Study on Structural Improvement to Reduce Thermal Stress of Reactor Enclosure System of Sodium-cooled Fast Reactor

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Abstract

The Small, Advanced, Long-cycled and Ultimate Safe SFR(SALUS) which is being developed by Korea Atomic Energy Research Institute(KAERI) is a sodium cooled fast reactor(SFR) which is based on prototype generation IV sodium-cooled fast reactor(PGSFR). The reactor enclosure system(RES) of SALUS is composed of reactor vessel(RV), reactor head(RH), reactor support structure(RSS) and containment vessel(CV). Since each part of RES is exposed to different temperatures, thermal stress is generated by temperature gradient. In this study, the sensitivity analysis about thermal stress was conducted on RES of SALUS by changing the main design variables of reactor vessel and the designs to decrease thermal stress of RES were discussed and presented.

Introduction

- The SALUS which is being developed by KAERI is a SFR which is based on PGSFR[1].
- The RV of SALUS contains hot pool sodium(510 °C) and cold pool sodium(360 °C), so it is exposed to high temperature conditions. On the other hand, RH and RSS are in low temperature condition due to cooling system.
- These temperature conditions can cause the temperature gradient in RES. Therefore, the thermal stress which is caused by temperature gradient in RES is one of the main interest in structural design.
- In this study, the structural design to decrease the thermal stress of RES of SALUS is discussed and suggested.

Design analysis and modification

- **Structural analysis**
  - The SALUS was designed on the base of PGSFR, so the structural concept and shape are similar to PGSFR.
  - The RES of SALUS was suggested that RV is supported by RSS and RH is supported by RV as shown in Fig. 1[2].
  - To analyze the thermal stress of RES of SALUS, FE analysis model was built by using ANSYS S/W as shown in Fig. 2[3].
  - Thermal boundary conditions were assumed like Fig. 3[2].
  - The thermal stress analysis results are shown in Fig. 4
    - ➢ High thermal stress was generated in upper part and middle part of RV.

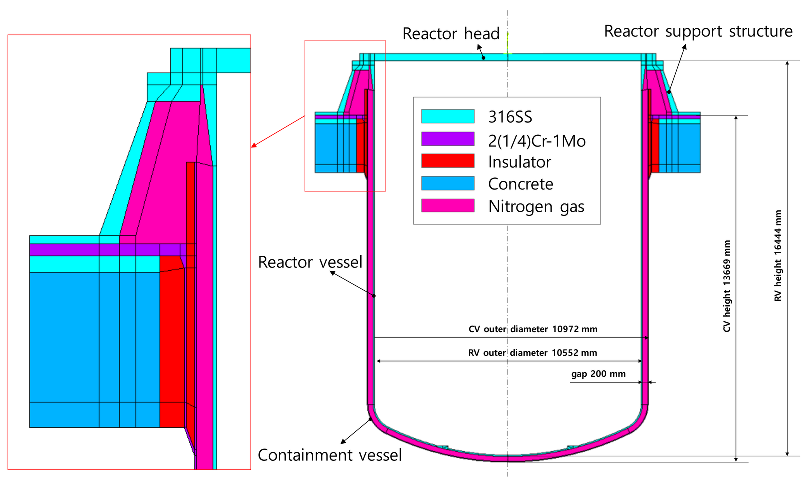


Fig. 1 Geometry of RES of SALUS (front view)

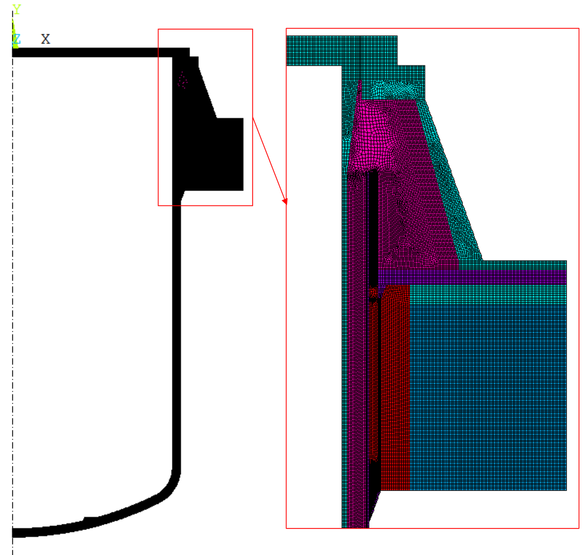


Fig. 2 FE analysis model of RES of SALUS

RV Height (m)	RV inner Bulk Temp. (℃)	Film coefficient (W/m^2℃)
-0.3	250	5
-1.3	300	5
-4.0	440	20
-5.183	360	10000
-15.344	360	

