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Development of an Algebraic Method for the Heat Transfer Analysis of a HTGR RCCS

Sim Yoon Sub, Kim Seyun, Cho Bong Hyun
KAERI, 150 Deokjin-Dong, Yuseong-Gu, Deajeon, Korea, 305-353, yssim@kaeri.re.kr

1. Introduction

Development of a new design usually requires a lot of iterative works and an analysis method of a simple input/output structure and a fast running capability makes the development work more efficient. As a work at the initial stage of the development for an improved RCCS design, a simple analysis method based on algebraic equations has been developed. The structure of the developed method is so simple that it can be run on the PC Software, MS-Excel.

2. Development of the method

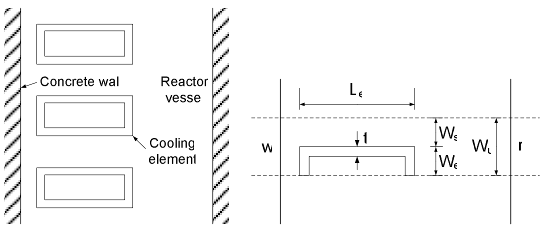
2.1 GT-MHR RCCS type

o Basics

The heat transfer from the reactor vessel surface to the cooling air inside the element mainly relies on the radiation to the external surface of the element and the convection inside the element[1][2]. From this, a method for a pre-analysis in the design development can be greatly simplified.

o Geometry and treatment of the symmetry

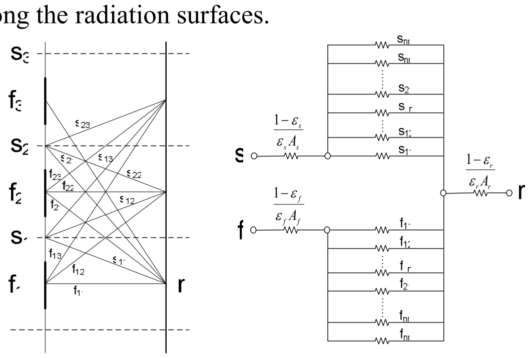
Simply one half region of a single cooling unit can represent the whole RCCS panel physics because of a symmetry in the configuration, and thus the analysis region was set as Fig. 1b.



a) panel configuration b) analysis region

Fig.1 The cooling device structure and analysis region

A method for treating the radiative symmetric condition was devised. Fig 2 shows the interaction among the radiation surfaces.



a. radiative interaction b. radiation network

Fig.2 Interaction among the radiation surfaces

Since the view factor describes the interaction effects and it is only a function the solid angle, the group of the elements can be represented as a single straight line consisting of segments.

As shown in Fig.2a, each surface is interacted with many surfaces but direct interaction is made only between opposing surfaces. Also the surface of each element is decomposed into two, i.e., the front surface and the lateral surface. Since the element configuration is repeatedly made, there exist only two different surface temperatures in the entire element region and this feature makes the description of the complicate radiative connections simple as shown in Fig.2b. It can be further simplified as shown in Fig. 3.

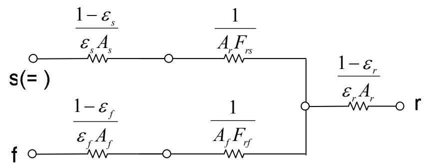


Fig.3 Representation of the radiation network

The view factors from the RV (reactor vessel surface) to the front side, *f* and to the lateral side, *l* become simply the ratios *Ws/Wu* and *We/Wu,* respectively since the solid angle from the RV to the lateral surface is the same as that to the opening between the elements.

o Overall network for the heat transfer

With the representation of the radition network by that of Fig.3, the whole network from the RV to the cooling air inside the element becomes that in Fig.4.

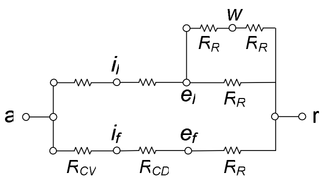


Fig. 4 Overall network

In the figure, the paths connected to *w* represent the radiative interaction with the cavity wall but its effects were reported to be very small[2] and ignored in this study.

