Small Scale Helium Liquefaction Systems

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Abstract. We have developed two small-scale helium liquefaction systems that provide solutions for liquid helium usage in laboratories. These helium liquefaction systems use two-stage pulse tube cryocoolers to provide cooling at 4 K. The cold head/liquefier resides inside of the neck of a dewar. The room temperature helium gas to be liquefied enters the neck of the dewar and is efficiently pre-cooled down to 5-6 K by means of the regenerators and pulse tubes of the cold head before being liquefied. Two models of liquefaction system, LHeP12 and LHeP18, produce liquid helium from room temperature gas with the rates of >12 L/day and 18 L/day.

1. Introduction

While many laboratories have applications which require liquid helium, at the present time the most widely used liquid helium producing system, is larger than most sites need to operate their experiments. Some small-scale helium liquefiers developed are mostly using a combined Gifford-McMahon and Joule-Thomson cycle refrigerator [1]. The systems are complicated, unreliable and costly.

Currently many helium dewars and helium cryostats for dilution refrigerator, MRI, NMR, SQUIDs etc. are operating in the field. Some of them are not cryo-refrigerated and, thus, have higher liquid helium boil-off rates. The world’s helium supply is finite and irreplaceable. Growing demand for helium worldwide continuously increases pressure on costs and supply in recent years and in the near future. One of the promising solutions is recovery and recycling of helium by using small helium liquefaction and recondensing systems.

We have developed two helium liquefaction systems to provide solutions for liquid helium usage in the laboratories. The helium liquefaction system uses one 4 K pulse tube cryocooler to liquefy helium in a dewar. The 4 K pulse tube cryocooler is a new generation of cryo-refrigeration system. Owing to the absence of moving parts in the cold head, the 4 K pulse tube cryocooler has demonstrated greater reliability, lifetime and lower vibration in the applications than traditional cryocoolers using GM and Stirling cycles [2]. The regenerators and pulse tubes in the two-stage 4 K pulse tube cryocooler are able to provide excess cooling and efficiently pre-cool the helium gas to be liquefied [3,4]. This feature significantly improves the helium liquefaction rate and efficiency with the 4 K pulse tube cryocooler [5].

This paper reports on design and performance of the helium liquefaction systems.

2. Principle and design of the helium liquefaction systems

Two models of helium liquefaction system, LHeP12 and LHeP18, have been developed to provide the liquefaction rate of >12 L/day and 18 L/day. The LHeP12 employs a model PT410 two-stage 4 K pulse tube cryocooler which provides ≥ 1.0W at 4.2 K and 35W at 45 K on both cooling stages. The
LHeP18 employs a model PT415 pulse tube cryocooler which provides $\geq 1.5\text{W}$ at 4.2K and 40W at 45K.

Figure 1 shows a schematic of the helium liquefaction system. A photo of the LHeP12 is given in figure 2. The LHeP mainly consists of a liquefier (a pulse tube cryocooler (7), (12) and (13)), a liquid helium dewar (4), an extraction line (6), a liquid helium level sensor (10) and a controller (11). The pulse tube cold head (7) resides in the neck of the dewar where it liquefies the helium gas. The helium gas enters the neck of the dewar. It is first precooled by the heat exchangers on the pulse tube cold head, and then condensed on the condenser on the 4 K stage of the cold head. The liquid drops into the dewar belly and is stored there. The liquid extraction line and liquid level probe are inserted into the same neck of the dewar and reach the bottom of the dewar. The LHeP12 or LHeP18 use a 60L or 150L dewar respecting for liquid storage.

The flow meter (1) is used to precisely measure the helium gas flow into the dewar which indicates a liquefaction rate. The pressure regulator controls helium gas flow and maintain constant vapour pressure in the dewar during the operation.

The liquid helium system is fully automatic and controlled by a liquid level controller/monitor and a control panel on the helium compressor (12). It will shut down the cryocooler when the dewar is full and will automatically restart the system at a preset low liquid level. There is a silicon diode temperature sensor (9) on the condenser for monitoring the operating temperature. If the helium gas supply stops, the cryocooler will shut down at preset low temperature on the control panel due to the low temperature reading on the condenser.

