DEVELOPMENT OF SEPARATOR COOLING SYSTEM FOR HELIUM

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Abstract

A helium phase separator with a condenser is under fabrication and assembled at National Synchrotron Radiation Research Center (NSRRC). The objective of a helium phase separator with its condenser is to separate two-phase helium flow and to re-condense vaporized gaseous helium with a cryocooler of Gifford-McMahon type. We developed a 100 litre (ltr) helium phase separator with a small heat loss as a prototype. The experimental results for the total cooling capacity of the phase separator are 0.73 W at 1.67 bara, which includes the effect of thermal conduction and thermal radiation from the environment. The helium liquefaction rate is 2 ltr/day with a 100 ltr vessel. The mechanism of heat transfer in phase separator was investigated and discussed. This paper presents the experiment of helium liquefaction process of 100 ltr separator with condenser, which was a key component of the helium phase separator.

INTRODUCTION

At present study, liquid helium (LHe) is required widely as a working fluid in many cryogenic laboratories and industries. Many types of liquefier with different cryocooler were build, such as pulse tube liquefier [1] and Gifford-McManhon liquefier [2], etc. The liquid helium produce form the liquefier system transmission to many cryostats by using cryogenic transfer line. The heat loss will be brought into the liquid helium after a long distance of transfer, and cause two-phase flow with considerable pressure gradient. This situation seriously affects that not only discontinuously filled with liquid helium of cryostat, but also decrease the transfer efficiency of liquid helium.

To solve this problem, we designed a 100 ltr helium phase separator placed at the upstream side of the cryostat [3]. The system can separate liquid and gaseous helium, and condense gaseous helium by the Gifford-McMahon (GM) cryocooler, without additional cooling power or Joule-Thomson stage. Due to the lower temperature of two-phase helium flow from the cryogenic transfer line, the liquid helium should not touch the first stage of cryocooler to avoid the additional heat loss when flowing in. The total head load of the separator should be as lower as possible to get higher liquefaction rate for the cryocooler.

In the present study, we analyse the effects of the cool down process on the helium liquefaction and the performance of separator with condenser system. A prototype of 100 ltr helium separator with condenser system has been built using a GM cryocooler Sumitomo RDK-415D. When the gaseous helium is at 295K and cooled down by the separator system, a liquefaction rate of 2 ltr/day has been obtained in the preliminary experiment.

EXPERIMENTAL SETUP

Figure 1 shows the configuration of the separator. The height of outer vessel is 1854 mm and diameter is 956mm, we implemented a Sumitomo GM cryocooler (RDK-415D with compressor F-50L) with fin type condenser on the second stage cool head. Other components composed of three cryogenic valves, liquid helium level sensor, pressure gauge, maintain valve and safety valve. Cryogenic valves (WEKA, model PM-TEV) are to control the flow direction of gaseous and liquid helium in/out the separator system, and also kept the fluctuation of liquid helium level and the pressure in the separator system within ±3 mbar and ±2%, respectively [4].

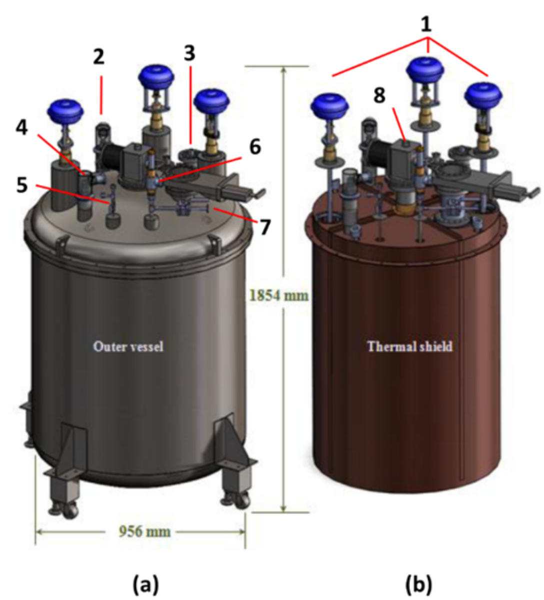

Figure 1: (a) The frame of the separator, (b) thermal shield of connect with first stage of cryocooler; (1) cryogenic valves; (2) exhaust of gaseous helium; (3) incoming helium gas port; (4) exhaust of liquid helium; (5) pressure gauge of inner vessel; (6) safety valve; (7) maintain valve (inlet of gas helium in the study); (8) cryocooler of RDK-415D.

