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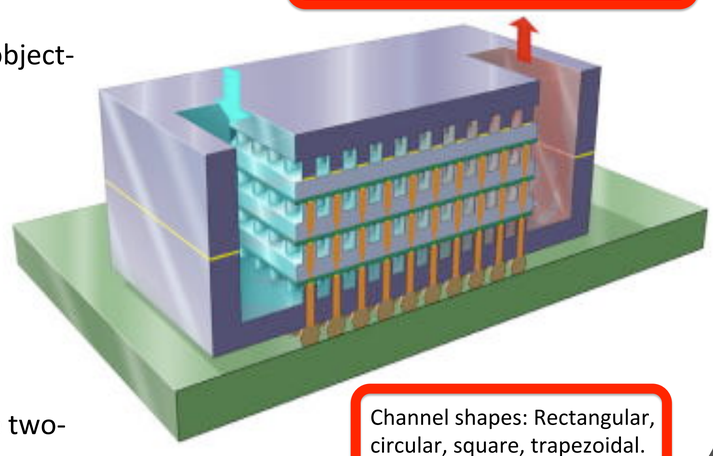
Motivation and approach

Channel sizes: 50µm to 200µm.
Fluids: water, nanofluids, refrigerants

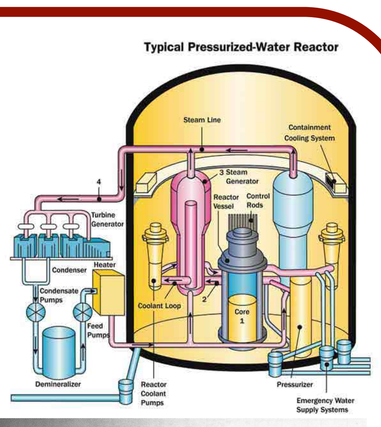
- Develop a 3D Arbitrary Lagrangian-Eulerian Finite Element code using object-oriented programming;
- Develop a platform for modeling microscale two-phase flows;
- Predict flows in complex microscale geometries;
- Couple heat/mass transfer and two-phase flow;
- Exhaustive benchmark tests on the implemented code;
- Numerical simulations of microscale two-phase flows in cooling devices.

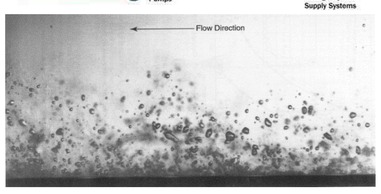


Channel shapes: Rectangular, circular, square, trapezoidal.

Motivation and approach

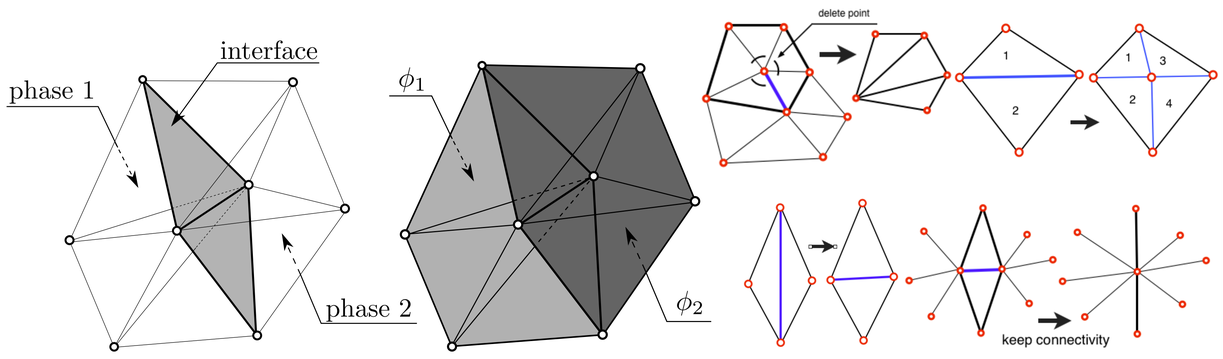
- Accurate prediction of the bubble size, which depends on the bubble departure diameter (initial condition) and the condensation rate;
- Identification of the PWR flow conditions including bubble sizes, shapes, non-dimensional numbers, etc;
- Literature review of data and empirical correlations for bubble condensation;
- Benchmark test cases to spot one physical effect at a time are divided as: Heat Transfer from a solid sphere, 1-dimensional Stefan Problem, Isothermal Bubble rise, Bubble growth in a liquid at rest (boiling), Bubble collapse in a liquid at rest (condensation).



