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Assessment of the Accuracy of the Thermal Radiation Methods in Commercial Codes

Park Rae Young*, Sim Yoon Sub
Fluid Sys. Eng. Div., KAERI, 150 Deokjin-Dong, Yuseong-Gu, Deajeon, Korea, 305-353, rypark@kaeri.re.kr

1. Introduction

In analyzing the characteristics of the heat transfer in the RCCS of a HTGR, a use of a commercial code can be considered essential in a practical sense since the geometry of the heat transfer elements is not simple, and there are multi-dimensional effects and also there are all of the heat transfer modes in the heat transfer. Among the heat transfer modes, the radiation heat transfer is the dominant one[1] and accuracy in treating the radiation becomes important in the analysis for the RCCS. Therefore the accuracy of the calculation methods for the radiation heat transfer in various commercial codes was assessed.

2. Evaluation Approach and Results

2.1 Thermal radiation calculation method

Two calculation methods available from commercial codes were evaluated. One is the MCM(Monte Carlo method) and the other is the DTM(Discrete transfer model).

The MCM simulates the radiation heat transfer using a large number of randomly generated photons and traces the history of the photons from their points of emission to the points of absorption. Its advantage is that it does not require the calculation of the view factors and a complicated problem can be handled relatively easily. Its disadvantage is, however, that it is subject to a statistical error.

The basic approach in the DTM(Discrete transfer model) is similar to that of the MCM and it uses the concept of representative rays but the number of rays and their directions are chosen in advance in this method.

For a case where the medium absorption rate is zero or very small such as the RCCS cavity medium, commercial code vendors generally recommend the use of the MCM but not the DTM. However, at the early assessment stage, the performance of the MCM appeared to be not satisfactory and the DTM was also evaluated as a possible substitute.

2.2 Development of a code for benchmarking

To evaluate the accuracy of the radiation methods, an accurate solution is required and a computer code RadRec was developed. The code uses a deterministic approach to ensure its accuracy as a benchmarking code. Instead of using the statistical approach of the commercial code by photons or radiation rays, view factors are internally calculated in RadRec and the error resulting from the use of the statistical approach is avoided. RadRec calculates the radiation heat transfer equation for a non-participating medium, Eq. (1) without any simplifications.

$$\frac{Q_k}{A_k}\left(\frac{1}{\varepsilon_k} - F_{kk}\frac{1-\varepsilon_k}{\varepsilon_k}\right) - \sum_{j=1, j\neq k}^{N} F_{kj}\frac{Q_j}{A_j}\frac{1-\varepsilon_k}{\varepsilon_k} \quad (1)$$

$$= (1 - F_{kk})\sigma Tj^4 - \sum_{j=1, j\neq k}^{N} F_{kj}\sigma T_j^4$$

The required view factor is calculated by the following equation[2].

$$F_{1-2} = \frac{1}{2\pi A_1}\iint_{C1}\left(\ln S dx_2 dx_1 + \ln S dy_2 dy_1 + \ln S dz_2 dz_1\right) \quad (2)$$

2.3 Test condition and results

As shown in figure 1, a rectangular enclosure without a participation medium was considered. Radiation waves are emitted and reflected diffusively at all walls.

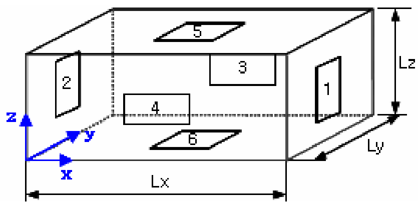
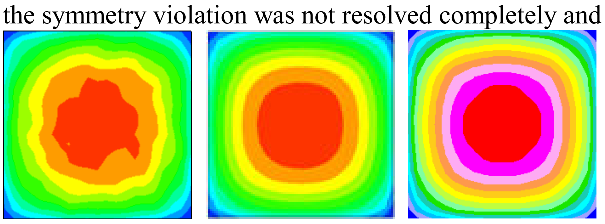


Figure 1 Calculational geometry

To evaluate the calculation accuracy, major parameters which affect the calculation accuracy were changed for the tests and the parameters were the number of rays(DTM), histories(MCM) and the number of grids. To represent various levels of a geometrical complexity, the aspect ratio of the calculation domain was changed, and also the implementation of a boundary symmetry condition was tested.

Figure 2 shows the distribution results of the radiative heat flux from the tested methods. Because of the symmetrical arrangement of the geometry and boundary conditions, the radiative flux distribution must be symmetrical.