In the separator system, the thermal shield is made of oxygen-free high conductive copper (OFHC) for superior heat transfer connect with first stage of cryocooler, and surround the inner vessel to reduce the radiant heat transfer. The 30 layers of super insulator is wrapped on

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the inner vessel. The maximum volume of the inner vessel is 100 litres. Four rods of G10 is installed to sustain the inner vessel to connect with the outer vessel. The structure of the outer and inner vessel were designed by detailed calculation [3]. The top of the inner vessel is linked to the condenser of the second stage of cryocooler as shown in Fig. 2, and the precooling system of gaseous helium was built before the inlet of the inner vessel.

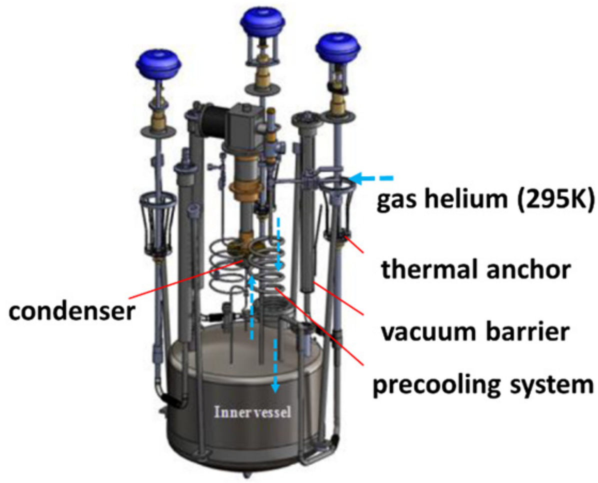

Figure 2: the flow direction of gaseous helium during liquefaction process, and the element of cryogenic.

For isolation of heat transfer from the environment, the thermal anchors are in contact with the precooling system, cryogenic valves, rods and pipeline are to decrease the heat loss of inner vessel. Thermal anchors is made of OFHC which is connected with thermal shield. A vacuum barrier is also added on the port of inlet and outlet of pipeline of the separator, the distance of heat transfer is increased to diminish the heat loss of the inner vessel. The rate of leakage of the vessel was tested to be 8.2 x 10^{-10} mbar L s^{-1} and vacuum can be achieved to 1.2 x 10^{-5} mbar.

Energy expression of the helium liquefaction process are shown in Fig. 3. T_e and h_e are the temperature and specific enthalpy of a standard 40 ltr x 12 gaseous helium bundle (environment temperature) equipped with a pressure-reducing valve. Q_1 is the heat transferred to the first stage of the precooling system from the gaseous helium. T_1 and h_1 are the temperature and specific enthalpy of gaseous helium, respectively after the precooling. Q_S is the heat released from the helium gas at T1 under 4.8K (saturated temperature of inner vessel at 1.67 bara), and Q_L is the latent heat of condensation at 4.8K. Q_2 and Q_L are the total heat load of second stage cool head. Where h_{2G} and h_{2L} are the specific enthalpies of the saturated gas and liquid at 4.8K. We have the following energy equations：

$$Q_1 = \dot{m}(h_e - h_1) \tag{1}$$

$$Q_s = \dot{m}(h_1 - h_{2G}) \tag{2}$$

$$Q_L = \dot{m}(h_{2G} - h_{2L}) \tag{3}$$

Where $\dot{m}$ is the mass flow rate of gas helium at 295K. The cooling capacity of the second stage of cryocooler is obtained：

