Helical Coiled Steam Generator for 150Mwe Prototype Sodium Cooled Fast Reactor

Eui Kwang Kim [*], Ji-Woong Han, Do-Hee Hahn, Tae-Ho Lee
Korea Atomic Energy Research Institute, Fast Reactor Technology Development Division, 1045 Daedeok-daero,Yuseong-gu, Daejeon 305-353, KOREA
[*] *Corresponding author: ekkim1@kaeri.re.kr*

1. Introduction

A steam generator is a critical component determining the plant availability in the heat-transport system of a fast breeder reactor. The helical coil steam generator for a 150MWe Prototype SFR has been designed and optimized based on foreign manufacturing experiences with a focus on improved economics. An optimization study is carried out, and the design results are presented.

2. Optimization of tube size

In this section, a detailed optimization study is described. The study includes the selection of the tube thickness and number of tubes.

2.1 Design condition

Thermal hydraulic design conditions of a steam generator based on two IHTS loops are given by the following [1].

- Thermal capacity: 196.8 MWt
- Sodium flowrate: 757.95 kg/s
- Sodium inlet temperature: 527 ℃
- Sodium outlet temperature: 324 ℃
- Feedwater temperature: 230 ℃
- Steam temperature: 503℃
- Steam pressure: 16.5 MPa

2.2 Tube Thickness Selection

The pipe wall thickness is determined by the following equation from ASME B&PV Section III Division 1-NC-3640 [2].

$$t_m = \frac{Pd_i + 2SA + 2yPA}{2(S + Py - P)} \quad ,$$

where, t_m = the minimum required wall thickness (mm)
P = internal pressure (kPa)
d_i = tube inner diameter (mm)
d_o = tube outer diameter (mm)
S = maximum allowable stress (kPa)
A = additional thickness (mm)
y = 0.4 for pipe with a d_o/t_m ratio of less than 6

Mod. 9Cro-1Mo steel is selected as the tube material. The most conservative additional thickness (A) is 1.65mm; however, the determined value for the present design is 1mm according to the results of applying the above equation to an India PFBR steam generator [3]. The maximum allowable stress of mod. 9Cro-1Mo steel is 104.3 MPa for a design life of 30 years under the operation temperature of 527℃ [4]. The calculated tube size from the tube ID 10mm to 22mm in step increase of 2mm is provided in Table 1.

Table 1. Tube ID, thickness and OD

ID	10	12	14	16	18	20	22
tm	2.05	2.22	2.40	2.57	2.75	2.92	3.10
OD	14.1	16.4	18.8	21.1	23.5	25.8	28.2

With an increase in tube ID, the capital cost, capitalized operating cost, and overall cost as a sum of both capital and operating costs of an SG for the design life are shown in Fig. 1. The basis for the capital and operating costs are estimated to be about 12.1 billion won/m^3 of mod. 9Cro-1Mo steel tube material volume, and 36,219 won/watt of pumping power [3]. The pumping power is calculated from the volumetric flow rate multiplied by a pressure drop. The detailed hydraulic and thermal performances with respect to the tube size are estimated with a 1-D thermal hydraulic code (HSGSA) [5].

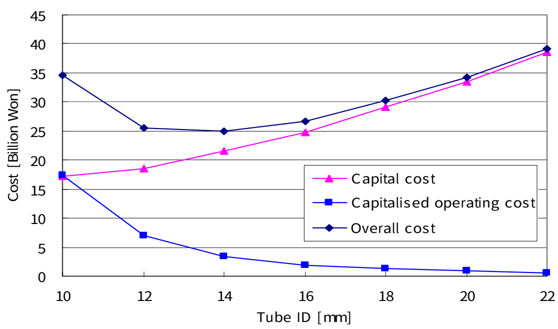

Fig. 1. Tube ID vs costs

An increase in the tube ID results in an increase in the tube wall thickness, which raises the thermal resistance, and hence, requires a larger heat transfer area, but a reduction in the pressure drop on both shell and tube side. The optimum tube ID lies around 14 mm. For a 14mm tube ID, the required number of tubes and water mass flux are given in Table 2. The recommended water side mass flux and steam velocity limits are 2000 kg/m^2-s and 60m/s, respectively [3]. One of the advantages of the helical coil SG is the use of a longer tube to reduce the number of tube-to-tubesheet joints for minimizing the possibility of an SWR, since the expected major source of leakage in the steam generators would be failures in tube-to-tubesheet welds and is considered to depend on the total length of the weld joints. A lesser number of tubes and longer tube are preferred considering these, and hence the tube with 19.4 mm ID, 25.4 mm OD, 3.0 mm thickness is recommended for the Prototype SFR SG taking into consideration domestic tube manufacturing products [6].