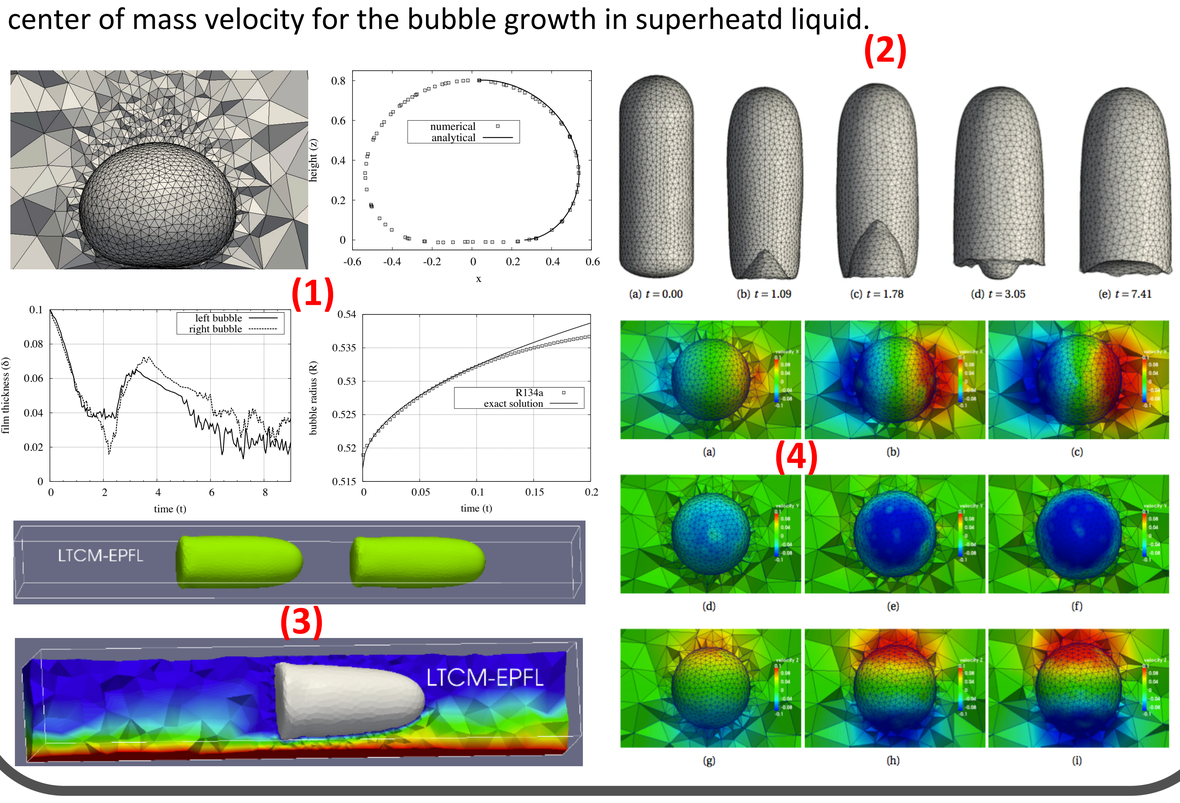


Implementation and results

Illustrated by the figure below, the Lagrangian approach differs from the standard approach by the addiction of points on the surface between the fluids. In fact, no artificial smoothing is required to deal with high properties ratio (Φ_1/Φ_2). This methodology leads to a sharp representation of interface and accurate results. The next figure represents schematically the surface remeshing operations, namely deletion and insertion of nodes and flipping and contraction of edges. These operations are extremely required to keep the mesh consistent.



