DEVELOPMENT OF A CONDENSER FOR THE HELIUM PHASE SEPARATOR AT NSRRC

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Abstract

A helium phase separator with a condenser is under fabrication and assembly 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 cryo-cooler of Gifford-McMahon type. This paper presents the design and fabrication of the condenser, a key component of the helium phase separator. A preliminary steady-state simulation of the efficiency of the helium condenser is also presented.

INTRODUCTION

To increase the efficiency of helium transfer and to re-condense the vaporized liquid helium as described [1], a test helium phase separator was designed and assembled at NSRRC. The phase separator will be tested for the efficiency of helium condensation in the condenser, and it could also be a cryogenic platform for sample testing at cryogenic temperature at sample port which is designed in the phase separator [1]. Fig. 1 illustrates the components of the phase separator; it includes cryogenic valves for liquid helium into and from the inner helium storage vessel, for gaseous helium from the vessel, a safety valve and a pressure meter. The condenser and sample port are also shown in Fig. 1.

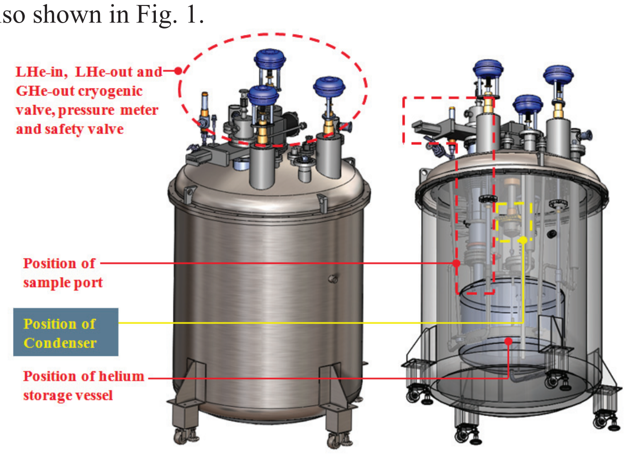

Figure 1: Components of the phase separator

FABRICATION

Dimensions of the condenser

The components of the condenser are shown in Fig. 2. The condenser is assembled with a stainless-steel (SUS-316L) cover for its superior weather resistance. Oxygen-free high-thermal-conductivity copper (OFHC) is used as the material of the condenser because of its small rate of out-gassing and large conductivity. The fin shape is suggested in references [2] and [3]. The thickness of each fin is 3.3 mm for rigidity; the length of each fin is 40 mm. There are 15 fins on the condenser; the gaps between fins are all 1.3 mm, which serves to prevent the interference of the thermal and flow boundary layers. A thermocouple is placed on the stainless steel cover to measure the temperature of the condensed zone for the saturated helium. Another thermocouple installed at the side of the condenser base-plate measures the temperature near the center of the plate. The diameter of the side cavity to place the thermocouple is 1.5 mm. A CLTS sensor is placed near the second stage of the cryo-cooler, for use with a side thermocouple to determine the temperature gradient down the condenser plate by extrapolation, and to obtain the temperature data directly with another thermocouple located at the cover of the condensed zone.

