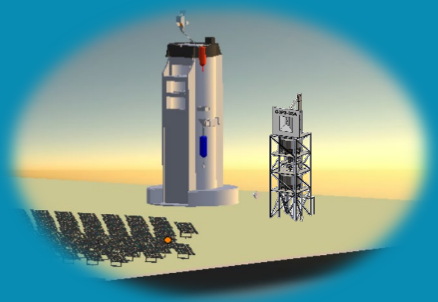
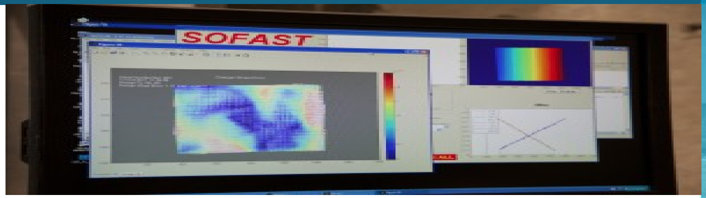
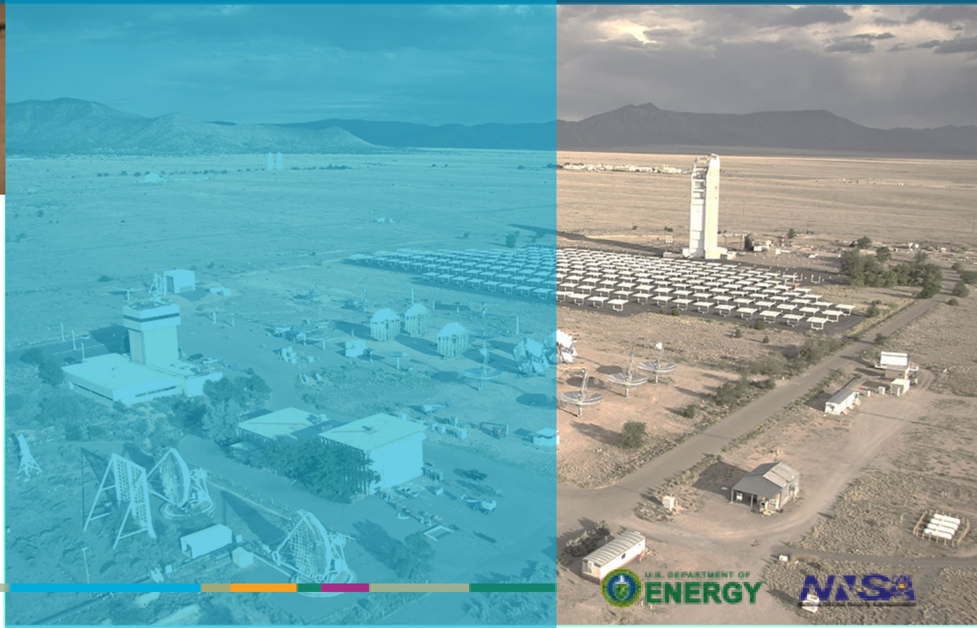
Sandia National Laboratories

OPTIMIZATION OF STORAGE BIN GEOMETRY FOR HIGH TEMPERATURE PARTICLE-BASED CSP SYSTEMS







Gen 3 Particle Pilot Plant (G3P3)

Jeremy Sment, Kevin Albrecht, Joshua Christian, Clifford K. Ho

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Overview

- Introduction to G3P3 and Hot Particle Storage Design Considerations
- G3P3 Hot Particle Storage Vessel Design
- Design Analysis
  - Static
  - Cyclic Steady-State
- Conclusions and Next Steps