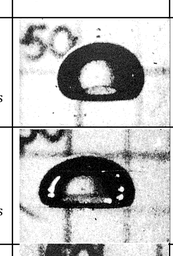
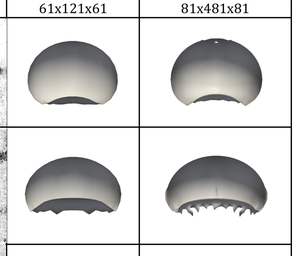
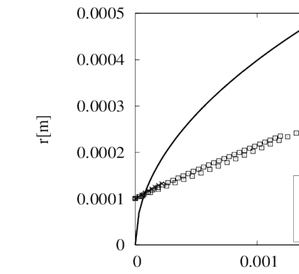
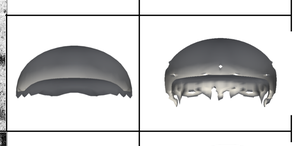
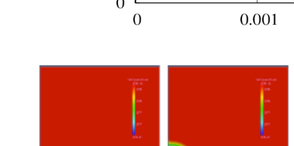
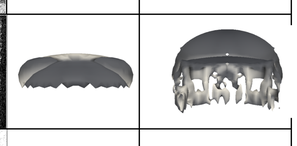
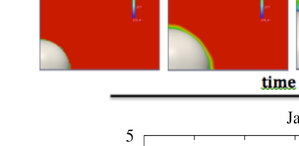
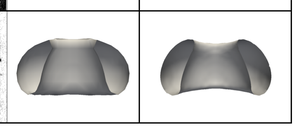
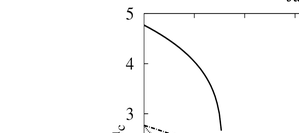
Some of the code validations are shown in Figs. (1), which includes the sessile drop testcase and comparison of Scriven's solution of a bubble growth in superheated liquid. Figure (2) shows the time progression of a Taylor air bubble immersed in a sucrose solution. In the transient evolution, the bubble's velocity reached its maximum velocity at time $t \approx 1$, and its terminal velocity at time $t \approx 3.7$. Two simulatinos are presented in Figs. (3), for single and multiple bubbles. Figure (4) presents the transient solution of the bubble's center of mass velocity for the bubble growth in superheatd liquid.



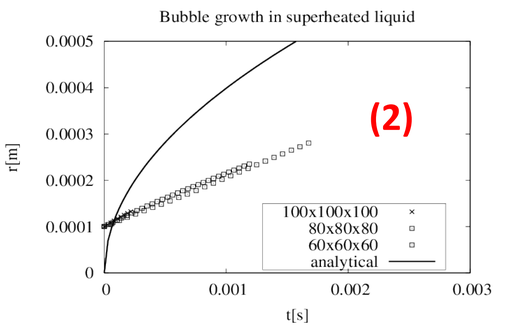
Preliminary results

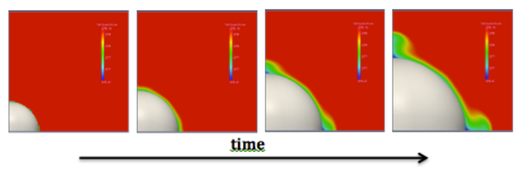
Table (1) shows benchmark results for 2 different mesh refinement levels compared to experimental results for a isothermal rising bubble. In Fig. (2), the numerical simulation of a bubble growth in a liquid at rest is compared to the well known Scriven solution for the bubble history. Table (3) presents a summary of conditions and applicability for pressurized water reactor (PWR) and 4 different models found in the literature. It shows that none of the currently available correlations is suitable for PWR application. These 4 correlations are plotted in Figs. (4) for the PWR conditions. As can be seen, the discrepancy of predicting bubble history and Nu_c is large among them.

