Analysis of Decay Heat Removal by Natural Convection in LMR with a Combined Steam Generator

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1. Introduction

Liquid metal reactors (LMRs) conventionally employ an intermediate heat transport system (IHTS) to protect the nuclear core during a sodium-water reaction (SWR) event. However these SWR-related components increase plant construction costs. In order to eliminate the need for an IHTS, a combined steam generator, which is an integrated heat exchanger of a steam generator and intermediate heat exchanger (IHX), was proposed by the Korea Atomic Energy Research Institute (KAERI) [1]. The objective of this work is to analyze the natural circulation heat removal capability of the rector system using a combined steam generator. As a means of decay heat removal, a normal heat transport path is composed of a primary sodium system, intermediate lead-bismuth circuit combined with SG and steam/water system. This paper presents the results of the possible temperature and natural circulation flows in all circuits during a steady state for a given reactor power level varied as a function of time.

2. Design Description

KALIMER 150 [2] was used as a reference design, which is a pool-type reactor with two IHTSs, four IHXs, and two steam generators. It has a configuration with a 19 m pool height, 4.5 m core height, 6.5 m IHX height, 13.1 m SG height, and 13.5 m thermal center distance between the core and SG. Figure 1and Figure 2 show a typical configuration of these systems. For the present analysis, the existing SG from the reference plant was replaced with a DTBSG, and a loop-type LMR was assumed. The heat is transferred to a combined SG, i.e., DTBSG (double tube bundle SG) through the primary sodium loops.

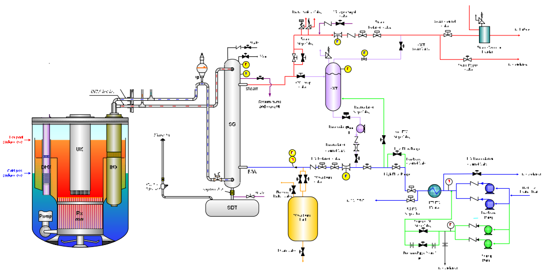

Fig. 1. Configuration of the KALIMER system.

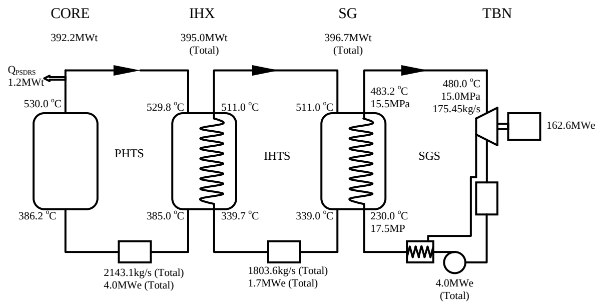

Fig. 2. Heat Balance of KALIMER 150.

Figure 3 shows an integrated double-region bundle type of the combined SG, and shows cross sectional view of the bundle-type configuration. All of the tubes are helical, and the black and white colors represent cold and hot fluid tubes, respectively. The shell side is filled with a medium fluid, i.e., lead-bismuth, which is circulated by a pump. Heat is transferred from the hot side to the cold side through a medium fluid.

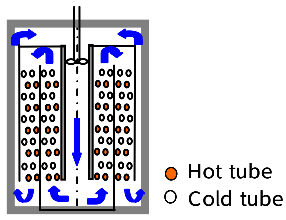

Fig. 3. Configuration of the DTBSG.

Table 1. Design data of the DTBSG (200 MWe)

	Integrated Single-Region Type	Integrated Double-Region Type
hot tube OD, m	0.025	0.025
cold tube OD, m	0.025	0.025
hot tube thickness, m	0.0008	0.0008
cold tube thickness, m	0.003	0.003
hot tube length, m	57.47	59.5
cold tube length, m	57.47	59.5
hot bundle height, m	8.9	13.1
cold bundle height, m	8.9	13.1
bundle region height, m	8.9	13.1
hot tube Pitch/OD, (R-plane)	1.5	1.5
cold tube Pitch/OD, (R-plane)	1.5	1.5
# of tube rows,inner	33	15
# of tube rows,outer	-	7

