Decay Heat Removal System Cooling Effect Analysis of STELLA-2 using MARS-LMR

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1. Introduction

A large-scale integral effect test facility for Sodium-cooled Fast Reactor (SFR) development has finished its construction and installation in Korea Atomic Energy Research Institute (KAERI). Under the Sodium Integral Effect Test Loop for Safety Simulation and Assessment (STELLA) program[1], the STELLA-2 facility is just about to start the operation and will produce various experiment data to build up the database.

The focus of STELLA-2 is on the Decay Heat Removal System (DHRS) performance and capability during the Design Basis Event (DBE) condition as well as the Beyond DBE condition. Therefore, various transient analysis was conducted at the design stage for comprehensive evaluation[2]. On the other hand, the analysis to explore the limit and boundary of the facility was also conducted independently. This includes the transient behavior during full and/or zero power of the air blower for the heat exchangers, full power of the Electro-magnetic Pump (EMP) in the loop and etc.

In this study, the DHRS cooling effect to the primary side was analyzed using MARS-LMR code as a part of above evaluation by controlling the air flowrate in the sodium-to-air heat exchangers in DHRS. The scope of this study bounds within the observation of the phenomena and discussion about the reason. The application of the results will be a next step.

2. STELLA-2 Facility

The STELLA-2 is a down-scaled test facility to verify the performance of DHRS of the reference reactor. At the same time, the experiment database is used for V&V of safety analysis code[3].

The STELLA-2 includes all the major components of the reference reactor except the nuclear fuel core, the steam generator, and the mechanical pump. Instead, the electric core simulator, the straight tube-type sodium to air heat exchanger and the EMP replaces each component. In the STELLA-2, there are four lines of DHRS. Two loops are for the passive heat exchanger and the other two loops are for the active heat exchanger. All four heat exchangers are of same capacity.

The facility was designed to conserve the characteristic and transient behavior of the reference reactor and it was evaluated at several stages using various means and tools including CFD and system code.

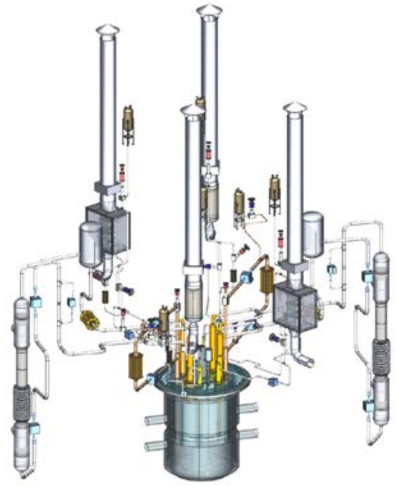

Fig. 1 STELLA-2 Facility Layout

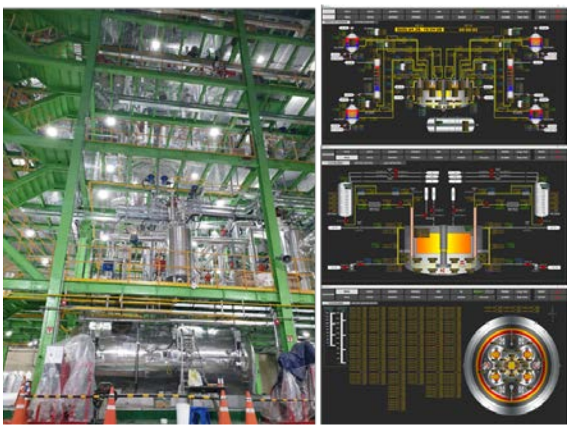

Fig. 2 STELLA-2 Installation and Control System

3. MARS-LMR Analysis

3.1 Representative DBE – Loss of Flow (LOF)

The representative DBE was selected for the cooling effect analysis, which is the Loss of Flow (LOF) event. This event occurs when all the power supplied to the pump is lost and it results in the immediate temperature rise of the coolant. One of the main reasons is the Loss of Offsite Power (LOOP) and thus the LOF with LOOP is usually considered as a representative accident. In this study, the LOF + LOOP condition was assumed and the transient behavior was observed.

