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A MINIATURE ADSORPTION ^{3}HE REFRIGERATOR

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A MINIATURE ADSORPTION ^{3}HE REFRIGERATOR

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ABSTRACT

A self-contained, recyclable laboratory ^{3}He refrigerator has been developed. The refrigerator is very compact, portable and is designed to be safe and reliable. The unit can easily be installed on the cold plate of a superfluid ^{4}He cryostat. Once bolted on the cold plate, operation of the refrigerator is controlled by a single heater.

In this new design the refrigerator has a cylindrical geometry. The adsorption pump is placed above the condensation point to prevent convection during the condensation phase and to improve the pumping speed. The inhibition of convection reduces the load on the ^{4}He bath and increases the condensation efficiency.

This refrigeration technique has great potential for space applications. The absence of moving parts makes the system reliable and vibration free. Its simplicity and the absence of external components facilitate its integration on a cryostat. In fact, a rocket-borne ^{3}He refrigerator has already been successfully flown and has demonstrated the feasibility of this method. An orbital refrigerator that can be recycled in zero-gravity has been developed and is being integrated in the Infrared Telescope in Space (IRTS).

Keywords: space cryogenics, ^{3}He refrigerator

INTRODUCTION

Until recently sub-Kelvin temperatures remained the exclusive domain of solid state physics. However the progress made in infrared astrophysics in detectors technologies have extended their field of application: the sensitivity improvement obtained by cooling bolometric detectors to sub Kelvin temperatures represents a major improvement. Thus there is a growing demand for devices, simple and reliable, that can provide this range of temperatures.

In this framework, using the experience we have gained during the development of a rocket-borne ^{3}Helium refrigerator (Ref. 1), miniature adsorption refrigerators have been developed.

The refrigerators described here achieve temperatures of less than 280 mK and provide typically 50 μW of cooling power at 320 mK when mounted on a 1.5 K cold plate. They are distinguished by their simplicity of installation and operation.

DESIGN AND CONSTRUCTION

The laboratory ^{3}Helium refrigerator, shown in Figure 1, is similar in its operation to that described by Torre and Chanin (Ref. 2). Two chambers, the evaporator and the charcoal sorption pump are joined by thin walled stainless steel tubes via the condenser, which is in good thermal contact with the cold plate of a superfluid ^{4}Helium cryostat. The refrigerator is charged with ^{3}He gas and permanently sealed by a crimped tool.

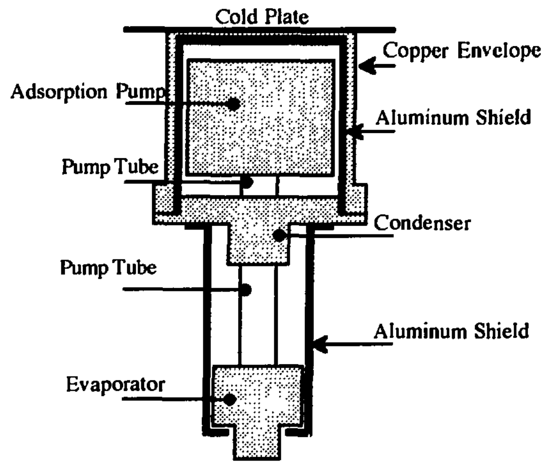

Figure 1: Schematic view of the refrigerator

In this refrigeration cycle, for a laboratory configuration, liquid ^{3}He is condensed at the condenser, falls by gravity into the evaporator and is then pumped down to obtain evaporative cooling. The ^{3}He pressure is controlled by the adsorption pump which can be temperature regulated. Details of operation have been described elsewhere (Ref. 1).

