RDECOM

Modeling And Simulation Of Melt Cast Explosives

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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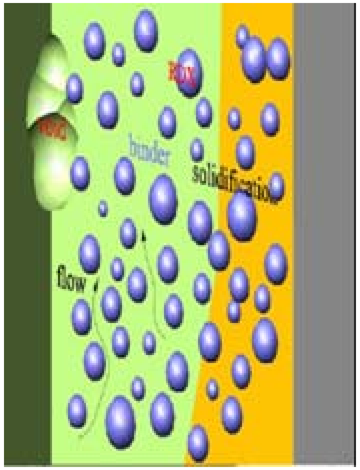
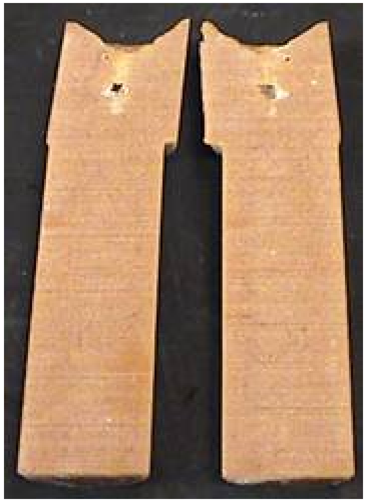
Introduction

- High energy, low-sensitivity explosives are desired for modern military applications
- Large amount of munitions are prepared by melt casting processes
- High quality explosives can be achieved using well-controlled casting parameters

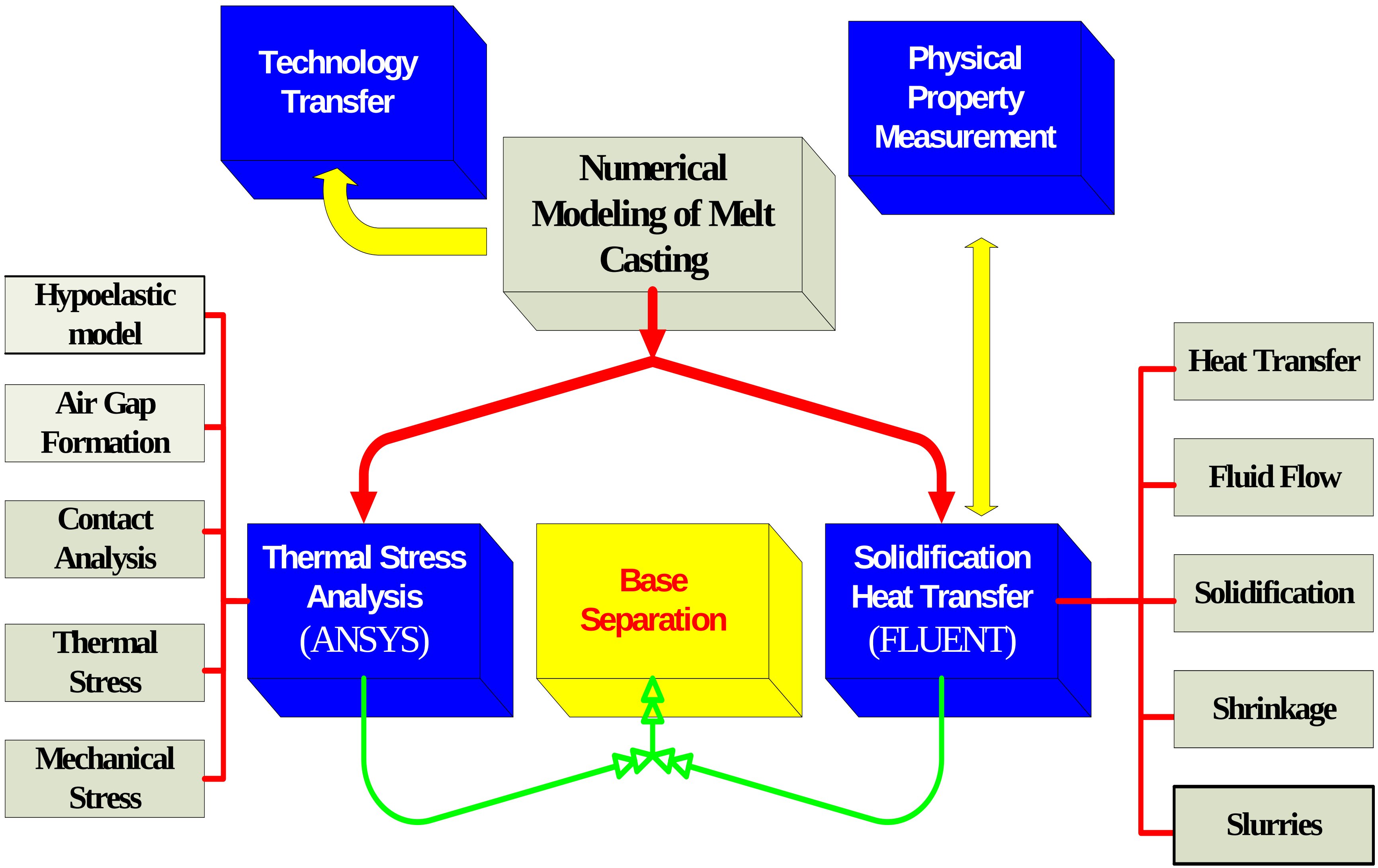
Motivation

- Component segregation
- Product non-uniformity
- Porosity and cavities
- Void formation
- Shrinkage
- Separation
- Cracks and micro-defects





Model Overview



Mathematical model

- Conservation of mass

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0$$

- Conservation of momentum

$$\frac{\partial \rho \vec{u}}{\partial t} + \nabla \cdot (\rho \vec{u}\vec{u}) = -\nabla p + \nabla \cdot \left[\mu\left(\nabla \vec{u} + \nabla \vec{u}^{T}\right)\right] + \rho_{\infty} \vec{g} \beta_{l} (T - T_{\infty}) + \frac{(1 - f_{l})}{\left(f_{l}^{3} + \varepsilon\right)} A_{mush} \vec{u}$$

- Conservation of energy

$$\rho\left(c_{p} + \frac{\partial f_{l}}{\partial T} \Delta H\right)\frac{\partial T}{\partial t} + \nabla \cdot \left(\rho c_{p} T \vec{u}\right) = \nabla \cdot (k \nabla T)$$

- Stress-strain relationship

$$\frac{\partial}{\partial t}\left(\rho \frac{\partial \vec{w}}{\partial t}\right) = \nabla \cdot \left[\mu\left(\nabla \vec{w} + \nabla \vec{w}^{T}\right)\right] + \nabla\left(\lambda \nabla \cdot \vec{w} + (3\lambda + 2\mu)\beta_{s} T\right) - \left\{\nabla \cdot \left[\frac{\sigma_{ij}^{d} \sigma_{kl}^{d}}{\vec{\sigma}^{2}}\left(\frac{9G^{2}}{H^{'} + 3G}\right)\nabla \vec{w}\right]\right\} + \vec{b}$$

