Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2011

Heat Transfer Coefficient Analysis for Coolant Channels in a VHTR

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1. Introduction

A very high temperature reactor (VHTR) is graphite moderated and helium cooled reactor and selected as a next generation nuclear reactor [1] for its ultimate safety among various advantages. This type reactor has become of great interest in terms of using a process heat. To utilize VHTR safely and practically, optimized heat flux analysis is necessary.

Empirical correlations for a Nusselt number have widely been applied to predict the convective heat transfer in coolant channels of a prismatic VHTR [2,3]. This approach has advantages of fast computation. However, there has been no in-depth study on their applicability to the thermo-fluid conditions of coolant channels of a prismatic VHTR. Therefore, this paper investigates the applicability of well-known empirical correlations to the coolant channels of a prismatic VHTR by using the detailed numerical results obtained from the 3-D computational fluid dynamics (CFD) analysis. In particular, the effect of two different wall heating condition on the applicability of empirical correlations is focused in this paper.

2. Modeling and Schematic of Reactor Core

In order to investigate the applicability of well-known empirical correlations, the following Nusselt number correlations for turbulent pipe flow [4,5] are selected in this work.

$$\mathrm{Nu} = 0.023 * \mathrm{Re}^{0.8}\mathrm{Pr}^{0.4} \quad (1)$$

$$\mathrm{Nu} = 0.021 * \mathrm{Re}^{0.8}\mathrm{Pr}^{0.4}\left(\frac{\mathrm{T_s}}{\mathrm{T}}\right)^{-0.5}\left[1+\left(\frac{\mathrm{z}}{\mathrm{D}}\right)^{-0.7}\right] \quad (2)$$

3D conduction and coolant flow model were solved by a commercial CFD code, ANSYS CFX. The standard k-ε model with the automatic wall treatment was applied. The CFD analyses were made for the unit cell region within the prismatic fuel element. Unit-cell idea was from that the fuel compact holes and coolant holes are arrayed regularly within the prismatic fuel element. The figure 1 shows a typical unit cell having one coolant hole surrounded by 6 fuel compact holes. The heat flux to the coolant hole is more or less uniform in this case. However, a different heating condition exists in the prismatic fuel block. In some regions such as fuel handling hole, burnable poison hole and etc., the helium coolant is heated up partially by irregular heat source as shown in Fig. 2. The coolant in Fig. 2 absorbs the heat from fission fuel non-uniformly unlike the coolant in Fig. 1. In this work, the applicability of Eqs. (1) & (2) has been investigated for these two different wall heating cases.

Six fuel elements are stacked axially to form a column with the height of 4.758 m. The helium coolant flows as fixed mass flow rate of 0.03kg/s. Inlet temperature and pressure are 490 ℃ and 70 atm, respectively. Uniform heat generation of 2.876E+7 W/m^3 in the fuel and constant thermo-fluid properties were applied. The additional inlet pipe is connected to the coolant channel to make fully developed flow at coolant inlet.

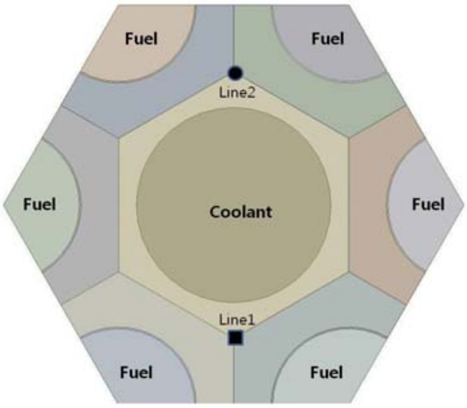

Fig. 1 Unit-cell in uniform heating condition

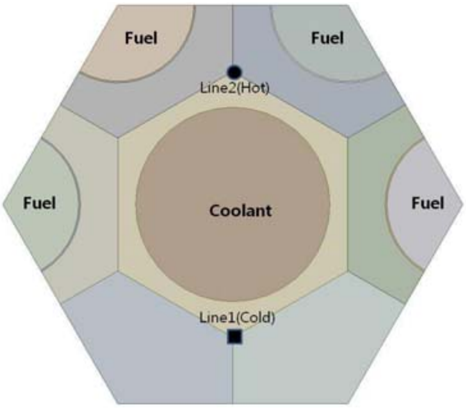

Fig. 2 Unit-cell in non-uniform heating condition

Line 1 and 2 are defined axially to figure out the local Nu number. The figure 3 and 4 show the results of the CFX and empirical correlations obtained for uniform and non-uniform heating cases, respectively. In the case of uniform heating, the CFX predicts almost the same Nusselt numbers for Line 1 and 2. Fig. 3 obviously shows that both empirical correlations somewhat over-predict the Nusselt number in the case of uniform heating. For the fully developed region, the deviations from the CFX results are 17.85% and 5.79% for the Dittus-Boetler (i.e., Eq. (1)) and McEligot correlations (i.e., Eq. (2)), respectively.

In the case of non-uniform heating condition, as shown in Fig. 4, significant differences in the calculated Nusselt numbers are observed. The maximum deviation from the CFX result reaches 32% and 19% for the Dittus-Boelter and McEligot correlations, respectively. The Dittus-Boetler correlation predicts the same Nusselt numbers regardless of the heating conditions (i.e., Fig. 3 vs. Fig. 4). The McEligot correlation is slightly affected by the heating condition. However, the CFX results are significantly affected by the heating conditions.

Different Nusselt numbers result in different wall surface temperatures which affect the fuel temperature. Therefore, an improvement on the empirical correlation is required for an accurate prediction of the fuel temperature. In particular, the effect of the heating condition has to be included in the empirical correlation.

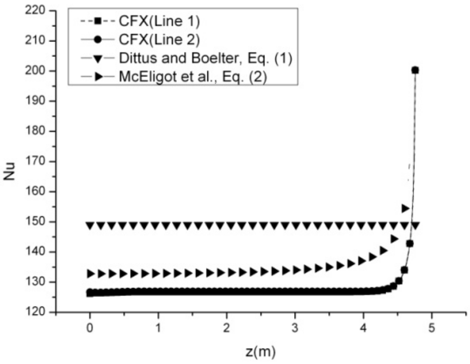

Fig. 3 Local Nu number comparison for uniform heating

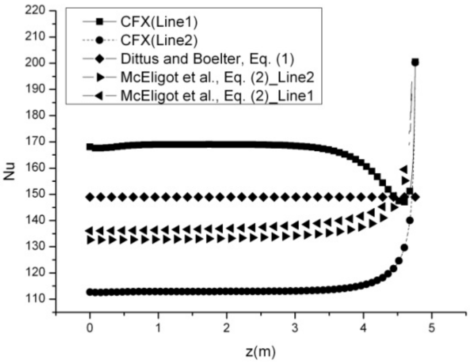

Fig. 4 Local Nu number comparison for non-uniform heating

3. Conclusions

The applicability of the two well-known empirical correlations for turbulent pipe flow to the coolant channels in a prismatic fuel block was investigated based on the CFX calculations. It is found that both correlations somewhat over-predict the Nusselt number in the case of uniform heating condition. Moreover, in the case of non-uniform heating condition, significant differences are found between the calculated Nusselt numbers by the CFX and empirical correlations. Therefore, it is concluded that the empirical correlation needs to be improved for an accurate prediction of the fuel temperature.

Acknowledgements

This work was supported by Nuclear R&D Program of the National Research Foundation of Korea (NRF) grant funded by the Korean government (MEST).

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