Static Molten Salt Freezing Experiment

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Project Overview

- Molten salt reactor designs such as the Fluoride Salt Cooled High Temperature Reactor (FHR) offer much better heat transfer and neutronic properties than current LWRs, in addition to much higher temperatures and thermal efficiencies.
- In order to effectively design these reactors and assess their safety in thermal transient events, an understanding of the freezing process and associated phenomena in these coolant salts must be developed.
- Supercooling is the degree to which the temperature decreases below the established freezing temperature before nucleation occurs and freezing commences. This phenomena has not been heavily researched in different kinds of salt.
- FLiBe and its simulant fluid FLiNaK must therefore have their supercooling characterized. Cooling rate and sample mass appear to be the most important factors in supercooling, so a map of the supercooling that occurs when these are varied will be developed

Potential applications:

- Advanced nuclear reactor designs such as the FHR
- Fusion reactor designs utilizing salt coolant loops
- Concentrated solar plants utilizing salt cooling loops

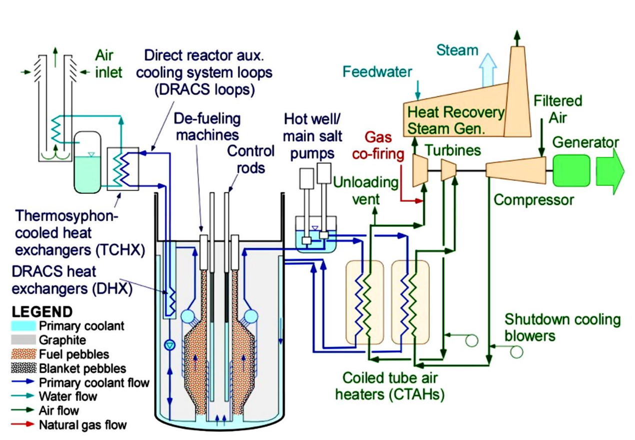

Figure 1: Mark 1 PBFHR Flow Schematic (FHR Design Report 2014)

Experimental Design

In order to measure supercooling in LiF-BeF salt (FLiBe) and LiF-NaF-KF salt (FLiNaK), as well as the nitrate salts to be used to test the methodology, multiple experimental methods must be used in order to cover the different special regimes which affect supercooling, designated as numbered phases:

1. The salts can be placed in a differential scanning calorimeter (DSC) in order to measure the supercooling that occurs in samples less than a milliliter in volume. Various cooling rates can be measured to determine the effect of cooling rate
2. A less quantitative experiment can be done by melting salt in a test tube using a Bunsen burner and allowing it to cool and freeze. A thermocouple can be added to the tube in order to determine supercooling and freezing temperature.
3. To measure supercooling on a macroscopic size scale, the salt is heated and cooled in a boiling flask placed in a nitrate salt bath. This allows the cooling rate to be controlled via the heat flux from the nitrate bath, and the volume can be changed using different size flasks. FLiBe and FLiNaK are the only salts sampled in this manner, due to their importance on the macroscopic scale as the FHR coolant fluid and its experimental simulant fluid.

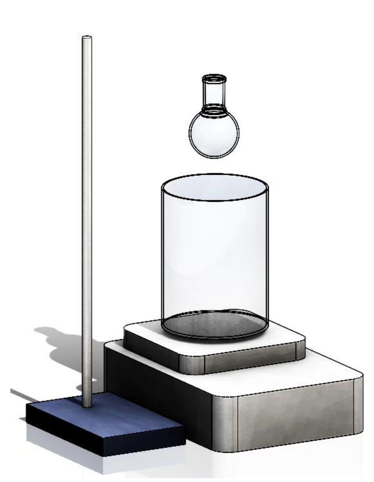

Figure 2: SFX Phase 3 setup. Shown are the sample boiling flask to be lowered into the nitrate salt bath held in the large beaker. The beaker is heated by electrical tape wrapped around the outside (and then insulated) and by the mixing plate on the bottom. The sample is held using a laboratory stand shown here, and a thermocouple array is inserted through the top to monitor freezing front propagation

