Preliminary Estimation of Local Bypass Flow Gap Sizes for a Prismatic VHTR Core

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1. Introduction

The Very High Temperature Reactor (VHTR) has been selected for the Nuclear Hydrogen Development and Demonstration (NHDD) project [1]. In the VHTR design, core bypass flow has been one of key issues for core thermal margins and target temperature of the core outlet. The core bypass flow in the prismatic VHTR varies with the core life due to the irradiation shrinkage/ swelling and thermal expansion of the graphite blocks, which could be a significant proportion of the total core flow. Thus, accurate prediction of the bypass flow is of major importance in assuring the core thermal margin.

To predict the bypass flow, first of all, local gap sizes between graphite blocks in the core should be determined. The objectives of this work are to develop a methodology for determining the gap sizes and to perform a preliminary evaluation for a reference reactor.

2. Methods

To evaluate the bypass flow in the VHTR core, dimensional changes of the graphite blocks by an irradiation and thermal expansion should be calculated. Graphite is a primary material for the construction of the VHTR core, serving as a low absorption neutron moderator and providing a high temperature and strength structure. There has been a large number of data on graphite accumulated not only from the operation of commercial gas cooled reactors since 1950s but also from experimental studies [2]. All of them are for identifying the characteristic of the irradiated graphite. In this section, introduced are methods for estimating the dimensional changes using those data.

2.1 Dimensional Changes in Irradiated Graphite Blocks

It is a known fact that graphite irradiated with energetic neutrons reveals considerable dimensional changes which should be taken into account in a reactor design. Neutron irradiation of graphite leads to initial bulk shrinkage at low neutron fluence, resulting eventually in a net expansion of the graphite with an increasing fluence after the reversal of the shrinkage, called turnaround. The initial bulk shrinkage of the graphite is caused by closure of small pores and cracks as a result of the *c*-axis expansion and contraction of the crystallites in the *a*-axis. As an irradiation temperature is higher, turnaround occurs at a lower neutron fluence, which is ascribed to a reduction in the extent of the accommodation available for an irradiation-induced *c*-axis expansion.

The amount of dimensional change of the graphite is assumed to be a function of the irradiation fluence and the irradiation temperature. Depending upon the manufacturing methods and raw materials, the type of graphite can be anisotropic or isotropic. Anisotropic graphite has a directional preference in its dimensional changes while isotropic one shows the same changes regardless of the directions.

Since the data accrued from the reactor operation and experiments are scattered, to simplify the evaluation procedure in the present study, it is assumed that the graphite is isotropic and a dimensional change at a fixed irradiation temperature can be represented by a single curve as shown in Fig. 1. For a given fluence and temperature, therefore, the dimensional changes of the graphite can be determined by a linear interpolation between the curves.

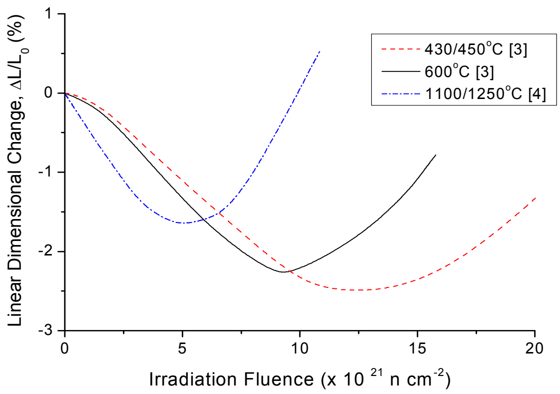

Fig. 1 Dimensional change with fast neutron dose

2.2 Thermal Expansion

Another major factor affecting the core bypass flow is the coefficient of the thermal expansion (CTE) which also depends on the neutron irradiation and temperature. A linear relationship of between the mean CTE in the range 20-120°C and the CTE in another range 20-*T*°C is proposed by Tsang et al. [5] as follows.

$$\alpha_{(20-T)} = \bar{\alpha}_{(20-120^{o}C)} + \bar{B}(T) \qquad (1)$$

The study by Marsden et al. [6] showed that their measured data compared well with the values predicted by the Tsang's linear relationship. Thus, Eq. (1) is adopted for the CTE calculation in this study.

