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Boiling in porous media: modelling for the next-generation cooling systems

PhD student: Ismail El Mellas
Supervisors: Mirco Magnini, David Hann and Matteo Icardi

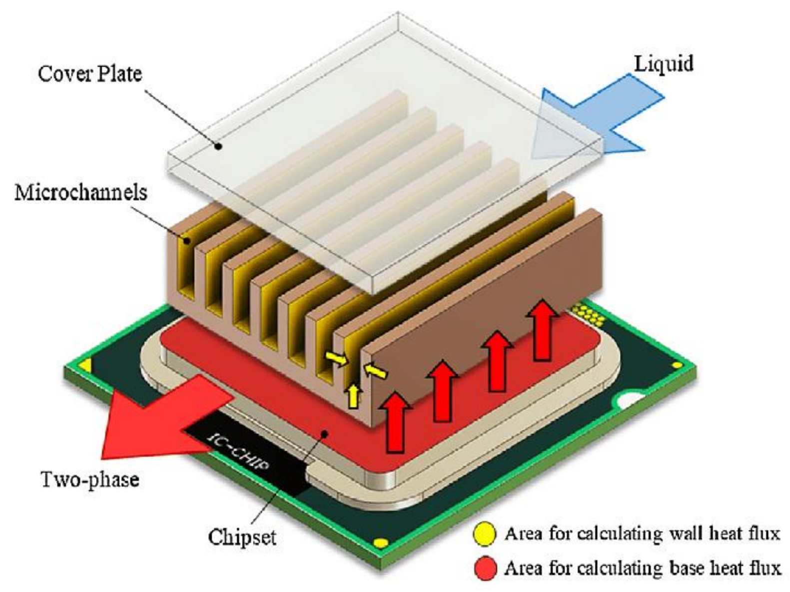
Background and problem statement

The recent advances in micro-electronic technologies and the exponential increase in **global electricity consumption**, made the conventional heat removal systems obsolete**.**

The **boiling flows** in **porous media**, seems a promising solution in a great range of application (e.g., computer chips, satellites, **fuel cells**, nuclear reactor and **EV battery packs**) due to:

- **High heat transfer rates**;
- The liq-vap mixture maintains the **same temperature**, avoiding complications;
- The porous medium enhance the heat transfer area and the **chaotic pattern** increase the mixing.

There is still disagreement on understanding the dynamics, conventional models does not apply reliable. Computational Fluid Dynamics (**CFD**) can be used to predict the fluid flow behavior.



Flow boiling of HFE-7100 in microchannels [1]

