One-Dimensional, Advanced Annular Two-Phase Flow Simulations with the Open-Source Platform OpenSTREAM

Jason Chan[1], Roman W. Morse[2], Nathan Hogan[3], Evan T. Hurlburt[3], Jean-Marie Le Corre[4]

[1]*Mechanical Engineering, University of Wisconsin-Madison, Madison, WI, USA, jason.chan@wisc.edu*

[2]*Department of Nuclear Science and Engineering, Massachusetts Institute of Technology, Boston, MA, USA, rwmorse@mit.edu*

[3]*Naval Nuclear Laboratory, West Mifflin PO Box 79, PA 15122, USA, evan.hurlburt@unnpp.gov*

[4]*Westinghouse Electric Sweden AB, Västerås, Sweden, lecorrjm@westinghouse.com*

Abstract

The new OpenSTREAM computational environment offers several open-source, one-dimensional simulation frameworks for modeling two-phase flow in a single straight channel, based on various multi-field approaches and reasonable simplifying assumptions. Among these, the implemented three- and four-field models consist of advanced frameworks for simulating annular two-phase flow, providing the foundations for future collaborative model development and validation. Field interaction terms have been implemented based on validated models from the literature. Simulations of a selected boiling water two-phase flow case show consistent and reasonable predictions for both steady-state and transient applications.

Keywords: annular two-phase flow, boiling, disturbance waves, solver, open-source

Introduction

The OpenSTREAM (**Open** **S**olvers for **T**wo-phase flow **R**esearch, **E**ngineering **A**nalysis and **M**odeling) computational environment, introduced by (Le Corre *et al.*, 2025), is a modern open-source platform designed to enable efficient and collaborative development and validation of one-dimensional, multi-field, two-phase flow models. The platform currently supports single-component, incompressible, steady-state and transient boiling two-phase flows in straight channels. In addition to the mixture and two-fluid models (Walter, 2025), OpenSTREAM provides advanced simulation frameworks for annular two-phase flow, which are currently limited to thermal-equilibrium conditions, i.e., applicable up to film dryout.

The three-field model is based on a simplified nine-equation framework, similar to the model implemented in the MEFISTO-T subchannel analysis code (Adamsson and Le Corre, 2014). The four-field model extends the three-field approach by separating the liquid film into a slower, continuous base liquid film and faster, dispersed disturbance waves. This model, recently developed by (Le Corre, 2022), is intended to capture the intermittency of disturbance waves and base liquid film (including evaporation) in annular two-phase flow.

Advanced annular two-phase flow models

The three- and four-field models of annular two-phase flow implemented in OpenSTREAM offer state-of-the-art frameworks for advanced simulations. While the three-field model has been successfully applied for years, such as in (Adamsson and Le Corre, 2014), the recently developed four-field model offers enhanced capabilities to capture hydrodynamic and thermal phenomena related to the intermittent transport of disturbance waves traveling over the thin liquid base film. Both models have been used in this work to demonstrate the capabilities of these simulation frameworks.

In the four-field model, disturbance waves are modeled as fluid particles, characterized by basic macroscopic parameters such as the wave shape factor (amplitude-to-width ratio) and the wave number density (spatial wave frequency). The model incorporates phase change and includes relevant closure relations for field mass and momentum exchange rates, such as drop entrainment, deposition and interactions between waves and the base film. A Boltzmann transport equation of wave number density is introduced to model the hydrodynamic non-equilibrium effects related to wave creation, merging and splitting, which are characteristic of developing annular two-phase flows (due to, e.g., inlet effect, phase change, geometrical change or transient). Lastly, base film mass and wave number density sink and source rates are modeled using a relaxation time approximation. This newly developed model, validated in high pressure boiling water two-phase flow, is thoroughly documented in (Le Corre, 2022).

Results and discussion

For demonstration purposes, boiling water two-phase flow was simulated in a channel with a diameter of 8.8 mm and a length of 5 m (with 3.5 m uniformly heated, followed by a 1.5 m adiabatic region) operating at a pressure of 6 MPa, mass flow rate of 0.07 kg/s, total power input of 87.5 kW and a slightly subcooled inlet (1.14 MJ/kg). Axial distributions of key parameters for the liquid field (field mass flow rates, velocities, and wave frequency) are shown in Figure 1. The simulation results for the threeand four-field models are displayed from the onset of annular two-phase flow (at 0.77 m). In this example, a basic model of drop velocity (assuming no slip with the vapor phase) was used instead of solving the full drop momentum conservation equation.

