Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Structural Integrity of Mini Heat Exchanger for Generation IV reactors Subjected to Pressure Load

Bong Yoo, Young-Il Kim, Yun-Jae Kim,
Mechanical Engineering Department, Korea University, Anam-dong, Sungbuk-ku, Seoul 136-701, Korea,
byoo3@korea.ac.kr

1. Introduction

In the development of a power conversion system using S-CO_2 Brayton Cycle for Liquid Metal-Cooled Fast Reactors, the design parameters of a mini heat exchanger were preliminarily determined for normal operation conditions (i.e., steady state) by A.V.Moisseytsev and J.J.Sienicki[1,2]. The design parameters are pressures, temperatures, average heat transfer coefficients, mass flow, flow area, heat flux, heat and so on at the inlet and outlet of the hot and cold channels. Among the many concerns for the Printed Circuit Heat Exchanger (PCHE) pointed out by S.J Dewson and other[3,4] is whether this concept can be applicable to nuclear systems. A structural issue is raised with the use of the PCHE because there are large temperature differences and pressure differences along the passages of the heat exchanger during normal and transient operation conditions.

The objective of this paper is to assess the structural integrity of the mini heat exchanger in the HTR (High Temperature Recuperator) with the normal operation condition of the S-CO2 Brayton cycle. Numerical models of the heat exchanger for Lead Fast Reactors have been developed for analysis with the ABAQUS finite element code. Stress analyses for the simple analytical models of the heat exchanger subjected to pressure load was performed using the heat exchanger design parameters. The stress result was compared with the ASME Section VIII design requirement. The structural integrity of the simplified heat exchanger model subjected to the pressure load during normal operating conditions of the S-CO2 Brayton cycle is evaluated.

2. Analytical Modeling of S-CO_2 Heat Exchanger

Under normal operation of the S-CO_2 Brayton cycle, the design pressures for the hot and the cold channels of the HTR are 7.463 and 19.99 MPa, respectively. The design temperatures for inlet and outlet of hot channel are 435.8 C and 186.8 C, respectively, and those for inlet and outlet of cold channel are 180.6 C and 402.1 C, respectively. The average heat transfer coefficients in the hot channels and cold channels are 0.548 Kw/m2-K and 0.629 Kw/m2-K, respectively. The design data for the heat exchanger in S-CO_2 Brayton cycle are shown in Table 1.

The dimension for the hot and cold channels were determined to be the same size, which was 1.0 mm diameter with 1.3 mm pitch to diameter with semi circular cylinder shape.

The simplified numerical models using tetrahedron element for the heat exchanger for Lead Fast Reactors have been studied using ABAQUS version 6.4.

To obtain solutions the size of the finite element model had to be further reduced down to a mesh that had 2 layers of 5 passageways in a side and 1 layer of either 4 passageways in the other side (5x4 model). The remainder of the layers was considered to be solid material. The number of the elements and nodes modeled are 38,890 and 60,553, respectively. The loading applied to the heat exchanger is the loading from the pressures in the passageways.

In modeling the heat exchanger, material properties are shown in Table 2. The structural boundary conditions applied to the models at the level of the operating floor considers one corner to be fully constrained from translations (i.e., no motion in the horizontal x, vertical y or horizontal z directions), one corner constrained from motion in the y- and z-directions, one corner constrained in the x- and y-direction and one corner constrained in the y-direction. The boundary conditions for the model are shown in Table 3. The pressures provided from normal operation condition are specified at the inner surfaces of the hot and the cold channels for calculating stresses. Figure 1 shows the FEM model for the 5x4 model.

3. Analyses Results and Discussion

Structural analysis of the model subjected to different pressures at hot channels, 7.463MPa, and at cold channels, 19.99MPa, respectively was performed.
The calculated maximum and mean mechanical stresses due to pressure loads for the model is 163.6 and 50.64MPa, respectively. With the ASME Section VIII, Division 1 design, the calculated maximum mechanical stresses is within the maximum allowable stress of 330 MPa for SS316. The mechanical stress distribution due to pressure loading and a cutoff view are shown in Figure 2.

4. Conclusion

With the limited computational models of the mini heat exchanger, the following conclusions are drawn:
- The calculated mean stresses induced by the pressure differences is well within the ASME Section VIII, Division 1 allowable stress for the 5x4 model.

The transient thermal analyses and the thermal stress analyses of the mini heat exchanger should be carried out to assess the structural integrity under transient and accident conditions of the Brayton cycle system.

