Computational fluid dynamics in nuclear reactor design and safety assessment

Dr. R.B. Grover

For the design of nuclear reactors with improved safety features, a thorough understanding of the complex phenomena at play inside the reactor core and various processes and safety systems is necessary. In recent years, computational fluid dynamics (CFD) has emerged as a dependable tool to develop that understanding and play with various parameters to understand their importance to design. The number of publications on the use of CFD for the design of reactors is too many and there is a need for a book that can help the designers to navigate this topic with ease. The book, edited by Prof. Jyeshtharaj B. Joshi and Prof. Arun K. Nayak, is a collection of 12 chapters and is an attempt in this direction.

The 1st chapter (Introduction) of the book provides a brief historical account of the development of nuclear reactors. It starts with notable early reactors and briefly describes the growth of nuclear power. It moves on to the safety in the design and the role of CFD in the safety assessment of the nuclear reactors.

The 2nd chapter titled Computational Fluid Dynamics is the longest chapter of the book. Authors illustrate the relationship of the 'physical world' with the 'mathematical world' and of the mathematical world with its numerical approximation. They remind the reader that the simpler versions of the models remain gross approximations of real-world engineering problems. However, they do provide specific insights. The chapter provides comprehensive coverage of turbulence models for single-phase flow, CFD modelling for multiphase flows including dense particulate flows. The chapter is immensely useful as a quick read for a reader who has some working knowledge of CFD.

The 3rd chapter describes physical processes involved in heat transfer, microscopic models for boiling, and macroscopic boiling models and their implementation in two-fluid CFD models for reactor-scale flows and geometries. The chapter is focussed on BWR and also covers bubble dynamics in the suppression pool.

The 4th chapter includes case studies on CFD modelling for the safety assessment of light-water-cooled reactors. Specifically, CFD modelling of coolant mixing in a test facility, and CFD modelling of horizontal stratified two-phase flows are presented.

The 5th chapter discusses the applications of CFD for designing passive safety systems for advanced nuclear reactors. CFD modelling of natural convection (buoyancy models and turbulence models) is discussed. CFD modelling of passive residual heat removal system, design of passive moderator cooling system, design of passive air-cooled condenser to condense steam coming from turbines, and design of venturi scrubber for filtered containment venting system are discussed as case studies for the applications of CFD in the design of passive systems for advanced reactors.

The 6th chapter is dedicated to CFD modelling of core melt accident scenarios in light and heavy water reactors. Modelling of in-vessel retention of corium in PHWRs, simulation of debris bed coolabilty, modelling to assess ex-vessel melt pool coolability are discussed as case studies.

The 7th chapter is focussed on using CFD for the assessment of reactor containment safety and covers the prediction of distribution inside the containment of hydrogen generated in a post-accident scenario due to oxidation of clad and other metallic components in the presence of steam. Subsequently, modelling of hydrogen recombination in plate type passive autocatalytic recombiners and tubular packed bed catalytic recombiner is presented. Modelling of hydrogen combustion and analysis of hydrocarbon fireballs are also discussed.

The 8th chapter is focused on CFD modelling of fire. It provides a useful introduction to various aspects of fire modelling and presents the fire hazard analysis of a nuclear power plant as a case study.

While chapters 3 to 8 are focussed on light water and heavy water-cooled reactors, subsequent chapters are focused on some of the Generation IV reactors. The 9th chapter is focussed on CFD applications in the design of sodium-cooled fast reactors. The 10th chapter provides an overview of the use of CFD for graphite-moderated gas-cooled Very High-Temperature Reactor and the Molten-Salt Cooled Reactor. The 11th chapter delves deeper into various aspects of heat transfer and CFD modelling for molten salt reactors.

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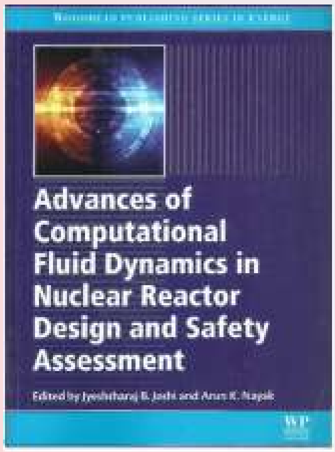
The last chapter titled 'conclusions and future recommendation' could have been expanded to include a section that presents an integrated view of all the chapters. Also, the recommendations should have been linked to what is included in the chapters of the book.

The book has a large number of high-quality figures and illustrations which make reading the book a pleasure.

The book is a must-read for researchers and designers working on the design and safety aspects of nuclear reactors.



The book is edited by Prof. Jyeshtharaj B. Joshi and Prof. Arun K. Nayak

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