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# Crucible Melter Simulation in Nek5000

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## Background

- Large-scale, Joule-heated, refractory-lined melters will be used to vitrify legacy tank waste at the Waste Treatment and Immobilization Plant
- Molten glass can corrode the refractory lining of the melter over time. The corrosion rate depends largely on the velocity of the glass flow along the lining. [1]
- To estimate refractory lifetime, Joule-heated melters and furnace-heated crucibles are simulated to determine:
  1. Glass flow in the melter (against lining)
  2. A relationship between glass composition, flow velocity and corrosion rate.

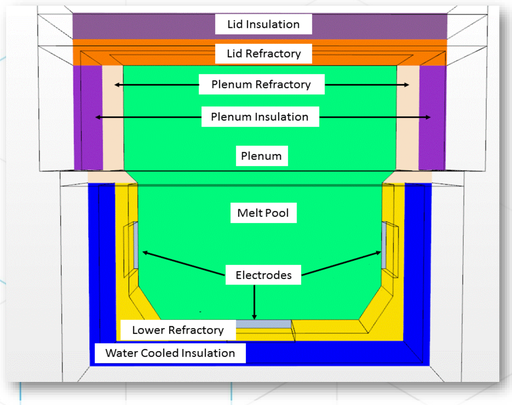


Fig. 1: Schematic of DM1200 pilot-scale melter.

## Objective

- Prior modeling had been done using STAR-CCM+ CFD software. Use of the Nek5000 code was pursued to develop a fast-running code with quick turnaround that can be run on the GPUs on the INL HPC. The purpose of this project is to reconstruct the geometry, fluid properties and heating of the crucibles and melters in Nek5000 to continue the modeling.

## Methodology

**Geometry:**

- Nek5000 requires four basic files to run a case: the *case_name*.par, *case_name*.usr, *case_name*.rea, and SIZE files.
- The .rea file determines the geometry of the case and was generated from a mesh file created in Cubit.
- A rectangular coupon of the melter refractory material is placed in the crucible. The coupon will be removed at the end of the tests to characterize the amount of corrosion as a function of time and temperature for different glass compositions.

**Adding properties of fluid (molten glass):**

- The crucible contains a small tube that injects air into the glass to promote mixing. To simulate this in Nek5000, the fluid around the bubbling tube was given a periodic upwards momentum source term in the .usr file to simulate rising bubbles.[2]
- All walls have a no-slip, constant temperature boundary condition, and the free surface of the glass is open to air and thus has a symmetric, constant heat-flux boundary condition.

**Piecewise fitting of Joule Heating:**

- Four Joule-heated melters, with different geometries were modeled in STAR CCM+, and since Nek5000 does not support Joule heating, each point in the melters was given its own volumetric heat source term to mimic the Joule heating.
- To ensure the volumetric heating reflected Joule heating, the heating profile was mapped from STAR-CCM+ simulations. These profiles were manually fit piecewise with polynomial or exponential functions.

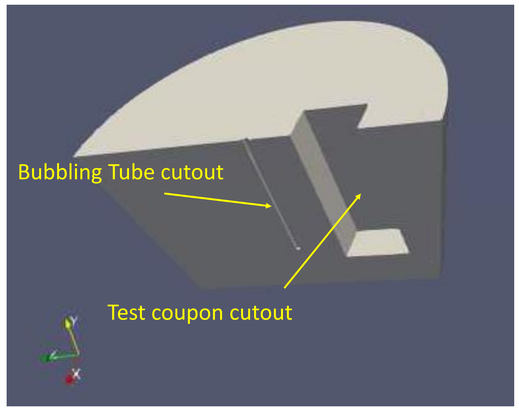


Fig. 2: Geometry of crucible (bubbling tube in middle and test coupon on left).

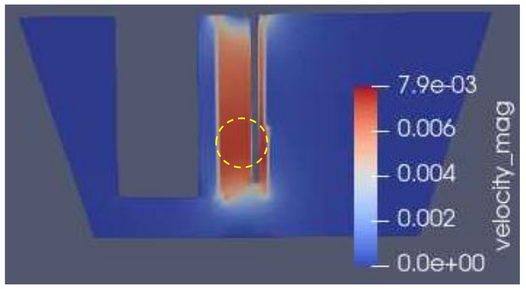


Fig. 3: Visualization in ParaView with momentum term added (circle in red area along bubbling tube marks location of rising "bubble").

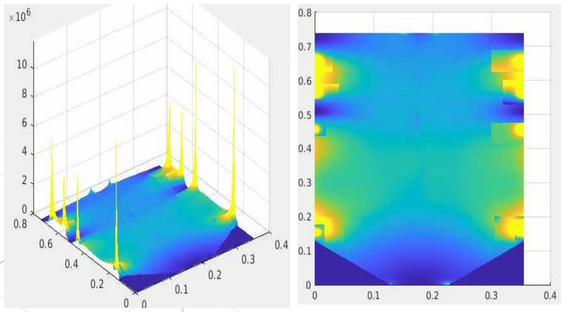

Fig. 3: Piecewise fit of Joule heating profile for the DM100 melter. Color scheme of right image is highly contrasted to show borders of regions where piecewise functions are applied.

## Results

**Geometry:**

- The crucible geometry from STAR-CCM+ imported correctly into Nek5000 as can be seen in Fig. 2. It is expected that the full-scale melter geometry will import readily, as well.

**Adding fluid properties:**

- The periodic momentum term used to simulate bubbling was tested in a MATLAB script to ensure the period (1.57Hz) and radius (5mm) of the simulated bubble was correct.
- Observations of the simulation in ParaView verified that the momentum term was working as expected.
- The no-slip, constant temperature, and symmetric boundary conditions were successfully implemented, but the flux term did not behave as expected (See Future Work).

**Piecewise Joule Heat Fitting:**

- The piecewise fits were compared to a scatter plot fit of the original profiles and all four had less than a 1% error in the integrated value of the Joule heating..

## Future Work

Further refinements of the crucible case will add heat transfer coefficients to the walls and a functional flux term. The cases will be run at varying viscosities to find a relationship between viscosity and velocity profile. More complex geometry will be added to include the plenum and air flow geometry. A buoyancy term will be added to the plenum region of Joule-heated melters to simulate natural convection.

## Acknowledgement

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## References

[1] Selkregg, K., "Fusion Cast Refractories: Roles of Containment", Monofrax, International School of Nuclear Waste Vitrification, September 24, 2019

[2] Abboud, A.; Guillen, D.; Pokorny, R. "Effect of cold cap coverage and emissivity on the plenum temperature in a pilot-scale waste vitrification melter," Int. Journal of Applied Glass Science 11, 357-368, 2020.