ACKNOWLEDGMENTS

This work has been carried out under the Basic Atomic Energy Research Program by MOST in Korea. One of the authors(BY) acknowledges the partial support from the NUTRECK.

REFERENCES

[1] A.V.Moisseytsev and J.J.Sienicki, The design data for heat exchanger in S-CO2 Brayton cycle, private communication, September 9, 2003.
[2] J.J.Sienicki and A.V.Moisseytsev, SSTAR Lead-Cooled, Small Modular Fast Reactor for Deployment at Remote Sites-System Thermal Hydraulic Development, Proceedings of ICAPP '06, Seoul Korea, May 15-19, 2005.
[3] S.J Dewson and B.Thonon, The development of high efficiency heat exchanger for helium gas cooled reactors, ICAP, Spain, May 4-7, 2003.
[4] S.J.Dewson, and Xiuqing Li, Selection Criteria for the High Temperature Reactor Intermediate Heat Exchanger, Proceedings of ICAPP '06, Seoul Korea, May 15-19, 2005.

Table 1 Design Data for Heat Exchanger in S-CO2 Brayton Cycle

		Heat Exchanger			
		HTR		**LTR**	
		Hot	**Cold**	**Hot**	**Cold**
P(MPa)	**Inlet**	7.548	19.99	7.463	20.00
	outlet	7.463	19.96	7.409	19.99
T(C)	**Inlet**	435.8	180.6	186.8	85.2
	Outlet	186.8	402.1	88.8	176.8
Length(m)		2	2	1.5	1.5
Diameter(m)*		0.001	0.001	0.001	0.001
h(Avg, KW/m2-K)		5.48E-01	6.29E-01	1.12E+00	1.17E+00
*** Per channel**					
**** At the middle of the HX**					

Table 2 Material Properties of SS316

Temp (C/F)	**Thermal conductivity (W/mmC)**	**Modulus of elasticity (KPa)**	**Thermal expansion (mm/mm/C)**
21.1/70	14.93E-3	195.13E6	15.30E-6
93.3/200		190.30E6	16.74E-6
178/350	17.47E-3	184.44E6	18.00E-6
301.7/575	19.37E-3	175.34E6	19.17E-6
426.7/800	21.10E-3	166.17E6	19.98E-6

Table 3 Boundary Conditions of 5x4 Reduced Models

Nodes	X-dir	Y-dir	Z-dir	X-rotation	Y-rotation	Z-rotation
2	C	C	C	C	C	C
4	F	C	C	F	F	F
5	C	C	F	F	F	F
6	F	C	F	F	F	F

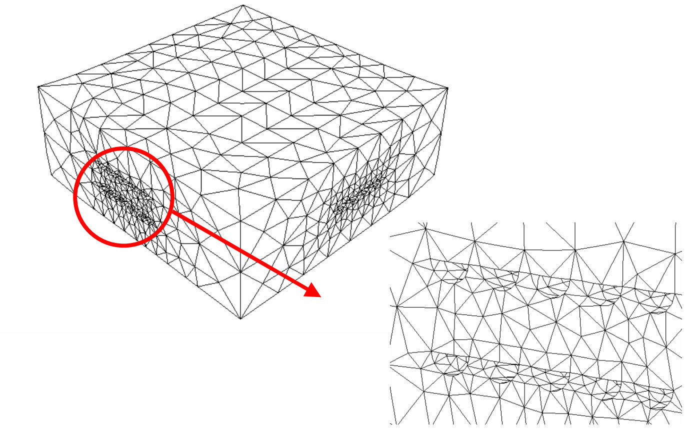

Figure 1 FEM Modeling

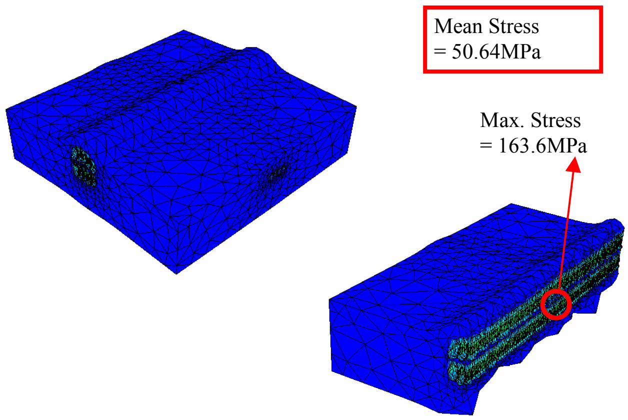

Figure 2 Pressure Stress Analysis Results