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A Plate-Fin Type SO_3 Decomposer for a Nuclear Hydrogen Production System

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1. Introduction

Very high temperature gas cooled reactor technology and IS cycle technology are being developed in KAERI for a nuclear hydrogen production system [1]. The outlet temperature of the high temperature gas cooled reactor developed so far ranges from 750 to 900°C. However, to produce hydrogen with an economical efficiency, the coolant outlet temperature of the VHTR should exceed 950°C. There are three important loops, the 1st loop transfers the heat generated from the core to the intermediate heat exchanger, the 2nd loop is an intermediate loop which connects the 1st loop and the 3rd loop of the IS process. The decomposer is a key component which transfers the heat of the 2nd loop to the 3rd loop. In this paper, a design concept has been presented based on the strength evaluation for the sulfuric-acid decomposer which shall be used at an elevated temperature and sulfa acid conditions. The heat exchanger is a plate-fin type exchanger in which the plate of Ni-based material is coated with SiC to enhance corrosion resistance. In addition to this, ion beam mixing technology has been developed to reduce a possible delamination between the SiC layer and base material by releasing the stress gradient. A parametric study was performed to determine the basic dimensions of the heat exchanger.

2. Design Study

Three types of heat exchanger can be used for the decomposer of a VHTR hydrogen production system. Helical tube type has been widely used for the intermediate heat exchanger but it is not an attractive candidate for a SO_3 decomposer any more due to the large volume and the unavailability of a catalyst space. Recently, a printed heat circuit has become a potential candidate of the intermediate heat exchanger at a high temperature and pressure. However, it can not provide enough space for catalyst [2]. The plate fin heat exchanger is another candidate which can be used at high temperature and pressure. Also, a catalyst space is available in this type of heat exchanger. Thermo-fluid characteristic of a plate fin type heat exchanger has been investigated for an application to an intermediate heat exchanger [3].

Plate fin type heat exchanger, where an ion beam coated plate has been used, is a promising candidate of the sulfuric-acid decomposer for a nuclear hydrogen production system. Thermal expansion coefficient difference between the coated material and base material and the mixing depth are important to the structural integrity of coating layer. However, they have a negligible influence on the overall structural behavior and they are being investigated separately. Plate fin type heat exchanger is shown in Figure 1 where the counter flow of He coolant and SO_3 gas is shown.

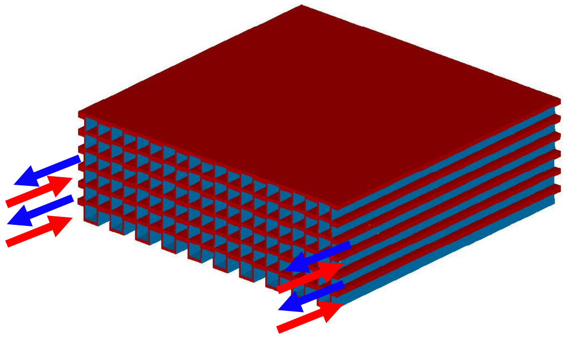

Figure 1. Sectional view of plate-fin type heat exchanger.

3. Strength Evaluation

Stress state was investigated to determine the key dimension of the plate fin type heat exchanger. ABAQUS was used to calculate the stress state of a unit section. Boundary condition is shown in Figure 2. Plane strain element with a symmetric boundary condition and a displacement coupling boundary condition were used to simulate a multi channel.

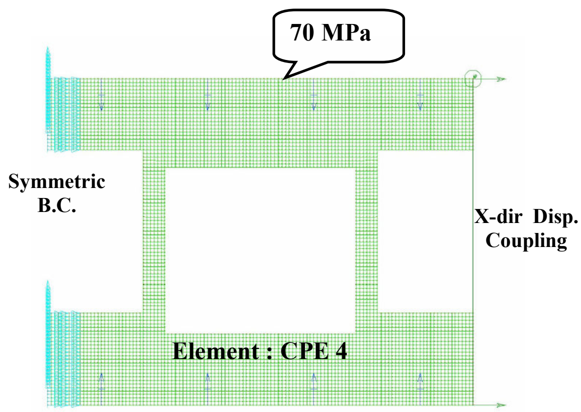

Figure 2. Boundary condition of FEA.

Maximum stress was found to be 60MPa when the differential pressure is 70MPa as shown in Figure 3.