Required Inputs for the Model

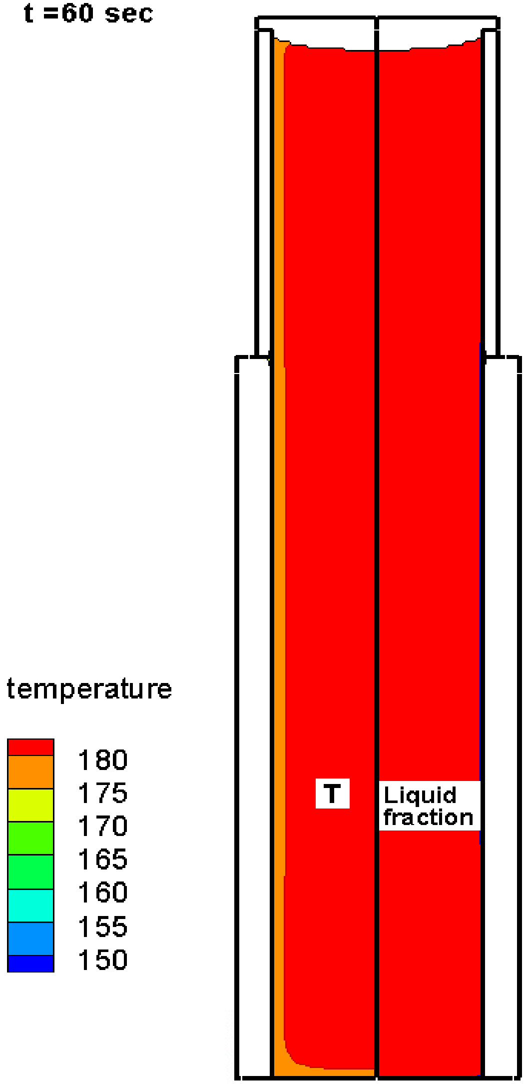
- Explosive Properties
  - Viscosity
  - Thermal conductivity
  - Thermal expansion coefficient
  - Density
  - Melting point
  - Latent heat
  - Liquid viscosity
  - Stress/strain curve

- Conditions
  - Melting temperature
  - Pour temperature
  - Projectile/metal part temperature at the time of pour
  - Operating/cooling conditions (i.e. steam panel temperature, water cart temperature, etc.)

Projectile/metal part properties: Thermal expansion coefficient, density, conductivity, specific heat

Shrinkage of TNT in a LSGT Cylinder

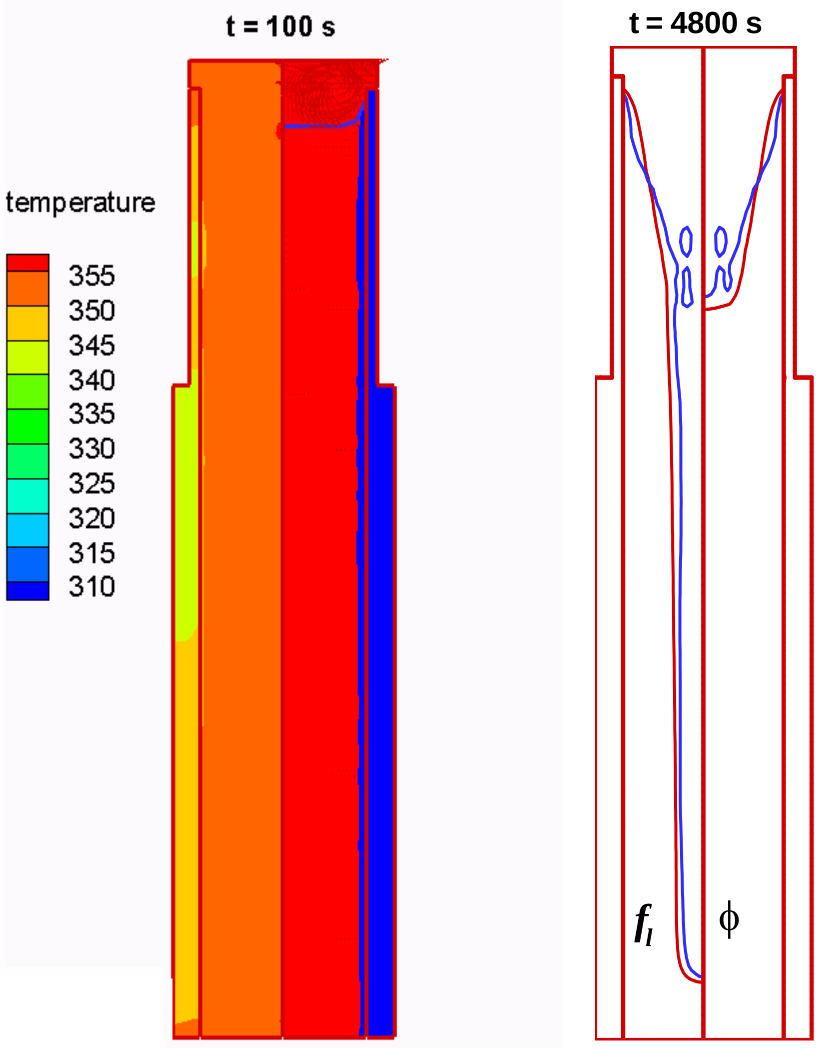
- A gap of 0.1 inch is kept between top heating plate and riser
- TNT is assumed to fill 98% of the volume in the tube initially
- Significant solidification shrinkage is observed during casting
- Very small time step has to be used to the strong nonlinearity of the process



Improvement

- Shrinkage of TNT in a cylinder under new experimental conditions is studied
- Faster solidification rate is observed under new cooling conditions
- It is expected that the shrinkage penetration depth in the new case is less the old one, confirming the experimental results

