Benchmark Simulation for the Development of the Regulatory Audit Subchannel Analysis Code

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1. Introduction

For the safe and reliable operation of a reactor, it is important to predict accurately the flow and temperature distributions in the thermal-hydraulic design of a reactor core. A subchannel approach can give the reasonable flow and temperature distributions with the short computing time. Korea Institute of Nuclear Safety (KINS) is presently reviewing new subchannel code, THALES, which will substitute for both THINC-IV and TORC code. To assess the prediction performance of THALES, KINS is developing the subchannel analysis code for the independent audit calculation. The code is based on workstation version of COBRA-IV-I [1]. The main objective of the present study is to assess the performance of COBRA-IV-I code by comparing the simulation results with experimental ones for the sample problems.

2. Numerical Method and Results

2.1 Code overview

COBRA-IV-I [1] is a multichannel analysis code for the thermal-hydraulic analysis of rod bundle and core based on the subchannel approach. The original COBRA-IV-I code is the Control Data Corporation (CDC) CYBER version, which has limitations on the computer memory capacity and gives some inconvenience to the user interface. To solve these problems, Korea Atomic Energy Research Institute (KAERI) converted the original COBRA-IV-I code from the CDC CYBER mainframe to a workstation version and verified the accuracy of the converted code. Because most of the available subchannel analysis codes are based on the main features of COBRA-IV-I [1], KINS selected this code as a candidate for the regulatory audit subchannel analysis code.

2.2 Code verification

Two sample problems are selected to assess the prediction performance of COBRA-IV-I [1]. One is the CNEN 4×4 rod bundle [2] and the other is GE 3×3 rod bundle [3].

2.2.1. CNEN 4×4 rod bundle

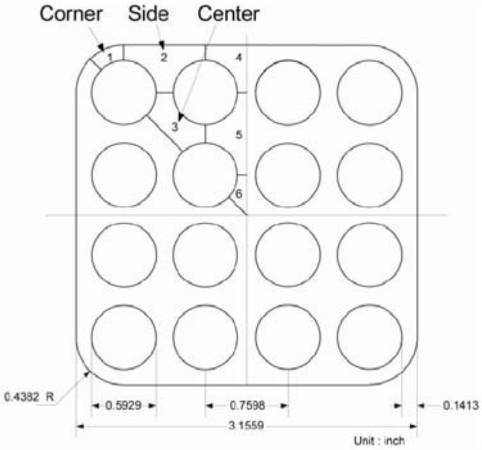
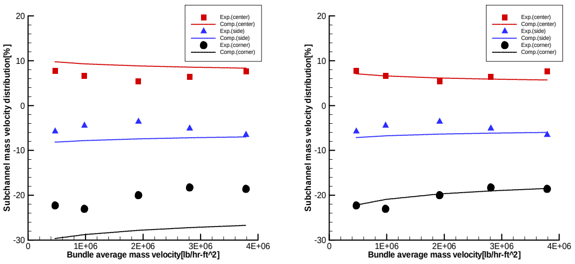


Fig. 1. Schematic diagram of CNEN 4×4 rod bundle

The distribution of the mass velocity in a 4×4 rod bundle was experimentally investigated at Studsvik Laboratory [2] to obtain accurate information about the heat transfer due to the turbulent flow mixing between the subchannels under single-phase flow regime.

Fig. 1 shows the geometry of the cross-section of the rod bundle with a subchannel number. The bundle has an unheated length of 15.744 inch, a heated length of 39.372 inch, an equivalent diameter of 0.516 inch, and a spacer grid with a loss coefficient of 0.3 in the middle.

Fig. 2 shows the comparison of the mass velocity distribution in the three typical subchannels (corner, side, and center) as a percent deviation from the average bundle condition. Two values of constants for the turbulent mixing correlation are used, that is, β=0.005 and 0.02. The calculated mass velocity distribution in the three typical subchannels for β=0.02 shows good overall agreement with the measurements.



