

# One-Dimensional, Two-Fluid, Two-Phase Flow Simulation Framework in the Open-Source Platform OpenSTREAM

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## 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 two-fluid model framework solves a six-equation system governing the conservation of mass, momentum, and energy for each phase, capturing hydrodynamic and thermal non-equilibrium phenomena. Simple interfacial and wall closure models have been implemented, providing the foundations for future collaborative model development. A comparison with the TRACE system code demonstrates that the OpenSTREAM two-fluid simulation framework predicts consistent and reliable results for the considered boiling water two-phase flow case.

**Keywords:** two-fluid, two-phase flow, phase change, non-equilibrium, open-source

## Introduction

The OpenSTREAM (**O**pen **S**olvers for **T**wo-phase flow **R**esearch, **E**ngineering **A**nalysis and **M**odeling) computational environment, introduced in (Le Corre *et al.*, 2025), offers a modern open-source platform designed to facilitate efficient and collaborative development and validation of one-dimensional, multi-field, two-phase flow models. The implemented models currently support single-component, incompressible, steady-state and transient boiling two-phase flows in straight channels.

While OpenSTREAM includes a simple mixture model (based on homogeneous equilibrium assumptions), as well as a three- and an advanced four-field model of annular two-phase flow, these are currently limited to thermal equilibrium conditions. To extend the platform's simulation capabilities to more general thermal non-equilibrium scenarios, a two-fluid, two-phase flow simulation framework has been implemented. This framework is based on a six-equation model derived from Euler averaging of local, instantaneous phase conservation equations (Ishii and Hibiki, 2011), developed under reasonable simplifying assumptions. It is intended to be nearly equivalent to typical simulation frameworks used in nuclear reactor system codes, such as the TRACE code (US-NRC, 2017), restricted to single straight channels.

## Two-fluid model simulation framework

The two-fluid model provides a theoretical framework for simulating two-phase flow, widely applied across many engineering fields. The approach uses the concept of interpenetrating continua, where two distinct phases (e.g., a liquid and its vapor) coexist and interact dynamically through mass, momentum and energy exchanges, including heat transfer and phase change. The Euler averaging process applied to the six-equation model requires interfacial exchange terms to be captured via closure relations. Although a complete two-fluid model can be complex, simplifying assumptions can be made without significant loss of accuracy, depending on the applications.

The simplified two-fluid model implemented in OpenSTREAM is fully documented in (Walter, 2024) and focuses on boiling two-phase flow within a single straight channel, accounting for both hydrodynamic and thermal non-equilibrium conditions, relevant to system code applications in the nuclear industry. The model allows the definition of any straight channel with a constant cross-sectional area, including local obstructions. Fluid properties for both phases are computed with the CoolProp library. Any steady-state or transient boundary conditions are supported, including any arbitrary axial power distributions.

The phase mass, momentum and energy conservation equations have been derived under reasonable assumptions. To address the ill-posedness associated with pressure-velocity coupling, the pressure gradient solution from the mixture model is used. This simplification stabilizes numerical convergence, though it introduces small inconsistencies in the conservation equations, which are negligible for many applications. Additional simplifications include neglecting surface tension forces and heating by friction.

Simple interfacial and wall closure models have been implemented, subject to future improvements. Within a generic two-phase flow simulation framework, such models involve (1) interfacial topology and volumetric interfacial area, (2) interfacial

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transfer fluxes and (3) wall transfer terms and transitions, such as Critical Heat Flux (CHF). Basic two-phase flow regimes have been defined, along with corresponding interfacial length scales, interfacial/wall transfer terms and transitions (Walter, 2024).

## Results and Discussion

For demonstration purposes, boiling water two-phase flow was simulated in a 8.8 mm diameter, 5.5 m long channel (3.5 m uniformly heated, followed by a 2.0 m adiabatic section) at 6 MPa pressure, with a mass flow rate of 0.07 kg/s, a total power input of 150 kW (beyond CHF) and a subcooled inlet enthalpy of 0.6 MJ/kg. Simulation results from both the mixture model (phase slip velocity ratio set to 2) and the two-fluid model in OpenSTREAM are compared with TRACE code outputs as shown in Figure 1. To ensure model consistency between codes, subcooled boiling models were turned off for all considered simulations.