2.3 Calculation of Local Gap Size

Four factors are considered for determining the local gap size for each block. They are the installation tolerance of the graphite blocks, the thermal expansion of the core support plate, the thermal expansion of the graphite blocks, and the irradiation shrinkage/swelling of the graphite blocks. The first and the second result in uniform gaps between the blocks. The others have effects on the local variation of the gap size.

A gap of 1*mm* between the blocks is assumed by considering the installation tolerance. The gap by the thermal expansion of the core support plate (CSP) can be calculated from an average temperature rise, CTE of the CSP, and its dimension along the diameter. With the same gaps obtained from the consideration of the installation tolerance and the thermal expansion of the core support plate, the local gap distribution can be determined from Fig. 1 and Eq. (1) for a given radiation dose and temperature of each block.

3. Results

A reference VHTR selected is a prismatic NHDD plant with a thermal power of 200MWth which has a cylindrical core of three rings consisting of 66 columns and 6 layers of fuel blocks. The inlet and outlet temperatures of the core are 490^{o}C and 950^{o}C, respectively. [7]

The unchanged gap size during the core cycle is those of the installation tolerance and the thermal expansion of CSP. The increased diameter of the CSP is equally distributed to each block. A basic gap size at a hot condition without considering the thermal expansion and the irradiation shrinkage of each block is 4.73mm.

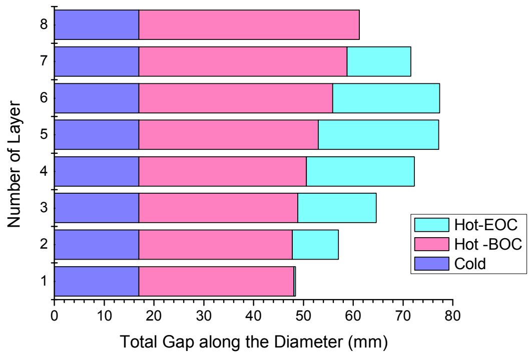

Fig. 2. Changes of total gap size

Neutron fluence and temperature for the block are computed by the MASTER-GCR code [1]. The local dimensional change of the block is determined by using Fig. 1 and Eq. (1). The radiation shrinkage reduces the dimension of the graphite block and increases the gap size while the thermal expansion increases the dimension and decreases the gap. Fig. 2 shows the total gap size along the diameter at each number of layers. The first and the last layers correspond to the bottom and the top reflectors. At a hot-BOC, there is only the effect of the graphite thermal expansion which leads to smaller gaps at the lower part of the core. At a hot-EOC, the irradiation effect is added to the gap of which the size increases.

A variation of the local gap size at a hot-EOC is illustrated in Fig. 3. The number is increased along the radial direction. The numbers 7, 11, and 16 correspond to the fuel blocks. The gap size between the fuel blocks is as larger as 7mm. The gaps between the reflectors are maintained below 4mm at a hot-EOC.

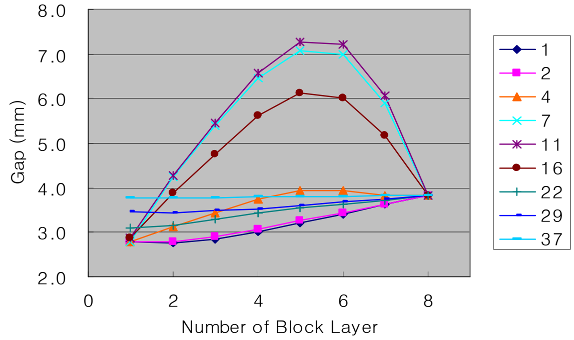

Fig. 3. Gap distributions at hot-EOC

4. Conclusions

The local gap size between the graphite blocks in a prismatic VHTR core was evaluated by using the available experimental data and a correlation with the assumption of isotropic graphite blocks. The results showed that the local distributions of the neutron fluence and the temperature have a great influence on the local sizes of the bypass flow gaps. Further study will be carried out to find the influence of the local gap sizes on the core flow distribution and the operation margin of the core during a normal operation.

Acknowledgements

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