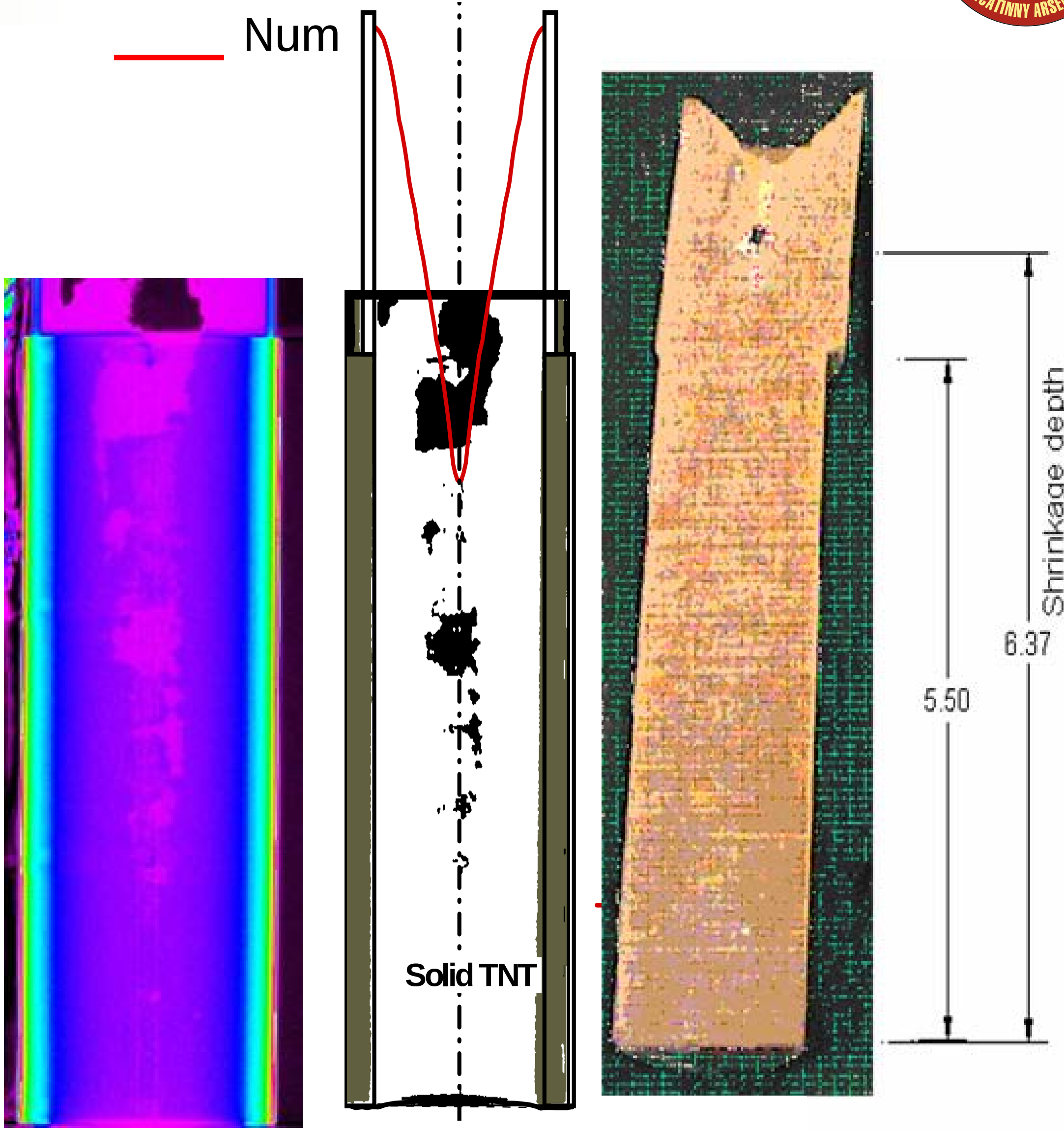
(Temperatures are in Kelvin)



Red: old, blue: new

Comparison of shrinkage shapes

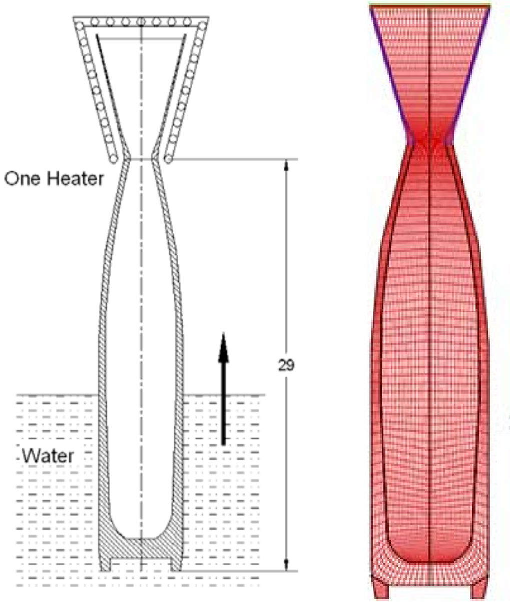
- CT scans are used to obtain shrinkage information
- Reconstructed shrinkage shape is superimposed on the numerical prediction
- Agreement between predicted and measured shrinkage shapes is satisfactory
- Significantly less shrinkage cavity is observed using new cooling conditions



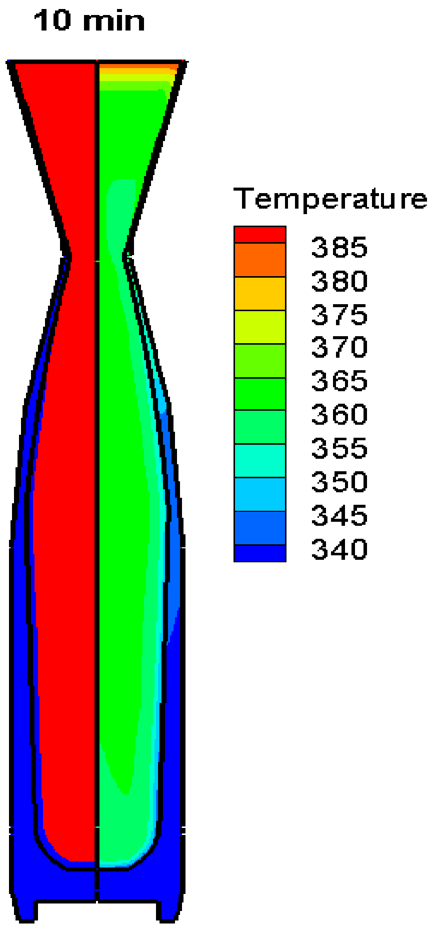
Casting of PAX 196 in M795

Conditions applied are:

- Pouring temperature: 190ºF
- Cooling conditions:
  - 0-6 ½ hours – water cooling: 145ºF
- > 6 ½ hours – ambient air cooling ~100ºF
- Heating conditions:
  - 0-3 ½ hours – steam heating: 260ºF
  - > 6 ½ hours – no heating, natural cooling