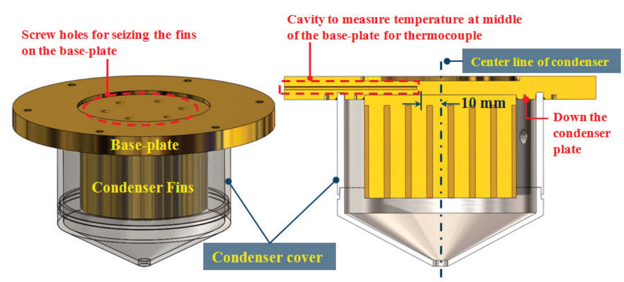

Figure 2: Appearance and cut views of the condenser

Vacuum brazing

Vacuum brazing is applied to combine the components between OFHC and stainless steel [4]. To join the condenser fins and the condenser base-plate and to sustain a state of high vacuum, the most important issue is to make the solder smooth and uniformly distributed among the gap after brazing. To solve this problem, six M2 screws (shown in Fig. 2) were bolted through the condenser base-plate and condenser fins. The brazing gap between condenser fins and base-plate is thus limited; the capillarity effect occurs in the brazing joint while the vacuum brazing is proceeding. This vacuum brazing is used also to join the components of the stainless-steel cover and the OFHC condenser. Fig. 3 shows the condenser before and after vacuum brazing, showing that the cylinder is completely brazed between the condenser cover and the base-plate. The cover and condenser base-plate are brazed in one shot. After all components of condenser are brazed, a test of vacuum leakage would proceed on the condenser module. The minimum value of the test of rate of leakage of the condenser module is 1.3 $\times 10^{-10}$ mbar L s^{-1}; the minimum value of the vacuum test

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is 7.2×10^{-7} mbar. This pressure is sufficient for the condenser module of the helium phase separator.

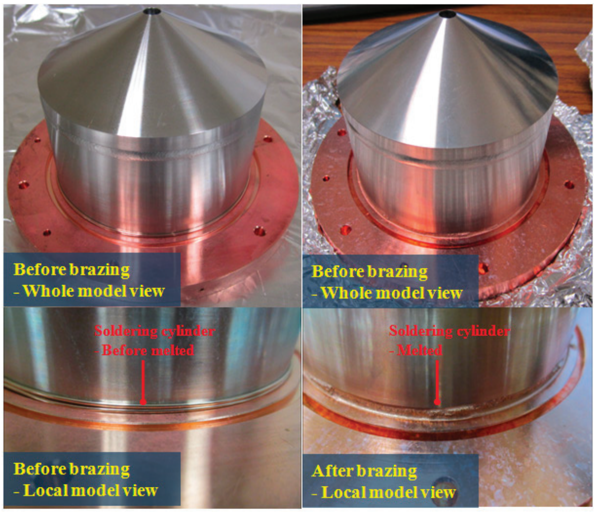

Figure 3: Model before and after vacuum brazing

COMPUTATIONAL SIMULATION

Simulation and boundary condition

The efficiency of helium condensation is simulated with ANSYS fluent. Fig. 4 illustrates the flow of the determination of the rate of helium condensation. The reference model must be initially set up according to [2]; the equations for condensation-evaporation mass transfer [5] applied to estimate the efficiency of helium condensation follow.

$$\dot{m} = coeff \times \alpha_{vap}\rho_{vap}\frac{(T - T_{sat})}{T_{sat}}. \quad (1)$$

$$\dot{m} = coeff \times \alpha_{l}\rho_{l}\frac{(T - T_{sat})}{T_{sat}}. \quad (2)$$

m dot denotes the rate of transfer of mass from liquid to vapour or from vapour to liquid. Subscripts *vap* and *l* denote vapour and liquid, respectively; for *T* that denotes temperature, its subscript *sat* marks the saturated state. ρ is density and α is volume fraction. These two equations are applicable to either evaporation or condensation conditions; the energy transfer of latent heat can therefore be simulated by multiplying the rate of mass transfer by the latent heat at the saturated temperature.

Secondly, coefficient *coeff* seems to be a primary factor that affects the simulation convergence [6]; an initial value should be carefully selected in the simulation to prevent divergence. An iterative simulation reveals that the range from 1×10^{4} to 1×10^{7} is chosen; the range of the simulated rate of condensation is from 9.64×10^{-5} to 9.94×10^{-5} kg s^{-1}. According to this result, coefficient *coeff* evidently affects the simulation result only within 4 %, which effect is negligible. After the simulation result of the referenced model is obtained, the same *coeff* could be used in a NSRRC condenser model under the same conditions to obtain the rate of condensation in simulation. The ratio of rate of condensation and experimental data in [2] serves to estimate the rate of condensation of our condenser.

