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Subchannel void distribution correction model for the two-stage core analysis method in boiling water reactors

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ABSTRACT

The two-stage core analysis method is widely used for BWR core analysis. The purpose of this study is to develop a subchannel void distribution correction model for the two-stage core analysis method using an assembly-based thermal-hydraulics calculation in the core analysis stage. The model assumes two kinds of subchannel void distribution gradients along with the two diagonal lines in the horizontal cross section of a BWR fuel assembly. The model appends and tabulates the difference of the subchannel perturbation condition from the base condition in the lattice physics, and evaluates the tilts within the 2D lattice physics scheme, and couples those results with 3D subchannel analysis which evaluates the thermal-hydraulics characteristics within the coolant flow area divided as some subchannel regions. The developed model is evaluated using a heterogeneous and a small core problem. The model gives a better power distribution compared with that of the authors' previous model. As a result, the model can incorporate the subchannel effect into the current two-stage core calculation method.

1. Introduction

The core analysis method for light water reactor (LWRs) is conventionally divided into two stages, the first one is lattice physics and the second one is core analysis. The lattice physics generally covers a 2D radial cross section of a LWR fuel assembly, where neutronics analysis is carried out without coupling to the thermal-hydraulics calculation, in other words, the thermal-hydraulics condition is fixed. The geometry of a cross section of an assembly is modeled in a lattice physics calculation, and finer or continuous energy groups are adopted than those used for core analysis. Since the core analysis stage needs homogeneous cross section constants that depend on the state parameters in the core nodes, the lattice physics tabulates the cross section constants as the results of parametric calculations. Core analysis covers a whole LWR core where the neutronics analysis is coupled with the thermal-hydraulics calculation. Especially in BWR core analysis, some of the assembly cross section constants are prepared in terms of the void fraction because the nodal-wise void fractions depend on the thermal-hydraulics calculation in the core analysis stage. Conventional lattice physics uses a uniform void fraction inside an assembly because the nodal average void fraction are obtained from the thermal–hydraulic calculation in core analysis.

As fuel design conditions become more complicated, e.g., use of a large water rod, it is known that the radial void distribution in a BWR fuel assembly, which is called the subchannel void distribution, becomes heterogeneous and has an impact on the neutronics core characteristics. Katono et al. (2015) experimentally observed the subchannel void distribution using X-ray CT.

A study of a single BWR assembly that coupled neutronics and subchannel codes revealed a difference in the multiplication factor due to the uniform and subchannel void distributions (Jatuff et al., 2006). Furthermore, a model that coupled neutronics and subchannel analyses was proposed for the single-assembly geometry (Ama et al., 2002). The method using the model adopted an axially stacked fine mesh 2D neutronics analysis and assembly-based subchannel analysis. Ikehara et al. (2008) improved the method so that it could carry out the two-step neutronics analysis with subchannel analysis which consisted of the 2D fine mesh neutronics and axially stacked 1D problem with the nodal homogenized cross section obtained from the 2D neutronics analysis.

Previously, the authors developed a subchannel coupling model for the two-stage core calculation method with subchannel analysis (Mitsuyasu et al., 2017). The subchannel void fraction obtained from the coupling model is based on the infinite lattice boundary condition. However, the pin-by-pin power distribution in the core

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analysis will differ from that obtained from the lattice physics calculation, that is, the subchannel void distribution will differ from that assumed in lattice physics because of the neutron leakage at the assembly boundary.

In this paper, the authors develop a subchannel void distribution correction model to deal with difference in the distributions and they also demonstrate the validity of the model for heterogeneous problems. The subchannel void distribution correction model, which is incorporated into the two-stage BWR core analysis method, is developed and evaluated while maintaining the conventional neutronics and thermal-hydraulics calculation. Utilization of the present two-stage core analysis method is useful for back-fitting to the conventional BWR analysis method. The conventional BWR analysis method in this paper means the core analysis coupling with the assembly-wise thermal-hydraulics calculation.

First, the calculation model is described in Section 2, then numerical results are described in Section 3, and finally conclusions are given in Section 4.

