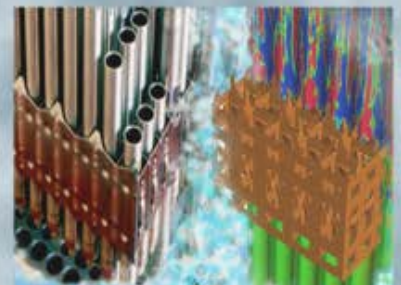
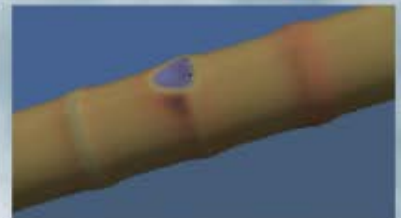
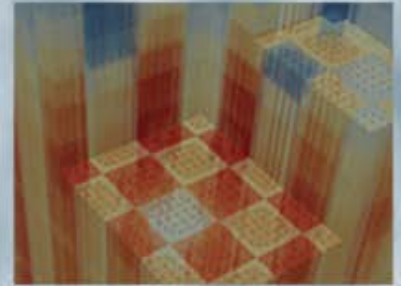


RPI Milestone: Development of a Mechanistic Subcooled Boiling Model for PWR Assemblies

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1 TOP FOCUS AREA ACHIEVEMENTS

- Top achievement 1 - The formulation of a mechanistic multidimensional model of vapor condensation in subcooled boiling. The new model allows to separately capture each: the near-wall condensation and bulk condensation, as functions of local flow and heat transfer conditions.
- Top achievement 2 - The validation of a complete computational model of subcooled boiling model against several experimental data sets. This work will continue, to be completed by the end of FY'14.
- Top achievement 3 - The prediction of size and trajectory of a vapor bubble subject to simultaneous evaporation and condensation in a nonuniform temperature field typical to near-heated-wall conditions in subcooled boiling.
- Top achievement 4 - Framework development for mechanistic model subcooled boiling two-phase flow in PWR fuel assemblies with spacers
- Concept development for a mechanistic model of DNB

2 NEW SCIENCE OR DISCOVERIES

- It has been demonstrated that a consistent coupling between physical two-phase closure laws and computational domain formulation imposes several new constraints on the best practice principles developed for single-phase flows.

3 NEW INSIGHTS OR DEEPENED UNDERSTANDING

- A new insight has been achieved into the multiscale (DNS vs, RANS) modeling approaches to two-phase flow with phase change.
- It has been demonstrated that the proposed models of subcooled boiling are applicable to different geometrical configurations, including PWR fuel assemblies with spacers.

4 CHALLENGES ENCOUNTERED

- The accurate predictions of local heat transfer at bubble/liquid interface during boiling and/or condensation, and the associated bubble deformation, have been identified as a major challenge when using a computational method based on interface tracking.
- To overcome this problem, a multiple-level approach has been proposed, combining simplified theoretical models, detailed simulations of flow and heat transfer around prescribed-size/shape bubbles, and parametric testing of a complete interface-tracking level-set model.

5 SCIENTIFIC OUTPUT

The results of the work a RPI have been published in the following papers:

1. I. Bolotnov, K. Jansen, D. Drew, A. Obrerai, R.T. Lahey, Jr. and M.Z. Podowski, "Direct Numerical Simulation of Two-Phase Turbulent Bubbly Channel Flow", Proc. 7th International Conference on Multiphase Flow (ICMF), 2010.

2. E.A. Tselischeva, S.P. Antal, M.Z. Podowski, D. Guillen, M. Beyer and D. Lucas, "Analysis of Developing Gas/Liquid Two-Phase Flows", Proc. 7th International Conference on Multiphase Flow (ICMF), 2010.
3. M.Z. Podowski, "Recent Developments in Mechanistic Modeling of Two-Phase Flow and Heat Transfer in Nuclear Reactor Systems", Proc. Int. Workshop on New Horizons in Nuclear Reactor Thermal Hydraulics and Safety, Mumbai, India, 2010.
4. M.Z. Podowski, "Computational Approach to Multiscale Multiphysics Modeling of Nuclear Reactors", Proc.SciDAC Conference, Chatanooaga, TN, 2010.
5. I.A. Bolotnov, K.E. Jansen, D.A. Drew, A.A. Oberai, R.T. Lahey, Jr. and M.Z. Podowski, "Detached Direct Numerical Simulations of Turbulent Two-Phase Bubble Channel Flow", International Journal of Multiphase Flow, 37, 2010, pp. 647-659.
6. M.Z. Podowski, "A mechanistic approach to the Modeling of Bubble/Bubble Interactions in Gas/Liquid Flows", ANS Transactions, ANS Winter Meeting, Las Vegas, NV, 2010.
7. D. Shaver, I.A. Bolotnov, S.P. Antal and M.Z. Podowski, "Interfacial Force Model Development for Turbulent Bubbly Flows", Proc. 63rd Annual Meeting of the American Physical Society's Division of Fluid Dynamics, Long Beach, CA, 2010.
8. I.A. Bolotnov, D.A. Drew, R.T. Lahey, Jr. and M.Z. Podowski, "Influence of Bubbles on Liquid Turbulence based on the Direct Numerical Simulation of Channel Flows", Proc. 63rd Annual Meeting of the American Physical Society's Division of Fluid Dynamics, Long Beach, CA, 2010.
9. M.Z. Podowski, "Role of Computational Fluid Dynamics in Advanced Nuclear Reactor Design and Safety Analysis: Current Status and Future Needs", Proc. Technical Meeting on Application of CFD Codes for the Design of Advanced Water Cooled Reactors, Vienna, Austria, 2010.
10. I. Bolotnov and M.Z. Podowski, "On the Modeling of Gas/Liquid Flows using DNS", Trans. ANS, 2011 Annual Meeting, Hollywood, Fl., 2011.
11. D.R. Shaver, S.P. Antal and M.Z. Podowski, "Multidimensional Modeling of Interfacial Boiling and Condensation", ANS Transactions, 2011 Winter Meeting, Washington, D.C., 2011.
12. M.Z. Podowski, "Toward Mechanistic Modeling of Boiling Heat Transfer", Nuclear Engineering and Technology, V44, No.8, 2012, pp.1-8.
13. D. R. Shaver, S. P. Antal and M. Z. Podowski, "Multidimensional Mechanistic Modeling of Interfacial Heat and Mass Transfer", Proceedings of ICAPP'12, Paper 12274, pp.2062-2072.
14. M.Z. Podowski, "Mechanistic Modeling of Boiling Heat Transfer", Proc. Embedded Topical Meeting: Advances in Thermal-Hydraulics, 2012 ANS Winter Meeting, San Diego, CA, 2012, pp.1-5.
15. I. A. Bolotnov and M.Z. Podowski, "Investigation of Turbulence in Bubbly Gas/Liquid Flows using Interface Tracking Simulations", Proc. Embedded Topical Meeting: Advances in Thermal-Hydraulics, 2012 ANS Winter Meeting, San Diego, CA, 2012, pp. 29-37.
16. H. Jiao and M. Z. Podowski, "An Analysis of Multidimensional Models of Gas/Liquid Flows", ANS Proc., 2012 Winter Meeting, San Diego, CA, 2012, pp.1393-1394.
17. D.R. Shaver, S.P. Antal, and M.Z. Podowski, "Development, Testing, and Validation of a Multidimensional Model of Subcooled Boiling", ANS Transactions, 2012 Winter Meeting, San Diego, CA, 2012, pp. 1366-1368.