Solidification Behavior

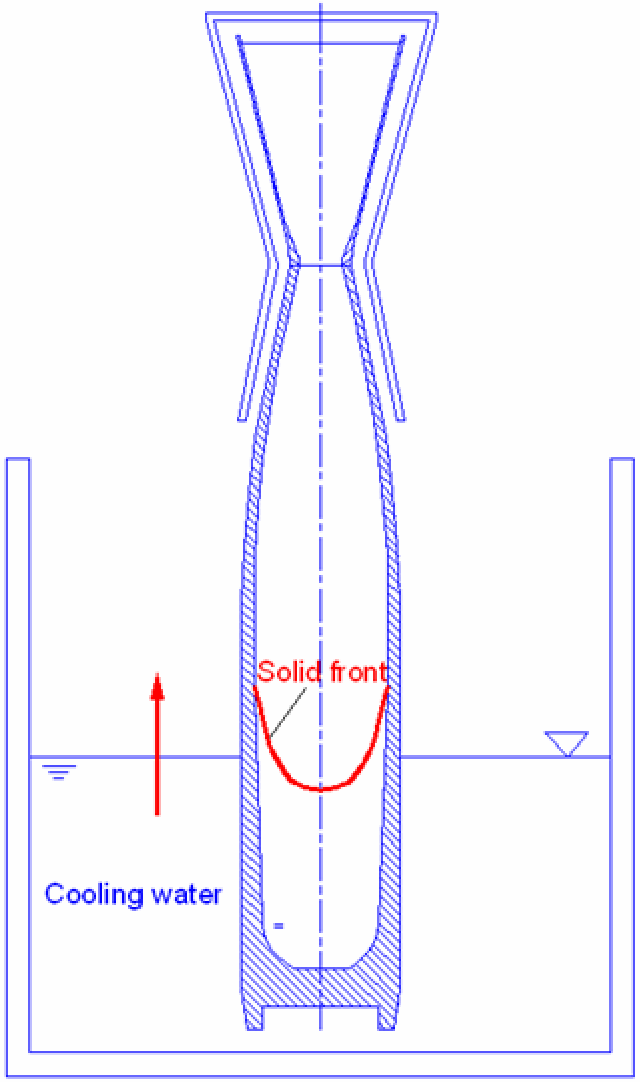


(Temperatures are in Kelvin)

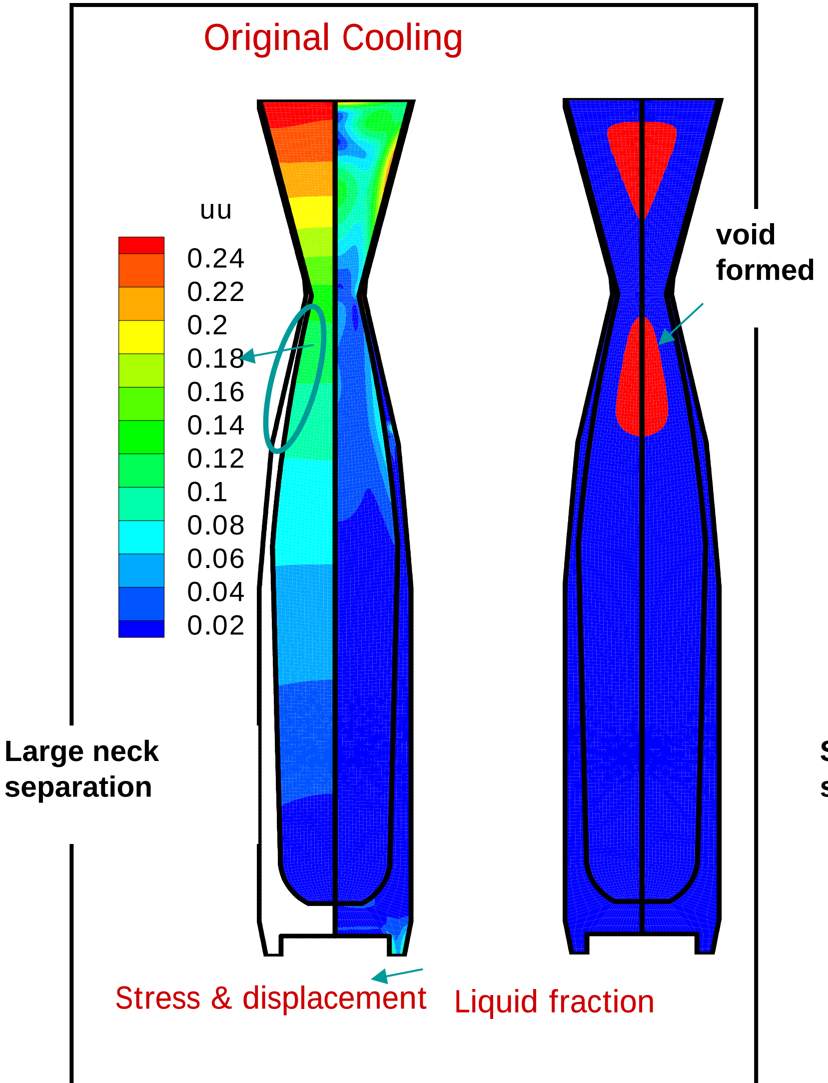
- Explosive near the neck region solidifies after that in the projectile
- A small void will be formed near the center of the projectile
- It takes ~10.5 hours for the solidification process to complete
- Large temperature gradient exists in region below the steam heater; this is the part where separation is expected to occur

