Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

Preliminary Structural Analysis of High Temperature Vessel

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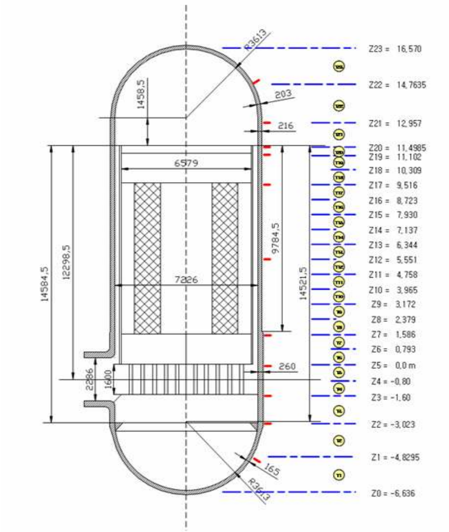
1. Introduction

The structural evaluation of the high temperature vessel concept has been performed in general accordance with Subsection NB and NH. For the high temperature vessel concept, modified 9Cr-1Mo steel is considered for the chosen material which has a variety of applications in pressure retaining components in service at elevated temperature. Since the maximum temperature of the high temperature vessel calculated by the thermal hydraulic analysis is below 371 ^{o}C for a normal operation, the creep damage and deformation are not significant and ASME Section III, Subsection NB is applied. Two cases of accident conditions are considered for the structural integrity evaluation. During the accident conditions such as HPCC and LPCC, the maximum temperature reached above 371^{o}C. Thus, the high temperature design rule of Subsection NH is applied. A reactor vessel is evaluated for thermal and mechanical loads during a normal operation and the accident conditions. The adequacy of the reactor vessel structures to sustain a normal operation load and the given accident loads is demonstrated through comparison of their structural responses with the ASME Code stress limits and the structural deformation limits. Analysis details and evaluation results are summarized and described. Fig. 1 shows a schematic of the high temperature vessel concept with the evaluation cross sections.



Section	Node No. (In)	Node No. (Out)
Z22	4700	4670
Z21	1683	1660
Z20	4487	4481
Z19	1624	1611
Z17	1448	1429
Z12	993	974
Z7	448	435
Z5	363	344
Z3	20	1
Z2	121	92
Z1	1821	1852

Fig. 1 A schematic of the high temperature vessel concept with the evaluation cross sections

2. Modeling of a Reactor Vessel

A reactor vessel is composed of a vertical cylinder, hemispherical top and bottom closures, and the nozzle. Its major dimension are 7.7 m in diameter, 23.2 m in height and the thicknesses are various at the different parts of the surface as shown in Fig. 1. The finite element analysis was performed using FEA software ANSYS. Two dimensional model of a complex three dimensional geometry is assumed and the simple model without the main connections such as nozzle or flange are presented in Fig. 2. The vessel is analyzed for the design pressure and thermal load given from the thermal hydraulic analyses.

The accident loadings and corresponding steady state conditions are obtained from the transient analysis. The major design parameters are presented in Table 1. During a normal operation, the inlet and outlet gas temperatures are 490^{o}C and 850^{o}C, respectively and the design pressure is 7 MPa. The limiting accident conditions considered in this analyses are HPCC(High pressure Conduction Cooldown) and LPCC(Low pressure Conduction Cooldown).

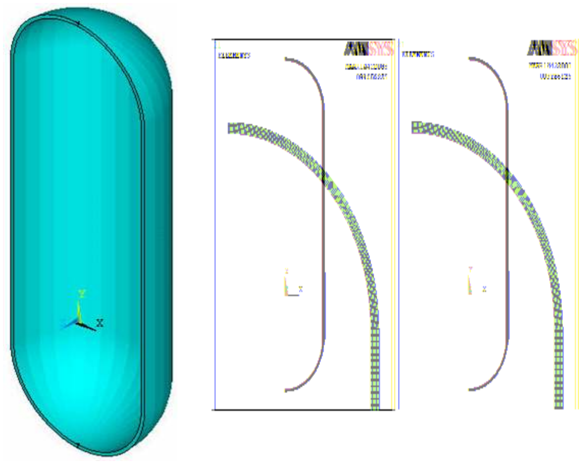


Fig. 2 Finite element model of a reactor vessel

The steady state condition is analyzed corresponding to each transient case. The used temperature dependent material properties of modified 9Cr-1Mo steel are based on ASME Section II, Part A, Part D and Section III, NH[1].