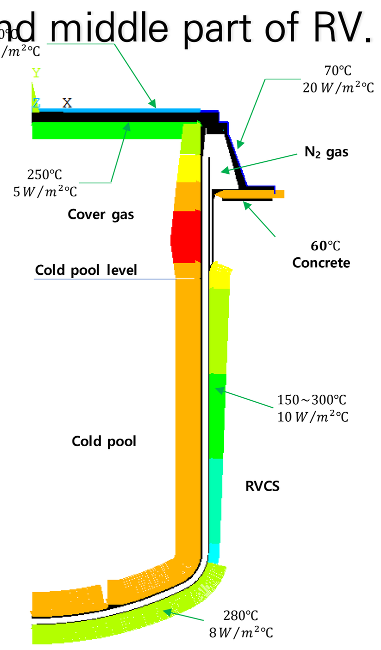
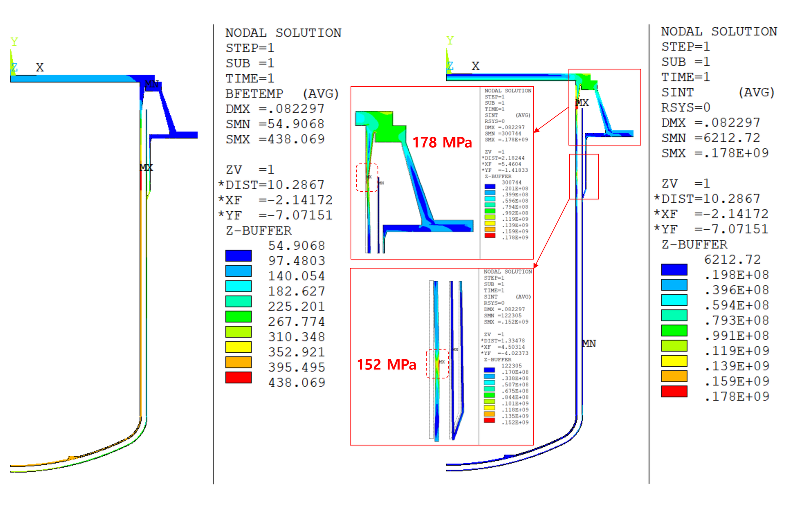


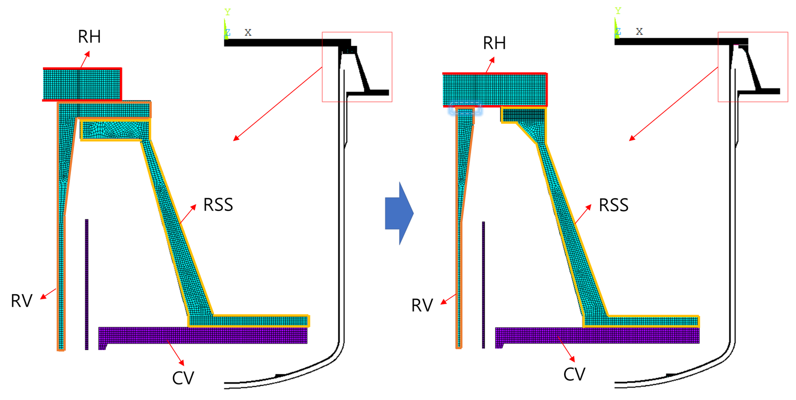
Fig. 3 Thermal boundary conditions of SALUS



(a) Temperature (b) Stress intensity

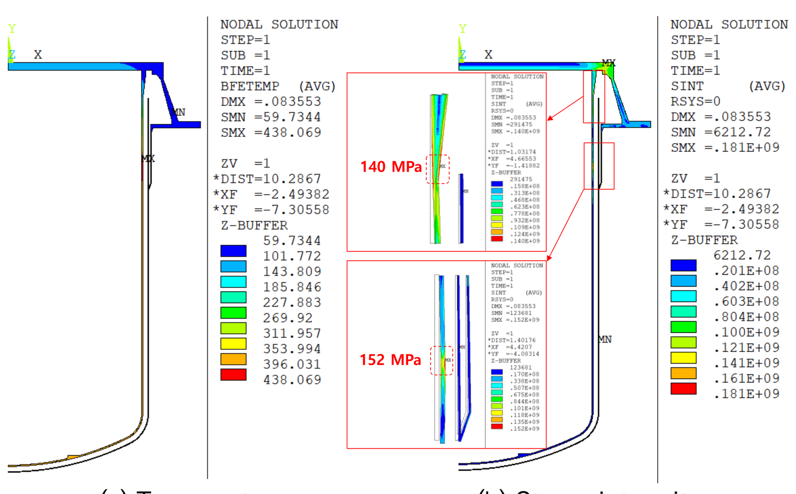
Fig. 4 Thermal stress analysis results of SALUS

- **Design modification**
  - To reduce the thermal stress of upper part of RV, the design of RES was modified.
    - ➢ RV was connected directly to RH and RH was supported by RSS as shown in Fig. 5.
  - The thermal stress analysis was conducted on modified design.
    - ➢ The thermal stress intensity was decreased from 178 MPa to 140 MPa in upper part of RV as shown in Fig. 6.