**Figure 1.** Schematic of helium liquefaction system. 1. mass flow meter; 2. pressure regulator; 3. vacuum valve for dewar pumping; 4. liquid helium dewar; 5. liquid helium; 6. liquid withdrawal line; 7. cold head of pulse tube cryocooler; 8. safety unit; 9. temperature sensor; 10. liquid helium level sensor; 11. liquid helium level indicator/controller; 12. helium compressor of cryocooler; 13. high & low SS flexible lines of cryocooler; 14. cooling water.

Figure 3 shows the natural convection flows of helium gas to be liquefied in the neck of the dewar. This shows how the helium gas is precooled and liquefied in the neck of the dewar by the cold head of the pulse tube cryocooler. There are temperature gradients from the room temperature flange to the first stage cooling station (300K to $\sim$45K) and from the 1$^\text{st}$ stage cooling station to the 2$^\text{nd}$ stage cooling station/condenser. The surfaces of the 1$^\text{st}$ and 2$^\text{nd}$ stage regenerators and pulse tubes cool the helium gas and generate a strong downwards flowing boundary layer. A portion of the downward flow enters
into the condenser and is liquefied. The helium gas before entering into the condenser is pre-cooled down to the temperatures of 5-6 K. Other portions of the downward flow enhance the thermo-syphon mass flow in the neck. This flow enhancement will thereby increase the vapor cooling of the dewar neck and reduce the heat leak and boil-off of the liquid bath.

Figure 4 shows natural convection flow in the dewar belly during the cool-down process. The condenser cools helium gas and creates a downward stream flow. Heating helium gas by the wall of dewar belly generates a natural convection flow up the wall.

Figure 2. Photo of the LHeP12

Figure 3. Helium liquefaction with pulse tube cold head in dewar neck. 1. dewar neck; 2. a portion of down stream flow of helium gas to be liquefied; 3. a thermosyphon loop; 4. 2nd stage regenerator; 5. 1st stage regenerator; 6. cold head; 7. 1st stage pulse tube; 8. 1st stage cooling station; 9. 2nd stage pulse tube; 10. 2nd stage cooling station/condenser.

Figure 4. Natural convection in the dewar belly during cool-down. 1. dewar belly; 2. dewar neck; 3. condenser; 4. natural convection flow.
3. Test results

Figure 5 shows the typical cool-down curves of the LHeP12 and LHeP18. The cryocooler and dewar start at room temperature. It takes 13 hours for the LHeP12 to reach the steady temperature of 4.11 K for liquefaction. Then the dewar will start to collect liquid helium in 2 hours. The condenser of LHeP18 reaches the steady temperature of 4.17 K for liquefaction in 33 hours. After that the dewar will start to collect liquid helium in 4 hours. During the cool-down process, the strong natural convection generated by the cold head cools the dewar belly down efficiently (see figure 4). The liquefaction systems can have steady helium liquefaction in the period of time which can be accepted by users. The LHeP18 has a longer cool-down time than LHeP12 because of its larger size dewar (150L).

Figure 6 shows the typical liquefaction rate of the LHeP12 and LHeP18 during the steady operation. The liquefaction rate is obtained by measuring the mass flow rate of the helium gas into the dewar. The LHeP12 has a typical liquefaction rate of 15 L/day and the LHeP18, 20.3 L/day.

4. Conclusion

We have developed two small scale helium liquefaction systems for providing solutions of liquid helium usage in laboratories. The helium liquefaction uses a two-stage 4 K pulse tube cryocooler to liquefy helium gas in the neck of a dewar. They can provide typical liquefaction rate >12 L/day and >18 L/day respectively. Unique designs of the helium liquefaction system results in low cost, high reliability and high efficiency. These portable helium liquefaction systems can be used for the helium recovery and liquefaction from multiple cryostats on site.

5. References

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