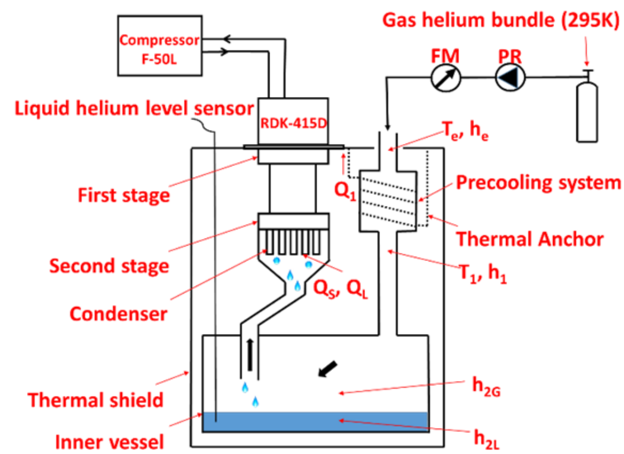

Figure 3: energy expression of the helium liquefaction process. PR, pressure reducer; FM, flow meter for gas helium; T_e, h_e, temperature and specific enthalpy of the inlet gaseous helium (295K); T_1, h_1, temperature and specific enthalpy of gaseous helium after the precooling; Q_1, heat transferred to the first stage from the gaseous helium by precooling system. Q_S, Q_L, the heat transferred to the second stage from T_1 to 4.8K; h_{2G}, h_{2L}, specific enthalpies of the saturated gas and liquid at 4.8K.

$$Q_{2nd} = Q_s + Q_L \tag{4}$$

In the present study, the temperature T_1 of gaseous helium after the precooling system is 54.2K at the first stage temperature of 34.5K. The Q_1 3.3W was calculated, and the smaller heat load of about 13.8W on the first stage can be extrapolation from load map of cryocooler. Future work, the first stage can provide extra cooling capacity to increase the efficiency of precooling system.

EXPERIMENT AND RESULTS

Before the experiment is started, we keep the separator system filled with gaseous helium of 2 bara to prevent the impure gas into system, then turn on the cryocooler. Control the pressure reducer to about 1.67bara, and open the inlet ball valve, the cool down curve of the helium liquefaction process give in Fig. 4. Cooling down the temperature of shield to bellow 80K took about 35.9 hr, due to large heat capacity from the carry of the thermal anchor and gaseous helium precooling system. The temperature of condenser achieves 4.8K after 90.8hr, and begin liquefying gaseous helium in the condenser.

During the liquefaction process, gaseous helium is precooled from 295K to 54K by the precooling system with thermal anchor, and the first stage temperature of cryocooler is 36K. A temperature difference between first stage and precooling system was 18K. We may enhance the efficiency of precooling system by using inefficiency of the second stage regenerator, and reduce the separator cool down time in the future [1][2].

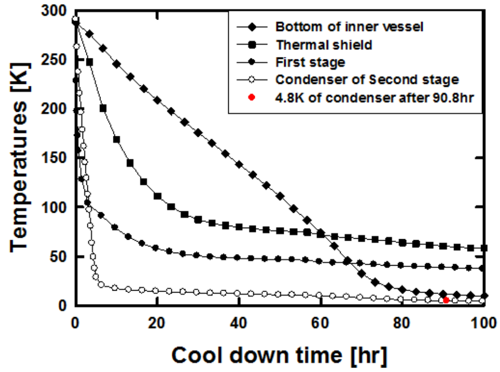

Figure 4: helium liquefaction process for P = 1.67 bara.

During the helium liquefaction process, temperature of condenser, first stage and inner vessel was monitored by the silicon diode temperature sensor and CLTS. The temperature are as shown in Fig. 5 (a) and (b) after the liquefaction process is reached steady sate. When pressure of inner vessel is 1.67 bara, the temperature of helium was liquefied at 4.8K, and the temperature of condenser is kept at 4.7K, sub-cooling 0.1K. The first stage temperature is 34.6K, and the corresponding heat load of 13.8W extrapolated from the cryocooler load map.