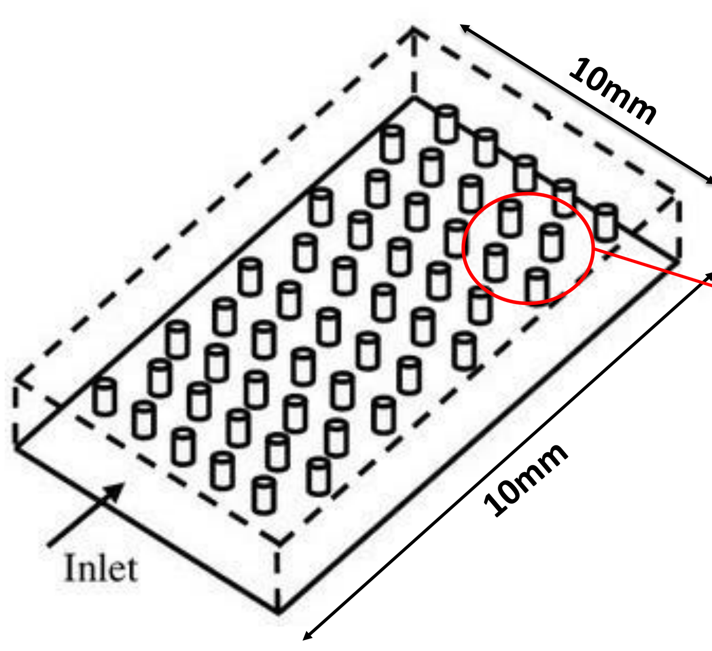
Methodology

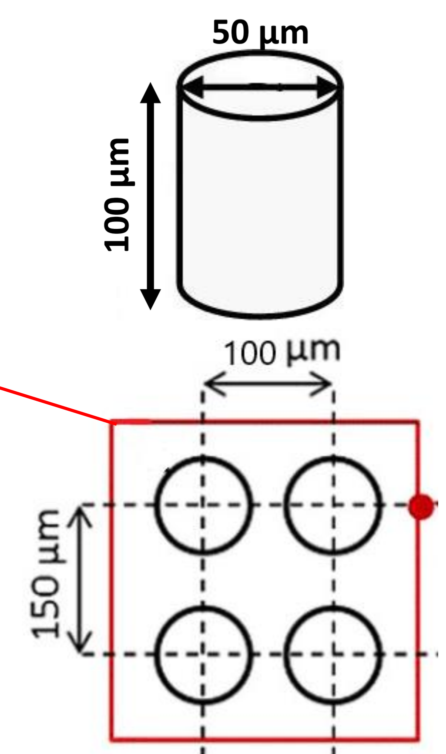
A in-house solver is under development on **OpenFOAM,** used to solve the incompressible **Navier-Stokes Equations**:

- The interface is resolved with the **VOF** method:
  $$\frac{\partial \alpha}{\partial t} + \nabla \cdot \bar{u}(\alpha) = 0$$
- The Continuity equation take into account the phase change effect:
  $\nabla \cdot \bar{u} = \frac{\dot{\rho}}{\rho}$ (**Hardt and Wondra** model [2]) $\dot{\rho} = \dot{m}\delta_s = \phi[T - T_{sat}(p_v)]|\nabla\alpha|$
- In the momentum equation the **surface tension effect** are function of the α
  $$\frac{\partial(\bar{u}\rho)}{\partial t} + \nabla \cdot (\rho\bar{u}\bar{u}) = -\nabla p + \nabla \cdot \tau + \rho\bar{g} + \sigma k \bar{n} \delta_s$$
- The **energy equation** is formulated to **ensuring global mass conservation**
  $$\frac{\partial(\rho c_p T)}{\partial t} + \nabla \cdot (\rho \bar{u} c_p T) = -\nabla \cdot (\lambda \nabla T) - \dot{q}$$

Aim & objective

- Improve the phase change and heat transfer models to obtain high fidelity simulations of boiling in porous media;
- Implement the Phase-Field model in the solver to improve the interface tracking.