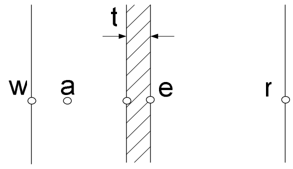
In setting up the algebraic transfer equations based on the network in Fig.4, the radiation path resistance was represented by the following equation.

$$R_R = \frac{T_r - T_e}{Q} = \frac{\frac{1-\varepsilon_e}{\varepsilon_r}\frac{1}{A_r} + \frac{1}{A_r F_{re}} + \frac{1-\varepsilon_e}{\varepsilon_e}\frac{1}{A_e}}{\sigma(T_r^3 + T_r^2 T_e + T_r T_e^3 + T_e^3)} \quad (1)$$

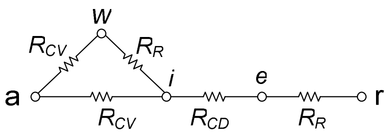
The resultant equation set is solved by the successive iteration method using the VBA in MS-Excel.

2.2 Parallel Plates Type

The approach developed for the GT-MHR type was also applied to the element type of two parallel plates as shown in Fig. 5.a



a. structure



b. heat transfer network

Fig. 5 parallel plates type element

In this type, the radiative interaction with the wall is expected to be not small when considering the observation made for the RHRS of the liquid metal reactor KALIMER, and thus the interaction was included in the method.

2.3 Accuracy Assessment

The accuracy of the developed algebraic method was evaluated by comparing its calculated heat transfer rate to that calculated by the CFX code and the discrepancy was only 4% at the reference condition for the work of Park's[2] and thus the algebraic method is evaluated as sufficiently accurate for the application for a pre-analysis in the improved design development work

3. Application

As a demonstration of the applicability of the developed algebraic method, some of its application results are explained.

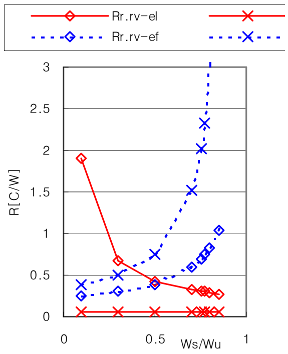
o Relative capability of the GT-MHR type

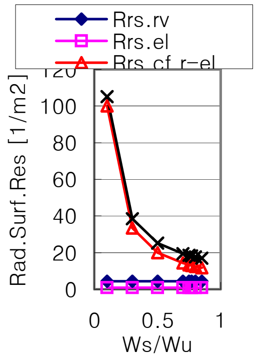
The heat removal capacities were compared as 1:1.32 between the two types. The magnitude of the actual increase can be somewhat different than the value from other reasons such as a flow resistance change which was not included in the calculation but the magnitude can be estimated at about the value, i.e, 30%.

o The effects of the element shape in the GT-MHR type

The aspect ratio *Ws/Wu* was changed while keeping the values of *Le* and *Wu* the same. At the aspect ratio increase, the heat transfer rate increased almost continuously and an investigation on this was made further by the algebraic method..

Figure 6a is for the change in the heat transfer resistance components and it shows that the ratio change causes a substantial change in the radiation heat transfer resistance (Rr.rv-el and Rr.rv-ef) which is the dominant resistance.





a. Rr and Rcv b. Surface components

Fig. 6 Effects on the heat transfer resistance components

The effects on the radiation sub-components which are related to the geometry and radiation condition of a surface are shown in Fig. 6b.

Among the sub-components, the one mainly representing the view factor effects changes rapidly. The resistance component for the lateral surface decreases while that for the front surface increases as the aspect ratio increases. It means the lateral surface is more efficient. The major reasons for this are found as the following from a more detailed analysis on the calculation results. 1) For the same solid angle, the lateral side can have a larger radiation area and it thus decreases the surface radiation resistance. 2) The temperature of the lateral side is lower than that of the front side and it also decreases the resistance. These features are considered as the major features to be addressed in improving the current RCCS design.

4. Conclusions

For the efficiency of the development work for an improved RCCS design, an algebraic method has been developed and its structure is very simple so that it can be run with the PC software, MS Excel and it is also sufficiently accurate to be used for a pre-analysis in the design development work.

By applying the developed method, the major heat transfer features to be addressed for improving the current RCCS design were identified.

Acknowledgment

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