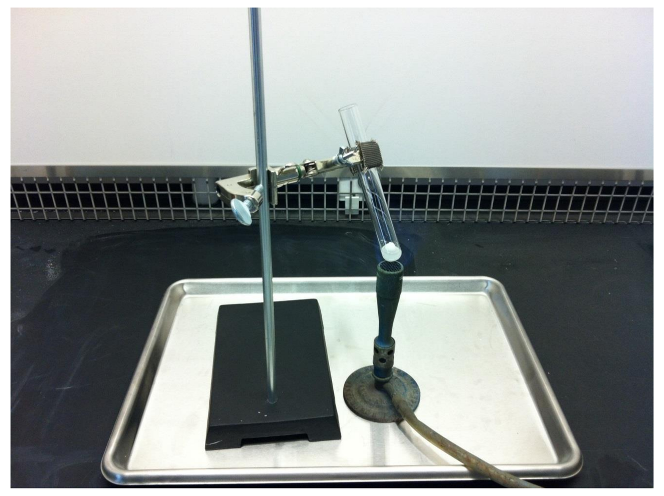

Figure 3: Bunsen burner melting

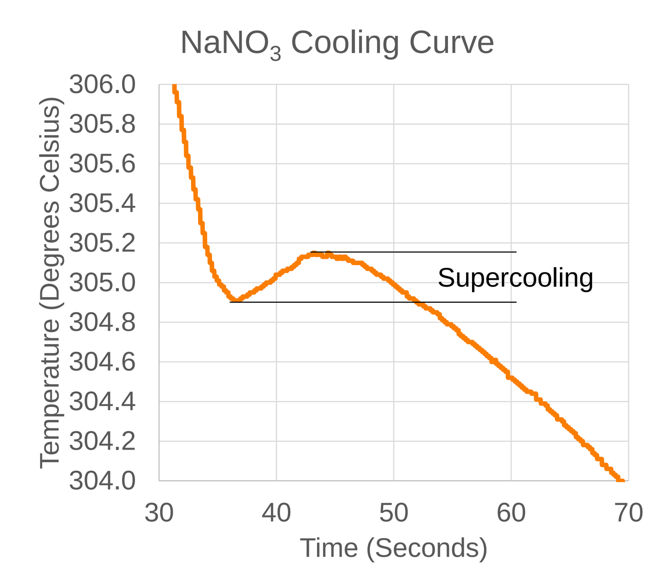

Figure 4: Sodium nitrate cooling in Bunsen burner experiment. Supercooling effect seen in this example, as shown in figure

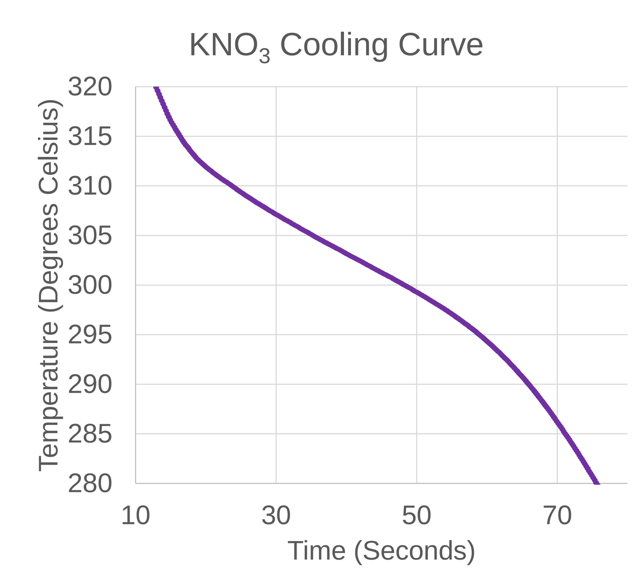

Figure 5: Potassium nitrate cooling in Bunsen burner experiment. Supercooling effect not seen in this example

Summary of Results

Experiments were undergone during the summer of 2015. Phase 3 is currently underway, but has yet to yield results. Results from Phase 1 and 2 are shown below for nitrate salts in order to demonstrate the desired final experimental outcome for FLiBe and FLiNaK. Simulation results of Phase 3 are shown as well.