3.2 Node layout and Assumptions

The node layout is shown in Fig. 3. Based on the heat balance of the reference reactor design, the steady-state point was set to match the temperature distribution inside the pool and the transient started by rapidly reducing the primary sodium flow. The intermediate loop flow also stops when the primary pump stops and the core heater starts to follow the decay heat curve after the flow reduction. To be consistent with the safety analysis methodology, each one of heat exchangers in passive and active DHRS was not working. The calculation was done up to approximately 50,000 sec.

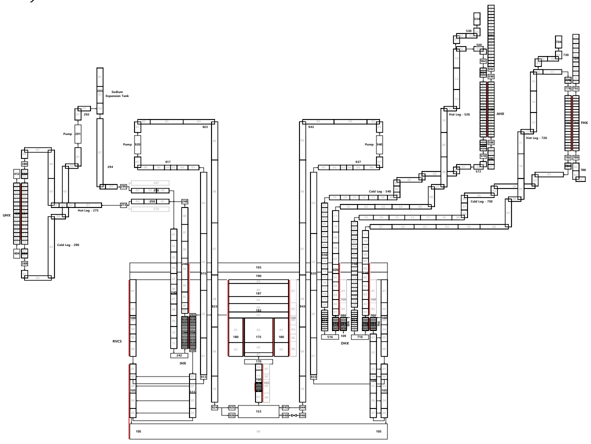

Fig. 3 Node Diagram

4. Results and Discussion

The air flowrate of the passive and active heat exchangers were changed from 30% to 80% of designed capacity by a step of 10%. The 0% flow is not indicated in the following results because the starting point of steady-state condition is 0% air flow. The result of 100% air flow is also not shown due to inconsistent trend caused by unidentified errors in calculation input.

4.1 Temperature Trend

In Fig. 4, the temperature change according to the air flowrate of HXs is shown. It is noted that the higher the air flowrate, the larger the ΔT through core in/out which results in higher core outlet temperature.

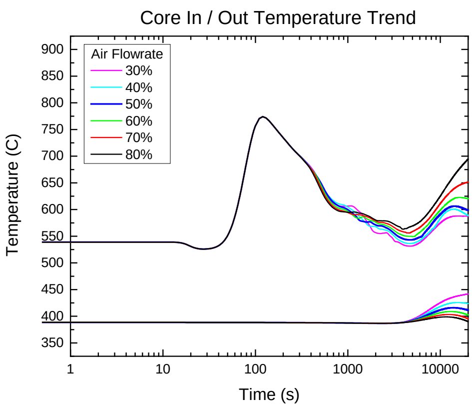

Fig. 4 Core In/Out Temperature Trend

In Fig. 5 and 6, the temperature of sodium in the tube of HXs are shown. As the air flowrate increases, the temperature decrease and the ΔT gets larger.

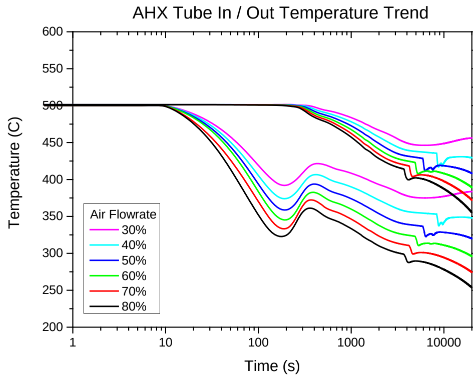

Fig. 5 AHX Tube Temperature Trend

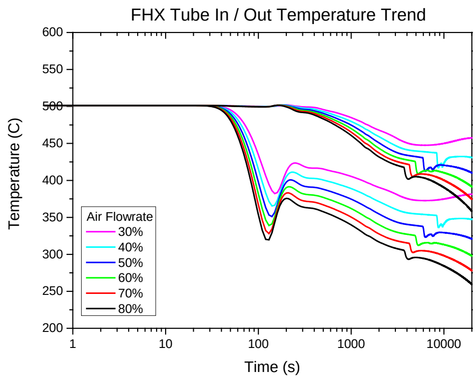

Fig. 6 FHX Tube Temperature Trend

4.2 Flowrate Trend

In Fig. 7, the sodium flowrate of primary side is shown. With the increasing air flowrate, the natural circulation flow decreases. It is seen that the primary side sodium flow is the highest at 30% of air flow.

