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Refrigerator Control Methods and Heat Exchanger Operating Condition for the CNS

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1. Introduction

The Cold Neutron Research Facility (CNRF) project had been embarked in the middle of 2003 in HANARO. The Cold Neutron Source (CNS) facility, one of the main parts of the CNRF project, includes the In-Pool Assembly (IPA) and related systems to moderate thermal neutrons through liquid hydrogen, moderator, into cold neutrons with the generation of the nuclear heat load. Since proper removal of the heat load is of significant to keep the desired liquid level in the moderator cell, the heat exchanger should be designed to meet its required thermal performance and the helium refrigeration system (HRS) should be controlled corresponding with the variable heat load dependent on the CNS operation mode. This paper describes the design specification of the heat exchanger and the conceptual control methods of the HRS.

2. Heat Exchanger Specification

In operation, the heat exchanger should deal with the total heat load of the IPA, which is approximately 1100W. The heat exchanger thermal capacity is actually 1100 W enough for the CNS; however, the heat exchanger has been designed with the thermal duty, 1500 W in accordance with that the thermal duty of designed heat exchanger is equal to the refrigeration power of the HRS which includes a refrigeration margin.

2.1 Operating Condition in the Heat Exchanger

In the design of the heat exchanger, the operating condition of the tube side is set to the maximum thermal duty, 1500W. Since the helium flow rate in the shell side affects the pressure drop, the operating condition can be determined within the allowable pressure drop in the chosen heat exchanger size if the operating pressure on the helium refrigeration loop constrains the pressure drop in the heat exchanger. Furthermore, the range of a helium flow rate for the required refrigeration capacity is favorable rather than a certain value of that in the viewpoint of flexibility in the HRS design. Considering above, the operating conditions of the heat exchanger are shown under the variation of helium flow rate, from 50 to 60 g/sec, in the table 1. As the helium flow rate is increasing, not only is the outlet temperature of helium decreasing but also the over design degree is getting higher in the same design at the identical thermal duty.

2.2 Heat Exchanger Specification

The thermal design of a heat exchanger is conducted by means of the commercialized design software, HTRI® [1]. The heat exchanger specification, represented in the table 2 for the removal of 1500W heat load, satisfies the required thermal performance under the operating condition as shown in the table 1.

Table 1. Operating condition of the heat exchanger.

	Shell side		Tube side	
	inlet	outlet	inlet	outlet
Case 1	Over design = 8.22 %			
Fluid name	GHe	GHe	GH_2	LH_2
Flow rate (g/sec)	50.0	50.0	3.41	3.41
Temperature (K)	14.0	18.58	21.85	21.85
Pressure (kPa)	202	197.6	152	151.7
Delta P (kPa)	4.4		0.3	
EMTD*/ Duty	5.0 K		1500 W	
Case 2	Over design = 19.01 %			
Fluid name	GHe	GHe	GH_2	LH_2
Flow rate (g/sec)	55.0	55.0	3.41	3.41
Temperature (K)	14.0	18.17	21.85	21.85
Pressure (kPa)	202	196.8	152	151.7
Delta P (kPa)	5.2		0.3	
EMTD/Duty	5.3 K		1500 W	
Case 3	Over design = 28.26 %			
Fluid name	GHe	GHe	GH_2	LH_2
Flow rate (g/sec)	60.0	60.0	3.41	3.41
Temperature (K)	14.0	17.82	21.85	21.85
Pressure (kPa)	202	195.9	152	151.7
Delta P (kPa)	6.1		0.3	
EMTD/Duty	5.6 K		1500 W	

* EMTD: Effective Mean Temperature Difference

Table 2. Shell and tube type heat exchanger specification.

	Shell		Center tube	Tube
Diameter	127 mm	Type	plain	plain
Baffles-cross	15	Number	1	38
Type	Single segmental	Diameter	35 mm	12.7 mm
% cut	28.30	Length	880 mm	880 mm
Material	Al 6061-T6	Pitch	15.87 mm 30deg	

3. Helium Refrigeration System

The helium refrigeration system (HRS) is to cool down and liquefy the gaseous hydrogen in the heat exchanger in order to create the thermo-siphon in the IPA. Under the safety reason against the hydrogen-oxygen chemical reaction, the helium pressure in the heat exchanger is determined higher than the hydrogen pressure, shown in the table 1, at the normal operation to avoid intruding the gaseous hydrogen through the postulated crack into the HRS. The other operating parameters on the helium refrigeration loop will be determined during the detail design of the HRS.