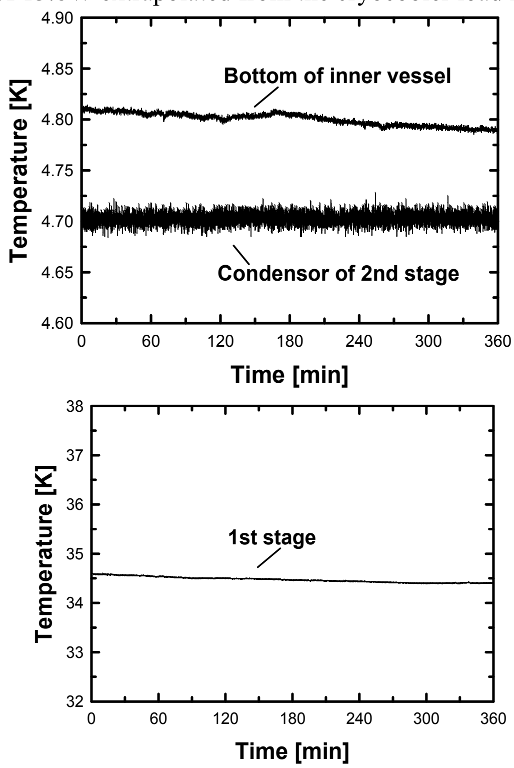

Figure 5: temperature on the first cooling stage and condenser of second cooling stage and the surface of the bottom of inner vessel.

Figure 6 shows the variation of liquid helium level of inner vessel during the liquefaction process from 295K to 4.8K. The accuracy of helium level sensor monitor is within ±0.2cm. The liquefaction rate is 2 ltr/day for 100 ltr separator at pressure 1.67 bara, show in Table 1, while the temperature of gaseous helium is cool down to 54K during precooling. During the cooling process of 54K to 4.8K, there are still a lot of sensible heat on the second stage, thus it will cause the liquefaction rate to minimize.

Considering reality application, the temperature of gaseous helium entering the separator is 4~5.2K which was much lower than 295K in present experiment. Therefore, the total cooling capacity 0.745W of Q_{2nd} can be used widely in liquefying helium (since there's no sensible heat waste for Q_{2nd}).

Table 1: Liquefaction Rate and Energy Data in the Liquefaction Process at 1.67 bara

	m	T_e	h_e	T_1	h_1	Q_1
	(g/s)	(K)	(J/g)	(K)	(J/g)	(W)
2 ltr/day	0.0026	295	1532	54	281	3.25
	h_{2G}	h_{2L}	Q_S	Q_L	Q_{2nd}	Q_{1st}
	(J/g)	(J/g)	(W)	(W)	(W)	(W)
	14.06	-1.34	0.69	0.04	0.73	13.8

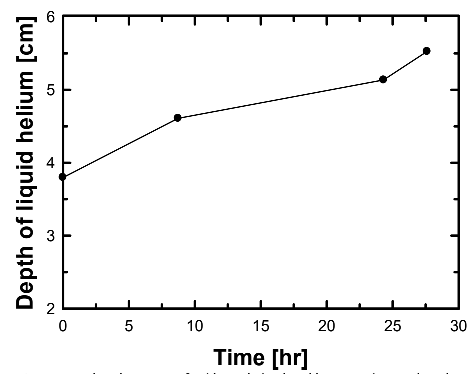

Figure 6: Variation of liquid helium level during the liquefaction process.

CONCLUSION

A separator with condenser RDK-415D cryocooler has been developed in NSRRC, and is successfully under operation in a 100 ltr inner vessel. The total cooling capacity of the second stage of cryocooler is 0.73W. The liquefaction rate of 2 ltr/day with 100 litre inner vessel by supplied from 295K gaseous helium. This experiment is our preliminary trial in NSRRC. We have gained major confident in developing the separator system. The results can be used to study the enhancement of cooling efficiency of condenser in the future.

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