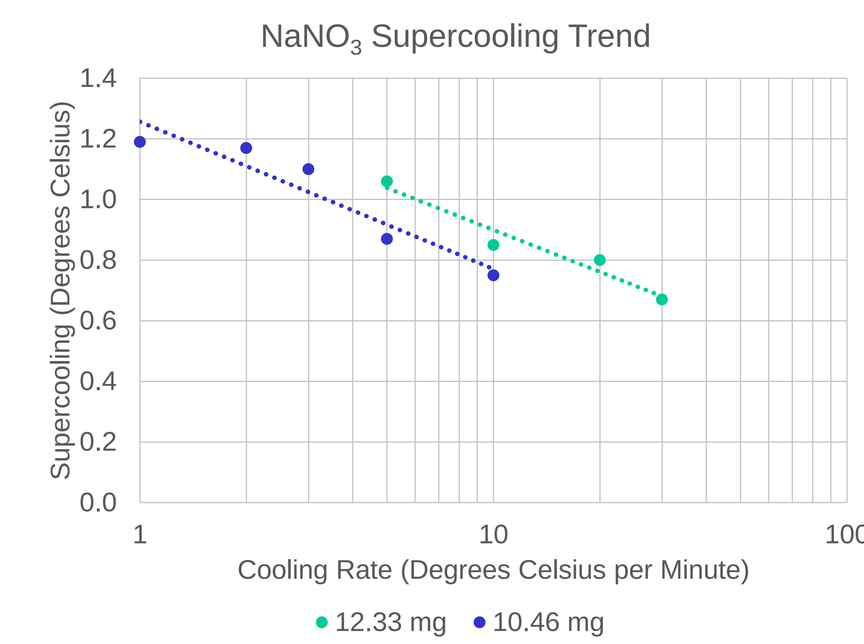

Figure 6: Sodium nitrate in DSC experiment, supercooling versus cooling rate shown. Mass variation shown, direct relationship between mass and supercooling is opposite of expected result

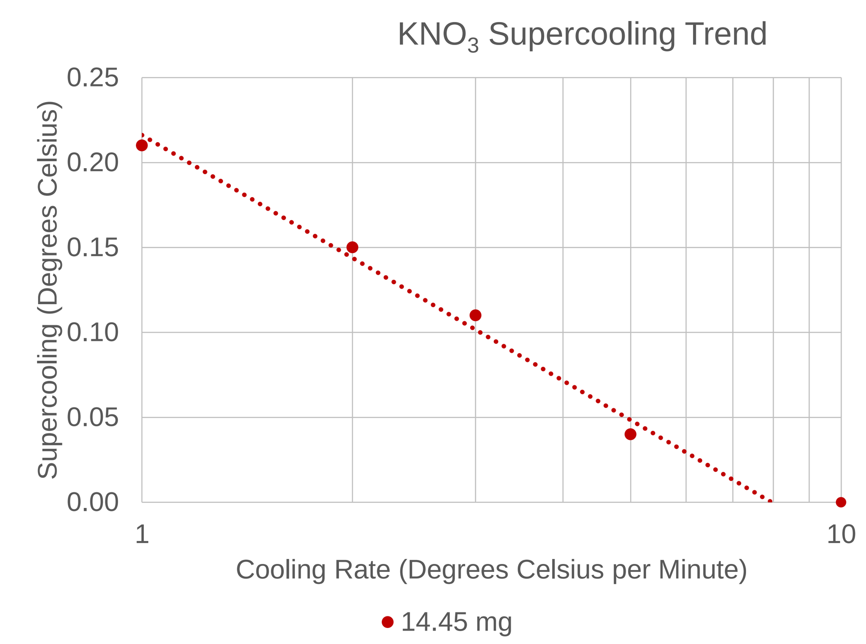

Figure 7: Potassium nitrate supercooling effect versus cooling rate. Supercooling threshold shown where trend intersects at 8 degrees Celsius per minute. Smaller sample showed no supercooling

