Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

A Preliminary Evaluation of Cold Trap Capacity in a Prototype Sodium-cooled Fast Reactor

Moon Oh Kim [a*], Seong O Kim [b], Ji Young Jeong [b], Tae Ho Lee [b] and Hee Do Lee [a]
[a]*Atomic Creative Technology, Hanbat Nat. Unv. Post Bl 705 Gwanpyeong-dong Yuseong-Gu, Daejeon, Korea*
[b]*Korea Atomic Energy Research Institute, DaeDeok Daero 989-111, Yuseong-Gu, Daejeon, Korea*
[*]*Corresponding author: bluewon@actbest.com*

1. Introduction

Recently, Korea Atomic Energy Research Institute (KAERI) has begun to design a 150MWe prototype sodium cooled fast reactor (SFR) for the construction of prototype by 2028. SFR, most notable among Gen. IV reactors, is characterized in that sodium is used as coolants. Therefore, it is required to control the level of impurities in sodium of Primary Heat Transport System(PHTS) and Intermediate Heat Transport System (IHTS).[1] Otherwise, they could cause corrosion, degradation of thermal or mechanical performance and flow blockage in system.

Generally, main impurities such as oxygen and hydrogen are removed by cold trap, life time of which has close relationship with its volume. Hence, it is important to calculate the compatible volume of cold trap with the replacement cycle of fuel and the plant design.

The object of this study is to evaluate the volume of the crystallizer, the most important factor in determining the volume of the cold trap, using the purification requirements of PRISM [2] and CRBRP [3]. The volumes of the crystallizer evaluated in this study can be referenced in the design of prototype SFR.

2. Evaluation of Cold Trap Capacity

2.1 Sources of Impurities in PHTS and IHTS

In the primary and intermediate systems of SFR, oxygen and hydrogen are major gaseous impurities, and tritium is a radionuclide impurity. The residual moisture on surface of fuel is one among the sources of oxygen and hydrogen into the PHTS. Additionally, oxygen could be introduced by intermittent air inleakage into the primary cover gas space and hydrogen be diffused into the secondary sodium from water-side corrosion of the S/G tubes.

The main sources of impurities in IHTS are the diffuse of hydrogen, ingress of oxygen from cover gas and the inleakage of air during maintenance. In IHTS, the contamination of hydrogen is higher 7 times than that of oxygen.

In SFR, the sources of tritium are the ternary fission of the fuel and the activation of boron in the control rods. Tritium also diffuses through reactor structural materials and, migrates throughout the reactor system by sodium circulation. Tritium could be removed quite effectively by the sodium cold trap.

These impurities such as oxygen, hydrogen, and tritium are controlled to low levels by cold-trapping of the primary and intermediate sodium systems. In this study, the cold trap requirements are focused on oxygen and hydrogen.

Table 1[4] shows the mass of impurities produced in PHTS and IHTS during each operation. In the process of initial cleanup, the most impurities are produced than in the others. 32.7lb of oxygen and 4.14lb of hydrogen in PHTS and 38.8lb of oxygen and 1.78lb of hydrogen in IHTS are produced, respectively.

Table 2[4] shows the effect of S/G leaks on cold trap requirements, and gives the trap mass consumed per year on the average. The frequency for these three intermediate leaks was assumed to be each one-third of the overall frequency for large leaks. In IHTS, S.G leakage must be considered.

Table 1. Cold trap requirements in PHTS and IHTS

Operation	**Impurity**	**Contamination**	
		PHTS	IHTS
Initial Cleanup	Oxygen	32.7 lb	38.8 lb
	Hydrogen	4.14 lb	1.78 lb
Normal Operations Including	Oxygen	2.4 lb/yr	0.27 lb/yr
	Hydrogen	1.2 lb/yr	3.2 lb/yr
Maintenance shutdown	Oxygen	2.0 lb/yr	1.0 lb/yr
	Hydrogen	-	-

Table 2. IHTS loop cold trap requirements for S.G. Leak and emergency

Leak Type	**Leak Amount**	**Frequency**	**Cold Trap Capacity Required**	
			Oxygen	Hydrogen
	lb	no./yr	lb/yr	lb/yr
Small	5	1/5	0.89	0.111
Intermediate				
Lower	100	1/54	1.65	0.206
Ave.	100	1/54	1.65	0.206
Upper	100	1/54	0.084	0.0067
Large	500	1/18	0.253	0.020
		Total	4.53	0.55

2.2. Calculation Cold Trap Capacity

In the evaluation of the capacity of the cold trap, the most important parameter is the ratio of the available volume of crystallizer used for trapping impurities to total volume. The capacity of cold trap is the pounds of oxygen or hydrogen that crystallizer could contain at the end of its life time. Although cold trap consists of crystallizer, economizer and cooling component, the capacity of cold trap in this study means that of crystallizer.

In early days, the available rate of crystallizer remained about 10~20%. Recently, however, the cold trap has been developed for its available rate to reach up to 30~50%[5].