The development of the rocket-borne ^{3}He refrigerator revealed to us two phenomena. During the condensation phase, the thermal conductance between the sorption pump and the condenser was an order of magnitude higher than that expected from the stainless steel tube and the thermal link to the cold plate. This anomalously high thermal conductance was due in part to Taconis oscillations and in part to thermal convection inside the pump tube. In this design the sorption pump was placed below the condenser. As a result the temperature gradient produced by dissipating such large amounts of power reduces the condensation efficiency and thus the hold time and may in fact be large enough to make it impossible to condense any liquid ^{3}He at all. Taconis oscillation are eliminated by

packing the pump tube with steel wool and convection is eliminated by simply placing the sortion pump above the condenser. Moreover this cylindrical geometry simplifies the building of the refrigerator.
Both the pump and the evaporator are made out of stainless steel except the bottom part which is made of copper. The charcoal is glued to thin copper cylinders inside the pump to get a good thermal contact to the copper bottom.
Thin copper cylinders inside the evaporator increase the surface area and therefore reduce the Kapitza resistance between the liquid and the copper bottom.
All tubes are made out of stainless steel 304L. The tubes that connect the sorption pump and the evaporator to the condenser are 8.5 mm in inside diameter and have wall thicknesses of 320 and 190 μm .
The condenser is made out of copper as well as the external envelope that provides the mechanical support and the contact to the cold plate.
Both the pump and the evaporator are surrounded by two aluminum shields. These shields, in addition to their thermal usefulness, protect the tubes and therefore increase the safety of operation.
The refrigerators are pressure tested and leak checked at 1.5 times their operating pressure.

The dimensions of the refrigerator have been determined on the basis of the following requirements: a hold time of one day, an operating temperature of about 280 mK, a bulk of less than 500 cc for a pressure at ambiant temperature limited to 7 MPa (70 atmospheres). In the design phase one has to find a good balance between the performance, the size and mass of the refrigerator and the energy dissipated on the cold plate. Details on the design process will be reported elsewhere. The specifications of one of the refrigerator units are given in Table 1.

Table 1: Refrigerator specifications

Helium 3 charge:	2 liters S.T.P.
Sorption pump volume:	27 cc
Condenser volume:	1 cc
Evaporator volume:	3.2 cc
stainless steel tubes	
pump to condenser:	Length: 10 mm
	Diameter: 8.5 mm
	Thickness: 320 μm
condenser to evaporator:	Length: 20 mm
	Diameter: 8.5 mm
	Thickness: 190 μm
Size, diameter x length:	61 mm x 110 mm
Pressure at room temperature:	6.6 MPa (66 atm.)
Charcoal weight:	7 g
Weight:	≈ 800 g

To help design and predict the performance of ^{3}He refrigerators, a computer program has been developed. In addition to the geometrical and thermal parameters of the cycle, this program takes into account the adsorption of the gas, the fraction of liquid lost in the cooldown process, the type of regim in order to calculate the flow impedance and the Kapitza resistance. This program has been tested on a number of ^{3}He refrigerators and the expected operating temperatures without any applied load fall within a few % of the measured performance. Under load, in some case, calculated performance differ from the experimental results, which might be attributed to our imperfect knowledge of the Kapitza resistance between the liquid ^{3}He and the evaporator walls.

RESULTS

An example of a cooldown curve is shown on Figure 2. During the condensation phase, the condenser was at 1.53 K and the sorption pump was heated to about 40 K for 15 minutes. The power on the sorption pump was then turned off and the evaporator temperature dropped below 300 mK within 20 minutes. Basically operation of the refrigerator can be controlled by a single heater.

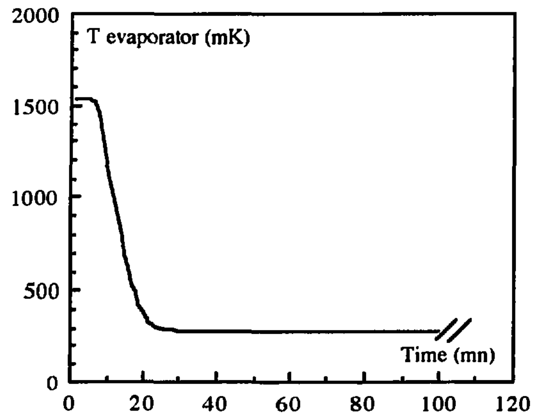

Figure 2: Typical cooldown curve

A typical refrigeration power curve is given in Figure 3 for a temperature of the ^{4}He bath of 1.5 K. Also shown is the expected performance according to the computer program.