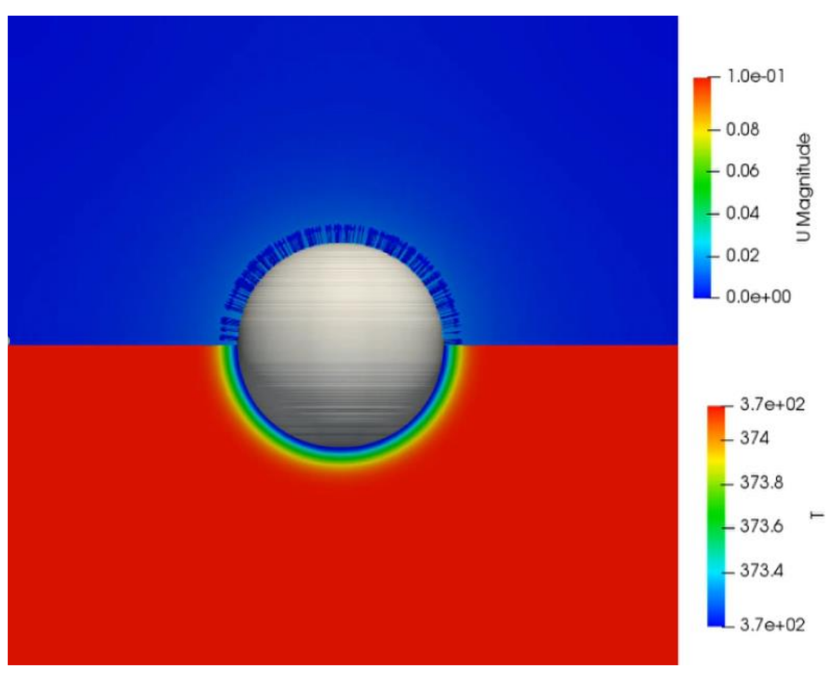




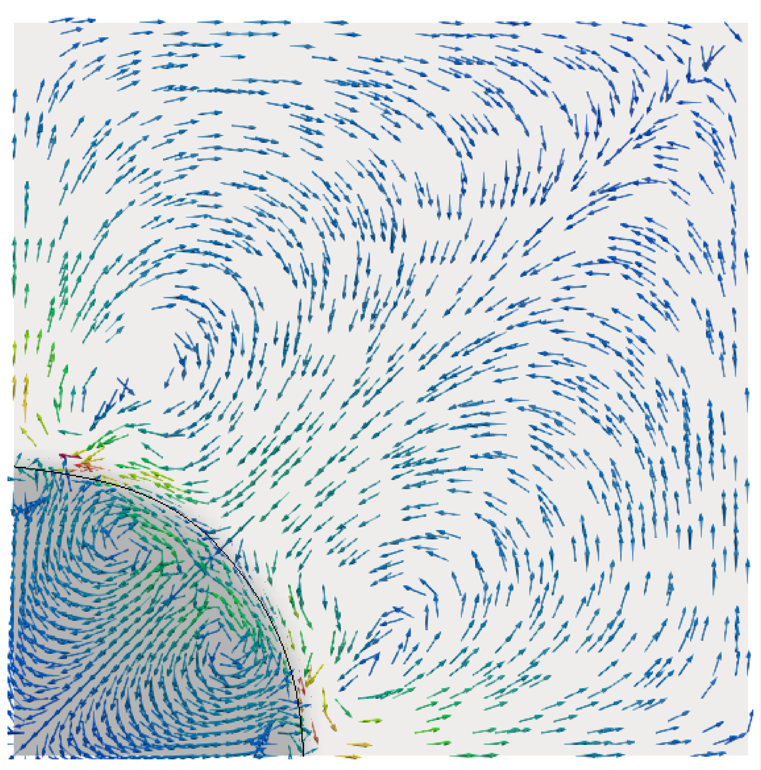
Schematic of the pin–fin geometry and configuration of the cylindrical pin fin and it typical dimensions [3]

Preliminary results

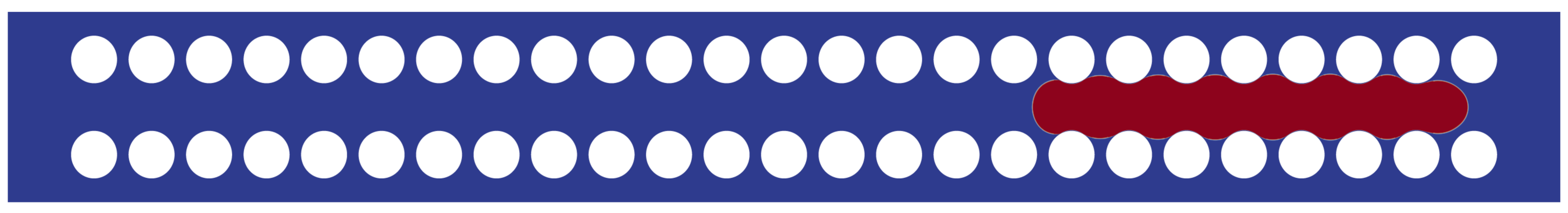
The accuracy of the method, was tested with a chosen set of problems, which represents a critical test for interface capturing methods.