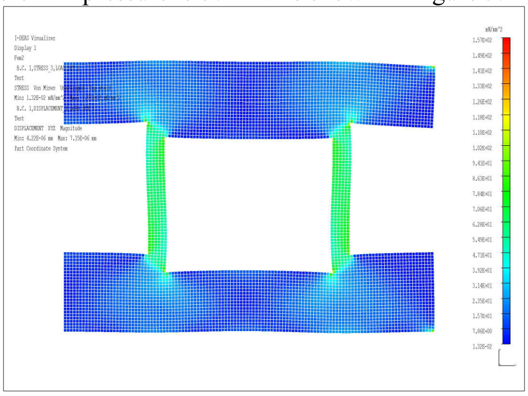

Figure 3. Boundary condition of FEA.

Parametric study has been carried out for various sectional dimensions such as the fin height, fin thickness, pitch of the fin, and plate thickness. Hydraulic diameter of the channel should be larger than 4mm in order to insert the catalyst required for a SO_3 decomposition. Allowable design stress changes not only with the temperature but also with time due to a creep effect in a high temperature. Allowable stress is plotted up to 1800^{o}F(983^{o}C) in Figure 4 for Alloy 617 as a function of the time and temperature [4].

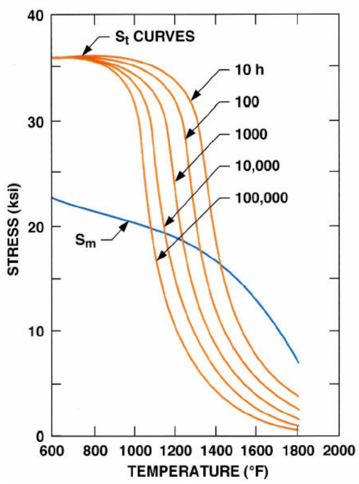

Figure 4 Allowable stress and creep data for A617

If only the temperature dependent strength is considered in the design of a heat exchanger, a plate fin type heat exchanger withstanding more than 100MPa of a differential pressure is possible. However, with the consideration of a creep, maximum pressure difference is around 20MPa in the practical design range. This value can be increased by increasing the thickness of the fin and the plate, which can cause inefficient in the view point of the heat transfer, the bending of fin, and the compactness. Also, maximum allowable differential pressure regarding a buckling was estimated based on the elasticity. It was found that a buckling was not a dominant design criteria.

Table 1 Parametric study for P-F type heat exchanger.

Parameter	Pitch	F_t	P_h	P_t	ASME				Strength			
					Allowable P (Strength)		Allowable P (Creep)		Allowable P (1000h)		Allowable P (100000h)	
					900	950	900	950	900	950	900	950
unit	mm	mm	mm	mm	bar		bar		bar		bar	
Case 1	2.40	0.30	1.75	0.90	98.5	75.7	15.4	10.2	51.6	34.4	19.3	12.8
Case 2	5.40	0.60	4.60	2.00	87.5	67.3	13.7	9.1	45.9	30.6	17.1	11.3
Case 3	5.00	0.80	4.60	2.00	126.1	96.9	19.7	13.1	66.0	44.0	24.7	16.3
Case 4	5.00	1.00	4.60	2.00	157.6	121.1	24.6	16.4	82.5	55.0	30.8	20.4
Case 5	5.00	1.20	4.60	2.00	189.1	145.4	29.5	19.6	99.1	66.0	37.0	24.5

Table 2 Buckling evaluation for P-F heat exchanger.

Parameter	Pitch	F_t	F_h	P_t	Buckling	
					Allowable pressure	
					900	950
Unit	mm	mm	mm	mm	bar	
Case 1	2.40	0.30	1.75	0.90	4514.1	4378.0
Case 2	5.40	0.60	4.60	2.00	2323.0	2252.9
Case 3	5.00	0.80	4.60	2.00	5946.8	5767.5
Case 4	5.00	1.00	4.60	2.00	11614.8	11264.6
Case 5	5.00	1.20	4.60	2.00	20070.3	19465.2

4. Conclusion

Plate fin type heat exchanger was studied for a possible use of a SO_3 decomposer in a nuclear hydrogen production system. Plate-fin type can be designed up to 20MPa based on the ASME design strategy which can not be obtained in a helical type heat exchanger.

ACKNOWLEDGEMENTS

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