Heat Exchanger Design for the CNS in HANARO

Jung Woon Choi, Kye Hong Lee, and Young Jin Kim
Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong-gu, Daejeon 305-353, Korea
ex-jwchoi@kaeri.re.kr

1. Introduction

The Cold Neutron Research Facility (CNRF) project had been carried out since the middle of 2003 in HANARO. The Cold Neutron Source (CNS) facility, one of main parts of the CNRF project, includes the IPA and related systems to moderate thermal neutrons through the cryogenic moderator, liquid hydrogen, into cold neutrons which is extracted into the guide, with the generation of the nuclear heat load. Since proper removal of this heat load is of importance to keep the moderator in the moderator cell liquid phase and to smoothly flow the moderator in the two-phase thermo-siphon loop, the heat exchanger, a main component of the IPA, should be designed to properly conduct its required thermal performance.

For the CNS, this paper describes from the selection of a heat exchanger type to calculations for a thermal design specification in the view point of the design.

2. Heat Exchanger Design

The heat exchanger removes the heat load on the moderator cell through the condensation of evaporated moderator. In the design of a heat exchanger, a key concept is the two-phase thermo-siphon flow runs in the IPA loop without any problem under the constant liquid moderator level in the moderator cell during the normal operation of the CNS.

2.1 Heat Exchanger type

In accordance with the type of a heat exchanger, a heat exchanger considered for the CNS is categorized as a plate type and a shell-tube type. A shell-tube type is the most commonly used exchanger configuration in the process industries due to easy construction and cleanness/repair, and utilization at extremely low and high temperatures and pressures [1]. On the other hand, a plate type is the most compact for of heat transfer surfaces therefore attractive for use in confined or weight-sensitive locations [1]. Upon the above basic features, the heat exchanger type should be determined under following considerations, such as installed space, fouling, easy repair/maintenance, and domestic cryogenic technology. In the CNS, fouling resistance is not a main factor while operating a heat exchanger by means of the high purification equipment. Focusing on the domestic cryogenic technology and no required repair/maintenance, the shell-tube type heat exchanger is chosen for a main component of the IPA [2].

2.2 Geometry

When HANARO was constructed in 1995, the vertical hole in the reflector tank was prepared for installation of the CNS; therefore, the heat exchanger should be vertically arranged above the reflector. When the evaporated phase is changed into the liquid phase, the volumetric flow rate of a condensed moderator becomes too small in the heat exchanger owing to large volume variation so the vertically arranged type is better for the flow characteristic of a condensed moderator inside the tube. As shown in the figure 2-1, the evaporated hydrogen flows through the center tube into the upper plenum of a heat exchanger then flows into the tubes to be condensed by a helium gas at the cryogenic temperature. Also, the helium gas flows into the shell side in which single segmental baffles are at a constant interval to improve the cooling efficiency. The condensed moderator is collected into the lower plenum then flows out downward into the moderator cell.

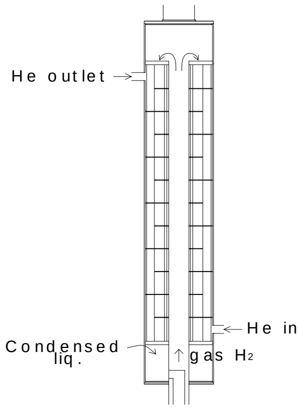

Figure 2-1 Heat Exchanger Schematic Diagram

2.3 Heat Exchanger Specification

The thermal design of a heat exchanger is conducted by means of the commercialized design software generally used for the design of a heat exchanger with a large scale heat transfer capacity. For the removal of 1.1 kW heat load, the heat exchanger specification is described in the table 2-2 to satisfy the required thermal performance under the operating condition, shown in the table 2-1.

