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for nuclear reactor system design)

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S11_CASL IC allocation review

(Advanced Modeling and Simulation (M&S) for nuclear reactor system design)

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Publication list

- Journal paper
 - M.H.A. Piro, F. Wassermann, S. Grundmann, B. Tensuda, S.J. Kim, M. Christon, M. Berndt, M. Nishimura and C. Tropea, “Fluid Flow Investigations within a 37 Element CANDU Fuel Bundle Supported by Magnetic Resonance Velocimetry and Computational Fluid Dynamics”, (submitted to International Journal of Heat and Fluid Flow on Nov. 30th 2016, under review)
- Conference Proceeding papers (*: presented by)
 - Seung Jun Kim*, DV Rao, Brett Okhuysen, Russell Johns, Emilio Baglietto, “A CFD simulation effort on the Departure from nucleate boiling in subcooled flow” OECD/NEA & IAEA Workshop on Computational Fluid Dynamics for Nuclear Reactor Safety (CFD4NRS), Cambridge, MA, Sep. 13-15, 2016
 - Seung Jun Kim*, Brett Okhuysen, Etienne Demarly, Emilio Baglietto, “CFD study of a multi-phase subcooled flow boiling model and the evaluation of the model’s predictive capability for boiling characteristics” International Topic Meeting on Nuclear Reactor Thermal Hydraulics, Operation and Safety (NUTHOS-11), N11P1233, Gyongju, Korea, Oct. 9-13, 2016
 - M.H.A. Piro, M. Bruschewski, Seung Jun Kim*, D. Freudenhammer, C. Azih, B. Tensuda, F. Wassermann, S. Grundmann, M. Christon, M. Berndt, and C. Tropea, “Experimental and computational investigations of flow by-pass in a 37-element CANDU fuel bundle in a crept pressure tube” OECD/NEA & IAEA Workshop on Computational Fluid Dynamics for Nuclear Reactor Safety (CFD4NRS), Cambridge, MA, Sep. 13-15, 2016
- Technical report
 - Seung Jun Kim, Emilio Baglietto, Etienne Demarly, LA-UR-16-28815, “Evaluation of DNB predictive capability in multiphase boiling model of STAR-CCM+”, L3.THM.CFD.P13.04, CASL FY16 Technical report
 - Emilio Baglietto, Seung Jun Kim, Etienne Demarly, LA-UR-16-29368, “Demonstration of DNB analysis methods using CFD”, L2.THM.P13.02, CASL FY16 Technical report

Research overview and LANL's contribution

- The CASL (Consortium of Advanced Simulation for Light water reactors) is dedicated to developing and demonstrating the Multiphase Computational Fluid Dynamics (M-CFD) capabilities toward the analysis of Departure from Nucleate Boiling (DNB) in Pressurized Water Reactors (PWR) fuel.
- The approach proposed leverages the M-CFD framework in order to introduce the necessary first principle generality and 3-dimensional capabilities, which offer the potential to overcome the limitations of current lumped-parameter methods, typically referred to as “subchannel models”.
- The demonstration and future assessment of first principle based DNB prediction capabilities has the promise to support the design and deployment of advanced nuclear fuel, capable of delivering improved economics and reliability.
- As a core partner in the CASL thermal hydraulics focus Area research, LANL team demonstrates a robust M-CFD (multiphase CFD) capability for the nuclear reactor safety application. Four key areas have been developed and are discussed in this study:
 - *Implementation and demonstration in STAR-CCM+ of the macrolayer based DNB model(i.e. Weisman & Pei approach).*
 - *Development of a conceptual model for consistent DNB representation in CFD based on heat flux partitioning between dry and wet surface area and leverage existing experimental data to evaluate the fundamental model representation.*
 - *Assessment of the DNB model robustness and overall performance against a larger subset of both experimental DNB data and CHF lookup-tables.*
 - *Activities toward the application of the macrolayer based DNB method to the full 5x5 NMV and V5H spacers in order to assess its performance against Westinghouse experimental database.*

Industry Challenge Problems (ICP) for nuclear reactor design in CASL

DNB prediction...

: Multiphase CFD

: subcooled boiling model

CRUD → AOA & CIPS...

: surface chemistry

Grid-to-Rod Fretting...

: fluid-structure interaction

Consortium for Advanced Simulation of LWRs
\$122M project over 5 years (FY15-19)

**** 2016 R&D100 awarded to the CASL team**

Axial & radial HTC calculation...

Sub-channel analysis...

Downcomer flow analysis...

DNB prediction with Multiphase-CFD (Boiling model test)

→ DNB model validation approaches

Path forward on DNB study

1. Analytical DNB correlation*

- Gunther (1951)
- Tong-68 correlation (1968)
- Tong-75 correlation (1975)
- Katto's CHF model (1984)
- Seung Jun Kim (2012)

* DNB correlation for flow boiling case only

2. Empirical CHF table

- CHF lookup table (Groeneveld, 2007)

3. Multiphase-CFD DNB model

- Heat flux partitioning model (RPI model)
- Eulerian based two fluid model
- Applicable to complex fuel geometry

Baseline Boiling model (GEN-1)

- **Eulerian – Eulerian framework** : two-fluid six equation model
- Turbulence model : Steady RANS model for both phase (Standard k-eps)
- Constant thermodynamic properties for both phase at given pressure
- **Wall heat flux partitioning approach** (proposed by Dr. Podolski)
- 2 phase interaction models (boiling closure setting): $\dot{q}''_w = \dot{q}''_{conv} + \dot{q}''_{evap} + \dot{q}''_{quench}$
 - Drag: Tomiyama model
 - Lift: Tomiyama or “constant” : in this study, constant Lift coefficient applied.
 - Ranz-marshall (continuous phase)
 - **Bubble departure frequency**: Cole
 - Interaction Length Scale: Kurul Podowski
 - Bubble influence wall area fraction: Kurul Podowski : **RPI heat partitioning approach**
 - **Nucleation site density**: Lemmert Chawla
 - **Departure diameter**: Tolubinski Kostanchuk
- DNB criterion: Wall void fraction= **90% at $Y^+=200$** (Weisman&Pei, 1983)

A pipe flow DNB data (ANL)

- 7.7mm tube water boiling test
- Pressure: 138bar
- Mass flux: 940-2650 kg/m²-s
- Inlet subcooled level: 0-1.25MJ/Kg (100K sub)

5X5 fuel bundle with spacer grids (WEC)

- Fuel bundle with mixing vane DNB test
- Pressure: ~156bar (close to PWR)
- Mass flux: ~3660 kg/m²-s
- Inlet subcooled condition : 292C (30K sub.)

Simulated Boiling Curve up to DNB Point

→ DNB validation with existing experiments and CHF look-up table

Calculated DNB by CFD (LANL, 2016)

DNB point predicted by CFD : **1.9 MW/m²**
Run by Starccm+ with Gen1 boiling odel

Measured DNB by Exp. (ANL, 1963)

DNB measurement at the same condition
: **1.85MW/m²**

CHF look-up table (Groeneveld, 2006)

CHF look table at similar condition
(140bar, 1000G, $X_{exit}=0.15$) : **1.73MW/m²**

**Current prediction capability
Less than 20% deviation**

3D visualization of various flow analysis using HPC

→ *two case studies of multiphase/ multiphysic fluid flow application under the CASL project*

Transient vortex shedding dynamics in the CANDU fuel bundle

Simulated 3D Void distribution for the PWR fuel bundle