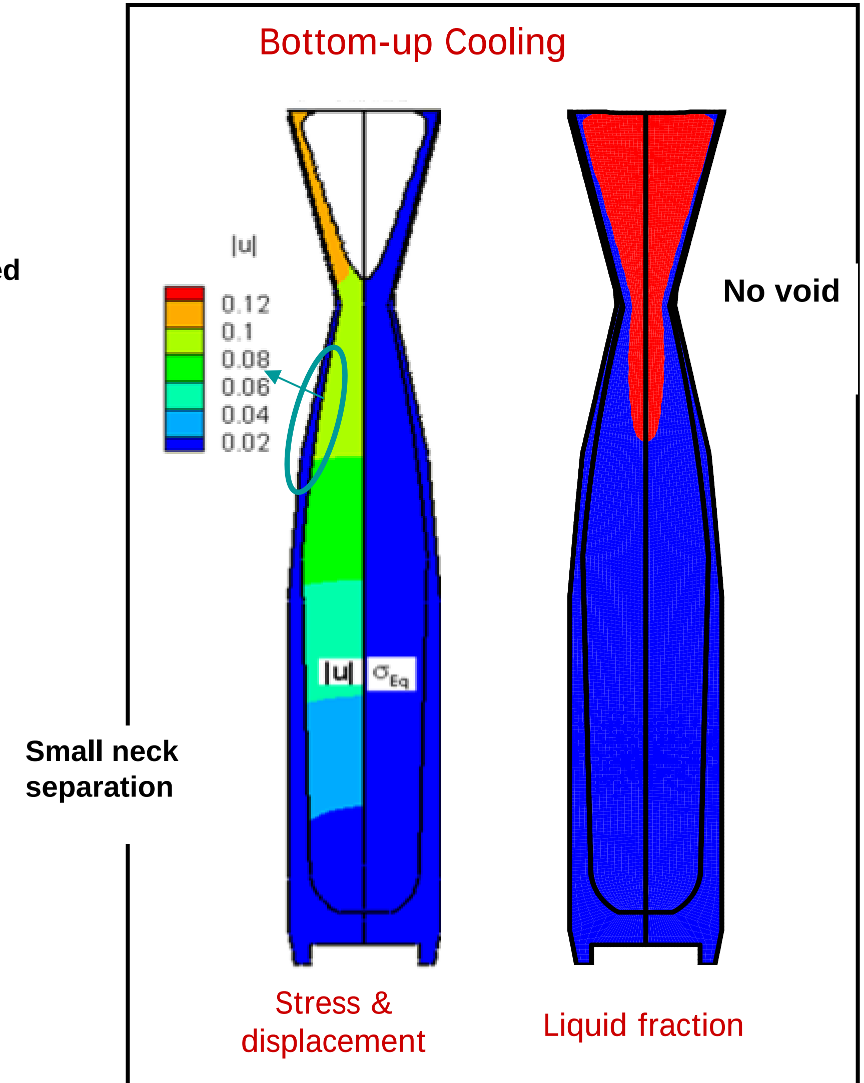
Bottom up cooling

- Cooling water was gradually filled into the water cart to make the solid front move in a relatively flat shape and from bottom to top, referred to as "upward solidification"
- Steam heater is held at **220F** for the first 6.5 hours, and then gradually decrease to **160F** at a rate of **-1 F/min**