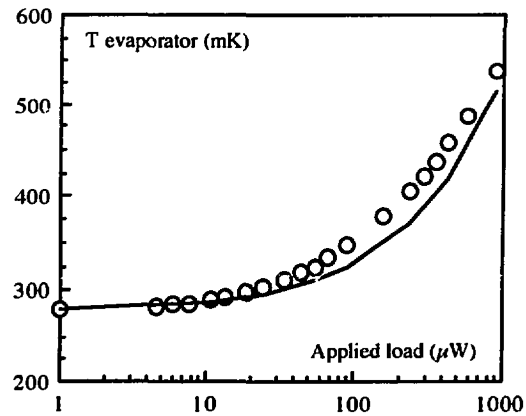

Figure 3: Refrigeration power curve for a ^{4}He bath temperature of 1.5 K
(O: experimental results, —: expected performance)

With the ^{4}He bath at 1.5 K and without any applied load, the refrigerator provides over 16 hours of cooling at 278 mK

The temperature remains stable until the liquid ^3He is exhausted. The refrigerator can be recycled indefinitely.

A new version of the miniature refrigerator has been developed and is currently being tested. Mounted on a 1.5 K cold plate, the operating temperature is expected to be below 270 mK.

The virtue of the ^3He refrigerator is the simplicity of its installation and operation.

SPACE APPLICATIONS

A refrigerator of this type is well suited for adaptation to a space environment. The absence of moving parts makes the system reliable and vibration free, the simplicity of operation and installation requires no major modification of the ^4He cryostat.

In a laboratory configuration gravity is used to move the liquid from the condenser to the evaporator and to confine the liquid to the evaporator. For operation in a zero-gravity environment, another mechanism is needed.

Prior to the laboratory refrigerator, a rocket-borne ^3He refrigerator was designed and developed specifically for use on a sounding rocket. In this design the evaporator was filled with a sintered copper sponge in order to confine the liquid to the evaporator by capillary attraction in zero-gravity. It was in fact possible to operate the refrigerator upside-down in the laboratory. This refrigerator relied on gravity only during condensation and was cycled prior to launch. It successfully flew on September 5^{th}, 1989, as part of a payload designed to measure the spectrum of the cosmic submillimeter background (Ref. 3). The performance of the refrigerator during flight was satisfactory and the temperature achieved is the lowest temperature ever obtained in zero-gravity.

An orbital refrigerator has also been designed (Ref. 4) that will be used to cool the bolometric detectors of the Far Infrared Photometer (FIRP) in the Infrared Telescope in Space (IRTS) (Ref. 5). The refrigerator will provide two weeks of continuous cooling at 285 mK and will allow cycling in orbit.

This more complex refrigerator does not rely on gravity for its operation and has been tested and cycled in a number of orientations. The sintered copper sponge is here replaced by a silicon sponge that reduces the mass and volume of the evaporator. An original mechanical support using Kevlar 29 braided cords was designed and has been successfully tested (Ref. 6).

Because the IRTS will be retrieved by the US Space Shuttle, the refrigerator has to meet severe requirements. The refrigerator is classified as a non-hazardous, leak-before-burst pressure vessel according to MIL STD 1522A and NSTS 1700.B. In this application the refrigerator is fitted with a commercially available burst disk that activates at 1.5 x room temperature pressure and defines the Maximun Design Pressure (MDP). The flight unit is then proof-tested to 1.5 x MDP in order to certify it for flight.

CONCLUSION

A miniature ^3He refrigerator has been developed. The refrigerator is compact, portable and is designed to be safe and reliable. The unit can easily be installed on the cold plate of a superfluid ^4He cryostat and operation of the refrigerator is basically controlled by a single heater. It achieves temperatures of less than 280 mK and provides typically 50 μW of cooling power at 320 mK.

This refrigeration technique is appropriate for space applications subject to some adaptations. In a laboratory configuration, gravity is used to move and keep the liquid in the evaporator. In a zero-gravity environment, liquid is condensed directly onto the evaporator and porous materials are used to confine the liquid in the evaporator. A rocket-borne ^3He refrigerator was developed prior to the laboratory refrigerator and successfully flew on September 5^{th}, 1989, as part of a payload designed to measure the spectrum of the cosmic submillimeter background. An orbital refrigerator that can be cycled in zero-gravity has also been designed and is currently being integrated in the Infrared Telescope in Space (IRTS).

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