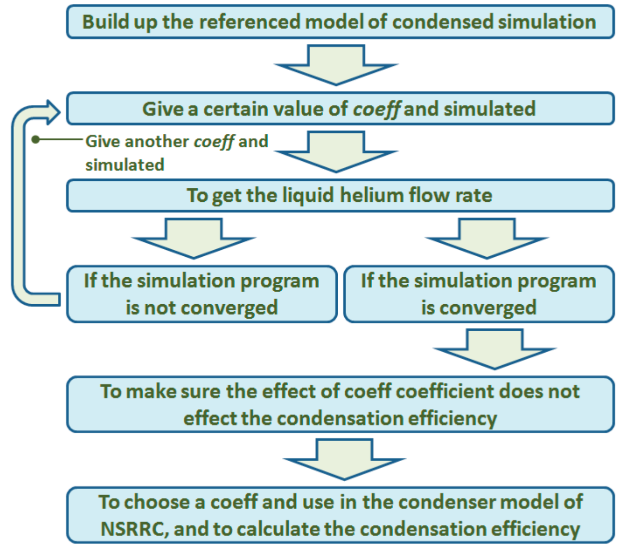

Figure 4: Process to find the rate of condensation of NSRRC condenser by simulation

A scenario for a boundary condition appears in Fig. 5. A symmetric boundary condition is assumed in this model; the inlet/outlet boundary condition of fixed pressure is that, when gaseous helium in the condensed zone is becoming liquid helium, the pressure in the condensed zone would decrease, to let the gaseous helium flow into the condensed zone via the inlet. Meanwhile, because of the saturation pressure existing at the inlet and outlet in actual conditions of the condenser boundary, the outlet is set to have the same boundary condition as the inlet. Because of the length, 254 mm, of the liquid tube in [2], the location of the recording surface for the liquid flow rate is 254 mm lower than the top of the liquid tube. The heat flux 226 W m^{-2} (0.75W) would be set at the top of the condenser because of the location of the cryo-cooler assembled on the top plate of the condenser.

The simulation model of our condenser is shown in Fig. 5; all boundary conditions are identical with that of the reference model. Only a steady-state situation is considered in the simulation. Coefficient *coeff* is set to 5×10^{6}, as indicated by a series of test runs.

Result of the condensed simulation model

The result of the reference model is shown in Fig. 6. The lowest temperature appears at the top of the fin due to the heat absorbed. The liquid helium is distributed uniformly in the calculated domain because the phase change is determined only by the temperature field. There is no volume fraction of liquid helium in the inlet, because the gaseous helium flows into the calculated domain. The rate of condensation is calculated in the reference model to be 9.82×10^{-5} kg s^{-1}.

The result of a condensation simulation of the NSRRC condenser is shown in Fig. 7. The distributions of temperature and volume fraction of liquid helium are similar to those of the reference model because of the same boundary conditions. The rate of condensation of the model is 7.19×10^{-5} kg s^{-1}. According to the ratio of the rate of condensation between the reference paper, 7.4×10^{-5} kg s^{-1}, we estimate the rate of condensation of the NSRRC condenser to be 5.42×10^{-5} kg s^{-1}. This rate is less than the value in [2] because there is less area of heat exchange in the NSRRC condenser. The value and coefficient *coeff* will be verified after the phase separator at NSRRC is assembled. The rate of condensation in the simulation is greater than the actual value because there is no extra heat load in the simulation model.

