TWO-PHASE FLOW CFD IN NUCLEAR REACTORS - II

Yassin A. Hassan
Department of Nuclear Engineering
Texas A&M University, USA

1 INTRODUCTION

The focus of this part II of the “Two-Phase Flow CFD in Nuclear Reactors” lecture will be on application of CFD in nuclear industry. During the last few years it is clear that the CFD has started to find its way in certain application in some components of nuclear system. In the large “system thermal hydraulic codes” as CATHARE, RELAP, TRAC among others, the whole reactor system are modeled with 0D and1D modules. Recently 3D modules with coarse meshing are added in these system codes to partially account of the 3-dimensional phenomena effects in module. Here the basic equations are still averaged like in RANS approach for single phase but the space resolution is coarser than conventional CFD. Additional closure relations should be included to account for the averaging process.

From CFD origin as a tool primarily for use in fundamental aerodynamics, usage of computational fluid dynamics has spread to a wide range of fields such as mechanical and chemical engineering and other basic sciences such thermal sciences, chemistry, physics and Environmental Sciences. Recently, the use of CFD has made its several applications in nuclear engineering, especially with the renaissance of nuclear energy and the new research areas of advanced design of nuclear reactors. The CFD simulation is used to describe and simulate fluid dynamic phenomena to forecast or reconstruct the behavior of normal and transients operations under assumed or measured boundary conditions. A variety of reasons can be cited for the increased importance simulation techniques have achieved in recent years:

- Need to forecast performance
- Cost and/or impossibility of experiments
- The desire for increased insight
- Need for design of new nuclear reactor concepts and advances in computer speed and memory (1:10 every 5 year)
- Advances in solution algorithms, coding and software
- Substitute some of the intensive verification and demonstration test of high cost and shorten the development periods of new component design of nuclear reactor systems
- Enhance the optimization level of the component design by acquiring the quantitative information to complement the experimental data and the influences of design parameters
- Visualization techniques

- User friendly codes (benchmarking, documentations...)

2 THE MULTI-SCALE APPROACH

The analysis of the industrial needs points out that different simulation scales are involved (Bestion, et al, 2004). A multi-scale approach has been developed (Morel, C. et al., 2000) for the next generation of codes and a strategy for improving two-phase 3-D modeling for nuclear safety applications was identified (Bestion, D., et al., 1999).

2.1 Multiscale classification

Multiscales can be classified into several scales related for the presentation of the physical phenomena. The following are important from the important flow process:

System scale: this scale is related to the global phenomena of the large system. For example, the system code should be capable of predicting condition change of one its component when modifications of boundary conditions occur in the system.

Macro-scale: these scales depend on the multi-zone (multi-regions) parameters. The phenomenon is usually correlated to the average local flow parameters. These scales are in the order of centimeters.

Meso-scale: The dynamics of the phenomena is controlled by local flow parameters. These scales are in the order of millimeters. The employed computational methods in this domain must employ ultra fine meshes and very limited models (see Figure 1)

Microscale: These scales are in the range of dissipation scale (Kolomogrov scale). It depends on predicting of all small scales for the continuum medium. The Direct Numerical Simulation (DNS) including accurate interface tracking methods are necessary to predict such small scale phenomena. With such advanced tools the constitutive relations of exchange mass, momentum and energy will be predicted and not correlated. However, today the use of this DNS approach is limited.

The significant steps forward (either in physical modeling or in numerical methods) have been identified for each scale and also for the coupling between them.

2.2 The scales for reactor thermal hydraulics

In two-phase flow thermal-hydraulics analysis for nuclear applications, one can distinguish four different simulation scales (Bestion, et al., 2004):

System scale: dedicated to the overall description of the circuits of the reactor. The main applications are accidental transient simulations for safety analysis, operation studies and real time simulators. The RELAP and CATHARE codes, for example, are system codes developed for nuclear industry. The primary and secondary circuits of a reactor are modeled by coupling 0D, 1D, and 3D modules together with sub-modules for pumps,