Post-doctoral position

Multiphase Simulation of Thermal Energy Injection into a Liquid

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Background

Thermal energy injection phenomena into a liquid are typical of several application areas: the defense sector with underwater explosions or the nuclear energy sector with reactivity insertion accidents (RIA[1]).
A RIA is a hypothetical accident scenario studied to estimate the consequences of a sudden increase in reactivity within a fuel rod, such as during an accidental ejection in control rod clusters. In the context of a RIA, the temperature and pressure will increase within the rod. If the rod cladding is weakened, it can rupture. In this case, two successive phenomena can occur: 1- The fission gases contained in the rod create a shock wave that propagates in the liquid 2- Fuel particles are expelled into the coolant. In the latter case, these very hot particles vaporize part of the liquid around them, which causes the creation of another shock wave in the coolant.
These phenomena involve three fluid phases: fission gas, liquid water and its vapor for the RIA, explosion gas, liquid water and its vapor for underwater explosions. At IMSIA a physical and numerical model for three-phase compressible flows has been developed [2], specifically a 9-equation model constructed from a two-phase 6-equation model previously developed [1]. The implementation of this three-phase model has also started [8] in the EUROPLEXUS[2] (EPX) code, based on the developments made for the 6-equation model [5,6] during Marco De Lorenzo's doctoral thesis, which was co-supervised by Philippe Lafon and Marica Pelanti. In this same thesis, new thermodynamic tables were developed for water and its vapor [4], while in Yu Fang's doctoral thesis tables were also developed for CO2 [7].
In the context of the two-phase and three-phase models previously mentioned, relaxation processes play a crucial role, particularly in the case of non-instantaneous relaxations when it is important to take into account metastability effects. These relaxation processes were studied in Marco De Lorenzo's thesis [6], and later by Marica Pelanti for the 6- and 9-equation models [3].

Research Project Objectives

The objective of this post-doctoral position is to model and simulate the heat transfer and phase change phenomena that occur in a situation of thermal energy injection into a liquid. In this work, after completing the necessary developments and validations, these phenomena will be modeled either globally using a source term or locally by focusing on the physical phenomena surrounding a hot solid particle suddenly immersed in a cold liquid. This modeling and simulation work will be carried out based on what has already been introduced in EPX. The work program is as follows:

- Finalization of the validation of the 6-equation two-phase model developed in EPX, combined with relaxation algorithms interfaced with water thermodynamic tables;
- Development and validation of the 9-equation three-phase model already introduced in EPX, combined with relaxation algorithms interfaced with water thermodynamic tables;
- Analysis of thermal energy injection phenomena into a liquid using the previously mentioned models according to the following scenarios:
  - Global scenario -- Here, we consider energy injection in the form of a source term;
  - Local scenario -- Here, we aim to model physical phenomena locally at the level of a hot particle: vaporization, pressure waves, and liquid/vapor interface dynamics.

[1] RIA = Reactivity Insertion Accident
[2] EUROPLEXUS is a simulation software for fast transient fluid structure dynamics, co-owned by the European Commission (Joint Research Center) and the CEA, and co-developed by EDF

Supervision

The postdoctorate will be supervised by Marica Pelanti (ENSTA) and Philippe Lafon (EDF).
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Duration

The postdoctoral fellowship has a duration of 12 months, starting possibly in Spring 2025.

Location

The postdoctoral work will be carried at the IMSIA offices of EDF Lab Paris-Saclay (7 boulevard Gaspard Monge, Palaiseau), which is located close to the ENSTA laboratories (828, Boulevard des Maréchaux, Palaiseau).

References

[1] M. Pelanti, K.-M. Shyue, A mixture energy consistent six-equation two-phase numerical model for fluids with interfaces, cavitation and evaporation waves, Journal of Computational Physics 259, 331–357 (2014)
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[4] M. De Lorenzo, P. Lafon, M. Di Matteo, M. Pelanti, J.-M. Seynhaeve, Y. Bartosiewicz, Homogeneous two-phase flow models and accurate steam-water table look-up method for fast transient simulations, International Journal of Multiphase flow, 95, 199-219 (2017)
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[6] M. De Lorenzo, P. Lafon, M. Pelanti, A hyperbolic phase-transition model with non-instantaneous EoS-independent relaxation procedures, Journal of Computational Physics, 379, 279-308 (2019)
[7] Y. Fang, M. De Lorenzo, P. Lafon, S. Poncet, Y. Bartosiewicz, An Accurate and Efficient Look-up Table Equation of State for Two-phase Compressible Flow Simulations of *Carbon Dioxide*, Ind. Eng. Chem. Res., *57*(22),7676–7691 (2018)
[8] Hala Ghazi, Numerical modelling of multiphase liquid-vapor-gas flows with realistic tabulated EOS, IMSIA research report (2021)