3.1 HRS Components

As shown in the figure 1, the HRS consists of mainly the compressor station, oil removal system (ORS), helium buffer tank, and cold box. For the CNS-HRS, the oil flooded screw compressor is very reliable and robust due to its simple design and a few moving parts. The ORS, directly connected to the discharge port of the compressor, is made up two stages of coalescer and one char coal adsorber, where the compressed helium is purified through the separation of oil mist, aerosol, and moisture from it. The helium buffer tank is joined to the gas control module in the compressor station for maintaining the required helium pressure in the helium refrigeration cycle loop. The cold box contains all components, working at the cryogenic temperature, such as turbo expander, and one or more heat exchangers and so forth. The compressed helium gas is expanded to get a cryogenic temperature in the turbo-expander and then flows into the heat exchanger in the IPA.

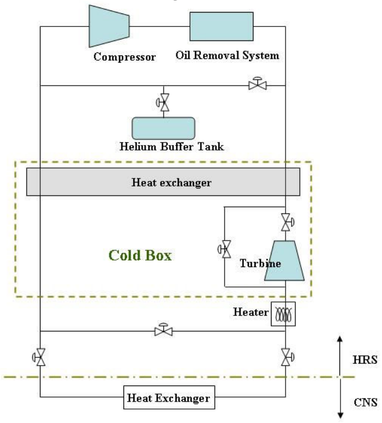

Figure 1. Schematic of the helium refrigeration loop

3.2 HRS Control Methods for the CNS

The transferred heat load on the helium in the heat exchanger of the IPA should be handled in the helium refrigeration loop. Hereafter, it is described how the HRS manages the heat load variation during the normal operation [2]. The HRS operation can be incorporated in 3 different methods for the CNS operation modes based on the reactor operating conditions, shown in the table 3.

Table 3. Operation modes of the CNS

Modes	Shutdown (SD)	Start-up (SU)	Normal (NO)
Reactor	Shutdown	Shutdown	Operation
IPA (CNS)	GH_2	$GH_2 \rightarrow LH_2$	LH_2 in moderator cell
HRS	Stop	Operation	Operation

Firstly, it is to use the electric heater to be installed in the return line from the heat exchanger. The control system turns it on or off in accordance with the variation of the transferred heat load from the IPA. For example, if the reactor power reduces then the heat load on the heat exchanger gets smaller, the system increases the heater capacity to compensate the decreased heat load. This control method not only is easy to implement but also has a very fast response characteristics; on the other hand, it gives rise to an unstable oscillation in the HRS. It is recommended that the control method using the heater be good to apply to the case of a small variation, less than 10% variation of the refrigeration capacity.

Secondly, the control of the turbine speed and bypass valve is used to regulate the flow rate of the cryogenic helium gas as well as its temperature. If it is used when the reactor operates at low power during the start-up mode or for specific physics tests, this control method will be the best. When the heat load need to be reduced by around or a little more than 10% from its nominal value, through the control algorithm the turbine bypass valve is opened to reduce the helium flow rate into the turbine and then the turbine speed reduces. Accordingly, a little warmer helium gas flows into the heat exchanger. The valve control will be done by the PID control algorithm.

Lastly, there is a method to control the helium flow rate into the compressor so that its motor speed is regulated under the VFD (Variable Frequency Drive) control for the minimization of electricity loss. This method is adequate to the large variation of the heat load happening at the HRS, that is, the flow rate through the bypass valve is required much more than 10 % of the total flow rate. When the helium flow rate needs to be reduced more than the required limit under the turbine speed control method, the compressor bypass valve should be opened then the compressor motor will be appropriately regulated at a certain lower speed in order to reduce the system pressure as well as the helium flow rate of the high pressure helium side in the loop. Also, the surplus helium goes back to the helium buffer tank.

The electric heater control and the turbine speed control is a relatively fast response while the controlled compressor speed under the VFD control is a slow response.

4. Conclusion

The shell and tube type heat exchanger in the IPA has been designed through the HTRI at the thermal performance of 1500W for the CNS. To maintain the thermo-siphon in the IPA, the HRS should deal with the transferred heat load from the heat exchanger through its control algorithms. The HRS is controlled by the following methods under the heat load variation: 1) to turn the heater on and increase its capacity as much as the variation; 2) to reduce the turbine speed by opening the turbine bypass valve if the variation keeps going above the limit of the heater capacity then the helium temperature goes up; 3) to regulate the compressor motor speed under VFD control if this situation lasts longer.

ACKNOWLEDGEMENTS

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REFERENCES

[1] HTRI, Licensed by Heat Transfer Research Inc., License user: Donghwagiyen.

[2] Hank Rho Kim et al., Report on the visit of the CNS operation in FRM-II and technical meeting with manufactures for the HRS, KAERI, KAERI/OT-1474/2005.