Development of a Large Cold Trap Design Technology-II

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1. Introduction

In a Sodium-cooled Fast Reactor (SFR), liquid sodium is subject to the formation of impurities by its high chemical reactivity with a number of elements and common compounds used in construction materials by nuclear reactor. The impurities are mainly in the form of hydrides, oxides, metallic compounds, metallic and carbon particles, which originate primarily from steam generator corrosion, moisture from the system component surface, and leakage of air into the system. These are finally deposited in the form of crystallization of sodium hydride (NaH) or sodium oxide (Na_2O) at the cold points of the circuit, which may lead to the clogging of the narrowed sections or may damage the pump. Therefore, it is important to research the purifying performance of a cold trap.

Thus far, many studies for cold traps have been accomplished but studies on performance are still transpiring [1~3]. KAERI secured the design technology for a new high-capacity cold trap through technical cooperation with Kawasaki in Japan. It will be used in a Sodium integral effect Test Loop for safety simulation and Assessment (STELLA-1) to purify the sodium after a performance test in an instruments performance test loop. This paper follows the Design Technology-I which was presented in KNS' 11 Spring Meeting.

2. Design of Cold Trap

Figure 1 shows the schematic diagram of a sodium purification loop. The cold trap consists of an economizer, a central return pipe, mesh packing, and other internals inside a casing. Externally, there is an air-jacket including cooling fins and sheathed heaters.

The sodium passes through the economizer consisting of tubes rolled into coils around the upper central pipe. The effective part of the trap includes two zones; one is an unpacked and cooled shell which promotes the deposit of hydride crystals through its surface condition, the other is an isothermal zone packed with a metal mesh packing. In order to increase the sodium inlet surface into the packing and hence the trap capacity, the packing has been arranged in two layers of concentric elements around the central pipe. The oxide crystals are deposited in this packing, and the purified sodium then rises through a central pipe and exchanges heat with the incoming sodium through the economizer. This insures hydraulic behavior of the trap is running properly.

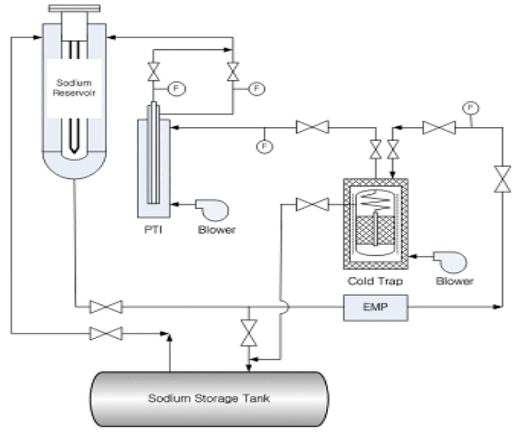

Fig. 1. Schematic diagram of sodium purification loop.

2.1 Design Basis

Figure 2 shows the heat and material balance chart.
The design basis for a large cold trap is as follows:

- Total amount of sodium in the whole facility : 18 ton
- Degree of the sodium purity in initial filling stage and during operation as an oxygen concentration : less than 30 ppm, 5 to 10 ppm, respectively
- Design temperature and pressure : 450℃, 1.0 MPa
- Operating flow rate of sodium : 0.5 kg/s
- Inlet and outlet temperature of sodium : 300℃, 255℃, respectively
- Inlet and outlet temperature of air : 30℃, 41℃, respectively

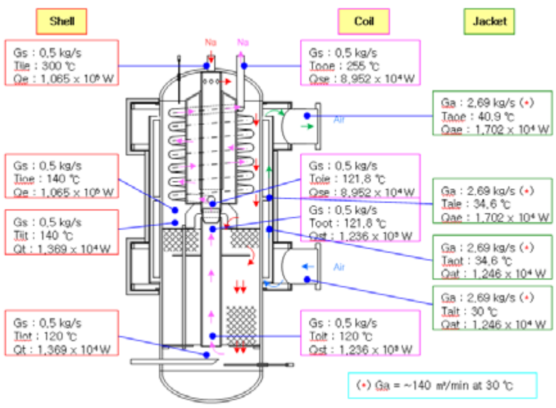

Fig. 2. Heat and material balance chart for cold trap.

2.2 Heat Transfer Calculation

The cold trap is divided into two sections, a trap section and an economizer section as shown in Fig. 2.

To design the cold trap, heat transfer calculations for the trap and economizer section were carried out. Inlet sodium flowing into the shell is cooled by both cooling air and outlet sodium flowing into the coil tube. So heat balances of the trap and economizer section are as follows, respectively.

$$Q_t = Q_{st} + Q_{at} \tag{1}$$
$$Q_e = Q_{se} + Q_{ae} \tag{2}$$

Q was determined from the heat balance between the inlet and outlet sodium, and between the inlet sodium and the cooling air in each section. From the fluid-flow conditions, the heat transfer coefficients, overall heat transfer coefficients, mean temperature differences, required heat transfer areas, effective heat transfer areas, allowance rates of het transfer areas, and the pressure drops were calculated. For this calculation, thermophysical properties at average temperature were applied.

Among these parameters, the equations for overall heat transfer coefficients, mean temperature differences and effective heat transfer areas in each section are described below.