The symmetry is satisfied in the DTM results, however, it is not satisfied in the MCM results. Increasing the histories improved the results a little but the problem of the symmetry violation was not resolved completely and



(i) MCM History 200000 (ii) DTM(Code1) Rays 32^2 (iii) DTM(Code2) Rays 32^2

Figure 2 Radiative heat flux distribution these test results raises the validity of the MCM method in a heat transfer property distribution results, i.e, qualitative results.

Though the qualitative performance of MCM was evaluated as poor, its quantitative results appeared much better and the MCM showed a good agreement with RadRec as shown in Fig. 3. In the figure, the error in the vertical axis denotes the normalized difference of the commercial code result from the RadRec code result. The test was made for different aspect ratios of the test box. The MCM results showed a maximum of a 4% error in a high aspect ratio. Quantitative tests on DTM, however, showed that the method has a very poor accuracy as shown in the same figure, and is interpreted as the reason why vendors do not recommend DTM for a calculation with a transparent medium.

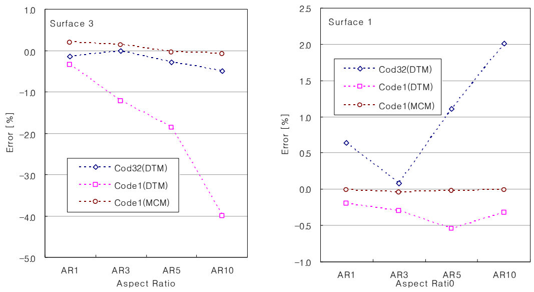
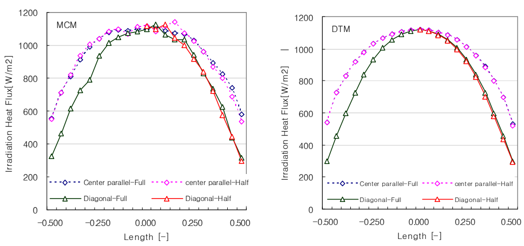


Figure 3 Results on the change of the aspect ratio

A symmetric condition in radiation is treated as a mirror in the commercial codes and it is simulated by a perfectly specular reflector. The test results for use of the symmetric condition are shown in figure 4. The accuracy of the symmetric condition implementation was evaluated by comparing the results from a full domain calculation with those from a half domain calculation. The DTM shows a good agreement between the full and half domain calculations in its distributions. However, the MCM shows a poor agreement in its distributions. On the total heat transfer rate, however, the error of the DTM and that of the MCM were 0.03% and 0.02%, respectively.



a. MCM b. DTM

Figure 4 Radiative heat flux distribution in the symmetric boundary condition

The test conditions treated up to now were for a uniform temperature distribution in each side of the test geometry in Fig.1 and for the emissivity of 1.0 for all the surfaces, i.e, the black body condition. Tests were also made for the condition of a non-uniform temperature distribution and the non-black body with a emissivity of 0.7. The test was made only for the MCM by considering the poor quantitative performance of DTM and the results are shown in Fig.5. The results were similar to those for the condition of the uniform temperature distribution and the black body, and the maximum error was about 1%. In this condition, the aspect ratio was 5. Also from this, one can find the accuracy of the MCM strongly depends on the aspect ratio.

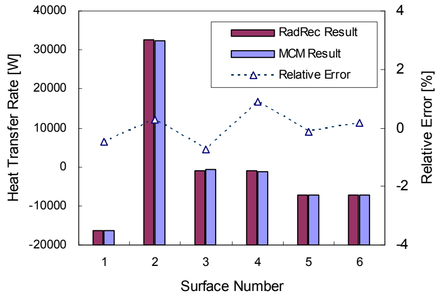


Figure 5 Result on the non-uniform distribution and non-black body condition

3. Conclusion

The applicability of the radiation heat transfer calculation methods available from commercial codes was assessed for the application to the HTGR RCCS analysis. The major outcomes from the assessment are as follows.

- The MCM shows a poor accuracy in qualitative results such as a heat flux distribution but its accuracy is acceptable in quantitative results such as a total heat transfer rate.
- The DTM shows a good accuracy in a qualitative result but its application for a transparent medium results in a very poor quantitative accuracy.
- The overall recommendation in applying a commercial code for a transparent medium is to use the MCM with some cautions in interpreting its calculation results.

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