In this study, according to the available rate and life time of cold trap, its capacities are calculated. When the pressure drop in the cold trap increases rapidly and it finished the life time, the apparent densities of sodium oxide and sodium hydride are calculated by Eq (1) and Eq. (2), respectively. In Eq. (1) and (2), symbol “a” means the available rate of the cold trap, correctly crystallizer. The available rate of cold trap would vary from 10 to 50.

$$\frac{1}{141.31}\,\frac{ft^3(Na_2O)}{lb(Na_2O)}\,\frac{100\,ft^3(mesh)}{a\;ft^3(Na_2O)}\,\frac{62}{16}\,\frac{lb(Na_2O)}{1lb(O_2)} = \frac{2.74}{a}\,\frac{ft^3(mesh)}{lb(O_2)} \qquad (1)$$

$$\frac{1}{57.4}\,\frac{ft^3(NaH)}{lb(NaH)}\,\frac{100\,ft^3(mesh)}{a\;ft^3(NaH)}\,\frac{24}{1}\,\frac{lb(NaH)}{1lb(H_2)} = \frac{41.8}{a}\,\frac{ft^3(mesh)}{lb(H_2)} \qquad (2)$$

From Eq. (1) and (2), and Table 1, the capacity of the cold trap in PHTS can be obtained as Eq. (3). The capacity will be calculated according to the available rate and the lifetime of the PHTS cold trap.

$$\begin{aligned} V &= t\,yr \times \left(2.4\times\frac{2.74}{a} + 1.2\times\frac{41.8}{a} + 2.0\times\frac{2.74}{a}\right)\frac{ft^3}{yr} \\ &\quad + 21.6\times\frac{2.74}{a}\,ft^3 + 2.7\times\frac{41.8}{a}\,ft^3 \qquad (3) \\ &= \frac{1}{a}\left(62.22\times t + 172.04\right) ft^3 \end{aligned}$$

Also, from Eq. (1) and (2), and Table 1~2, the capacity of the cold trap in IHTS can be calculated as Eq. (4). According to the available rate and the lifetime of the IHTS cold trap, the capacity will be calculated and the leakage of S/G is considered in probabilistic.

$$\begin{aligned} V &= t\,yr \times \left((0.27+4.53)\times\frac{2.74}{a} + (3.2+0.55)\times\frac{41.8}{a} + 1\times\frac{2.74}{a}\right)\frac{ft^3}{yr} \\ &\quad + 22.1lb\times\frac{2.74}{a}\times\frac{ft^3}{lb} + 0.8lb\times\frac{41.8}{a}\times\frac{ft^3}{lb} \qquad (4) \\ &= \frac{1}{a}\left(172.64\times t + 93.99\right) ft^3 \end{aligned}$$

The volume capacities of cold trap according to its life time and available rate are calculated in Table. 3. The capacity of cold trap has linear relation with available rate and life time as shown in Table 3.

Table 3. Volume capacities of cold trap with various conditions

Life Time (yr)	Ratio of available to total cold trap volume					
	10%		25%		50%	
	PHTS (ft^3)	IHTS (ft^3)	PHTS (ft^3)	IHTS (ft^3)	PHTS (ft^3)	IHTS (ft^3)
5.00	48.31	95.72	19.33	38.29	9.66	19.14
10.00	79.42	182.04	31.77	72.82	15.88	36.41
20.00	141.64	354.68	56.66	141.87	28.33	70.94
30.00	203.86	527.32	81.55	210.93	40.77	105.46
60.00	390.52	1045.24	156.21	418.10	78.10	209.05

The differences of the primary and intermediate sodium volume between prototype and CRBRP might have effect on the amount of impurity during each operation. Each sodium volume in prototype is 17660 ft^3 in primary and 4343 ft^3 in intermediate, and in CRBRP 26764 ft^3 and 7543 ft^3, respectively. Therefore, the impurities depending on sodium volume in prototype would be reduced to about the 70% level of CRBRP.

According to the reduced sodium volumes, the cold trap volume capacities of prototype PHTS and IHTS with 60yr of life time and 50% of available rate are 54.6 ft^3 and 146.3 ft^3, respectively, which are similar to the capacities of CRBRP with 20yr of life time and 25% of available rate.

3. Conclusions

The capacity of cold trap is suggested as the function of its available rate and lifetime, and calculated with various conditions. Based on the proposed equation, the volume capacities of cold trap required in prototype SFR are calculated. If the replacement cycle of cold trap is determined according to the operation strategy of sodium purification equipment, the dimension of cold trap would be dependent on its available rate.

Acknowledgement

This study has been performed under a contract with the Korean Ministry of Educational Science and Technology.

REFERENCES

[1] Preliminary Conceptual Design Report of Gen-IV SFR Demonstration Plant, KAERI/TR-4335/2011

[2] PRISM Preliminary Safety Analysis Report, GE, 1987

[3] CRBRP Preliminary Safety Analysis Report

[4] Cold Trap Requirements for PHTS and IHTS Sodium Purification, H.L. Sletten, 1974

[5] Sodium Technology Handbook, 2005