# of hot tubes	416	365
# of cold tubes	415	360
# of tubes	831	725
# tubes.inner/#tubes.outer	-	0.55
shell ID,m	2.96	2.34
Q: heat transfer rate, MW	200.0	200.1

3. Analysis Model

3.1 Mathematical method for solving the problem

The following seven equations govern the three heat transport systems, i.e., PHTS circuit, DTBSG, and feedwater/steam circuit. There are seven unknowns in these equations when the power level, temperature and flowrate of the feedwater, and heat transfer areas of the DTBSG are given.

$$Q = \dot{m}_p C_p (T_{p,h} - T_{p,c})$$
$$C_P \cdot \dot{m}_P^2 = \Delta H_P$$
$$Q = \dot{m}_i C_p (T_{i,h} - T_{i,c})$$
$$C_i \cdot \dot{m}_i^2 = \Delta H_i$$
$$Q = \dot{m}_{fw}(h(T_s, P_s) - h(P_{fw}, T_{fw}))$$
$$Q = UA_{IHX} \Delta T_{LMTD,IHX}$$
$$Q = UA_{SG} \Delta T_{LMTD,SG}$$

The flow of the PHTS and DTBSG circuits are established by matching the buoyancy head with the frictional pressure drop caused by the coolant flow. The solution of the equation is obtained by an iteration manner.

3.2 Results

The results of the calculations are given in Figures 4 and 5. From these results it can be seen that the temperature of the hot side of the DTBSG is less than about 400 ℃ after a certain time period from the initial transient.

Generally speaking, the higher temperature of the hot side of the heat exchanger necessarily enhances the heat removal rate.

From the view of the design temperature limits (about 600 ℃) for unlikely events, which includes decay heat removal, the decay heat could be removed without exceeding the temperature limits.

Therefore, it can be said that the LMR with the DTBSG has a natural circulation heat removal capability.

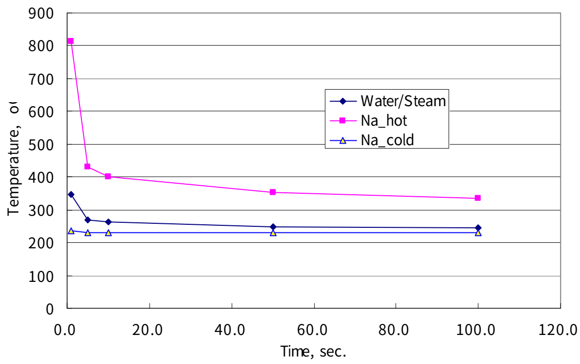

Fig. 4. Temperature as a function of time

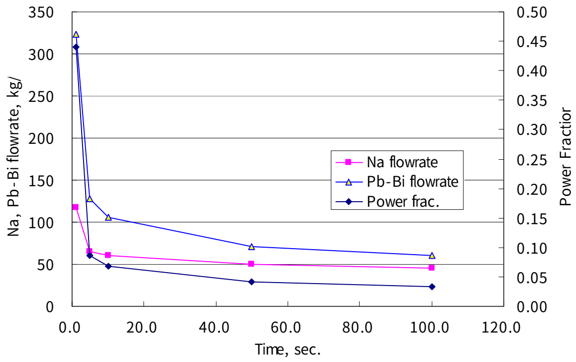

Fig. 5. Flow rates as a function of time

4. Conclusions

In the event of pump failure, natural circulation can be selected for the cooling of the hot pool. An analysis was performed to assess the adequacy of the decay heat removal capability of the LMR equipped with the DTBSG by natural circulation. The analysis results show the detailed values of the possible temperatures and natural circulation flows in all the coolant circuits for a given reactor power over time, as well as the feed water inlet temperature and flow rate. A transient analysis, however, is required to predict peak temperatures and the duration of structural materials subjected to high temperature.

REFERENCES

[1] Yoon Sub Sim, Eui Kwang Kim, Seong-O Kim, A new LMR steam generator free from SWR with a double tube bundle configuration, Nuclear Engineering and Design, 236, 1471-1480, 2006.
[2] Hahn, D.H. et al, KALIMER Conceptual Design Report, KAERI/TR2204/2002, KAERI, 2002.