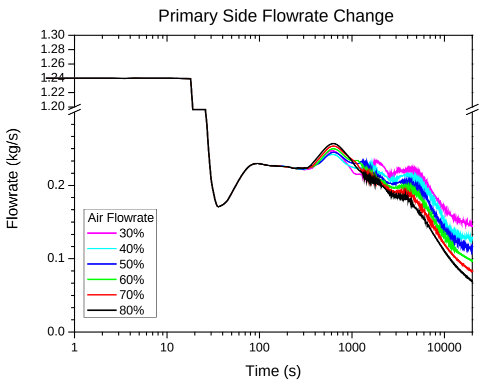

Fig. 7 Primary Side Flowrate Trend

In Fig. 8 and 9, the sodium flowrate of HXs tube side is shown. As the air flowrate increases, the sodium flowrate induced by the natural circulation also increases.

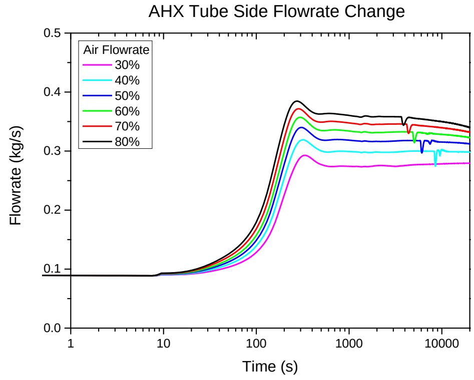

Fig. 8 AHX Tube Side Flowrate Trend

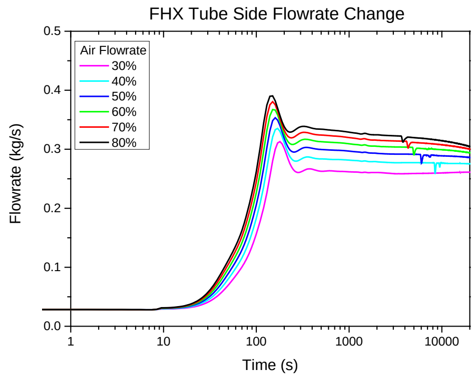

Fig. 9 FHX Tube Side Flowrate Trend

4.3 Discussion

The temperature rise of core outlet and its trend is not quite consistent with the common expectation. If the heat transfer through the final heat sink increases by increasing the air flowrate, the heat removal from the core should increase. And this should lead to lowering the core outlet temperature. However, the trend is in opposite as seen in Fig. 4.

One of the reasons can be found in Fig. 7 that the primary side sodium flowrate decreases as the air flowrate increases. The smooth flow development by the natural circulation is doubtful at this point and the thermal stratification at the bottom of cold pool can be presumed. However, in real situation this may not happen owing to the high thermal conductivity of the liquid sodium. In the case of STELLA-2 condition, the axial conduction within the fluid is large enough to influence the thermal energy distribution.

The MARS-LMR code doesn't consider the axial conduction of the fluid due to its origin and history of development based on the water system. Therefore it is strongly recommended to re-analyze the same phenomena by calculating the axial conduction term. Or more directly, the experiment data in near future will reveal the truth of reality.

5. Conclusion

The STELLA-2 is ready for operation and will soon produce large database of various transient experiments. The DHRS cooling effect to primary side is one of the most important aspects and it was observed by controlling the air flowrate of final heat exchangers. The result of heat transfer including temperature trend was inconsistent with the expectation and the cause of this opposite behavior was discussed. The liquid sodium has high thermal conductivity and thus the conduction within itself acts as an important factor. To verify this assumption, either re-calculation of fluid conduction or experiment data will be needed. Therefore, the next step of this study will be the verification of conduction term and the application to the modification of code.

ACKNOWLEDGEMENT

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