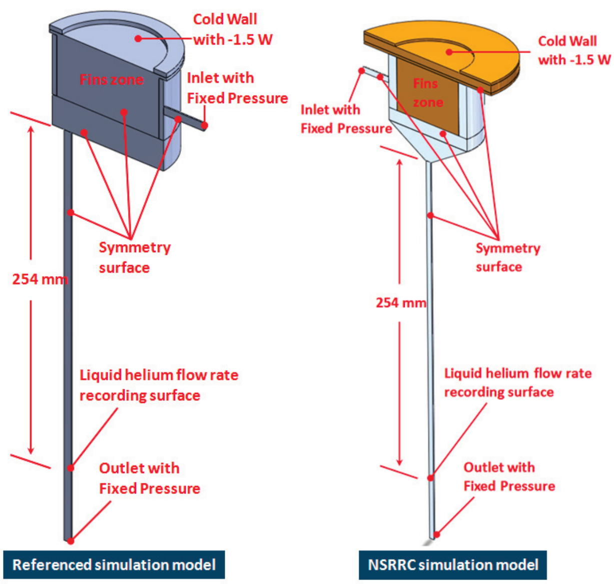

Figure 5: A condensed simulation model of the reference and NSRRC

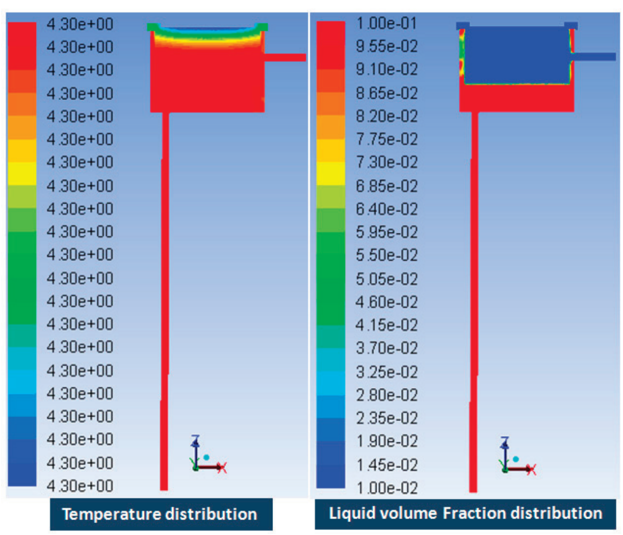

Figure 6: Temperature and liquid volume fraction of the reference model [2]

CONCLUSION

The development and manufacture of the condenser and a preliminary simulation of the rate of condensation in the steady state are presented in this paper. In the manufacturing part, the procedure of production was successful as the condenser passed the tests of leakage of gaseous helium and vacuum: the rate of leakage of the condenser is 1.3×10^{-10} mbar L s^{-1}; the minimum vacuum value of the condenser attained 7.2×10^{-7} mbar. According to the ratio relation that would be the same between the simulation and experiment, we estimate the rate of condensation of the NSRRC condenser to be 5.2×10^{-5} kg s^{-1} because of the decreased area of heat exchange area relative to the condenser in [2].

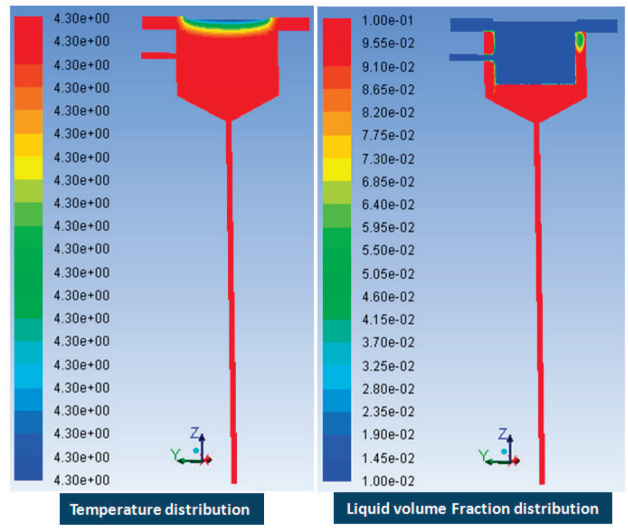

Figure 7: Temperature and liquid volume fraction of the NSRRC model

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