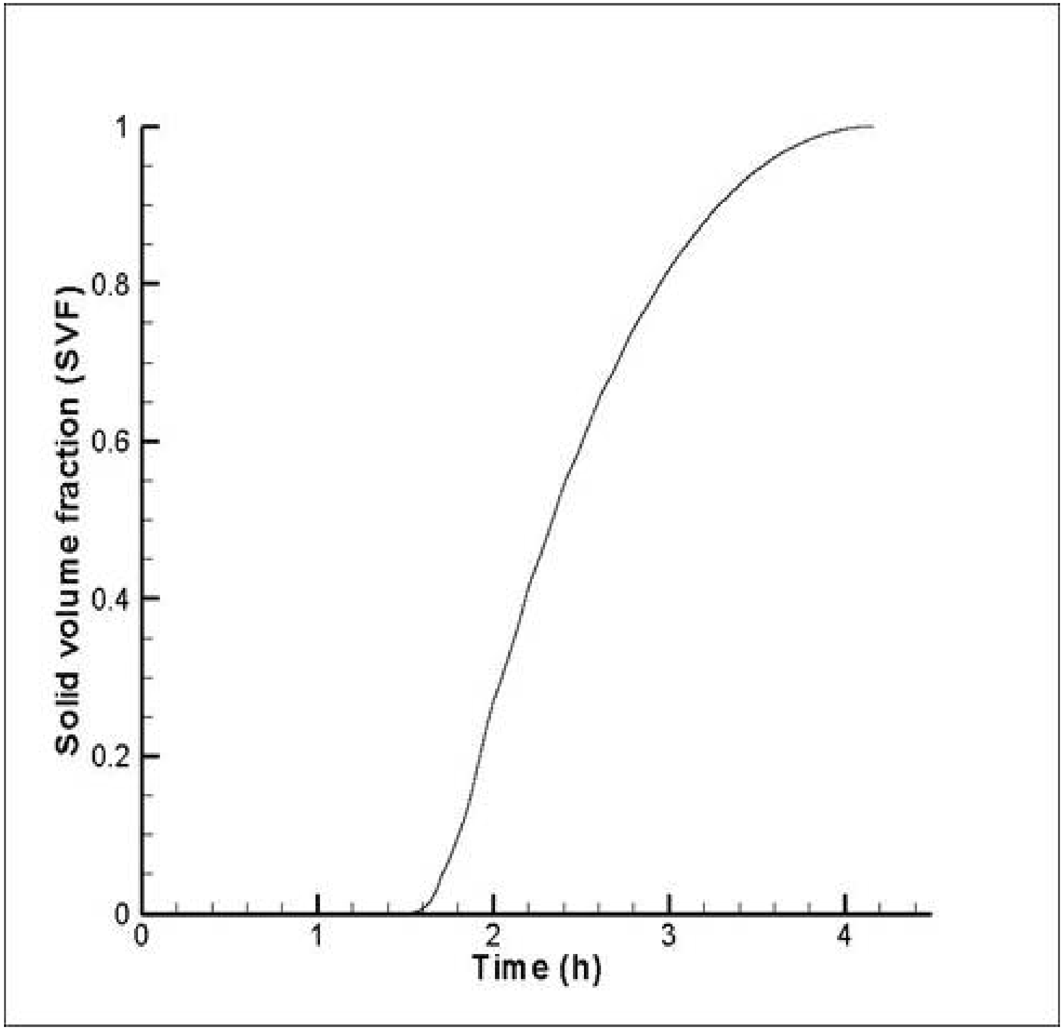


Displacement comparison

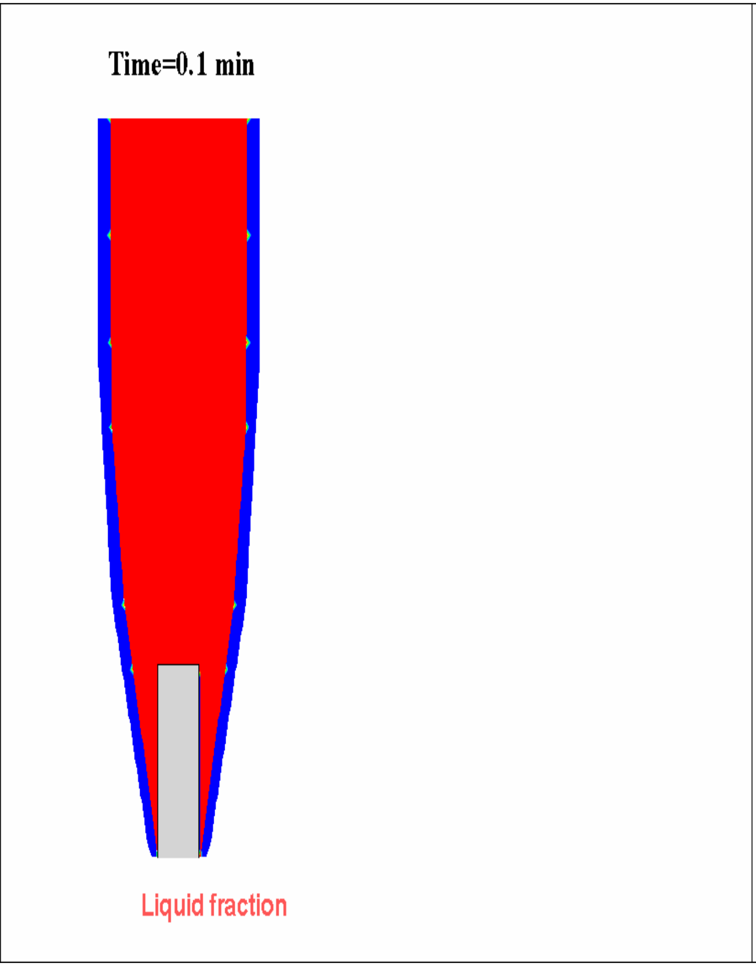


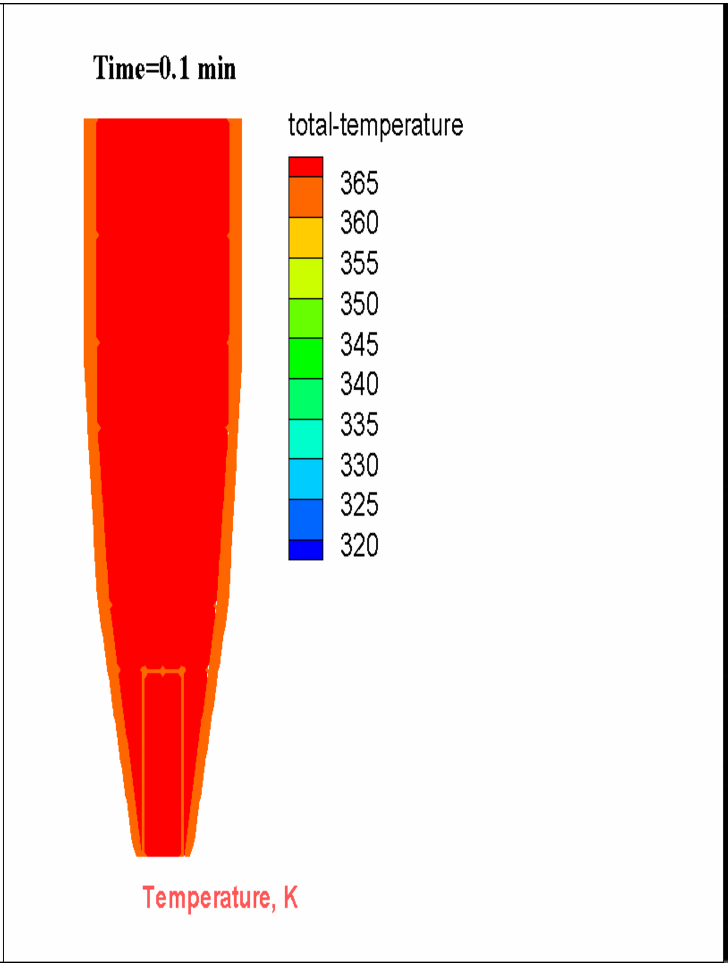


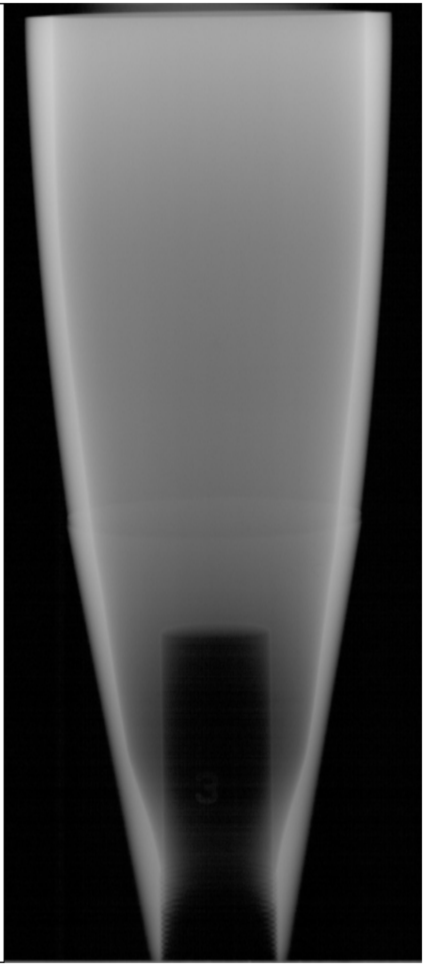
Casting of MCX-8-II in M795 Ogive section



Numerical and Experimental results







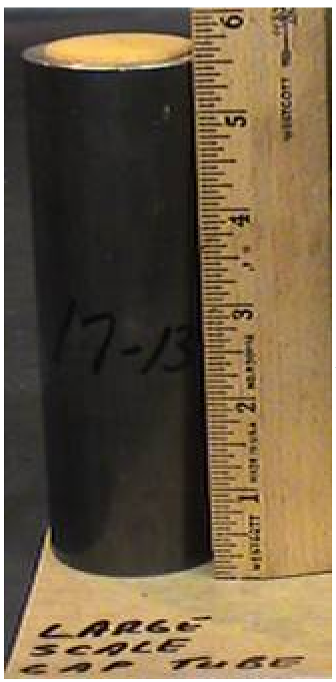
Conclusions

- A rigorously validated numerical model is developed for melt casting
- Numerical modeling offers extensive capabilities to analyze complex physical phenomena in melt casting.
- Engineering challenges such as solidification shrinkage, voids formation and base/neck separation can be addressed using our advanced model.
- Numerical simulation can significantly cut production cost and time for R&D.
- Process optimization, which can enable large-scale munitions production, can be achieved by using numerical parametric studies.

