International Journal of Engineering Research and General Science Volume 2, Issue 6, October-November, 2014
ISSN 2091-2730

An Investigative and Synoptic Review on Helium Liquefaction Using a Commercial 4 K Gifford- McMahon Cryocooler

Mahesh N[1], S A Mohan Krishna[2]

[1]PG Student, Vidyavardhaka College of Engineering, Mysore, India

[2]Associate Professor, Department of Mechanical Engineering, Vidyavardhaka College of Engineering, Mysore, Karnataka, India

[1]maheshgowda360@gmail.com, [2]mohankrishnasa@vvce.ac.in

Abstract: The review paper describes liquefaction of helium using a commercial cryocooler with 1.5 W cooling power at 4.2 K, equipped with heat exchangers for precooling the incoming gas. Measurements of the pressure dependence of the liquefaction rate are considered. Also liquefaction rate and temperature can be observed by placing resistors in series inside the liquefaction container. There by taking voltage reading we will get liquefaction rate. The assembly of Gifford - McMahon cryocooler with heat exchangers and helium liquefaction container is usually accomplished. The pressure gauge has to be connected to the container in order to examine the oscillation which gives the liquefaction rate. Also resistors are placed inside the container to measure the temperature and pressure of helium at different stages in container. This paper furnishes detailed information about the methodology and experimental technique about the utility of Gifford-McMahon cryocooler for Helium liquefaction.

Key words: Cryocooler, Gifford-McMahon, Liquefaction, Heat Exchangers, Pressure Gague and Resistors.

1. INTRODUCTION

Liquefaction is the process of converting a compressed gas into a liquid under reliable conditions. Liquid helium is required as a working medium in almost all low-temperature laboratories. Usually a large-scale liquefier serves as a central facility for helium liquefaction, for distribution of liquid helium to many cryostats in large transport dewars. With the availability of small closed-cycle cryocoolers a different scheme has become possible, where helium liquefaction may be performed nearby or even in the cryostat, thus allowing operation independent from cryogenic liquids support. Two variants of cryocoolers are available on the market, the pulse tube and Gifford-McMahon (GM) types. Without the aid of cryoliquids and Joule-Thomson stages an effective liquefaction rate of 542 ml/h has been achieved using GM cryocooler [1].

The work was motivated by a development of a versatile source for ultra-cold neutrons, which will employ superthermal production in a converter of superfluid Helium. First tests will be performed with a converter few litres in volume, which might later be upgraded to tens of liters. This volume has to be filled with helium and cooled down to 0.5 K. Liquefaction at the rate observed in the present study will enable us to do experiments independent of cryoliquids and Joule-Thomson stages. Liquid helium is required as a working medium in any low-temperature laboratory applications. Usually a large-scale liquefier serves as a central facility, for distribution of liquid helium to many cryostats in large transport dewars. With the availability of small closed-cycle cryocoolers a different scheme has become possible, where helium liquefaction may be performed nearby or even in the cryostat, thus allowing operation independent from cryogenic liquids support. The main application is a SQUID magnetometer.

2. LITERATURE REVIEW

After the introduction of the pulse tube cooler by Gifford and Longsworth in the mid 1960s essential improvements of this refrigerator type have been achieved in the past decade by two types of modifications: adding a buffer volume via an orifice valve to the warm end of the pulse tube led to phase shift between pressure and velocity with resulting improvements in cooling performance.

Thummes et al [2] reported a liquefaction rate of 127 ml/h obtained with a pulse tube cooler with 170 mW net cooling power at 4.2 K. A temperature of 3.6 K and a net cooling power of 30 mW at 4.2 K thus was first obtained with a three-stage pulse tube cooler by Matsubara. A regenerative tube at the warm end of the third stage pulse tube was used in their system. They obtained a lowest temperature of 2.75 K.Thummes achieved the lowest temperature of 2.75K using two stage pulse tube cooler and the process and performance of two configuration of 4K pulse tube coolers and GM cryocoolers are by C .wang in 1997.

