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AN EXPERIMENTAL INVESTIGATION ON HELIUM LIQUEFACTION USING TWO-STAGE GIFFORD McMAHON CRYOCOOLER

Mahesh N[1, a], S A Mohan Krishna[2, b], Dr. S Kasthurirengan[3, c], Dr. G B Krishnappa[4, d]

[1]Research Scholar, Vidyavardhaka College of Engineering,
Mysuru-570002, Karnataka, India
[2,4]Department of Mechanical Engineering, Vidyavardhaka College of Engineering,
Mysuru-570002, Karnataka, India
[3]Center for Cryogenic Technology, Indian Institute of Science,
Bengaluru, Karnataka, India

ABSTRACT

Helium recondensation or liquefaction system is the best platform to liquefy or to condense the helium in many applications namely Nuclear Magnetic Resonance (NMR), Magnetic Resonance Imaging (MRI) and Superconducting Quantum Interference Devices (SQUIDS). These applications make use of liquid helium as refrigerator. The large scale liquefaction systems serve as a central facility to provide liquid helium. The above applications require refilling on regular basis which is troublesome in case of large scale liquefaction system; one can make use of small scale liquefaction setup based on a cryocooler. An effort has been made to develop a small scale liquefaction system using two-stage Gifford McMahon cryocooler. This paper illustrates liquefaction of helium using a commercial cryocooler with 1.5 W cooling power at 4.2 K, provided with facility to precooling of incoming gas using special type of heat exchangers.

Key words: Recondensation, Liquefaction, Heat exchanger, cryocooler, Thermoacoustic oscillations.

1. INTRODUCTION

In low temperature laboratories liquid helium is used as working medium. Normally the large scale liquefaction system serves as main facility to produce and supply liquid helium. The applications like NMR, MRI and SQUIDS require liquid helium on regular basis and in medium amounts for functioning. The regular refilling using large scale liquefaction systems demands considerable efforts and also expensive. The compact closed cycle cryocoolers based liquefaction system serve as a replacement for large scale liquefaction. This small scale system developed based on cryocoolers such as pulse tube, Joule Thomson and Gifford McMahon (GM) systems. An effort has been made to develop successfully the GM cryocooler based on small scale Helium liquefaction system with temperatures of 4.2 K and 35 K available at the second and first stage of cryocooler respectively [1,2, 3 and 4].

Small scale helium liquefaction system was successfully developed using GM cryocooler, which demonstrate the liquefaction with a commercial two stage GM cryocooler, which delivers a cooling power of 1.5 W at 4.2 K at its second stage cold head and a cooling power of 30W is available at 35 K in the first stage. The incoming helium gas is pre-cooled at the first stage cold head subsequently it is passed on to second stage cold head through specially designed heat exchanger. The collection of liquid helium is monitored by thermo acoustic oscillation in the vapor pressure gauge connected outside.

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.

In 1998, Thummes and his associates reported 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 were 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 2.75 K using two stage pulse tube cooler and the process and performance of two configurations of 4 K pulse tube coolers and GM cryocoolers by C. Wang in 1997.

C. Wang, G. Thummes and C. Heiden investigated a two-stage double-inlet pulse tube cooler in 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. A research paper by P.Schmidt-Wellenburg explains helium liquefaction using a commercial cryocooler with 1.5 W cooling power at 4.2 K along with heat exchangers for cooling of incoming gas. They got a net liquefaction rate of 55.7g/h at one bar pressure.

3. HELIUM LIQUEFACTION EXPERIMANTAL SETUP

Fig.1 represents the schematic of the experimental setup for liquefaction of helium. The helium gas from the standard cylinder incorporated with pressure regulator which is at room temperature is drawn through flowmeter (in order to monitor the gas flow). A shut off valve placed after the flowmeter used to cut the flow of helium gas in the circuit.