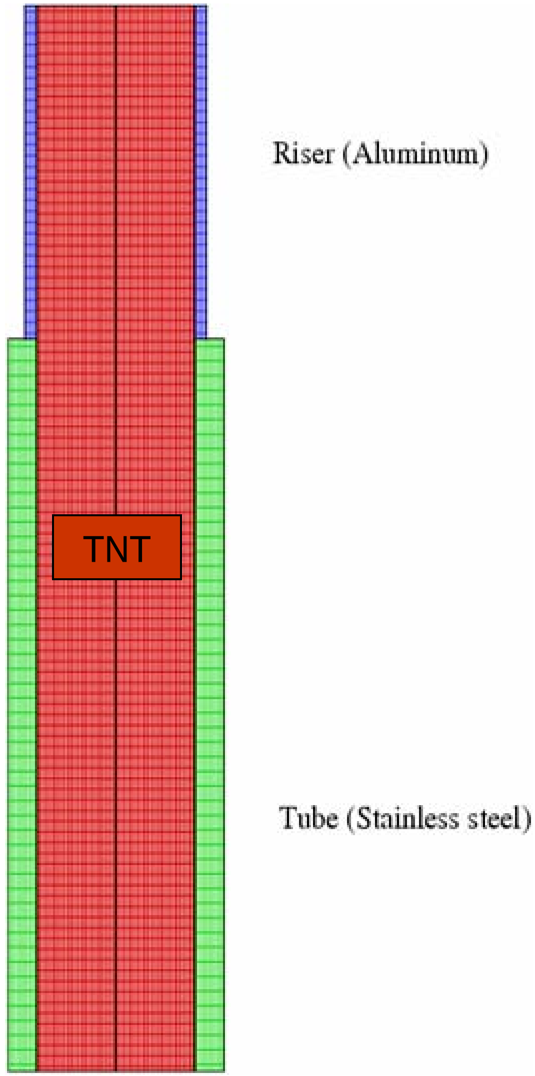
Backup

Casting of TNT in LSGT

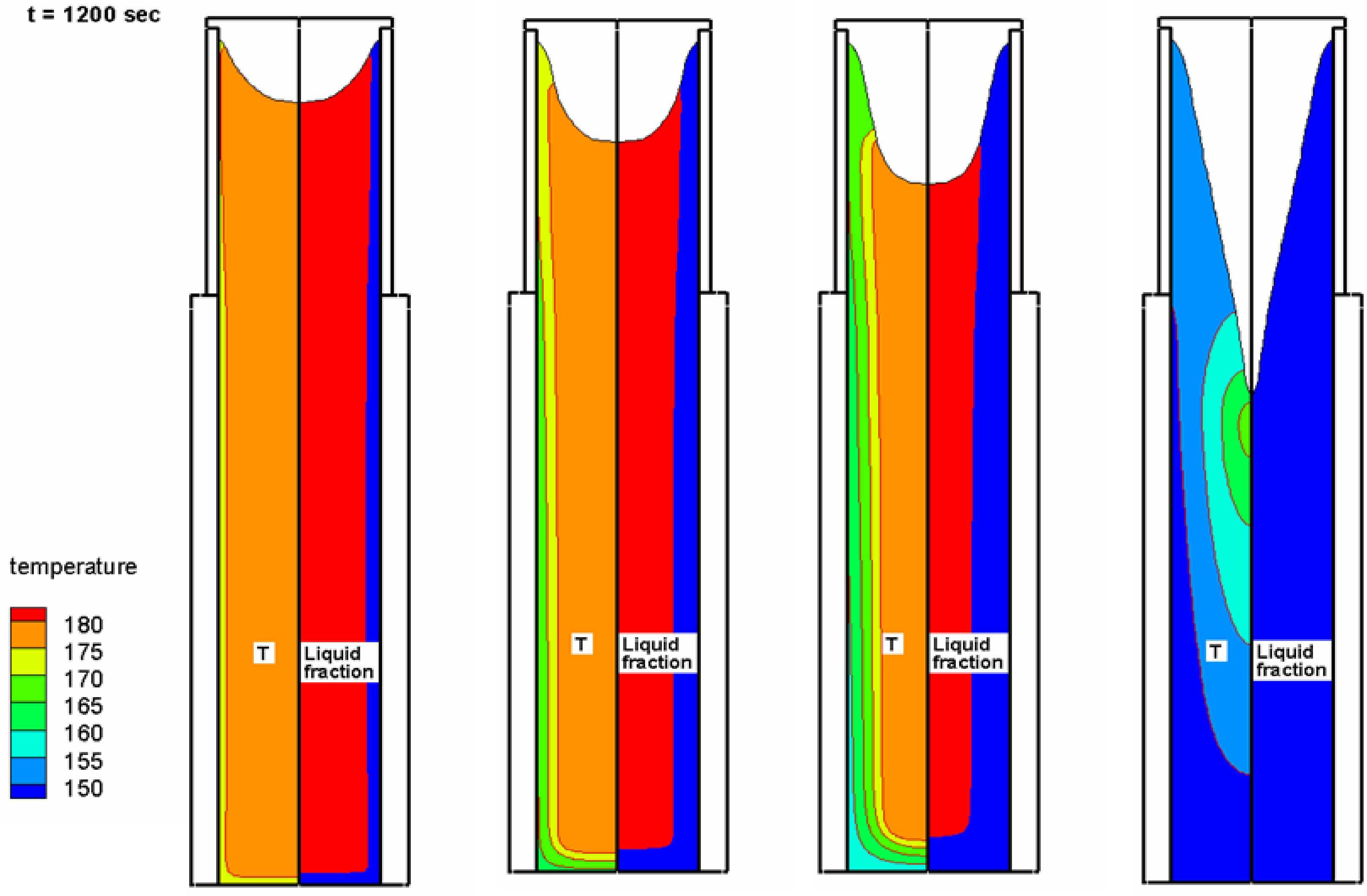
Riser



Tube



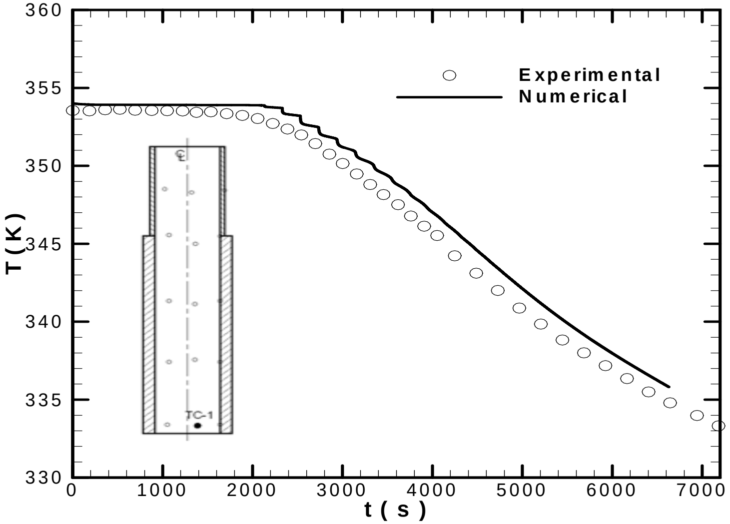
Temperature and Free Surface Evolution

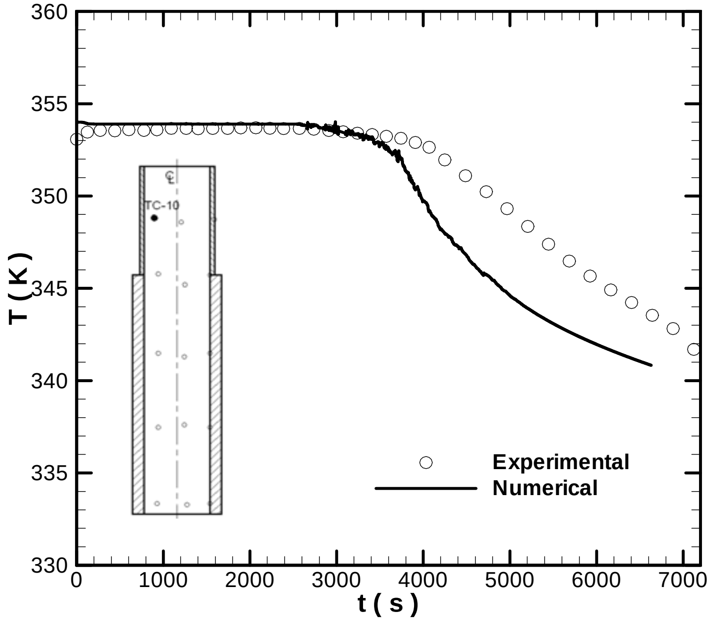


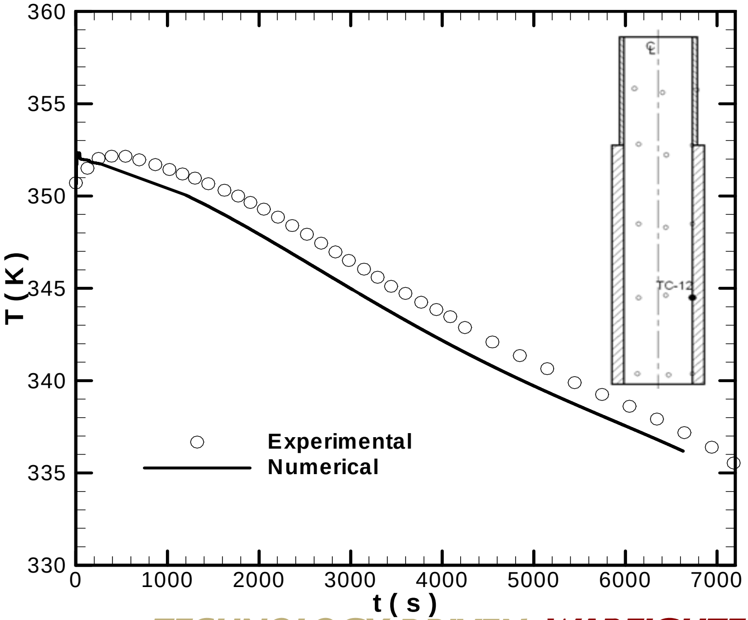
t = 20 min   t = 40 min   t = 80 min   t = 110 min

