UMo atomization - Numerical simulation with SPH method

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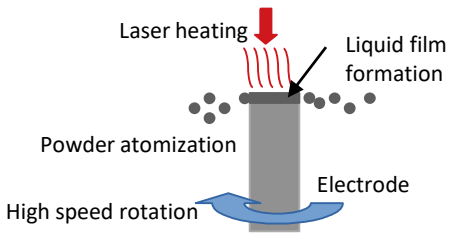
CONTEXT :

- Industrial motivations : Production of nuclear fuel for research reactors that provide solutions to scientific, medical and engineering issues of high societal importance.
- International nuclear non-proliferation agreements gradually lead to the replacement of highly enriched uranium with low enriched uranium (UMo).
- This research project focuses on the Rotating Electrode Process (REP) for synthesizing UMo particles. Essentially, the work consists of numerical simulations for the REP atomizer implemented at CERCA facilities.
- The aim of the research program is to simulate the REP and to obtain new data that will help in anticipating the appropriate operating conditions for the production of spherical powders particles with the desired PSD.

1. REP atomizer

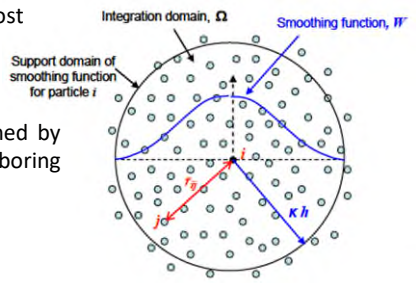
- REP pilot atomizer for UMo powder production implemented at Framatome CERCA
- Fragmentation mainly in the Direct Droplet Formation (DDF) regime
- Adding vibrations to the rotating electrode to control the PSD



2. SPH numerical simulation method

- **S**moothed **P**article **H**ydrodynamics
- **Mesh-free** Lagrangian numerical method
- **Advantage** : Adapted for free/deformable surfaces
- **Disadvantage**: High computational cost

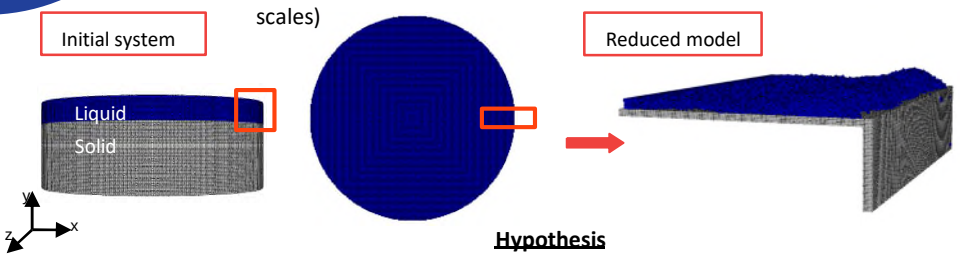
- Continuous fluid => **Series of particles**
- Interpolation using **Kernel/Smoothing function**
- The physical quantity of any particle can be obtained by smoothing the relevant properties of all its neighboring particles

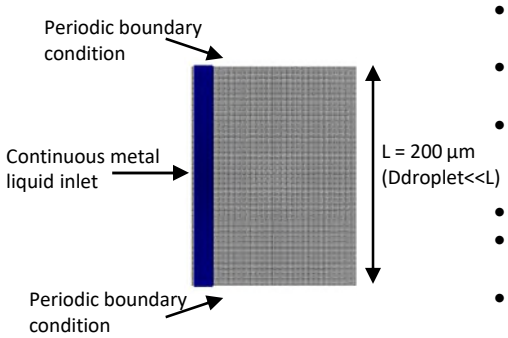


- **SPH basic algorithm** :
  - Density calculation
  - Pressure calculation using an EOS
  - Force calculation : $F = F^{pressure} + F^{viscosity} + F^{surface\ tension} + F^{body\ force}$
  - Properties update : Velocity, Position, Temperature, …

3. Simulation set-up

- Reduce the computational cost
  - => Reduce system size
  - => Decoupling of the thermal and fluid mechanics (different time scales)





Hypothesis

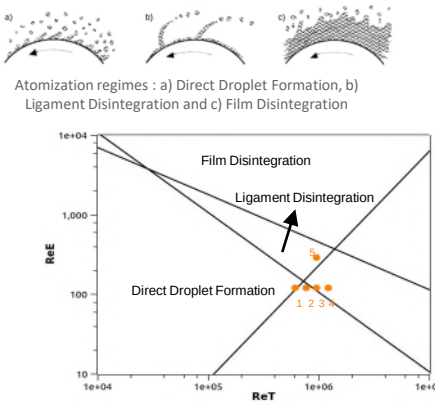
- Modeling a small part at the edge of the rotating rod (150 µm * 200 µm)
- No heat transfer (liquid metal film at the top of the rod at t=0)
- Imposed velocity profile and film thickness (calculated based on Navier-Stokes equations for a viscous driven flow)
- Coriolis acceleration neglected
- For a mass flow rate of 5-20 g/s the film thickness is <10 µm
- Complete wetting at the solid/liquid interface

