Thermal Hydraulic Analysis of Gas-Cooled Reactors with Annular Fuel Rods

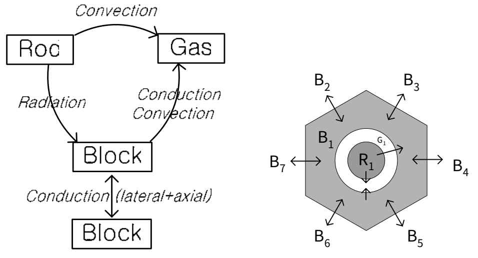
Kyu-Hyun HAN and Soon Heung Chang
Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea
Tel: +82-42-869-3856, Fax: +82-42-869-3810, Email: abbeyroad@kaist.ac.kr

1. Introduction

More than half of the world's energy is used in industrial processes and for heating applications which have hardly been touched by the nuclear industry. Nuclear power could be brought into a wide range of applications for industrial processes, provided that gas outlet temperatures of gas-cooled reactors are sufficiently high. The most limiting core design requirement which controls the core outlet temperature is the maximum acceptable fuel compact temperature. An innovative fuel design is required for a significant decrease in the fuel temperature. This study investigated the possibilities of implementing internally and externally cooled annular fuel rods in a gas-cooled reactor.

2. Methods

The existing wall model cannot be used for gas-cooled reactors where another heat source, a graphite block, is introduced. In pressurized water reactors, all of the heat generated from fuel rods is transferred to fluid by convection. On the other hand, in gas-cooled reactors, only part of heat from fuel rods is directed to fluid by convection, and the remaining part is transferred to the graphite block by radiation, as shown in Figure 1. The block undergoes axial and lateral conduction with the adjacent blocks while transferring heat to fluid by both convection and conduction.



(a) Heat transfer mode (b) Sub-block

Figure 1. Heat transfer in a gas-cooled reactor

The number of fuel rods in a fuel column remains unchanged since the dimension of the hole in a graphite block element is large enough for annular fuel rods. A calculation module [1] for a pressurized water reactor with annular fuel rods is capable of analyzing coolant flow distribution and heat transfer fraction in the inner and the outer sub-channels. The heat transfer fraction within a fuel rod is calculated by evaluating temperatures at seven points: the point of the peak fuel temperature as well as both outer and inner surfaces of the outer graphite sleeve, the inner graphite sleeve, and the fuel compact.

The heat transfer coefficient for the inner sub-channel is lower than that of the outer sub-channel because there is no spacer rib to cause turbulence in the inner sub-channel. The coefficient for circular channel [2] is as follows:

$$h = 0.02\left(\frac{k_h}{D}\right)\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}.$$

In the analysis, we assumed that the operating parameters of the annular fuel-based gas-cooled reactor are the same as those of the existing solid fuel-based one. Mass flow rate was kept constant at 89.7% of the total flow, assuming concentricity and no cross-flow. A graphite block element with annular fuel rods is shown in Figure 2.

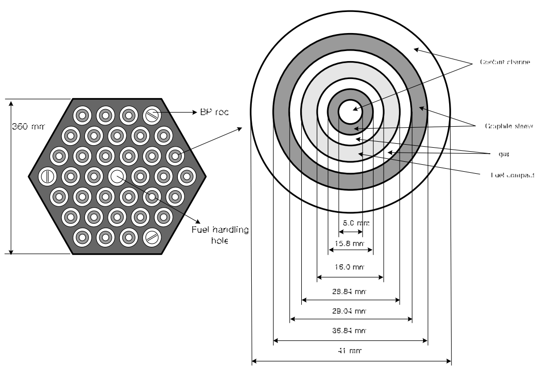


Figure 2. Dimensions of a gas-cooled reactor with annular fuel rods

3. Results and Conclusions

The radial temperature profiles of fuel rods at the hottest axial positions in the hot fuel rod are shown in Figure 3. The maximum temperature of the solid fuel was 1323℃, while that of the annular fuel was 1243℃. The temperature profile of the annular fuel was lower than that of the solid fuel, which indicates that the thermal margin was improved at the expense of a drop in pressure.

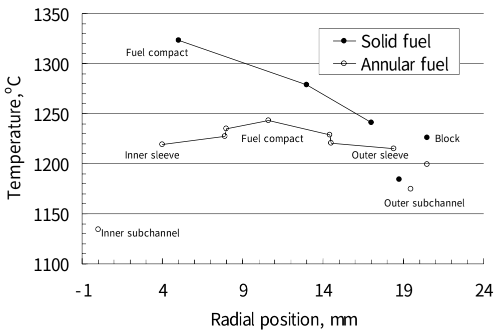


Figure 3. Radial temperature distribution at the hot spot

Thermal-hydraulic analysis revealed that annular fuel rods showed a higher thermal margin than solid ones, yielding an 80℃ lower peak temperature. Optimum dimension of the annular fuel was determined as a radius of 4mm for the same fuel compact volume. Seventy-nine percent of the heat generated from fuel rods was transferred to external fluid by both radiation and convection, and the rest to internal fluid by convection. Though the pressure drop was higher in the annular fuel, its overall thermal-hydraulic performance proved that annular fuel is a promising candidate for applications in high temperature reactors of next generation.

REFERENCES

[1] K. H. Han and S. H. Chang, “Development of a thermal-hydraulic analysis code for annular fuel assemblies,” Nucl. Eng. Des., **226**, 267 (2003).

[2] H. Fenech, Heat transfer and fluid flow in nuclear systems, p.341, Pergamon Press, New York (1981).