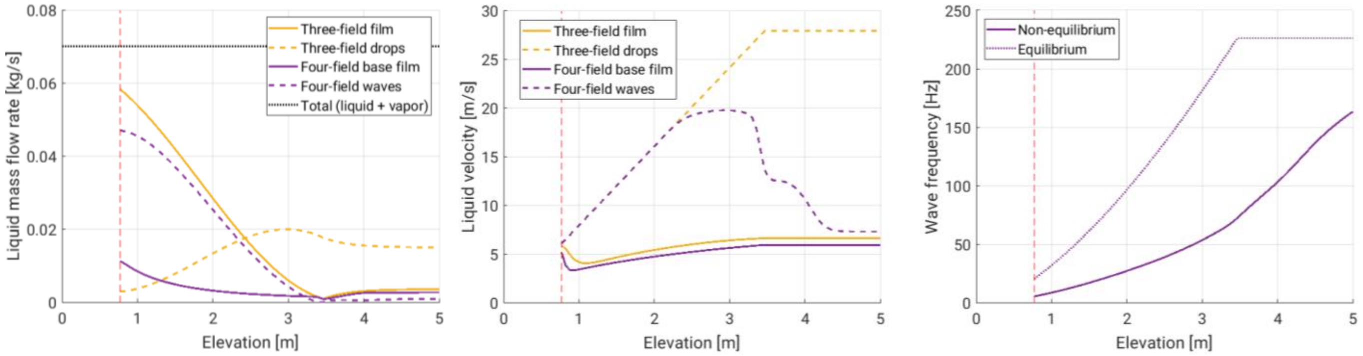

Figure 1: Simulated axial distributions of liquid film mass (left), velocity (center) and wave frequency (right).

The three-field model captures the development of the liquid film along the heated length, progressing nearly to complete film dryout near the end of the heated region. The four-field model further captures the mass transport and associated velocities for the base film and the disturbance waves. Notably, the wave velocity is predicted to decrease near film dryout, consistent with the discussion in (Le Corre, 2022). Moreover, the wave number density transport equation is able to capture the non-equilibrium development of wave frequency. In the adiabatic region downstream of the heated length, the system returns towards an equilibrium state (though the wave frequency remains away from equilibrium), with liquid mass redistributing toward the film.

Wave field properties from the four-field model are shown in Figure 2 (within the annular two-phase flow region) for a transient simulation initiated from the steady-state conditions listed above, with a 1Hz sinusoidal variation in total power input (between 87.5 and 0 kW). The simulations results are reasonable while exhibiting highly interesting patterns related to transient wave transport. Significant transient variations in wave field properties can be observed.

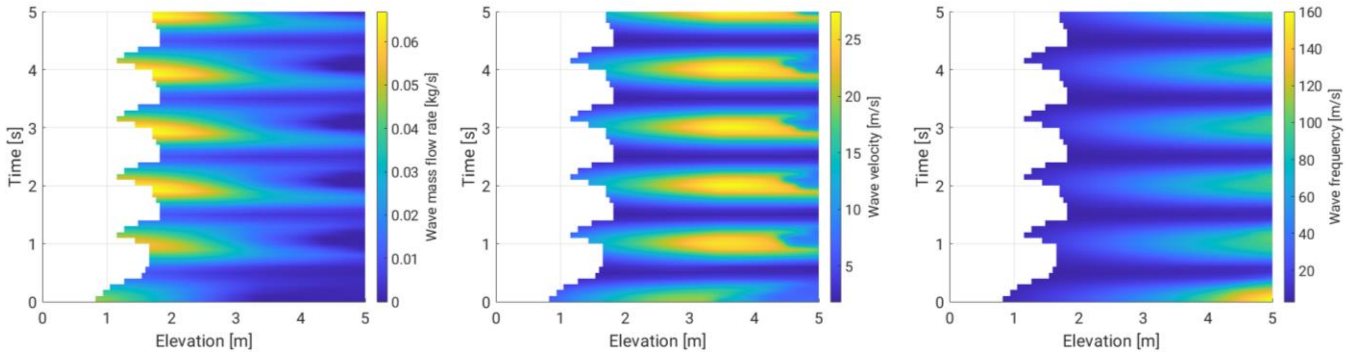

Figure 2: Simulated spatio-temporal distributions of wave properties for the four-field simulation framework.

Conclusion

Three- and advanced four-field annular two-phase flow simulation frameworks, applicable to a single straight channel, have been implemented within the open-source platform OpenSTREAM. These frameworks are based on a system of field mass, momentum and energy conservation equations under the assumption of thermal equilibrium, completed by closure relations to account for wall and interfacial transfer processes. The models effectively capture the transport of considered liquid fields (drops, base film and disturbance wave) considering phase change and relevant non-equilibrium hydrodynamic phenomena for both steady-state and transient scenarios.

Future collaborative enhancements to the three- and four-field simulation frameworks are expected, including the development of advanced closure models, support for thermal non-equilibrium (for post-dryout applications), and further explorations of intermittent base film dryout between disturbance waves. Alongside other available simulation frameworks (Le Corre *et al.*, 2025), OpenSTREAM aims to provide accessible two-phase flow simulation tools to support collaborative model development, performance evaluation, and validation across research institutions.

References

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