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Conceptual Design of a Co-axial Structure applicable to an Intermediate Heat Exchanger of a Pool-type Sodium-cooled Fast Reactor

Chang-Gyu Park,a Jong-Bum Kim, a Hyeong-Yeon Lee, a Jae-Han Lee, a
a Fast Reactor Development, Korea Atomic Energy Research Institute, 1045 Daedeokdaero, Yuseong-gu, Daejeon, 305-353, Korea, chgpark@kaeri.re.kr

1. Introduction

The IHX(Intermediate Heat eXchanger) in a pool-type SFR(Sodium-cooled Fast Reactor) system transfers heat from the primary radioactive sodium to the intermediate non-radioactive sodium. The IHXs of a pool-type SFR are generally supported at the top surface of the RH(Reactor Head). The IHX consists of an upper and lower tubesheet separated by a tube with a central downcomer and a riser for the incoming and outgoing intermediate sodium, respectively. The central downcomer and riser which are for the incoming and outgoing intermediate sodium consist of a co-axial structure. In this study, the structural features of a co-axial structure are investigated and the advanced design concept of a co-axial structure is proposed and compared with that of KALIMER-600[1].

2. Structural Features

A co-axial structure is one of the most critical parts in view of the structural integrity for SFR structures. And the inspection of this co-axial structure is not favorable because of its pipe-in-pipe structure. Figure 1 shows the schematic drawing of a co-axial structure, IHX mounting flange and reactor head.

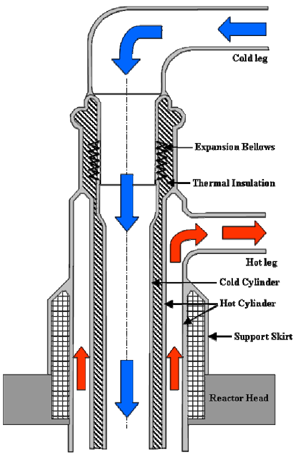

Figure 1. Schematic drawing of the IHX co-axial structure.

In the pipe-in-pipe structure, the cold intermediate sodium of over 320°C flows down the central pipe and the hot intermediate sodium of over 520°C flows into the annular space between the concentric external riser cylinder and the internal downcomer cylinder. The hot intermediate sodium leaves the IHX through the intermediate outlet nozzle for use in the intermediate heat transport loop. Therefore, the temperature distribution in the double-walled structure is a critical issue in a mechanical design to reduce the resultant severe thermal stress. A articulating expansion bellows is used in the upper part of the inner cold cylinder of the co-axial structure to accommodate the axial thermal expansion difference between the hot and cold cylinder.

As shown in Figure 1, the vertical skirt structure connected to the hot cylinder of the co-axial structure supports the dead weight of the IHX and the sodium weight in the IHX. The support skirt is connected to the mounding flange and the mounding flange is supported at the top surface of the RH of which the normal operating temperature is about 100°C. Therefore, the temperature difference between the upper part and lower part of the support skirt is about 350°C and thus a severe thermal stress may occur in it.

Additionally, the IHTS piping reactions caused by the IHTS piping layout and the dead weights induce a primary stress. To ensure the structural integrity of a co-axial structure, these loading conditions should be considered in a structural design.

3. Structural Analysis

3.1 Loading Conditions

A co-axial structure is subjected to a combined the mechanical and thermal loading for a reactor normal operating condition. In this study, the loading and boundary conditions are assumed to be determined from the KALIMER-600 system.

The loading conditions are mainly composed of primary and secondary loadings and the primary loadings in this study are the dead weight of the IHX and sodium and the IHTS piping reaction force. But a seismic loading which is the most critical structural loading in a reactor system is not considered in this study. The dead weight is assumed to be 80.0tons and the IHTS piping reactions are calculated from the 3-D FEA(Finite Element Analysis) of the IHTS hot leg piping. The calculated net piping axial force is 170.0kN and the vertical and perpendicular net forces in Figure 1 are 60.0kN and 6.5kN, respectively.

