Annals of Nuclear Energy 62 (2013) 264–268

Contents lists available at SciVerse ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Sub-channel analysis of 8 × 8 and 9 × 9 BWR fuel assemblies with different two-phase flow models

M. Hashemi-Tilehnoee *, M. Rahgoshay

Department of Nuclear Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

ARTICLE INFO

Article history:
Received 20 April 2013
Received in revised form 13 June 2013
Accepted 17 June 2013
Available online 12 July 2013

Keywords:
BWR fuel assembly
Sub-channel analysis
Drift-flux model
Two-fluid model
VIPRE-01
COBRA-EN

ABSTRACT

The present study aims at verifying two sub-channel analysis programs, one based on drift-flux model and one based on two-fluid model, by applying them to traditional boiling water reactor fuel assemblies. The calculated parameters by the two sub-channel programs are compared with the predictions of the COBRA-EN code and VIPRE-01 code. The performance of the drift-flux model sub-channel analysis program is comparable to advanced two-phase codes. Agreement among the results of the programs appears to be due to the lack of details in modeling two-phase flow rod bundle transport phenomena, or numerical solution schemes.

1. Introduction

The boiling water reactor (BWR) steam supply system is more attractive than other competing light water reactor (LWR) systems because of its basic simplicity, potential for greater thermal efficiency, better reliability, and lower capital cost (Lahey and Moody, 1993). Since introducing numerical sub-channel (SC) approach, a great number computer tools developed for using thermal hydraulics evaluation with this approach. Through a series of comparisons with full length/scale bundle data, it was verified that the SC codes can predict the thermal–hydraulic parameters of the conventional BWR fuel type, but the uncertainty remain high. The adequacy of fuel lattice geometries, spacer configurations is still confirmed costly experiments using partial-scale and full-scale mock-ups. The main reason for this situation is a shortage of high resolution and full-scale experimental data, on a SC basis, under operating conditions. The detailed void distribution inside the fuel bundle has been regarded as one of the important factors in the boiling transition in BWRs. In this research, the quality and void distribution in the two types of BWR fuel assembly (FA) are investigated with different SC analysis programs. Two-phase model sub-channel programs based on drift-flux model (DFM) and two-fluid model (2FM) are compared with the result of the COBRA-EN code and VIPRE-01.

2. Description of BWR fuel assemblies

2.1. Geometries

Two traditional BWR FAs are considered to verify the written SC programs. Because of few technical information and data sources incompleteness, the modeled assemblies' reference parameters are created from a mix of BWR-5 and BWR-6 plants (Everett Creighton IV, 2005), an 8 × 8 BWR, and general electric (GE) BWR-5 of nine-mile point unit 2 (NMP2)[1] (Karahan, 2006; Ferroni, 2006) as a 9 × 9 BWR. Fig. 1 shows the modeled regions of the two FAs with basis of the modeled region references.

2.2. Modeling key parameters

Table 1 shows the modeling reference parameters which are applied in simulating process.

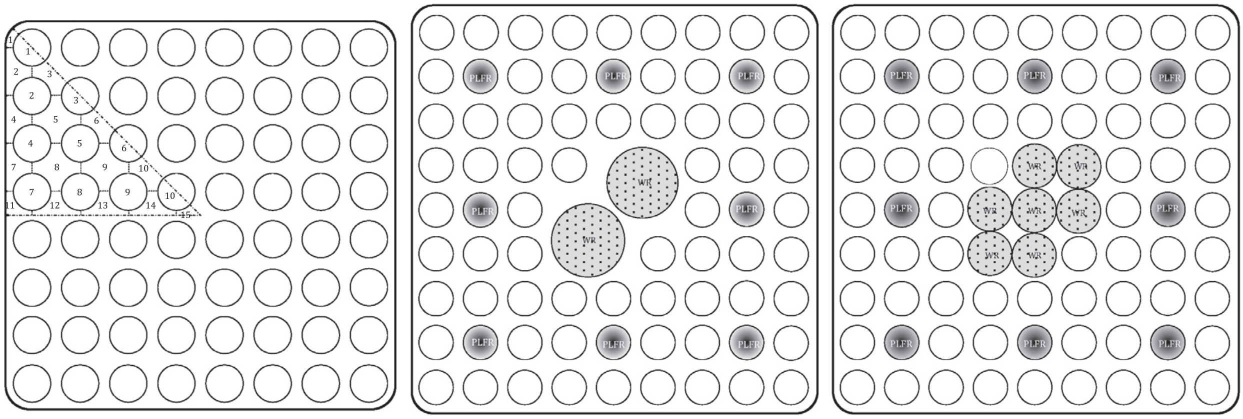
2.3. Power profile of the fuel assemblies

Figs. 2 and 3 show the radial power peaking factor (PPF) and axial power profiles in two FAs respectively.

[1] The references' assemblies do not represent any core, although most of their features are in common with the real plants. Because of lack of data, reference assembly with values derived from different but consistent sources. For example, NMP2 loaded with 8 × 8 assemblies while the reference BWR/5 contains 9 × 9 lattice assemblies (GE11 type).

* Corresponding author. Tel.: +98 911 353 2381.
E-mail address: mehdi.hashemi.t@gmail.com (M. Hashemi-Tilehnoee).