C. Wang, G. Thummes et al [3] investigated a two-stage double-inlet pulse tube cooler in the year 1996 for cooling below 4 K is designed and constructed by the aid of numerical analysis. The hot end of the second stage pulse tube is connected to the phase shifting assembly at room temperature without the use of a regenerative tube.

3. EXPERIMENTAL TECHNIQUES

Fig 3.1 shows a sketch of the setup. The helium gas is supplied by a standard helium gas cylinder equipped with a pressure-reducing valve. The mass flow is controlled by a needle valve and monitored by a mass flow meter calibrated for helium with accuracy better than 1.5% in the range of 0–100 g/h. The helium flow can be opened and closed with a valve. The cryocooler is integrated into a DN 320 top flange of a cylindrical vessel from stainless steel. A cylindrical vessel with diameter 290 mm from silver-coated copper connected to the first stage of the cooler serves as a heat screen to protect the colder parts of the liquefier from ambient temperature radiation. The estimated total heat load to the first stage additional to the unknown flow along the cooler itself is 7.4 W.

The gas first passes through a cold trap, which is connected to the top flange of the heat screen and thus kept at a temperature close to the first stage of the cold head. The cold trap consists of a copper cylinder filled with copper mesh, which also serves to freeze out gas impurities. An additional heat exchanger assures precooling to the temperature T_1 of the first stage. It consists of a stainless steel capillary with outer diameter 2 mm and wall thickness 0.25 mm, soft soldered to a copper sheet on a length of 0.5 m and fixed to the first stage with a hose clamp. The same capillary was chosen for the subsequent heat exchangers, ensuring turbulent flow of the helium gas for good radial heat transfer across the capillary wall.

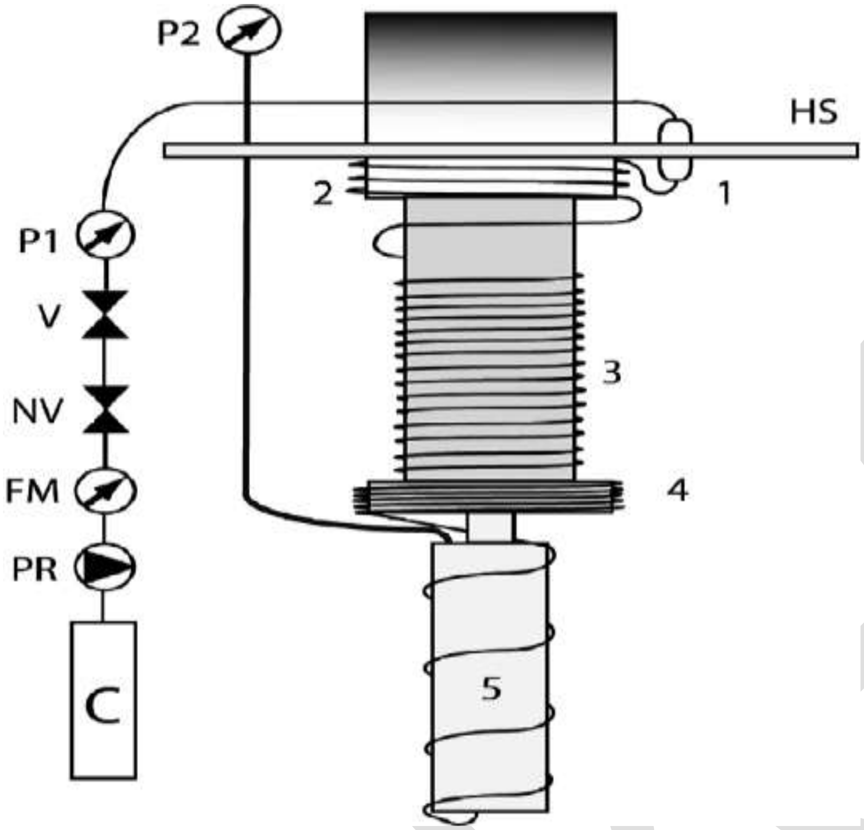

Fig. 3.1 Schematic of helium liquefaction rig (not to scale). Fifty litre helium cylinder (C), pressure reducer (PR), flow meter (FM), needle valve (NV), cut-off valve (V), inlet pressure gauge for measuring Pin (P1), top flange of heat screen (HS), cold trap (1), heat exchanger on first stage of cryocooler (2), heat exchanger between first and second stage of cryocooler (3), condenser spiral on second stage (4), storage volume (5), pressure gauge (P2) for measuring the pressure bath above the bath.

