Development of a Large Cold Trap Design Technology-I

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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 so many elements and common compounds used in nuclear reactor construction materials. 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 system component surface, and leakage of air into the system. These are finally deposited in the form of the 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 purifying performance of a cold trap.

Up to now, many studies for cold traps have been accomplished but the studies for their performance are still under execution [1~3]. KAERI secured a design technology for a new high-capacity cold trap through a technical cooperation with Kawasaki in Japan. It will be used in Sodium integral effect Test Loop for safety simulation and Assessment (STELLA-1) to purify the sodium after performance test in a instruments performance test loop.

2. Design of Cold Trap

Figure 1 shows the schematic diagram of sodium purification loop. The cold trap consists of an economizer, a central return pipe, mesh packing, and other internals inside of the shell. Outside of the shell, there is 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 useful part of the trap includes two zones; one is an unpacked and cooled shell whose surface condition promotes the deposit of hydride crystals, the other one is an isothermal zone packed with 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 proper hydraulic behavior of the trap.

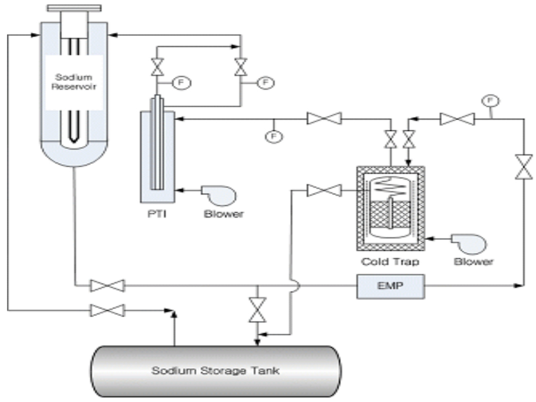

Fig. 1. Schematic diagram of sodium purification loop.

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 the sodium in 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

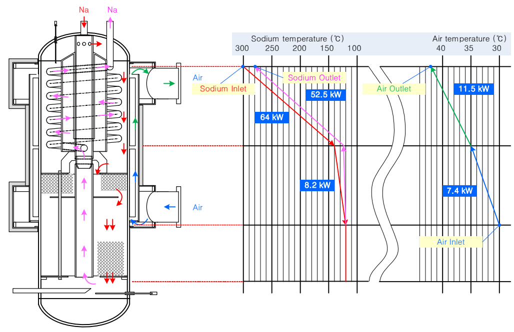

Fig. 2. Heat and material balance chart for cold trap..

2.2 Computation of mesh volume

Estimation of Total Impurity Into Sodium

Although the lifetime of cold trap depends on design concept, rarely it is replaced in lifetime of the facility. So, cold trap needs to have the capacity to capture all amount of impurity in-service period of facility. At first, estimate the total impurity of sodium in whole facility that is caused by oxygen and hydrogen existing the facility. In case of oxygen and hydrogen contamination into the sodium, we should consider the cause of contamination the impurity: (i) initial oxygen and hydrogen in the sodium loaded in the facility, (ii) transfer oxygen and hydrogen from the surface of structural materials, (iii) transfer oxygen and hydrogen for the cover gas, (iv) additional oxygen and hydrogen caused by maintenance and repair.

But here the additional impurity contamination was disregarded as it is depending on the plan of maintenance and repair.

The amount of oxygen and hydrogen into the sodium can be estimated by using the following equations.

$$Wa(O_2) = (C_{O1} - C_{O2}) \times 10^{-6} \times W, \text{(kg)} \quad (1)$$
$$Wa(H_2) = (C_{H1} - C_{H2}) \times 10^{-6} \times W, \text{(kg)} \quad (2)$$
$$Wb(O_2) = 1.0 \times 10^{-3} \times S, \text{(kg)} \quad (3)$$
$$Wb(H_2) = 2.6 \times 10^{-4} \times S, \text{(kg)} \quad (4)$$
$$Wc(O_2) = V \cdot \rho \cdot Y_o \times 10^{-2}, \text{(kg)} \quad (5)$$

The amount of initial oxygen and hydrogen into the sodium can be estimated by using equations (1) and (2), respectively. If the structural material is stainless steel, the transfer oxygen and hydrogen abundance from the surface of structural can be estimated by using equations (3) and (4), respectively. The transfer oxygen abundance into cover gas can be estimated by using equations (5). The cover gas is used when the charge up the sodium into facility, drain the sodium of facility, and control the pressure in facility. All factors is taken into calculation. Oxygen concentration is depends on the quality of using gas. To estimate correctly, the gas specification used at the facility should be confirmed. The transfer hydrogen abundance into cover gas can be estimated in the same way with oxygen.

The oxygen and hydrogen solubility into the sodium depending on the temperature was calculated by using the following Eichelberger's equation (6) [4] and Visser's equation (7), respectively.

$$\text{Log } C_O \, [O_2, \text{ppm}] = 6.239 - 2447 / T \quad (6)$$
$$\text{Log } C_H \, [H_2, \text{ppm}] = 6.067 - 2880 / T \quad (7)$$

Estimation of Mesh Volume

The mesh volume should be prepared with a sufficient volume to capture oxygen and hydrogen. The stainless mesh volume ($Vm(O_2)$) for above all estimated oxygen can be estimated using the following equation.

$$Vm(O_2) = (Wa(O_2) + Wb(O_2) + Wc(O_2))/53, \ (m^3) \quad (8)$$

The value of 53 that is capacity for capturing oxygen as oxide form per 1 m^3 is experimental. For hydrogen, it can be estimated in the same way by using the following equation.

$$Vm(H_2) = (Wa(H_2) + Wb(H_2) + Wc(H_2))/3.5, \ (m^3) \quad (9)$$

Consequently, total mesh volume can be calculated as below.

$$Vm = Vm(O_2) + Vm(H_2), \ (m^3) \quad (10)$$

Table I shows the calculated result using data for STELLA-1 facility. According to table 1, the calculated amount of oxygen and hydrogen is 1.41 kg and 0.24 kg, respectively. Here the total surface area of the equipments in STELLA-1 facility is about 643 ㎡. The essential stainless mesh volume is as shown in table II.

Table I: Calculated amount of oxygen and hydrogen

	Abundance (kg)		Remarks
	O_2	H_2	
Initial impurity	0.63	0.064	Sodium weight : 18 ton
On the surface	0.64	0.17	
In cover gas	0.14	0.0094	Cover gas volume is assumed To be 1.5 times larger than sodium volume : 30.3 ㎥
Total	1.41	0.24	

Table II: Essential stainless mesh volume

	Mesh volume (㎥)	Remarks
For oxygen	0.027	Capture rate 53 kg/ ㎥
For hydrogen	0.069	Capture rate 3.5 kg/ ㎥
Total	0.096	-

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.

This time, the estimation of total impurities into sodium and mesh volume was described in this paper. Heat transfer calculation for design of the cold trap will be followed next time. And then, a performance test of it will be performed.

REFERENCES

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