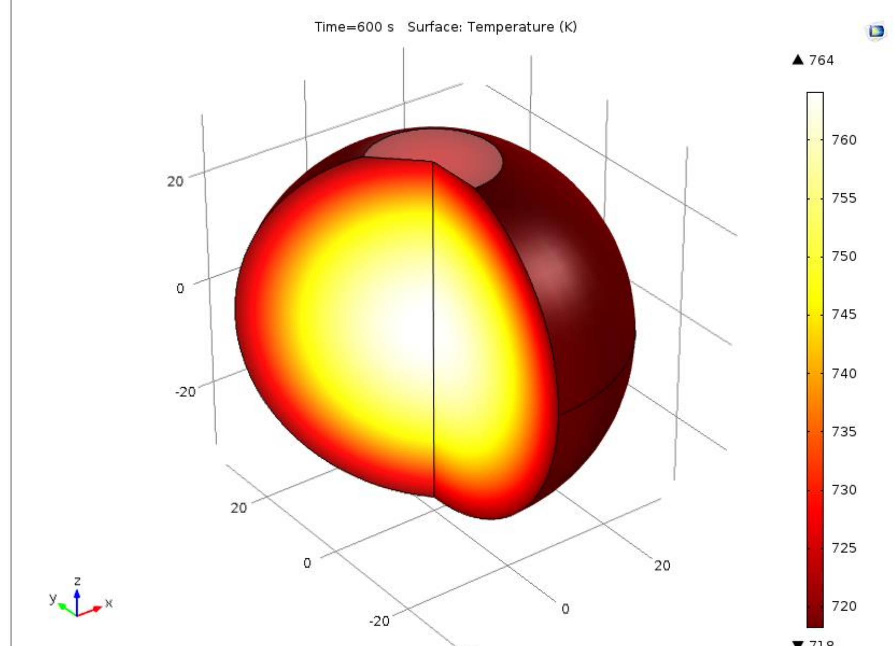

Figure 8: Predicted temperature profile at time of freezing at minimum heat flux of 4000 W/m²

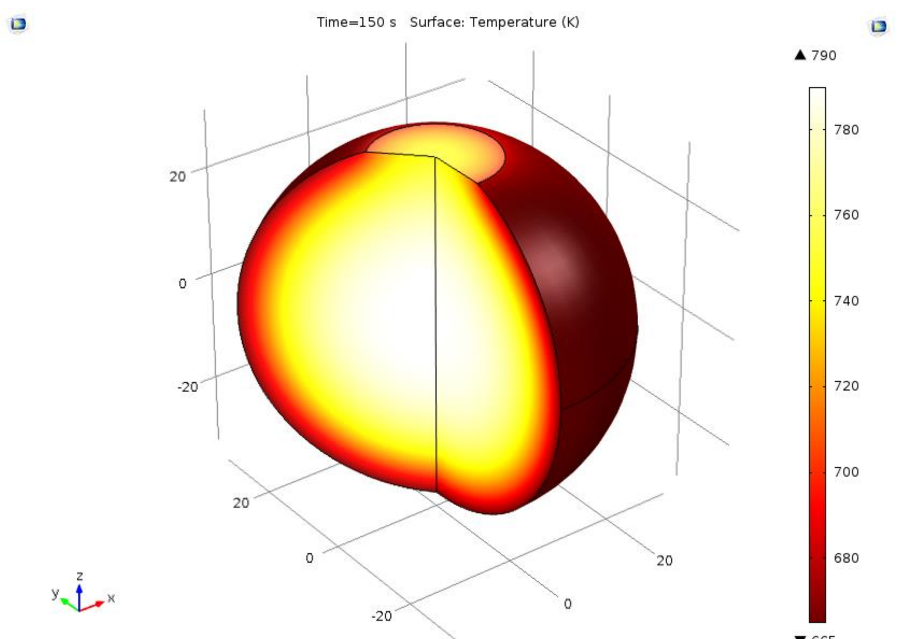

Figure 9: Predicted temperature profile at time of freezing at maximum heat flux of 180000 W/m²

