OpenSTREAM: A New Open-Source Platform for Two-Phase Flow Model Development

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Abstract

The new OpenSTREAM computational environment provides several open-source, one-dimensional, multi-field, two-phase flow simulation frameworks designed to facilitate efficient and collaborative model development and validation. These frameworks include a homogeneous equilibrium model, a two-fluid model, a three-field model, and an advanced four-field model of annular two-phase flow. The implemented models support single-component, incompressible, steady-state and transient boiling two-phase flows in single straight channels developed under reasonable simplifying assumptions. Basic closure models have been implemented, subject to future improvements. All frameworks were shown to provide reasonable simulation results for the presented case. OpenSTREAM will soon be publicly available on a dedicated GitHub repository under the MIT license.

Keywords: two-phase flow, boiling, solver, open-source

Introduction

Simulation models for one-dimensional, two-phase flow are generally well documented in the literature. These include not only generic frameworks based on averaging methods, such as in (Ishii and Hibiki, 2011), but also the necessary closure models, which are typically applicable only within specific validation ranges. However, the implementation of these simulation models is often confined to complex proprietary computational codes, such as system and subchannel analysis codes used in the nuclear industry. These restrictions limit access and hinder the development, performance evaluation, and validation of the models.

In order to promote two-phase flow research and more efficient development of one-dimensional simulation models for both steady-state and transient, the new computational environment OpenSTREAM (**Open S**olvers for **T**wo-phase flow **R**esearch, **E**ngineering **A**nalysis and **M**odeling) has been developed. This open-source platform is designed to facilitate collaborative research in two-phase flow modeling, including heat transfer and phase change. OpenSTREAM offers access to generic simulation frameworks and closure models, while providing a flexible platform for future developments and enhancements.

Simulation frameworks

The OpenSTREAM computational environment is developed using MATLAB programming language following a modern object-oriented architecture. Any straight channel can be defined (with constant cross-sectional area), including local obstructions and multi-walls. Phase fluid properties are computed with the CoolProp library. Any steady-state or transient boundary conditions are supported, including the definition of any arbitrary axial power distributions.

Currently, OpenSTREAM offers four different one-dimensional incompressible two-phase flow simulation frameworks:

1. **Mixture model**: This framework is based on a three-equation homogeneous equilibrium model. Non-equilibrium conditions can be accounted for by using constitutive relations (e.g., void fraction and subcooled boiling models).
2. **Two-fluid model**: This framework is based on a six-equation model allowing for hydrodynamic and thermal non-equilibrium (Ishii and Hibiki, 2011). It is intended to be nearly equivalent to simulation frameworks used in nuclear reactor system codes (in a single straight channel). The implemented two-fluid model is further documented and validated in (Walter *et al.*, 2025).
3. **Three-field model**: This framework is based on a nine-equation model simplified for annular two-phase flow simulation up to liquid film dryout (i.e., under thermal equilibrium assumption), similar to the model implemented in the MEFISTO-T subchannel analysis code (Adamsson and Le Corre, 2014).
4. **Four-field model**: This framework builds upon the three-field model by splitting the liquid film into a slower, continuous field (base liquid film) and the faster, dispersed disturbance waves. The non-equilibrium nature of these disturbance waves is modeled using a wave number density transport equation. This model, recently developed by (Le Corre, 2022) is intended to capture the intermittency of disturbance waves and base liquid film evaporation in annular two-phase flow.

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Simple interfacial and wall closure models have been implemented, subject to future improvements. To address ill-posedness due to pressure-velocity coupling, the pressure gradient solution from the mixture model is applied across all frameworks. This simplification stabilizes the numerical convergence, though it introduces inconsistencies in the conservation equations, which are negligible for many applications. Additional simplifications include neglecting surface tension forces and heating by friction.

Results and discussion

For demonstration purposes, boiling water two-phase flow was simulated using all available OpenSTREAM simulation frameworks in a 8.8 mm diameter, 5 m long channel (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). Although all primary (field mass flow rates, velocities, and enthalpies) and secondary parameters (e.g., source terms in conservation equations) are readily accessible, Figure 1 presents only the simulated mass flow rate distributions. The results from the three- and four-field models are displayed from the onset of annular two-phase flow (at 0.77 m). Due to the saturated assumptions, the vapor mass flow rate distribution remains unchanged for the mixture, three- and four-field models.

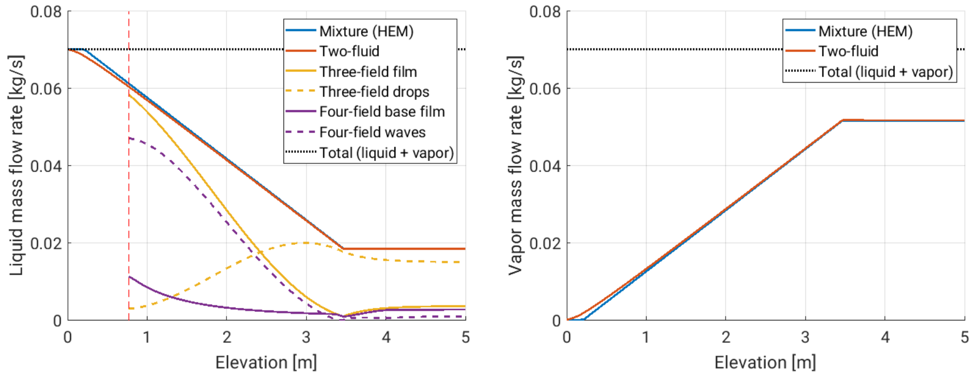

Figure 1: Example of simulated liquid (left) and vapor (right) mass flow distributions for the available simulation frameworks.

As expected, boiling is initiated near the inlet up to the end of heated length (3.5 m). The two-fluid model effectively captures thermal-non-equilibrium between the phases in the subcooled region and beyond (up to 0.75 m), resulting from an imbalance between wall boiling and interfacial condensation. The three- and four-field models capture the mass transport of all considered liquid fields (drops, film, base film, waves) along the annular flow region. Near complete film dryout is predicted at the end of heated length, followed by a return to equilibrium conditions along the adiabatic region. Further details and applications of the three- and four-field models of annular two-phase flow implemented in OpenSTREAM are documented in (Chan *et al.*, 2025).

Conclusion

A new and modern open-source computational environment for one-dimensional, multi-field, two-phase flow simulations in straight channels has been presented. Typical simulation frameworks were implemented under simplifying assumptions, along with an advanced four-field model of annular two-phase flow. All frameworks demonstrated consistent and reasonable results for the presented steady-state case. The tool is aimed at facilitating access to such two-phase flow simulation frameworks to support collaborative model development, performance evaluation, and validation across research institutions.

The OpenSTREAM computational environment will soon be publicly available on a dedicated GitHub repository under the permissive MIT license, following the completion of documentation and user guides. In addition to the development and validation of two-phase flow closure models, collaborative implementation of new capabilities is anticipated, including a drift flux (four-equation) simulation framework, improved pressure-velocity coupling, support for multi-component fluids, interfacial area transport, wall condensation, and thermal non-equilibrium for the three- and four-field models (for post-dryout applications). Additional improvements may also focus on more computationally efficient numerical solvers, a wall thermal model, support for non-uniform channel cross-sections and addressing neglected terms in the momentum and energy conservation equations (depending on application needs). Furthermore, the implementation of OpenSTREAM in more accessible programming languages, such as Python or Julia, could be considered.

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