(a) Before (b) After

Fig. 5 Modification of RES of SALUS (before and after)



(a) Temperature (b) Stress intensity

Fig. 6 Thermal stress analysis results of SALUS (modified model)

- **Sensitivity analysis**
  - The sensitivity analysis about thermal stress was conducted on modified design by changing the main design variables of RV.
  - The thickness t and length L of upper connecting part of RV were selected as design variables as shown in Fig. 7.

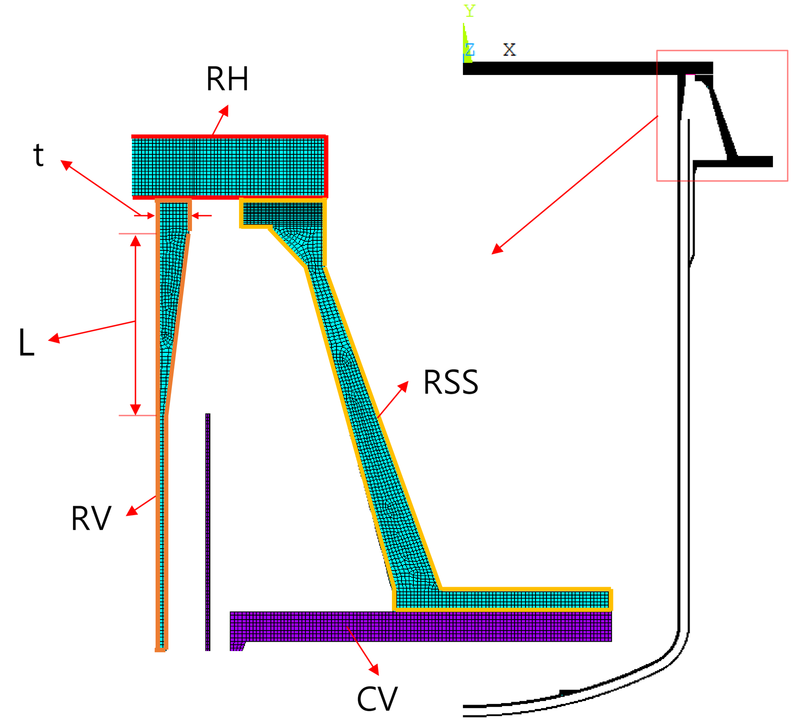


Fig. 7 Geometry of RES of SALUS(front view)

a. Analysis case1

- The change of thermal stress in upper and middle part of RV was investigated by increasing thickness t from 60 mm to 173 mm.
  - ➢ The thermal stress in upper part of RV was increased according to increasing t as shown in Fig. 8.
  - ➢ The thermal stress in middle part of RV was maintained constantly.