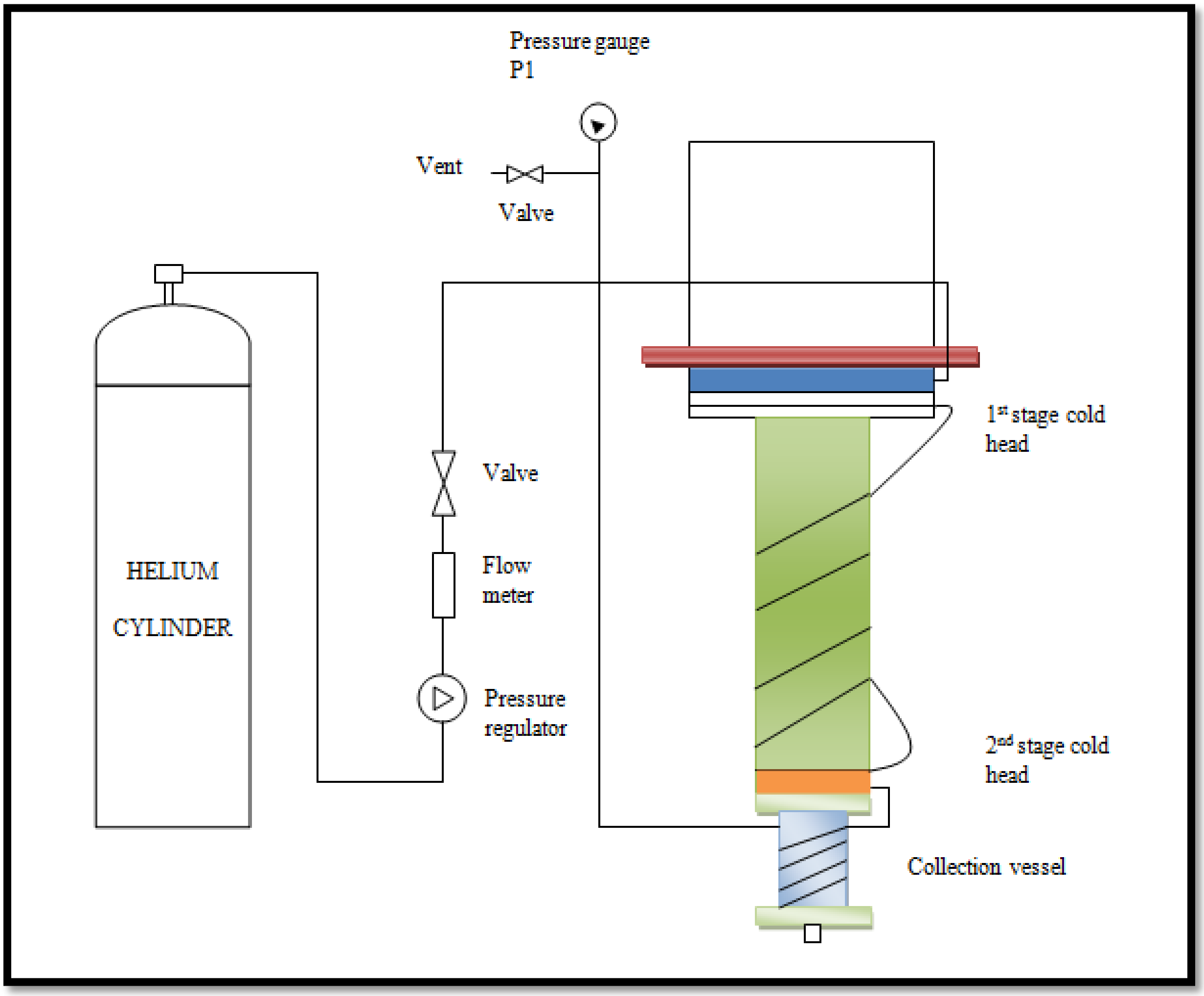

Fig. 1. Helium Liquefaction Setup

The spirally wounded copper tube heat exchanger around the cryocooler stages involved in the precooling of incoming gases. The gas first passes through the heat exchanger in the first stage cold head which ensures the precooling of helium gas to first stage temperature. Later through intermediate stainless steel tubes arrangement the helium gas passes to the heat exchanger in second stage because of turbulent flow effective radial heat transfer takes place. The helium gas gets liquefied in the heat exchanger of second stage. The liquid helium thus leaving the condenser heat exchanger collected in the collection vessel with an approximate volume of 150 cm^3. Fig. 2 depicts the first and second stages of GM cryocooler with mounted heat exchanger and collection vessel on respective positions.

Fig. 2. GM cryocooler with heat exchanger and collection vessel mounted on second stage

Silicon diode sensors are mounted on first, second stages and vessel surface to monitor the temperature at these surfaces. Later, the second stage of cryocooler and the collection vessel are encapsulated by several layers of insulation called super insulation shown in fig. 3 in order to avoid the radiation heat transfer to collection vessel from atmosphere. Later on the entire system is enclosed in a vacuum jacket and is evacuated in order to reduce the number of gas molecules there by reducing the conduction and convection heat transfer from the atmosphere.

Fig. 3. Multilayer insulation applied to second stage and collection vessel

On achieving the adequate vacuum pressure the cryocooler is started and is allowed to cooldown gradually to its lowest possible temperature. During this cool down process it has been ensured that, the helium gas inlet pressure is positive always. After some time, a steady state in temperature of system is achieved and liquid helium starts to collect in the collection vessel. Fig. 4 shows the overall liquefaction setup involved in this experimentation.

Fig. 4. Helium liquefaction setup using GM cryocooler

4. RESULTS AND DISCUSSION

Experimentation has been carried out using 150 cm^3 collection vessel. Fig. 5 indicates the cooldown temperatures of first, second and vessel stages respectively. Fig. 5 gives the indication of time of thermoacoustic oscillation which in turn confirms the vessel filled with liquid helium.