Table 2. Tube ID and water mass flux

ID [mm]	# of Rows	# of Tubes	Tube length [m]	Heat transfer area [m^2]	Tube volume [m^3]	Water mass flux [kg/s-m^2]
14	11	209	63.48	680.7	1.588	2654.2
14	12	234	57.57	691.2	1.612	2370.6
14	13	260	52.75	703.7	1.641	2133.6
14	14	287	48.72	717.4	1.673	1932.8
14	15	315	45.27	731.6	1.707	1761.0
14	16	344	42.53	750.6	1.751	1612.6
14	17	374	39.98	767.2	1.789	1483.2
14	18	405	37.82	785.9	1.833	1369.7

2.3 Number of Tube Selection

For a fixed tube size, the selection of the number of tubes is important for the design of an SG, as a lower number of tubes is preferred in terms of capital cost, manufacturing, inspection, and safety consideration, but a larger number of tubes is preferred for an increased flow area, which reduces the pressure drop and operating costs.

With an increase in the number of tubes, the tube lengths and pressure drops are shown in Table 3. Based on this table, 187 tubes per SG are found to be optimal (Fig. 2). Table 3 shows the design results of the helical coil SG with a 10% tube plugging margin.

Table 3. Number of tubes with tube length and pressure drop

# of Rows	# of Tubes	Tube length [m]	Water mass flux [kg/s-m^2]	Orifice DP [Bar]	Tube DP [Bar]	Shell DP [Bar]
9	144	77.5	2006.2	6.55	8.2	0.218
10	165	69.35	1750.8	6.55	5.98	0.160
11	187	62.9	1544.9	6.55	4.5	0.122
12	210	57.6	1375.7	6.55	3.47	0.095
13	234	53.42	1234.6	6.55	2.73	0.076
14	259	49.75	1115.4	6.55	2.2	0.062

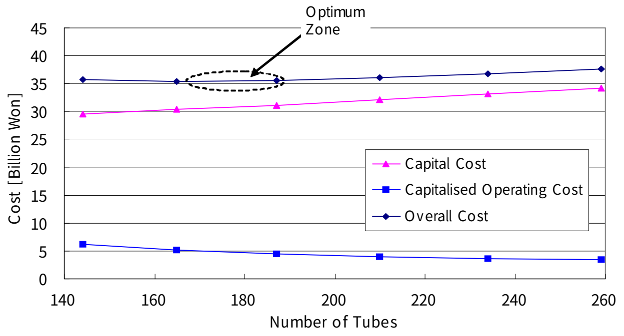

Fig. 2. Number of Tubes Vs costs.

Table 3. Design Results of Helical Coil SG

configuration	Helical coil
thermal capacity [MWt]	198.4
number of tubes	210
tube ID [mm]	19.4
tube OD [mm]	25.4
overall tube length [m]	61.7
tube material	mod. 9Cr-1Mo
overall tube heat transfer area [m^2]	1033
heat transfer area margin [%]	10
tube bundle transverse pitch	1.80
tube bundle longitudinal pitch	1.50
tube pitch angle	7.6
number tube coil rows	12
helical coil bundle height [m]	8.10
helical coil bundle diameter [m]	2.15
inner shroud diameter [m]	1.05
SG height [m]	15.8
tube side pressure drop [Kpa]	385
shell side pressure drop [Kpa]	10
tube side mass flux [kg/s-m^2]	1376

3. Conclusions

Through detailed optimization studies, a helical coiled steam generator with 210 tubes of 61.7 m, 19.4 mm ID and 25.4 mm OD was designed for a 150MWe Prototype SFR.

REFERENCES

[1] Ji-Woong Han, Reactor core thermal-hydraulic design requirements, SFR-FS200-IOC-03-2012Rev.00, 2012.
[2] ASME Boilier and Pressure Vessel Code, Section III Division 1-NC, 07/01/1998.
[3] R. Nandakkumar et. al., "Steam Generators for Future Fast Breeder Reactors", Energy Procedia 7, 351-358, 2011.
[4] ASME B&PV Section III Division 1-NH, 9Cr-1Mo-V allowable stress, 2007.
[5] Yeon-Sik Kim, “User Manual for HSGSA Computer Code”, KALIMER/FS-4CM-98-001, 1998.
[6] SeAh Steel Pipes and Tubes, 2006.