Snapshot of the temperature and velocity field for the case bubble growth in a superheated liquid (Scriven wedge)



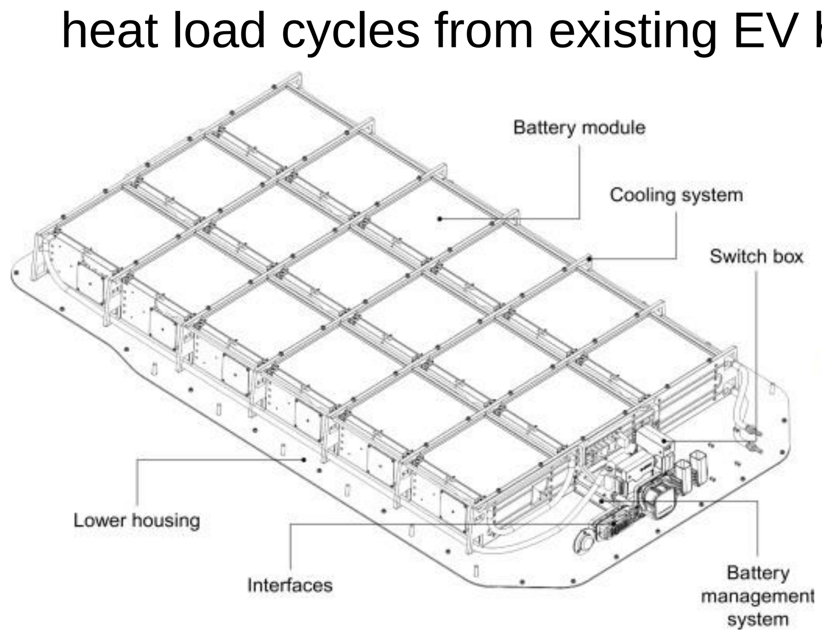
Spurious currents generated by Mules solver for the case static bubble under zero gravity



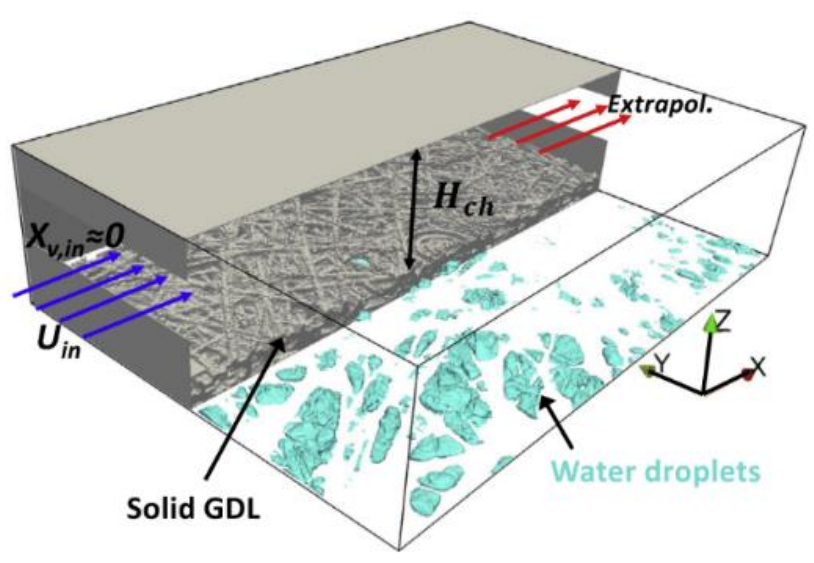
Motion of an elongated bubble through a channel formed by a sequence of in-line cylindrical obstacles

Future work

- Analysis of boiling in porous media made of actual geometries from **tomography data**, to validate the novel tool with experimental data;
- Test the numerical tool's capability using geometrical constraints and heat load cycles from existing EV battery packs during operation.



A flat battery pack for an EV based on pouch-bag lithium-ion cells[4]



A GDL gas diffusion leayer of a PEMFC [5]

[1] A review of data centre cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities, Ebrahimi 2014
[2] Evaporation model for interfacial flow based on continuum-field representation of source term, Hardt & Wondra 2008
[3] Investigation of flow and heat transfer characteristics in micro pin fin heat sink with nanofluid, M. Hasan 2013
[4] Design of high-voltage battery packs for EV, C. Linse et al. 2015
[5] A porelevel direct numerical investigation of water evaporation characteristics under air and hydrogen in the gas diffusion layers of polymer electrolyte fuel cells, M. Safi et al. 2019