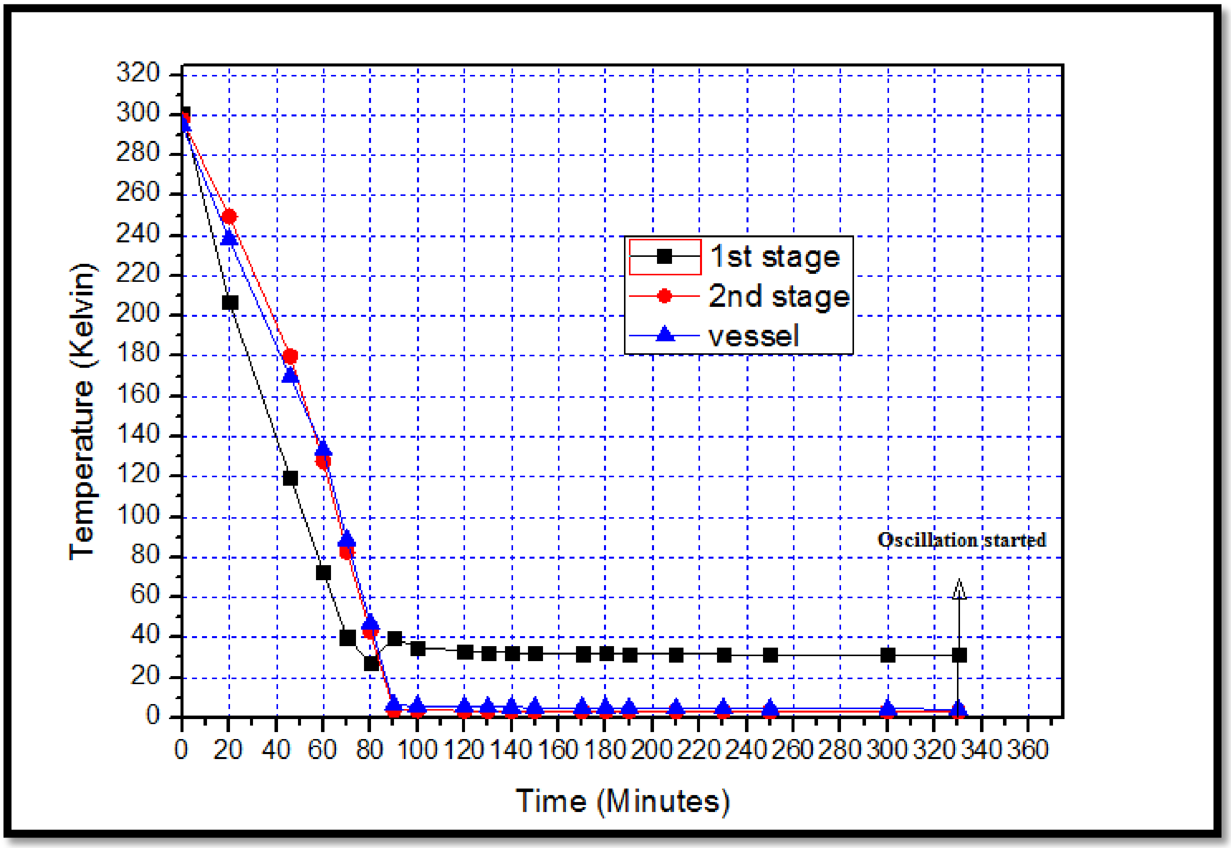

Fig. 5. Cooldown temperatures of first, second stages and vessel

The cooling at these stages is due to the continuous expansion of compressed helium gas in the cryocooler stages. At steady low temperature, the liquid helium starts to collect in the collection vessel when the liquid helium level touches the end of capillary tube to which vapor pressure gauge is connected the thermoacoustic oscillations are seen in the pressure gauge shown in Fig 6. The oscillation caused is because of the pressure difference that exists between the helium in liquid phase and in gaseous phase [5, 6].

During batch liquefaction with suitable arrangement the outlet to liquid helium is closed and helium gas is drawn from the external helium gas cylinder through pressure regulator and flow meter. Using pressure regulator, the gas pressure is adjusted such that positive head exist in system. Initial cooldown occurs in nearly 5 hours and liquid helium gets collected in the collection vessel. When the liquid helium level touches the capillary end thermoacoustic oscillation is seen, thereafter the liquid helium is vented out to ambient conditions. The vent is closed after venting cold helium; now warm helium gas enters the collection vessel resulting in high frequency thermoacoustic oscillations. In batch liquefaction first collection of liquid occurs in nearly 5 hours, later liquid collection takes place with a time interval of nearly 60 minutes.

5. CONCLUSIONS

In this work, the fabrication and experimentation of helium gas liquefaction system using two stage GM cryocooler. The mounted heat exchangers are used to pre-cool the incoming helium gas in first stage and the gas starts to liquefy in the heat exchanger of second stage. The liquefied gas drips down to collection vessel of approximate volume of 150 cm^3. The pressure gauge arrangement is used to monitor the thermoacoustic oscillation caused by collection of liquid helium. This system yields a liquefaction rate of 150 cm^3/ h.

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