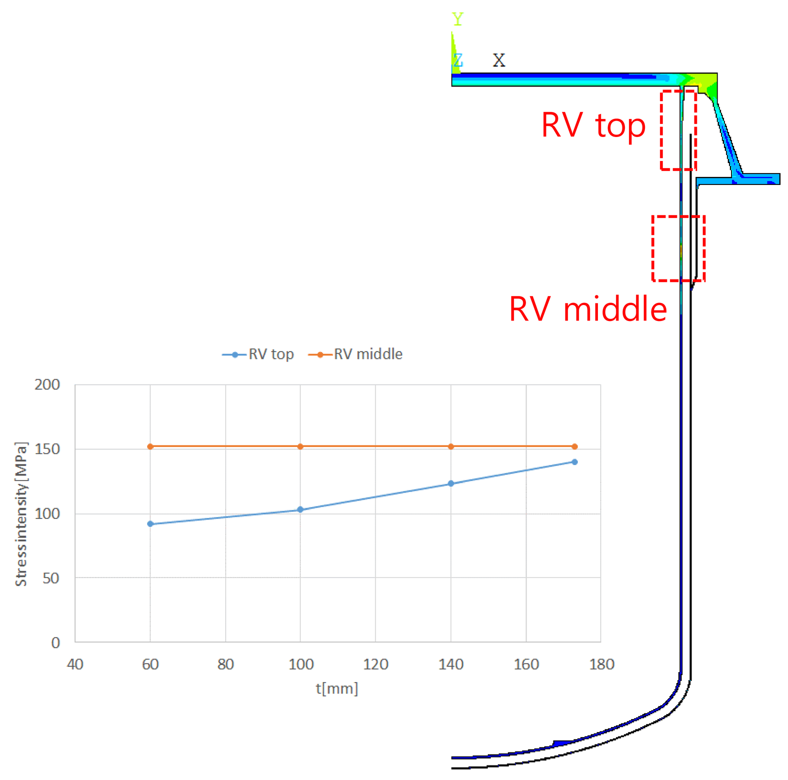


Fig. 8 Thermal stresses according to t of upper part of RV

b. Analysis case2

- The change of thermal stress in upper and middle part of RV was investigated by increasing length L from 800 mm to 1400 mm.
  - ➢ The thermal stress in upper part of RV was decreased according to increasing L as shown in Fig. 9.
  - ➢ The thermal stress in middle part of RV was increased slightly when L increased over 1300 mm.

❖ To reduce thermal stress of RV

- ➢ Decreasing thickness t
- ➢ Increasing length L

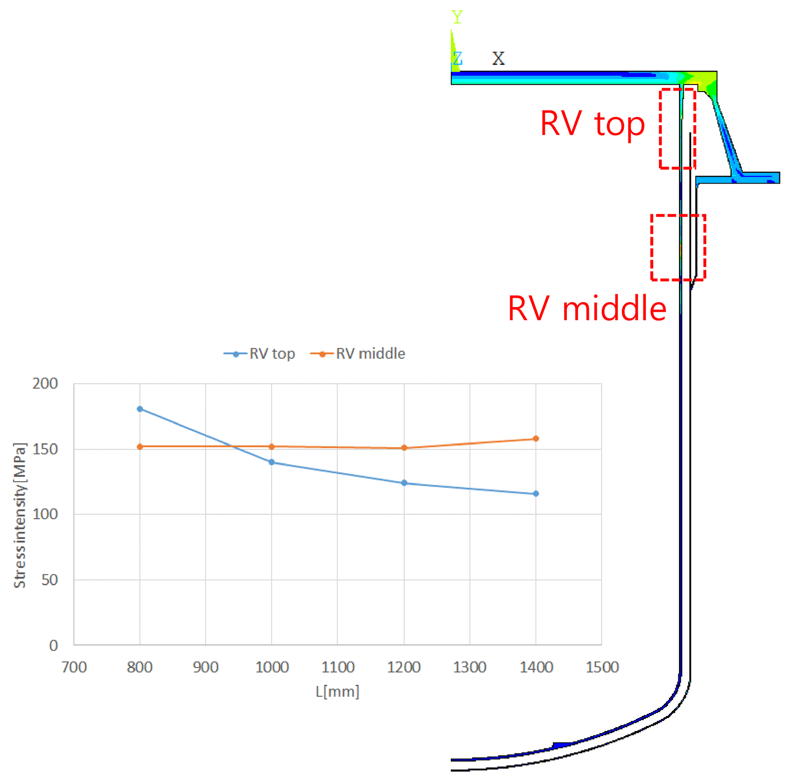


Fig. 9 Thermal stresses according to L of upper part of RV

Conclusions

- The RES of SALUS was modified like that the reactor vessel was connected directly to reactor head and reactor head was supported by reactor support structure to decrease the high thermal stress in upper part of reactor vessel. The thermal stress in upper part of reactor vessel was decreased more than 20 % through these design modifications.
- To investigate the effect of design variables which can affect thermal stress of reactor enclosure system, the sensitivity analysis was conducted by changing thickness t and length L of upper connecting part of reactor vessel.
- The sensitivity analysis showed that the smaller thickness t and the longer L results in decreasing thermal stress of upper part of reactor vessel. On the other hand, it was shown that the thermal stress in middle part of reactor vessel was hardly affected according to changing given design variables.

References

[1] J. W. Yoo, J. W. Jang, J. Y. Lim, J. S. Cheon, T. H. Lee, S. K. Kim, K. L. Lee and H. K. Joo, Overall system description and safety characteristics of prototype Gen IV sodium cooled fast reactor in Korea, Nuclear Engineering and Technology, vol. 48, pp.1059-1070, 2016.

[2] J. H. Lee, Reactor Assembly Structural Analysis, Korea Atomic Energy Research Institute, SFR-200-DM-306-001, rev03, 2017.

[3] ANSYS User's manual, Release 19, ANSYS Inc..