The secondary loading is mainly caused by a structure temperature difference. It is assumed that thermal insulation is inserted between the hot and cold cylinder of the co-axial structure and thus a heat transfer from the hot cylinder to the cold cylinder is prevented. The outer surface of the co-axial structure as well as the annular space between the hot cylinder and support skirt are assumed to be insulated. The top surface of the reactor head is subjected to the head air cooling condition of 40°C and the bottom surface is subjected to the reactor cover gas region of about 150°C. The heat convection coefficients of the top and bottom surface of the RH are assumed to be 90 $W/m^2 \cdot K$ and 10 $W/m^2 \cdot K$, respectively.

Modified 9Cr-1Mo steel is chosen as the material of the co-axial structure because its thermal conductivity is higher than that of austenitic steels. A higher thermal conductivity material results in lower temperature differences and lower thermal stresses in the component sections. Also, using modified 9Cr-1Mo steel results in a considerable reduction in the required heat transfer area[5].

3.2 FE Analysis

Figure 2 shows the FEA results of the temperature and stress intensity distribution using the commercial FE program ANSYS[2] for the reactor normal operating condition. In Figure 2, it is supposed that the radial thermal expansion difference of the junction part between the RH lower part and the hot cylinder of the co-axial structure shown in Figure 1 can be accommodated. The material properties are based on the ASME[3] and RCC-MR[4]. The cold and hot cylinders are maintained of about 320°C and 520°C for the normal operating condition, respectively. The maximum stress intensity is caused at the junction part between the support skirt and the hot cylinder of the co-axial structure and it is mainly caused by the thermal stress. The combined primary membrane plus bending stress intensity is 42.4MPa but the primary plus secondary stress intensity is about 327MPa. The primary plus secondary stress intensity of the junction part between the RH and the hot cylinder and its value is 284 MPa at 470°C mainly due to the thermal expansion.

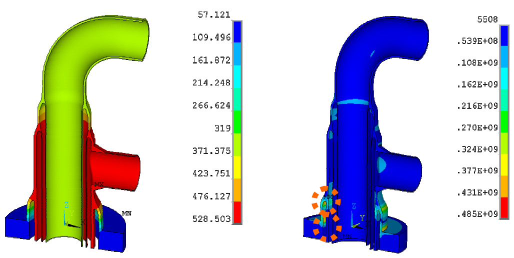

Figure 2. Temperature and stress intensity distribution results for normal operating condition.

3.3 Modified Design Concept

To reduce the high stress intensity of the co-axial structure, a modified design concept is proposed. Figure 3 shows the modified design concept and its stress distribution for a normal operating condition. For the primary loading, the high stress occurs at the nozzle of the IHTS hot leg piping and the junction part of the hot cylinder with the support riser. As shown in Figure 3, the maximum stress intensity of the primary plus secondary loading occurs at the junction between the hot cylinder and the support riser and its value is 63MPa at 520°C mainly due to the primary loading rather than the secondary loading.

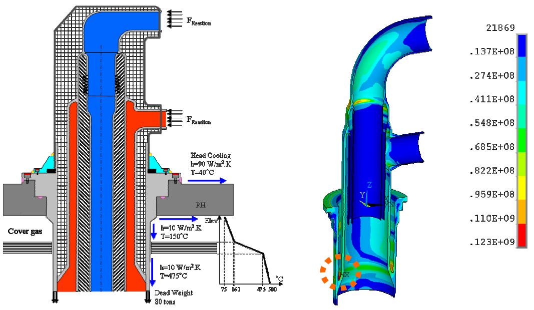

Figure 3. Schematic drawing of the modified design concept and its stress analysis result for normal operating condition.

4. Conclusion

In this study, the structural features of the co-axial structure applicable to the IHX of a pool-type SFR are investigated and the stress distribution is obtained by using FE analysis for a normal operating condition. The hot cylinder of the co-axial structure should be a thick cylindrical structure to sustain the reaction loading due to the IHTS hot leg piping expansion. And a structural discontinuity including a piping nozzle is delicate for a structural integrity and thus should be designed to minimize a stress concentration. The proposed modified design concept is effective in reducing the effect of the secondary loading and thus the maximum stress intensity of the support structure decreased to 20% of the existing co-axial structure.

This study is carried out on a conceptual design of the IHX co-axial structure and thus an advanced study based on this study including a detailed design for a structural discontinuity and a nozzle by considering a reactor system loading will follow.

ACKNOWLEDGMENTS

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