2 is about 0.25 s. Liquid-vapour interface remains flat and smooth instead of capillary with meniscus. The video frames for decreasing of vapour plug are presented in fig. 3. At this two-side motion superfluid helium inside the pores of the filling flows into different ways (as can be seen from fig. 2 and fig. 3) as from the heater and to the heater.

For different series of experiments the oscillation amplitude is about10–15 mm, and the oscillation frequency is about 0.2–0.3 Hz.



a) b) c) d) e)

Figure 3. Experimental results of vapor plug decreasing

The analysis of video frames gives the following dependence of the vapour-liquid interface position on time for one episode (blue line on fig. 4). For the zero there was an upper position of vapour-liquid interface. For all experiments this upper point was about 10 mm from the heater (this volume is filled by the vapour). This dependence should be approximated by the harmonic function with good qualitative agreement (yellow line on fig.4). At this we should devoted the mathematical description for this oscillation taking into account peculiarities of heat and mass transfer processes into superfluid helium in confined volume.

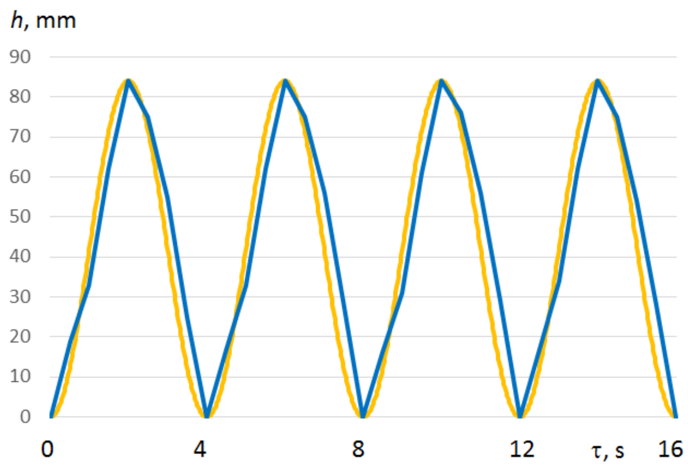


Figure 4. Dependence of vapor-liquid interface position on time

It is necessary to note, that during the experiments there was the moment, when oscillations stopped and the interface remained at the stable position for a few tens of second. But then the oscillations began again. The stable position is in the middle between two extreme positions (fig. 2a and fig. 2e).

4. Conclusion

The experiments of superfluid helium flow in a channel with a monodisperse backfill were carried out. The heat flux and pressure were measured and video was taken into consideration. Previously, a mathematical model was developed for the case of a horizontal channel [4]. Preliminary analysis allows to assume the possibility of helium flow to the heater. But the experimental results show the oscillation of interface surface and liquid column at different parameters. At this vapor-liquid interface remained smooth in all experiments, and the vapor accumulated in the upper part of the internal cavity of the experimental cell.

Thus, the helium-II flow in the constrained conditions was unlike the flow boiling of ordinary liquids. Therefore, in the future, it is proposed to carry out an analysis of heat and mass transfer processes, leading to the oscillations of the vapor volume and the damping of oscillations.

Acknowledgments
This work was supported by the Russian Science Foundation (project No. 19-19-00321).

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