4. Results and discussion

$$Oh = \frac{\mu}{\sqrt{\rho\sigma R}} \qquad Re_T = \frac{\rho\omega R^2}{\mu} \qquad R_E = \frac{\rho Q}{\mu R}$$

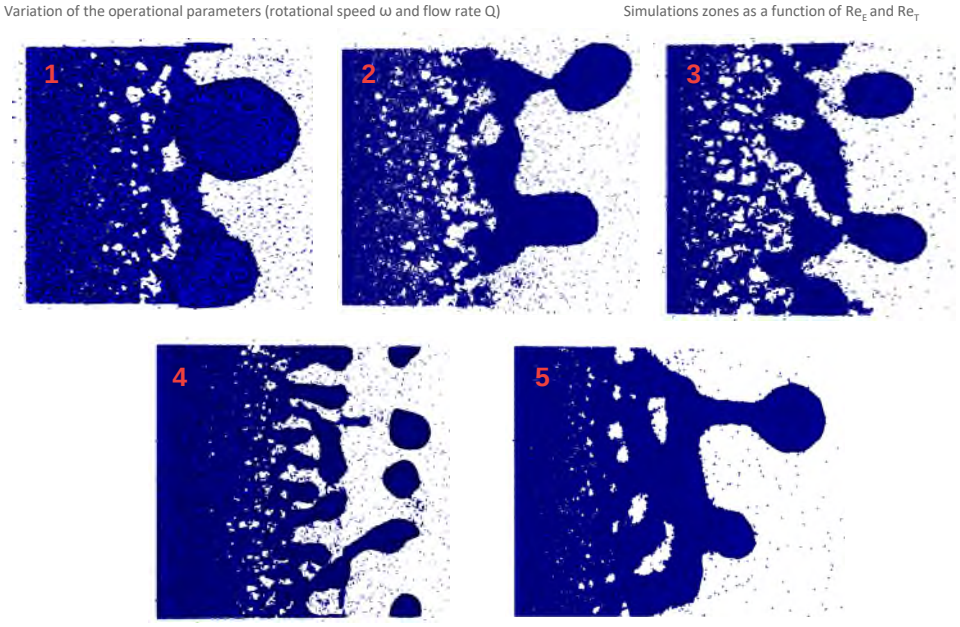
sim #	Oh	Re_T	Re_E	Regime
1	0.00036	620000	120	DDF
2	0.00036	770000	120	DDF
3	0.00036	950000	120	DDF
4	0.00036	1230000	120	DDF
5	0.00036	950000	290	LD

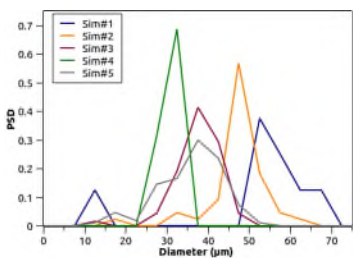
Variation of the operational parameters (rotational speed ω and flow rate Q)



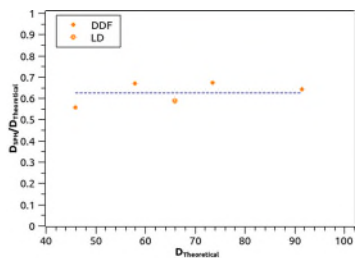
Simulations zones as a function of Re_E and Re_T

Atomization regimes : a) Direct Droplet Formation, b) Ligament Disintegration and c) Film Disintegration





Particle size distribution



Comparison between the semi-emperical diameter and the one obtained by SPH simulations

- Numerical convergence of the model was validated (system size, spatial discretization and time step)
- The SPH diameter was compared to the semi-empirical model of Champagne and Angers
- SPH simulations under-estimate the droplet diameter by a factor of 1.5-1.6
- This can be in part due to the hypothesis of a homogeneous liquid film whereas experimentally we might have higher flow rate locally

CONCLUSION AND PERSPECTIVES

- Development of a predictive SPH model for simulating the REP atomizer
- Prediction of the atomization regime and satellite formation
- Future steps and perspectives:
  - Comparison between experimental data and SPH results
  - Study the effect of applying external vibrations on the PSD
  - Complete the sensibility study + model reduction (fit data/curves that can qualitatively describe the REP)

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