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Basic Heat Transfer Characteristics in the Element of the HTGR RCCS

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1. Introduction

The RCCS(Reactor Cavity Cooling System) is a heat removal system designed to remove the decay and residual heats and its heat removal capacity is one of the major parameters limiting the plant capacity. Improving the cooling capacity of the RCCS can improve the plant economy. To develop an improved RCCS with an increased capacity, the basic heat transfer characteristics in the heat transfer element of RCCS were investigated by using the multi-dimensional code CFX[1].

2. Analysis

2.1 Calculation Method

The heat transfer from the reactor vessel wall to the RCCS heat transfer elements is made with all the heat transfer modes, i.e, the conduction, convection and radiation. The convection in the cavity was ignored in this paper since the purpose of the study is to investigate the basic heat transfer characteristics in the RCCS heat transfer element and the cavity convection effects were found to be very small[2].

By utilizing the symmetry in the elements region, one half of a single element unit was considered for the computation as shown in Fig. 1.

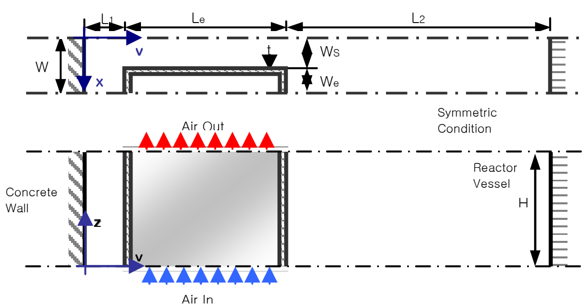

Fig. 1 Computational domain

The basic characteristics of the element performance are two-dimensional and the calculation condition was set up by focusing on the two-dimensional effects, i.e, the effects on the plane shown in Fig. 1. Based on this basic approach of this work, a symmetric condition was applied to the top and bottom boundaries for the radiation. For the flow condition inside the element, the same mass flux condition was applied for the all investigated cases, and the fully developed velocity profile with a temperature of 160℃ is used as the inlet condition.

The reactor vessel wall temperature was treated as uniform at 500℃ and the opposite concrete wall was assumed adiabatic. The Monte-Carlo method was employed to calculate the radiation heat transfer. The surface was 0.7 for all the surfaces.

The multidimensional code CFX was used for the analysis and all results represented in this paper have a maximum 0.1% energy imbalance.

2.2 Calculation results and Analysis

o Basic characteristics in the element

The temperature distribution in the element structure is shown in Fig.2 for the internal and the external surfaces. The region between 0.27m and 0.3m is the vertical section facing the reactor vessel, i.e, the front side. The distribution curves reveal the basic characteristics in the element such as 1) The front side gets the highest heat flux and transfers a part of it to the lateral side by the conduction inside the element structure but its magnitude is not significant. 2) The heat the lateral side gets is mainly by the radiation and the heat moved by the conduction inside the structure in this region is mainly from the heat received by the radiation of its own but not by the heat from the front side. 4) For an approximate analysis, the front side and lateral side may be decoupled without seriously loosing the validity.

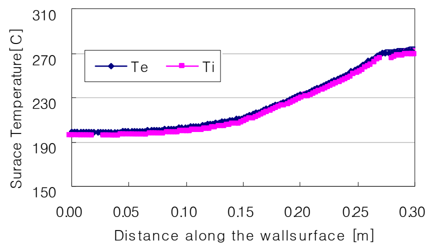

Fig. 2 Temperature distribution at the wall surfaces

o Parameter changes and the overall heat transfer rate

For a discussion of the effects of the parameter changes, the calculation conditions and results are summarized below.

Table 1 Parameter Changes and Effects on the Heat Transfer

parameter,x	x/x_o	We/Wu	Le/We	No. of Elements	$[Q/Q_0]$re.sum	$[Q/Q_0]$RCCS.sum	S.dQ/dx
	0.5	0.5	10	97	0.99	0.99	0.02
	1	0.5	10	97	1	1	
t	1.5	0.5	10	97	1.01	1.01	0.02
	0.6	0.5	6	97	0.96	0.96	0.09
	0.8	0.5	8	97	0.99	0.99	0.06
	1	0.5	10	97	1	1	
Le	1.2	0.5	12	97	1	1	0.02
	0.5	0.67	10	129	0.73	0.98	0.05
	1	0.5	10	97	1	1	
Ws	1.5	0.4	10	77	1.25	0.99	-0.02
	0.4	0.2	25	97	1.05	1.05	-0.08
	1	0.5	10	97	1	1	
	1.2	0.6	8.3	97	0.97	0.97	-0.16
We	1.4	0.7	7.1	97	0.95	0.95	-0.13

In the table, the number of elements are that in one side of the cavity. $Q_{re.sum}$ and $Q_{RCCS.sum}$ are the total radiation heat transfer rates in the external surfaces. The former is that for a single element and the latter is for the entire RCCS. *S.dQ/dx* is the sensitivity of the total heat transfer change on the parameter change.