Table 2-1 Operating Condition of the Heat Exchanger

	Shell side		Tube side	
	Inlet	Outlet	Inlet	Outlet
Fluid	Gas-He	Gas-He	Gas-H_2	Liq-H_2
Temperature	14 K	17.5 K	21.6 K	20 K
Pressure	2 atm	2 atm	1.5 atm	1.5 atm

Table 2-2 Heat Exchanger Specification

	Shell		Center tube	Tube
Diameter	127 mm	Type	plain	plain
Baffles-cross	10	Number	1	16
Type	Single segmental	Diameter	35 mm	17 mm
% cut	15	Length	780 mm	780 mm
Material	Al 6061-T6	Pitch	23.81 mm 30deg	

2.4 Overall Heat transfer Coefficient

For the heat transfer analysis in a heat exchanger, it is necessary to calculate the overall heat transfer coefficient, U [W/m^{2}K], which shows the overall heat transfer characteristic of the heat transfer area contacted individually with the two fluids flowing in the shell side and the tube side.

$$U_i = \frac{Q}{NA_i F \Delta T_{lm}} \quad \text{(Eq. 1)}$$

$$U_i = \frac{1}{\frac{1}{h_i} + \frac{\ln(d_o/d_i)}{2k} d_i + \frac{1}{h_o}\frac{d_i}{d_o}} \quad \text{(Eq. 2)}$$

In order to calculate the overall heat transfer coefficient in Eq. 2, the evaporated hydrogen condensation in a tube is assumed with a laminar film condensation [3], the heat transfer in a tube wall made of aluminum is considered as conduction, and the helium flow in the shell side is dominated by a forced convection [4] as shown in the figure 2-2.

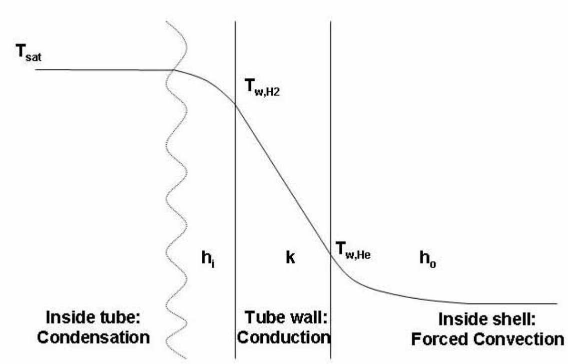

Figure 2-2 Temperature Profile in the Heat Exchanger

The calculated overall heat transfer coefficient is 517.48 [W/m^{2}K]. In the comparison of the calculated heat transfer area based on U_i to the real heat transfer are, the safety factor is 1.57 which means the margin of the heat transfer capacity of the heat exchanger, which is generally larger than 1 in the design of a heat exchanger.

2.5 Pressure Drop in the Heat Exchanger

In general, for the optimized design of a heat exchanger, the pressure drop calculation is simultaneously carried out with the overall heat transfer coefficient calculation since it affects the heat transfer effect in the case that the size of a heat exchanger should be changed to satisfy an allowable pressure drop range. To estimate the pressure drop in the tube side, the followings are considered: friction loss of a gas flow in the center tube and of a condensed flow in the tubes, and friction loss of a gas flow caused by the sudden expansion at the end of the center tube [5]. In the pressure drop in the shell side, on the other hand, the considered pressure drops caused by are following: a flow in a cross flow regime, a flow through the window region, a flow in the separated space by a baffle at the helium inlet/outlet, and a flow at the helium inlet/outlet on the shell [5]. Table 2-3 shows the calculated pressure drop in the tube side and in the shell side. The pressure drop in the tube side is much smaller than that in the shell side since the condensed moderator flows vertically along the tube, so the caused pressure drop may be negligible. In addition, total pressure drop in the shell side is just 59 kPa which is allowable in comparison with the operating pressure of the helium gas, 2 atm.

Table 2-3 Pressure Drop Caused in the Heat Exchanger

	Shell side	Tube side
Total pressure drop	23.5 Pa	59.4 kPa

3. Conclusion

For the CNS, the heat exchanger optimized to remove the required heat load in the two-phase thermo-siphon is designed through the commercialized heat exchanger design program applicable for the large scale heat exchanger. To evaluate the design specification from the program, two significant factors, pressure drop and overall heat transfer coefficient, are calculated. From the calculated results, the designed heat exchanger is concluded proper for the CNS with the safety factor, 1.57. This designed heat exchanger will be tested in the second thermo-siphon test for the CNS.

Nomenclatures

Q	Heat load
U_i	Overall heat transfer coefficient on the inner surface
ΔT_{lm}	Log mean temperature difference
F	Correction factor of ΔT_{lm}
A_i	Inner surface area per tube
N	Tube number
h_i/h_o	Inner/Outer convective heat transfer coefficient
k	Thermal Conductivity
d_i/d_o	Inner/Outer diameter of a tube

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