β=0.005 β=0.02

Fig. 2. Comparison of subchannel mass velocity distribution as a function of bundle average mass velocity

2.2.2. GE 3×3 rod bundle

Two-phase flow tests were performed to measure subchannel exit flow and enthalpy in an electrically heated 3×3 rod bundle under the pressure of 1,000psia, which is typical of BWR operating conditions [3]. Fig. 3 shows the geometry of the cross-section of the rod bundle with a subchannel number. The bundle has an unheated length of 48 inch, a heated length of 72 inch, a rod diameter of 0.57 inch, a rod-to-rod center distance of 0.738 inch, and eight spacer grids in the axial direction. Details of test conditions (ID: 2B2~2G3) can be found in Reference [3]. Axial and radial heating is uniform. It is assumed that spacer grid loss coefficient is 0.7 and the constant for the turbulent mixing correlation is 0.013. Levy's model as the subcooled void formation correlation, modified Armand model as the void fraction correlation, and the Armand model as a two-phase friction multiplier are used.

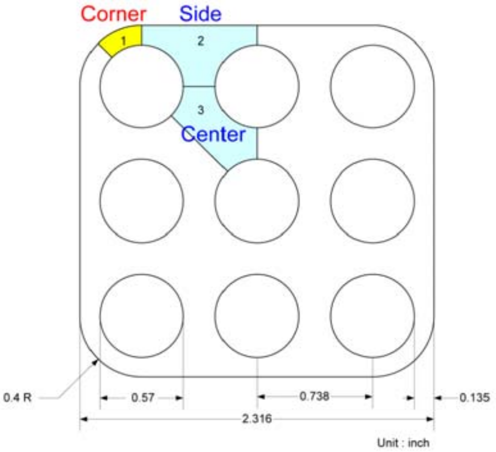


Fig. 3. Schematic diagram of GE 3×3 rod bundle

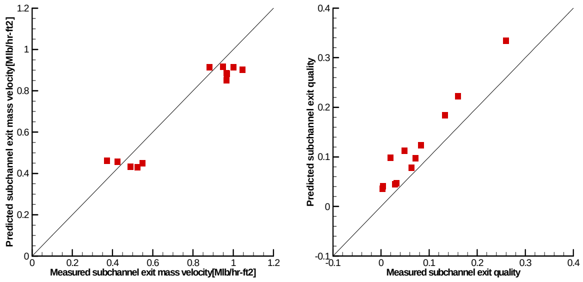
Fig. 4 shows the measured and predicted subchannel exit mass velocity and quality. The subchannel analysis code shows the good overall agreement with the measurements for the side and center subchannel in comparison with the corner subchannel.

2.3 Future Plan for the Code Development

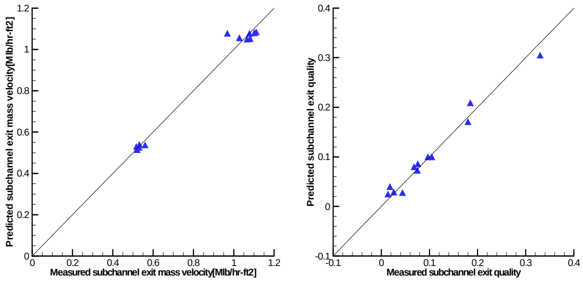
The empirical correlations used in the COBRA-IV-I code [1] to calculate the heat transfer coefficient, the pressure drop and the void fraction will be updated with the most recent correlations available. These correlations will be added to the code, which will be run parametrically to determine how different combinations of old and new correlations affect code performance.

3. Conclusions

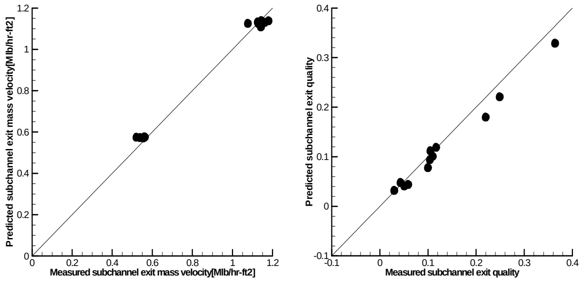
In this study, the performance of COBRA-IV-I code was assessed by comparing the simulation results with experimental ones for the sample problems. The simulation results showed good overall agreement with the measurements. The COBRA-IV-I code will be updated with the most recent correlations available in the future.



(a) Corner



(b) Side



(c) Center

Fig. 4. Measured and predicted subchannel exit mass velocity (left) and quality (right)

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