18. B.M. Waite, D.R. Shaver and M.Z. Podowski, "Multidimensional Analysis of Flow through Sudden Expansions and Contractions in Pipes", ANS Transactions, 2012 Winter Meeting, San Diego, CA, 2012, pp. 1336-1368.
19. D. R. Shaver and M. Z. Podowski, "Model Development for Large-Scale Nuclear Power Reactor Simulations", Proc. American Nuclear Society 2013 National Student Conference, MIT, Boston, Massachusetts, 2013.
20. H. Jiao, S.P. Antal and M.Z. Podowski, Modeling and Analysis of Thermal Phenomena Governing Bubble Growth and Collapse in Subcooled Boiling", Proc. American Nuclear Society 2013 National Student Conference, MIT, Boston, Massachusetts, 2013.
21. B.M. Waite, D.R. Shaver, M. Z. Podowski, "Multidimensional Analysis of Local Flow Obstacles in Nuclear Reactors", Proc. American Nuclear Society 2013 National Student Conference, MIT, Boston, Massachusetts, 2013.
22. M. D. Zimmer, D. R. Shaver, M. Z. Podowski, "An Analysis of Multidimensional Models of Turbulent Flow in Nuclear Reactors", Proc. American Nuclear Society 2013 National Student Conference, MIT, Boston, Massachusetts, 2013.
23. D.R. Shaver, S.P. Antal, and M.Z. Podowski, "Modeling and Analysis of Interfacial Heat Transfer Phenomena in Subcooled Boiling along PWR Coolant Channels", Paper #586, Proc. 15th Int. Topical Meeting on Nuclear Reactor Thermalhydraulics (NURETH-15), Pisa, Italy, 2013.
24. H. Jiao, S.P. Antal and M.Z. Podowski, "Modeling and Analysis of Interfacial Heat Transfer Phenomena in Subcooled Boiling along PWR Coolant Channels", Paper#587, Proc. 15th Int. Topical Meeting on Nuclear Reactor Thermalhydraulics (NURETH-15), Pisa, Italy, 2013.
25. D.R. Shaver, S.P. Antal, and M.Z. Podowski, "Multiscale Modeling of Two-phase Flow and Interfacial Heat Transfer Phenomena in Subcooled Boiling", Proc. Int. Conference on Multiphase Flow, Jeju, Korea, 2013.
26. M.Z. Podowski and D.R. Shaver, "Recent Advancements in Multidimensional Modeling of Two-Phase Flow and Heat Transfer In Reactor Fuel Assemblies", Proc. International Seminar on Subchannel Analysis, CFD Modeling and Verification, CHF Experiments and Benchmarking, Xi'an, China, 2013.
27. D. R. Shaver, M. Z. Podowski, "A Fundamental Model for Predicting Bubble Size in Diabatic Multiphase Flows", ANS Transactions, 2013 ANS Winter Meeting and Nuclear Technology Expo, Washington, DC, 2013.
28. B.M. Waite, D. R. Shaver, M. Z. Podowski, "Prediction of Pressure Drop and Heat Transfer around Flow Obstructions", ANS Transactions, 2013 ANS Winter Meeting and Nuclear Technology Expo, Washington, DC, 2013.
29. B.M. Waite, D. R. Shaver, M. Z. Podowski, "Multidimensional Mechanistic Modeling of Fluid Flow and Heat around Spacer Grids", Proceedings of ICAPP 2014, Charlotte, USA, 2014.
30. H. Jiao and M.Z. Podowski, "3D Model of Evaporation/Condensation at Bubble/Liquid Interface using Level-Set Method", ANS Transactions, 2014 ANS Annual Meeting, Reno, NV, 2014.