(1)

Test name	Properties	Experimental	Numerical TransAT 61x121x61	Numerical TransAT 81x481x81
Test 1a	d_e=0.0261m ρ_L=1350kg/m³ μ_L=2.73kg/ms ρ_G=1.225kg/m³ μ_G=1.78E-05kg/ms σ=0.078N/m			
Test 1b	d_e=0.0261m ρ_L=1350kg/m³ μ_L=1.28kg/ms ρ_G=1.225kg/m³ μ_G=1.78E-05kg/ms σ=0.078N/m			
Test 1c	d_e=0.0261m ρ_L=1350kg/m³ μ_L=0.54kg/ms ρ_G=1.225kg/m³ μ_G=1.78E-05kg/ms σ=0.078N/m			
Test 1d	d_e=0.0261m ρ_L=1350kg/m³ μ_L=0.2857kg/ms ρ_G=1.225kg/m³ μ_G=1.78E-05kg/ms σ=0.078N/m			
Test 1e	d_e=0.0261m ρ_L=1350kg/m³ μ_L=0.0875kg/ms ρ_G=1.225kg/m³ μ_G=1.78E-05kg/ms σ=0.078N/m			

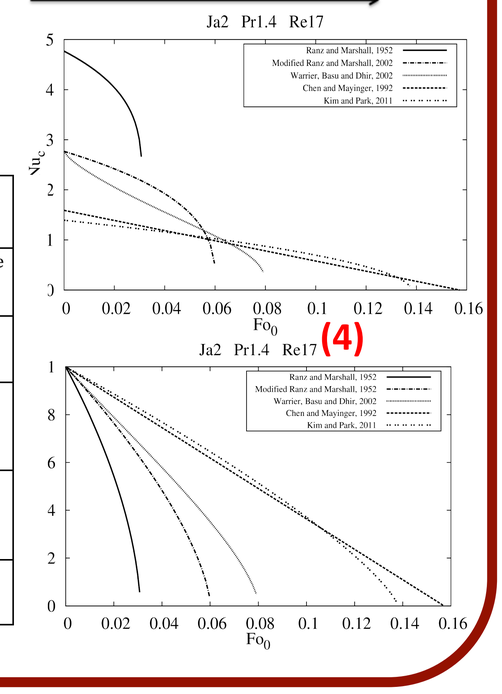
(2)





(3)

REFERENCE	DISPERSED PHASE	CONTINOUS PHASE	SHAPE	APPLICABILITY	OBS
PWR	Water	Water	Small, spherical	0.9<Pr<1.4, Re~17, Ja<2, D~0.1 mm	Representative operating conditions
Ranz and Marshall, 1952	Solid sphere	Water	Spherical	0<Re<200 6mm<D<11mm	No mass transfer, no turbulence
Warrier, Basu and Dhir, 1995	Steam	Water	Spherical	20<Re<100, 12<Ja<100, Nu>2 200<Fo<1100	Insufficient data information
Chen and Mayinger, 1992	Propanol, ethanol, steam, R-113	Propanol, ethanol, water, R-113	Not spherical	2<Pr<15, 1<Ja<120	Shape of bubble not spherical
Kim and Park, 2011	Steam	Water	Large, not spherical	1.87<Pr<2.03, 18<Ja<36, 0.8mm<D<6mm	Shape of bubbles not spherical



Conclusions

- Finite element method is a powerful and flexible way to discretize the numerical domain and to represent the fluid dynamics with accuracy;
- ALE technique for two-phase flow allows us to take advantage of the best aspects of both reference frames namely Lagrangian and Eulerian;
- Curvature calculation approach leads to faster accurate results, compared to classical distance function calculations;
- Several benchmark cases show that the methodology proposed to simulate two-phase flows with phase change provides good accuracy to describe the interfacial forces and bubble dynamics.

Conclusions and further work

- Correlations were testes using different conditions and further evaluated at the pressurized water reactor conditions in terms of the bubble history β and the condensation Nusselt number Nu_c during the condensation process of a detached vapor bubble.
- Current standard tool for prediction of liquid-to-bubble heat transfer is the Ranz and Marshall's correlation (Ranz & Marshall, Jr., 1952). It was found that the available resources are insufficient to describe accurately the condensation process occurring at PWR conditions. However, we suggest the Chen and Meyinger's correlation due to the easiness of implementation in numerical codes and its linear evolution with time (Fo);
- We have started direct numerical simulations of the bubble condensation process in subcooled flow boiling using the commercial code TransAT.