Model Validation

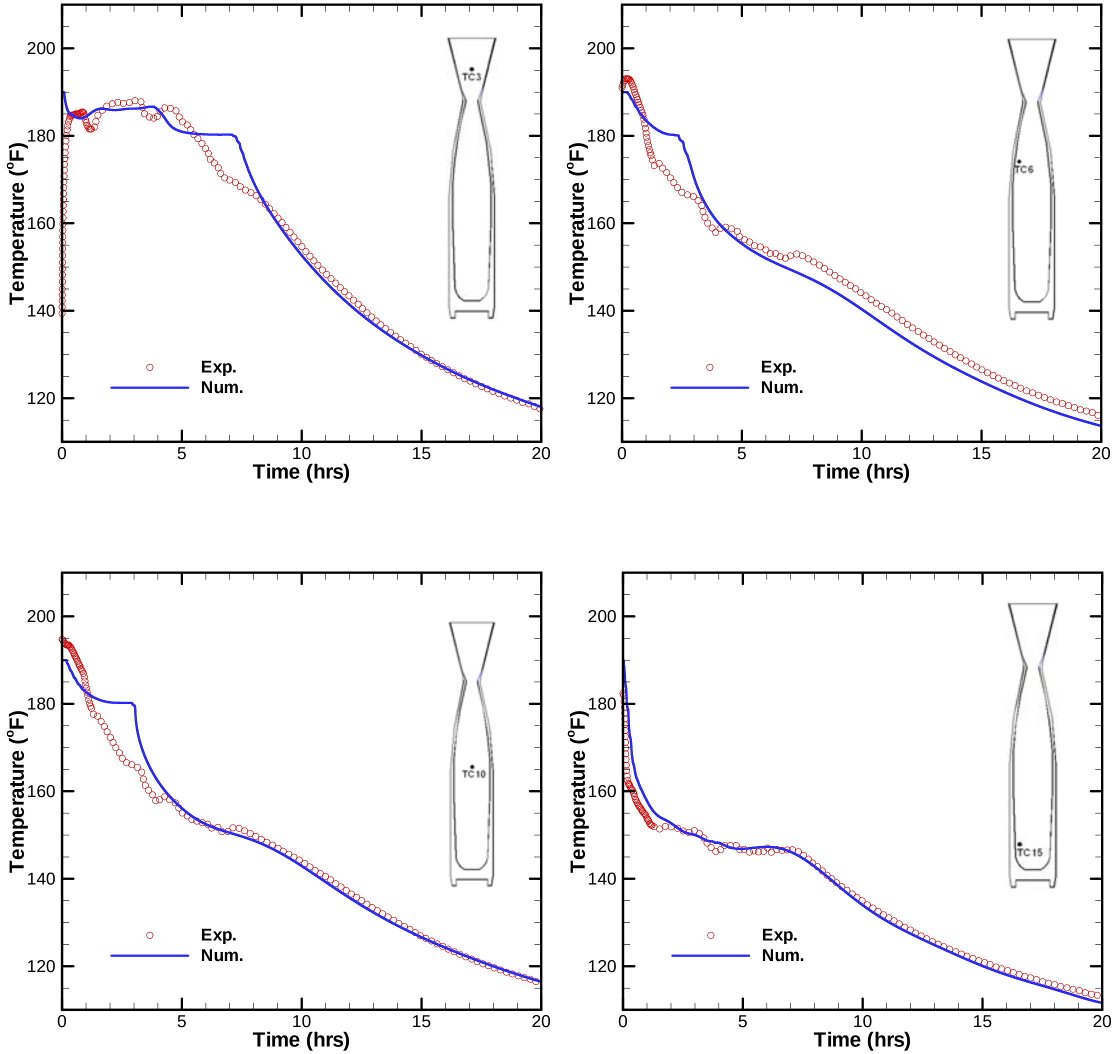
- Good agreement is observed between experimental and numerical data







Comparisons at Selected Locations



- Satisfactory agreement is observed by comparing experimental measurements and numerical predictions

Dynamic Water Level Changes