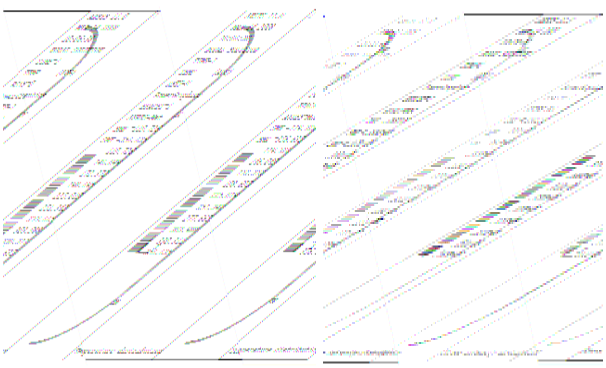
Table 1. Major design parameters

Vessel inside pressure	7 MPa
Helium gas temperature at reactor	490/850 °C
inlet/outlet	7.23 m
Vessel inside diameter	23.2 m
Vessel height	
Vessel thickness	203 mm
- Hemispherical top closure	165 mm
- Hemispherical bottom closure	216 mm
- Vertical cylinder(upper part)	260 mm
- Vertical cylinder(lower part)	

3. Results and Discussions

In the case of a normal operation, since the maximum temperatures of the reactor vessel at all evaluation sections considered for the stress linearization are below 371 °C in the condition of the steady state, the creep effect is not significant. Mechanical and thermal stresses are compared with the ASME NB stress limit[2]. The calculated stress levels remain within the elastic limits and the results of the analysis show that a reactor vessel is structurally adequate for a normal operation condition considered. The temperature and the stress intensity distributions for the steady state condition of a reactor vessel are shown in Fig. 3 (a) and (b), respectively.

Also, the structural integrity of a reactor vessel has been evaluated for thermal and mechanical loads during the accident conditions such as HPCC and LPCC. At the evaluation sections for which the maximum temperatures of a reactor vessel are above 371 °C, the creep effect is significant. Thus, the load controlled and the strain controlled design criteria are checked according to Subsection NH rule[3]. The calculated mechanical and thermal stresses are acceptable with adequate margins against the allowable stress limits as shown in Table 2 and Table 3.



(a) Temperature (b) Stress intensity

Fig. 3 Temperature and stress intensity distribution for the steady state condition

Table 2. Design margins for load controlled stress(HPCC)

Section	P_m (MPa)	P_L+P_b (MPa)	$P_L+0.8P_b$ (MPa)	S_{mt} (MPa)	$1.5S_m$ (MPa)	S_t (MPa)	$T_{max,m}$ (°C)	Margin
Z22	63.9	70.2	68.9	178.4	266.7	316.2	402.1	1.8-3.6
Z21	92.3	98.6	97.4	180.3	270	319.6	391.9	1.0-2.3
Z20	122	127.2	126.2	178.7	267.1	316.6	401.1	0.5-1.5
Z19	122.1	128.3	127.1	177.2	265.1	314.4	406.4	0.5-1.5
Z17	120.5	127.3	126	170.1	255.4	299.5	431.7	0.4-1.4
Z12	120.4	127.1	125.8	170.7	256.4	302.3	429.5	0.4-1.4

Table 3. Design margins for load controlled stress(LPCC)

Section	P_m (MPa)	P_L+P_b (MPa)	$P_L+0.8P_b$ (MPa)	S_{mt} (MPa)	$1.5S_m$ (MPa)	S_t (MPa)	$T_{max,m}$ (°C)	Margin
Z17	120.5	127.3	126	177.4	265.3	314.6	409.9	0.5-1.5
Z12	120.4	127.1	125.8	137.1	206	171.7	522.4	0.1-0.4

The elastic approach, the simplified inelastic approach and the creep fatigue evaluation are used to provide a quantitative assessment of the deformation and strain. The calculated inelastic strain and creep damage satisfy the ASM-NH rule with enough margins.

4. Conclusions

The structural integrity of the high temperature vessel concept to sustain a normal operation load and the limiting accident loads has been confirmed through comparison of their structural responses with the ASME code stress limit and the structural deformation limits. In this evaluation stage, the support load, the nozzle load and the seismic load are not considered because the detailed design loads are not decided.

Acknowledgements

This work has been carried out under the Nuclear R&D Program by MEST in Korea.

REFERENCES

[1] ASME Boiler and Pressure Vessel Code Section II, Part A, Part D, ASME, 2004.
[2] ASME Boiler and Pressure Vessel Code Section III, Subsection NB, ASME, 2004.
[3] ASME Boiler and Pressure Vessel Code Section III, Subsection NH, ASME, 2004.