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Master's Thesis Suggestion

Two-phase mathematical modelling of valve-controlled flash boiling and steam generation under vacuum condition

Background and Motivation:
Flash evaporation-based power and water purification systems hold strong potential for utilizing low-temperature heat sources, particularly those wasted in industrial processes. The performance and reliability of these systems depend heavily on a detailed understanding of the underlying two-phase flow phenomena, which are triggered by the rapid flashing of subcooled liquid water into a vapor–liquid mixture through an expansion mechanism. Accurate control of this complex, transient two-phase flow is essential for optimizing system efficiency, avoiding flow choking, and enabling robust, scalable system designs.

Objective:
The objective of this thesis is to develop a mathematical model based on a non-equilibrium Eulerian two-fluid approach to simulate the two-phase flow in flash evaporation systems. Interphase ex- change terms will be incorporated to account for mass transfer (phase change), momentum, and heat transfer between liquid and vapor phases, enabling accurate prediction of the transient behav- ior and flow characteristics within the system.

Tasks:
1. Develop and implement a two-fluid Eulerian model to simulate non-equilibrium two-phase flow, and solve the governing equations using a commercial CFD software package (e.g., STAR-CCM+, ANSYS Fluent etc.).
2. Validate the developed model by applying it to simplified geometries and comparing the simulation results with existing experimental or numerical data available in the literature.
3. Analyse interphase mass, momentum, and energy transfer, and investigate the influence of key flow parameters such as inlet mass flow rate, temperature, velocity profiles, and phase distribution on the overall system behaviour.
4. Evaluate the impact of bubble-induced turbulence on flow characteristics, phase interactions, and spatial distribution of vapor and liquid within the domain.

Karlsruhe Institute of Technology

5. Design a realistic expansion valve geometry using CAD tools to gain a deeper understanding of the flashing process inside the valve and related components within the flash evaporation system.

Methodology:

1. Literature Review: Conduct an in-depth review of existing studies, numerical approaches, and modelling techniques related to flashing flows and two-phase flow simulation using Eulerian twofluid models.
2. Model Familiarization and Initial Testing: Explore and apply existing Eulerian two-fluid models within a commercial CFD package (STAR-CCM+, Fluent etc.,) to achieve converged solutions for simplified geometries, such as converging–diverging nozzles.
3. Mass Transfer Model Implementation: Integrate flash evaporation mass transfer models from the literature using external programming tools (e.g., java, C++), or directly implement them through the user-defined function (UDF) interface of the CFD software.
4. Turbulence Modelling: Test various turbulence models available in the software to identify those best suited for highly transient and multiphase flashing flow conditions.
5. Interphase Momentum Interactions: Implement interphase momentum exchange mechanisms, including lift forces, added mass effects etc., to capture realistic droplet–vapor interactions.
6. Geometry and Meshing: Design a realistic 3D model of an expansion valve using CAD tools, and apply different meshing strategies provided by the CFD package (e.g., polyhedral, trimmed, or hexahedral mesh) to ensure numerical stability.
7. Design and Optimization Analysis: Use the validated Eulerian two-fluid model to investigate the influence of geometry and operating parameters on mass flow rate, and to determine design fea- tures that enable high-throughput operation without flow choking.

Expected results:

Establishment of a computational tool for the design and optimization of flash boiling-based power generation and water purification systems, enabling performance prediction under various operat- ing conditions. Enhanced understanding of steam generation mechanisms and the complex two- phase flow behavior in flash evaporation systems, including the influence of geometry, turbulence, and interphase interactions on separation efficiency and flow stability.

The start date for the work is scheduled for September 1, 2025.

The scope of the work is designed for 6 months including documentation.

Supervision by:

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