0306-4549/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.anucene.2013.06.024



(a) 8×8 BWR (b) 9×9 BWR (c) 9×9 BWR with distributed water rods (WRs)

Fig. 1. Modeled BWR fuel assemblies; (a) 8 × 8 BWR, (b) 9 × 9 BWR, dotted channels are water rods(WRs), partial length fuel rods defined by PLFR, (c) 9 × 9 BWR with distributed water rods (WRs).

Table 1
Key parameters of modeled fuel assemblies.

	8 × 8 BWR	Reference	9 × 9 BWR	Reference
Number of fuel rods	64	Everett Creighton IV (2005)	74[a]	Karahan (2006)
Number of water rods	–	–	2	Karahan (2006)
Fuel rod outer diameter (m)	0.01252	Everett Creighton IV (2005)	0.01118	Karahan (2006)
Clad thickness (m)	0.00355	Everett Creighton IV (2005)	0.00071	Karahan (2006)
Fuel pellet diameter (m)	0.01126	Everett Creighton IV (2005)	0.00955	Karahan (2006)
Fuel density (kg m^{-2})	10531.	Todreas and Kazimi (1999)	10531.	Todreas and Kazimi (1999)
Fuel specific heat (J kg^{-1} °C^{-1})	500.	Todreas and Kazimi (1999)	500.	Todreas and Kazimi (1999)
Fuel thermal conductivity (Wm^{-1} °C^{-1})	3.6	Todreas and Kazimi (1999)	3.6	Todreas and Kazimi (1999)
Clad density (kg m^{-2})	6552.	Todreas and Kazimi (1999)	6552.	Todreas and Kazimi (1999)
Clad specific heat (J kg^{-1} °C^{-1})	330.	Todreas and Kazimi (1999)	330.	Todreas and Kazimi (1999)
Clad thermal conductivity (Wm^{-1} °C^{-1})	17.	Todreas and Kazimi (1999)	17.	Todreas and Kazimi (1999)
Fuel rod pitch (m)	0.01615	–	0.01427	Karahan (2006)
Water rod outer diameter (m)	–	–	0.02489	Karahan (2006)
Water rod wall thickness (m)	–	–	0.00076	Karahan (2006)
Bundle inner width (m)	0.0133	–	0.013246	Karahan (2006)
Fuel bundle active heated length (m)	4.	Everett Creighton IV (2005)	3.708	Karahan (2006)
Partial length fuel rod height (m)	–	–	2.436	Karahan (2006)
Number of grid spacer axial points	7	Everett Creighton IV (2005)	7	Karahan (2006)
Grid spacer positions (m)	0.4, 0.8, 1.2, 1.6, 2., 2.4, 2.8	Everett Creighton IV (2005)	0.495, 0.990, 1.486, 1.998, 2.476, 2.971, 3.467	Karahan (2006)
Grid spacer pressure loss coefficient	1.24	Everett Creighton IV (2005)	1.203	Karahan (2006)
Hot bundle power (kW)	5124[b]	Everett Creighton IV (2005)	7259.4	Ferroni (2006)
Pressure (MPa)	7.2	Everett Creighton IV (2005)	7.136	Karahan (2006)
Inlet temperature (°C)	278.	Everett Creighton IV (2005)	278.3	Karahan (2006)

[a] Eight of these rods are partial length fuel rods.
[b] 5128. × 1.54 = 7890.96 kW considered for surveying safety margins (Everett Creighton IV, 2005).

3. Sub-channel analysis methodology

Two types of core component analysis method including SC analysis and distributed resistance analysis are available for rod-bundle analysis. On the other hand, from another method named distributed parameter analysis, most of the flow structure detail is achievable, but is restricted to small regions and not applicable between the fuel rods in the region. Among these methods, for many decades, there has been considerable interest in technology known as SC analysis. SC analysis consists of solution of mass, momentum and energy conservation equations written for elementary channels. Another important category of the thermal–hydraulic codes beside the analysis method is the type of two-phase flow model. The main types of flow models incorporated into thermal–hydraulic codes comprise the homogeneous mixture model, multi-fluid model, and diffusion model. Two written SC programs based on DFM and 2FM are applied to model the thermal–hydraulic of BWR FAs. The results of these two programs are compared with the outputs of reference codes, COBRA_EN and VIPRE-01 code.

3.1. Drift-flux sub-channel program

Conservation equations based on a flow regime dependent DFM (an appropriate choice between simplicity and complexity of fluid model) contains proper constitutive equations, turbulent mixing component, drift velocity and void fraction models (Hashemi-Tilehnoee and Rahgoshay, 2013). The conservation equations are solved by a marching type technique. For 8 × 8 BWR application, some developed parameters such as two-phase friction multiplier correlated with the void fraction data and friction pressure drop are applied (Yang et al., 2012; Hashemi-Tilehnoee and Rahgoshay, 2013).

3.2. Two-fluid sub-channel program

As an outcome of SC analysis code development, the six equations 2FM forms a suitable basis with the semi-implicit numerical solution scheme to predict highly transient flows with consideration of non-equilibrium conditions (Wolf and Fischer, 1987). As a development, the THERMIT code solution scheme was applied.