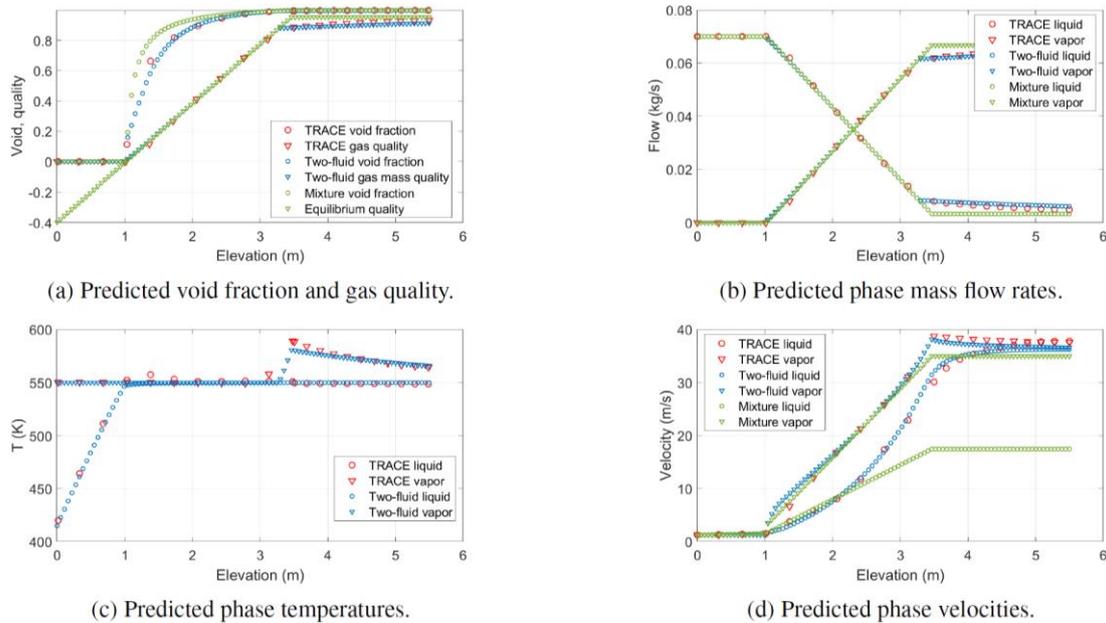


Figure 1: Axial distributions of phase variables predicted by TRACE (red), OpenSTREAM mixture model (green) & two-fluid model (blue).

Saturated boiling is predicted from 1 m to 3.25 m. Downstream CHF, the wall heat flux to the vapor phase results in thermal non-equilibrium, producing super-heated vapor alongside saturated liquid (Figure 1c), which drives interfacial evaporation (Figure 1a and Figure 1b). This process persists downstream the end of heated length (3.5 m), along with interfacial momentum transfers from the faster vapor to the slower liquid, towards hydrodynamic (Figure 1d) and thermal equilibrium.

The two-fluid model implemented in OpenSTREAM agrees well with the results from TRACE for this considered steady-state example. However, the current simplifying assumptions (particularly regarding flow regimes and interfacial topology transitions) restrict the model applicability to complex transient scenarios, as discussed in (Walter, 2024).

## Conclusion

A simplified two-fluid, two-phase flow simulation framework applicable to a single straight channel has been derived and implemented within the open-source platform OpenSTREAM, designed to be nearly equivalent to nuclear reactor system codes for such geometry. This framework solves a system of six conservation equations, complemented by wall and interfacial closure relations that are dependent upon flow regimes and wall heat transfer transitions. The model effectively simulates hydrodynamic and thermal non-equilibrium between phases. For the presented steady-state case, the implemented two-fluid model provided reasonable results, showing good agreement with the TRACE code.

Future collaborative enhancements to the two-fluid simulation framework are expected, including the development of advanced closure models, improved pressure-velocity coupling, support for multi-component fluids, interfacial area transport, and wall condensation. 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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