2. Calculation model

2.1. Subchannel coupling model

The subchannel coupling model which was previously developed for the two-stage core calculation method with subchannel analysis (Mitsuyasu et al., 2017) is described here because the subchannel void distribution correction model, which is shown in this paper, is based on this earlier model. The 2D lattice physics calculation normally has a fixed and uniform void fraction over all the subchannel regions, for example, 0, 40 or 70%. The 2D lattice physics calculation must be done with subchannel-wise void fractions. For subchannel analysis, the pin-by-pin radial power distribution can be obtained from the lattice physics. The axial power profiles however cannot be obtained from the lattice physics. Then, axial power profiles should be assumed as a cosine profile. The subchannel coupling model assumed the radial pin power distribution of the infinite lattice even though the radial pin power distribution is affected by the neighbor assemblies in an actual BWR core.

The subchannel void fractions in the subchannel analysis are obtained from the axial node for which the nodal average void fraction is closest to the one required by the lattice physics calculation. The lattice physics iterates the neutronic and the thermal–hydraulic calculations until the pin-wise power distribution converges because the pin power distribution depends on the subchannel void distribution. Those iterations are carried out for all cases of voided conditions. The core analysis is performed in the same manner as the conventional method because the nuclear constants obtained by this model are tabulated just as those for the conventional method are.

2.2. Subchannel void distribution correction model

The subchannel void distribution correction model is an extension of the subchannel coupling model. Schematic images of three models are shown in Fig. 2.1. The previous models using a uniform void distribution and a fixed subchannel void distribution are shown in Fig. 2.1(a) and (b). These two models ignore the gradient of the subchannel void distribution even if there is a large power gradient in the pin-wise power distribution in the core analysis. On the other hand, the developed model, shown in Fig. 2.1(c), will correct the subchannel void distribution in the core analysis. Simply stated, to correct the subchannel void distribution, a large number of perturbed conditions of each subchannel void fraction should be prepared in the lattice physics. Calculating a large number of conditions, however, is not practical for the two-stage core analysis because the number of conditions reach to tens of thousands, which is 1000 times or more than the number of cases

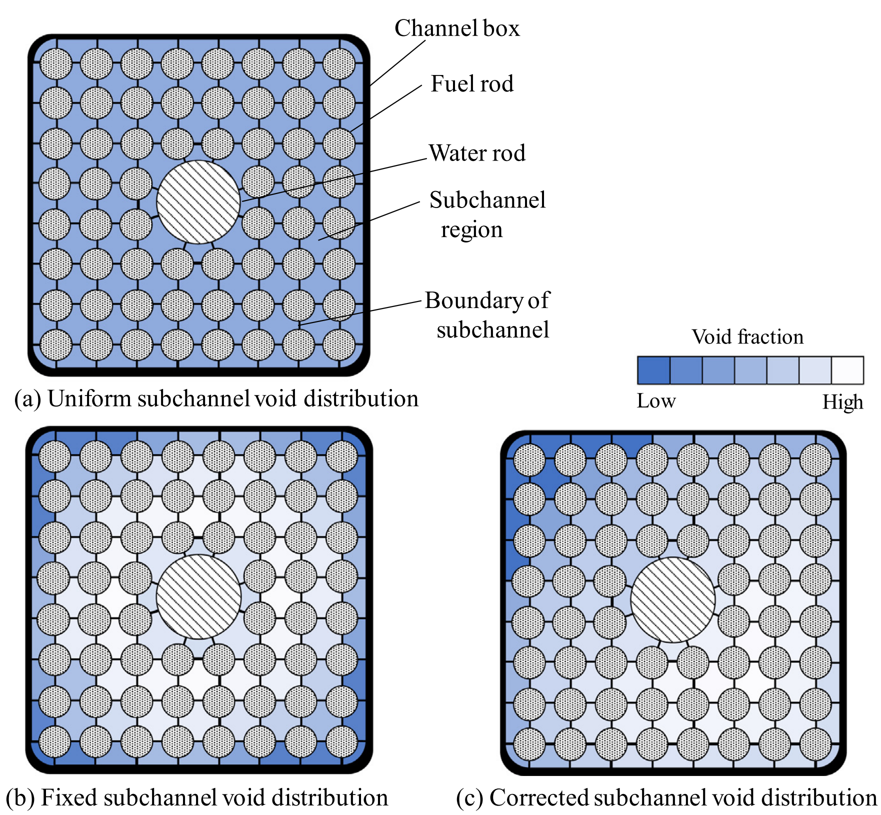

Fig. 2.1. Schematic images of subchannel void distribution.