Next Steps

- Complete remaining trials of final phase (Phase 3) of supercooling experimentation in salt bath, including both FLiBe and FLiNaK runs.
- Determine a quantitative correlation for supercooling in FLiBe and FLiNaK that factors in rate of cooling, sample mass, and other factors in freezing such as surface roughness or sample purity.
- Scale experiment to be larger or smaller if necessary in order to verify accuracy of experiment in important size regimes.
- Perfect the model to use this correlation to account for supercooling and verify correlation by comparing model results to experimental results.

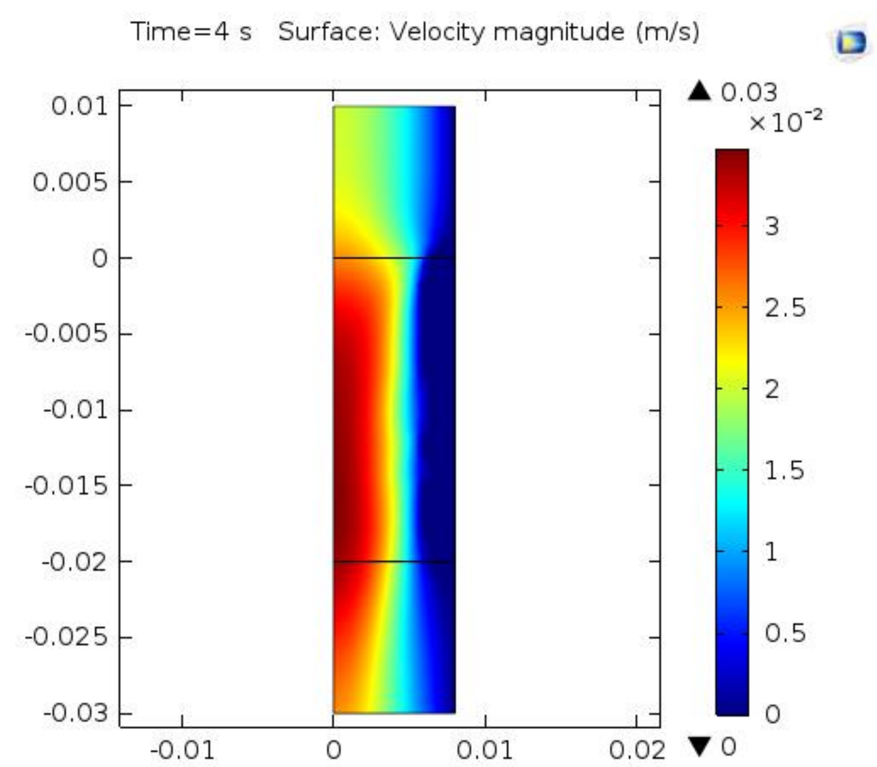

Figure 10: Predicted velocity profile during a pipe freeze in a discreet pipe section

- The next large experiment in this research is the Molten Salt Pipe Freezing Experiment:
  - Investigate the effect of removing heat from a discreet section of pipe in which molten salt is flowing by tracking the temperature profile and freezing front in multiple dimensions.
  - Develop a metric to quantify extend of pipe freezing during a cooling event.
  - Develop an effective model for this type of freezing that accounts for the possible effect of supercooling in the pipe flow.

- The data from these experiments can be used long-term to assess the safety of FHR designs in the case of overcooling transients to determine whether the reactor can recover from the events and how long it would take to do so.
- A code can be developed that utilizes the models developed from these experiments to simulate full reactor transients and search for potential design flaws that could impede their safety during these transients.
- The Chinese research reactor SINAP can utilize the results of these studies to help determine how their FLiNaK reactor will defer from FLiBe reactors in overcooling transients as well as to verify that the transients are causing expected behavior. SINAP is an important experiment for worldwide FHR development.