The role of each parameter in the heat transfer and the related heat transfer mechanism is discussed below.

o Element thickness, *t*

The thickness works as the major parameter in the conduction heat transfer but its effect is small as can be confirmed by the sensitivities in Table1.

o Element length, *Le*

When *Le* is increased, the solid angle from the reactor vessel to the gap between the elements where radiative rays pass does not change but the radiative surface resistance becomes decreased, and it makes the radiation heat transfer increase as observed by the curve Q_{rel} in Fig. 3.

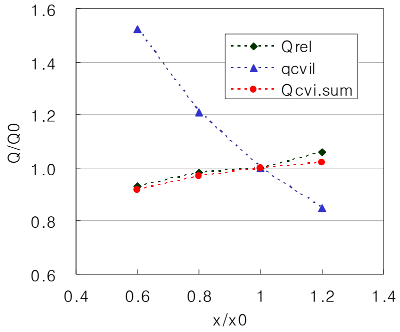

Fig. 3 Effects of the element length change

o Spacing between the elements, *Ws*

The spacing directly causes a change in the ratio of the view factors. As it increases, the view factor for the lateral side increases and more radiative rays from the reactor vessel arrive at the lateral surface and consequently the heat transfer to the lateral surface increases while those for the front side change reversely as shown in Fig. 4.

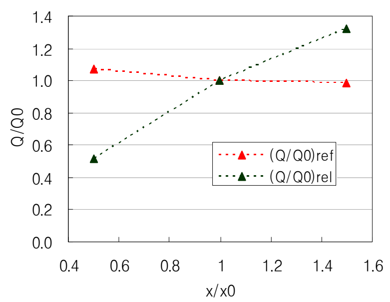

Fig. 4 Effects of the element length change

Since the increase rate in the lateral side is larger than that in the front side, the overall heat transfer rate of a single element increases as shown in Table 1. As the spacing increases, however, the number of elements in the whole RCCS decreases and the total heat transfer rate decreases after passing the optimum spacing as can be conferred from Table 1.

o Front side length of the element , *We*

The change in *We* is directly the change in the aspect ratio and also is the change in the ratio between the spacing and the front side length of the element, which determines the relative magnitudes of the view factors. Its decrease causes the view factor to the lateral side to increase and the radiation heat transfer to this side *Qrel* becomes increased while that to the front side *Qref* decreases as shown in Fig. 4. Also in the figure, the heat transfer rate continuously increases as *We* decreases.

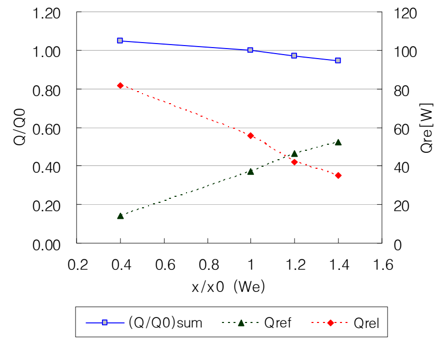

Fig. 4 Effects of the front side length change

An additional observation made from the calculation results was that the role of the radiation heat transfer at the rear side of the element with the RCCS wall is negligibly small. Its magnitude ranged from 1% to 5% for the various conditions investigated.

3. Conclusions

The basic heat transfer characteristics were investigated and the major conclusions are as follows.

- The heat transfer in the RCCS heat transfer elements has unique characteristics. The front and the lateral surface of the external surface in the element have different roles and characteristics in the heat transfer.
- The laterally extended shape of the element does not cause only a convection heat transfer area increase but also a decrease in the radiative surface resistance.
- The radiation at the rear side of the element is pretty small.

Acknowledgment

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[2] Kim S, Sim Y.S., "Treatment of the analysis for the heat transfer in the rector cavity of HTGR, KNS Spring Conference, Chunchon, Korea, 2006