The helium is finally liquefied in a condenser. It consists of a stainless steel capillary spiral, which is hard soldered on a length of 1165 mm to a copper disk, screwed to the bottom plate of the second stage. Liquid helium is collected in a copper bottle with volume 400 cm^3, which is thermally connected to the second stage. A 2 - 0.25 stainless steel capillary soldered into the top flange of the bottle serves to measure the pressure P_{bath} above the liquid. The P_{bath} and input pressure P_{in} monitored with calibrated piezoelectric silicon membrane pressure transducers. Different heat exchangers between the first and the second stage were investigated. Most experiments were performed using a spiral made from the 2 · 0.25 stainless steel capillary, onto which pieces of a 3 · 0.5 copper tube, with length 30 mm each, were hard soldered. Between each of these, a gap of 12 mm is left. The longest spiral is equipped with 46 such pieces, the medium size spiral has 36 pieces and the shortest one 20. Thus the thermal contact length is 138, 108, and 60 cm, respectively. On the inner side of the spirals, the copper pieces were milled to produce flat surfaces with width 1.8 mm. For good thermal contact with the stainless steel tube of the cold head, the spirals were tightened by 9 hose clamps Care has to be taken not to tighten the clamps too strongly, which may result in blocking the displacer in the cold head. Three spirals are mounted simultaneously, only a single one being used at a time in the experiments described below. Two Temperature measurements were performed with three calibrated Cernox resistance temperature sensors (Lake Shore, model CX-1030-CU). They were attached to the heat screen (T_1), the condenser (T_2), and the bottom of the bottle (T_{bath}).

Cooling down the copper heat screen to below 40 K took about 7.5 hours due to its large heat capacity. After this time the temperature T_2 of the condenser was 2.8 K. These values are close to the lowest temperatures of T_1 = 32 K and T_2 = 2.4 K reached with this apparatus. Opening the cut-off valve commenced the filling of the bottle with helium. At the beginning a large mass flow was set in order to attain quickly the desired pressure P_{in} or P_{bath}. The mass flow was measured for different values of input pressure P_{in} in the range of 0.7–2.58 bar. In most experiments the bottle was filled for a single value of pressure to a total mass m. A sudden rise in pressure indicated that the bottle was full, at which moment the cut-off valve was closed. In several experiments we let the cold head continue operation in order to measure the time for the subsequent cooling of the liquid to 4.2 K.

4. INVESTIGATIVE SUMMARY

The investigation of heat exchangers showed a monotonous increase of the liquefaction rates obtained as a function of the length of thermal contact of the gas with the tube of the cold head. Using the longest spiral heat exchanger, which has 28% more contact length than the second longest one, still increased the liquefaction rate by just about 8%. The longer spiral can increase the performance in terms of liquefaction rate. Also the commercial GM cryocooler can easily be converted into a most reliable and most powerful liquefier unit for application in low temperature laboratories without cryo liquids. This GM design exhibits a best higher liquefaction efficiency than the pulse tube cryocooler. It is even competitive to most complex design by its simple design and construction [4].

The technological differences of GM and pulse tube cryocoolers raised questions on the suitability of GM cryocoolers for helium liquefaction. Due to high thermal resistance between the incoming gas and the regenerative material, a typical GM type cooler with 1.5 W may provide at best a liquefaction rate of 2 litres per day.

REFERENCES:

[1**]** P. Schmidt-Wellenburg , O. Zimmer, Helium liquefaction with a commercial 4K GM cryocooler, 10 August 2006.

[2] C. Wang, Numerical analysis of 4K pulse tube coolers, 10 January 1997.

[3] C. Wang, G. Thummes and C. Heiden, A two stage pulse tube cooler operating below 4K, 22 October 1996.

[4] Wang, C, Ju, Y and Zhou Y, Experimental investigation of a two stage pulse tube refrigerator. Cryogenics, 1996