The equations for overall heat transfer coefficient, mean temperature difference and effective heat transfer area are as equations (3) to (5) in case of heat exchange between the inlet and outlet sodium in trap section, (6) to (8) in case of heat exchange between the inlet sodium and the cooling air in trap section, (9) to (11) in case of heat exchange between the inlet and outlet sodium in economizer section, and (12) to (14) in case of heat exchange between the inlet sodium and the cooling air in economizer section, respectively;

$$\frac{1}{K_{tt}} = \frac{1}{h} + \frac{D_{tt}}{2\lambda_{tt}} \ln\frac{D_{tt}}{d_{tt}} + \frac{D_{tt} \cdot 1}{d_{tt} \cdot h_{ot}} \tag{3}$$

$$\Delta T_{tt} = \frac{(T_{iit} - T_{oot})}{2} \tag{4}$$

$$Fe_{tt} = \pi \cdot D_{tt} \cdot n_{tt} \cdot L_{tt} \tag{5}$$

$$\frac{1}{K_{st}} = \frac{1}{h_{ft}} + \frac{D_s}{2\lambda_{st}} \ln\frac{D_s}{d_s} + \frac{D_s \cdot 1}{d_s \cdot h_{it}} \tag{6}$$

$$\Delta T_{st} = \frac{(T_{iit} - T_{aot}) - (T_{iot} - T_{ait})}{\ln\left(\frac{T_{iit} - T_{aot}}{T_{iot} - T_{ait}}\right)} \tag{7}$$

$$Fe_{st} = (A_{ft} + A_{sot}) L_{ft} \tag{8}$$

$$\frac{1}{K_{te}} = \frac{1}{h_{ie}} + \frac{D_{te}}{2\lambda_{te}} \ln\frac{D_{tt}}{d_{tt}} + \frac{D_{te} \cdot 1}{d_{te} \cdot h_{oe}} + R_{te} \tag{9}$$

$$\Delta T_{te} = \frac{(T_{iie} - T_{ooe}) - (T_{ioe} - T_{oie})}{\ln\left(\frac{T_{iie} - T_{ooe}}{T_{ioe} - T_{oie}}\right)} \tag{10}$$

$$Fe_{te} = \pi \cdot D_{te} \cdot \pi \cdot \frac{D_c}{Cos\,\theta_c} \cdot n_l \tag{11}$$

$$\frac{1}{K_{se}} = \frac{1}{h_{fe}} + \frac{D_s}{2\lambda_{se}} \ln\frac{D_s}{d_s} + \frac{D_s \cdot 1}{d_s \cdot h_{iet}} \tag{12}$$

$$\Delta T_{se} = \frac{(T_{iie} - T_{aoe}) - (T_{ioe} - T_{aie})}{\ln\left(\frac{T_{iie} - T_{aoe}}{T_{ioe} - T_{aie}}\right)} \tag{13}$$

$$Fe_{se} = (A_{fe} + A_{soe}) L_{fe} \tag{14}$$

The results of heat transfer calculation for the trap and economizer section are shown in table I.

Table I: Result of heat transfer calculation for the trap and economizer section

	Unit	Trap section			Economizer section		
		Tube side	Shell side	Jacket side	Tube side	Shell side	Jacket side
Free flow area	m^3	3.23×10^{-2}	0.465	0.156	2.17×10^{-3}	0.22	0.156
Hydraulic diameter	m	0.203	0.581	6.05×10^{-2}	5.25×10^{-2}	6.03×10^{-2}	6.05×10^{-2}
Velocity	m/s	1.68×10^{-2}	1.17×10^{-3}	15.1	0.255	2.52×10^{-3}	15.3
Reynolds number	-	5.06×10^{3}	1.05×10^{3}	5.49×10^{4}	2.55×10^{4}	319	5.41×10^{4}
Nusselt number	-	5.57	4.36	115	6.72	1.52	114
Heat transfer coefficient	$W/(m^2 \cdot K)$	2.37×10^{3}	642	50.5	1.05×10^{4}	2.03×10^{3}	50.5

	Unit	Trap section		Economizer section	
		Inlet & outlet sodium	Inlet sodium & cooling air	Inlet & outlet sodium	Inlet sodium & cooling air
Overall heat transfer coefficient	$W/(m^2 \cdot K)$	395	33.4	1.18×10^{3}	34.9
Mean temperature difference	℃	9.1	97.5	29.6	170.9
Exchanged heat	W	1.24×10^{3}	1.25×10^{3}	8.95×10^{4}	1.70×10^{4}
Required heat transfer area	m^2	0.344	3.83	2.56	2.85
Effective heat transfer area	m^2	0.392	4.2	3.1	3.25
Allowance rate of heat transfer area	%	14.2	9.93	21.1	13.7

3. Conclusions

KAERI has developed and secured a design technology for a new high-capacity cold trap which will be used in Sodium integral effect Test Loop for safety simulation and Assessment (STELLA-1) to purify the sodium.

In this paper, the heat transfer calculation for a design the cold trap are described following the computation of mesh volume which was presented in KNS'11 Spring Meeting. A performance test of it will be performed.

REFERENCES

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