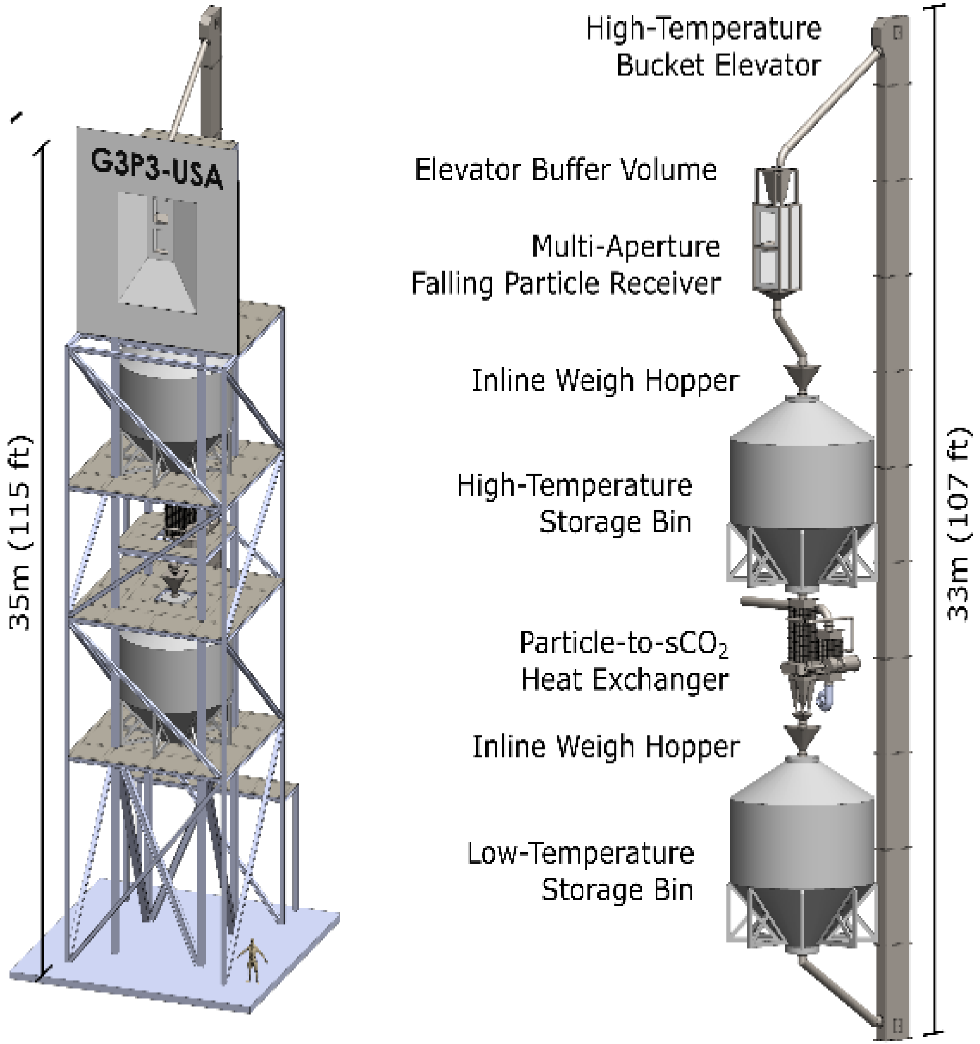
G3P3 and Hot Particle Storage

G3P3 1MW$_t$ pilot will be a vertically integrated falling particle receiver with 6MWh of thermal storage.

- ~100,000 kg of flowing particles
- Up to 60 m^3 of storage volume

Target particle inlet temperatures to hot storage bin will be ≤ 800° C and must be between 765-775° C upon outlet. Cold storage will have inlet temperatures ~600° C.

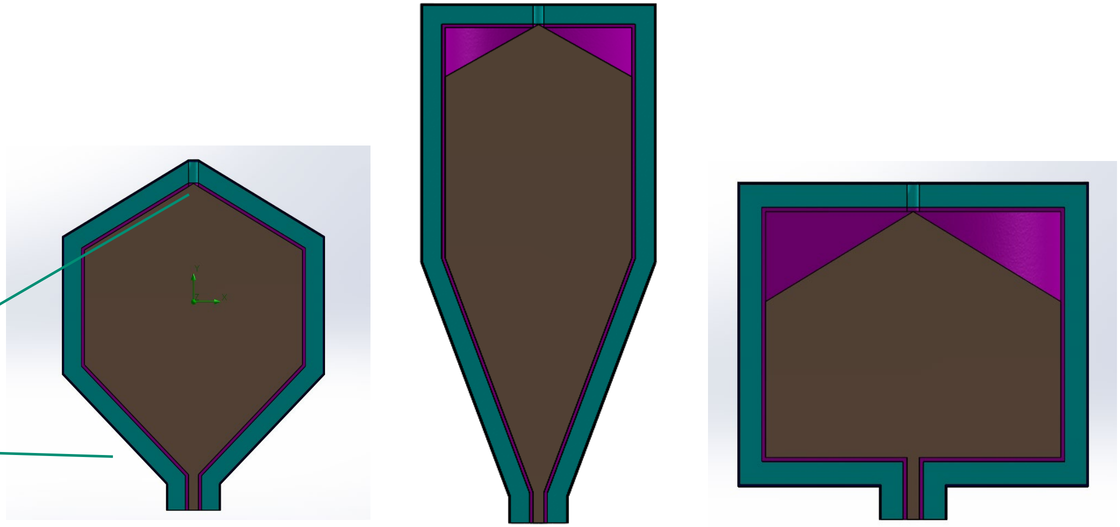
Storage tanks will be internally insulated to minimize thermal stresses on metal shell and tower connections.



Project Objective

Determine the basic geometry of the G3P3 particle storage bin. Use the metrics of heat loss and container stress to evaluate designs.

- Top Angle: compare solid fill vs. partially filled concepts.
- Bottom Hopper Angle: Mass Flow vs. Self Cleaning
  Funnel Flow vs. Flat-bottom (stagnant)
- How much does form factor affect heat loss and container stress?



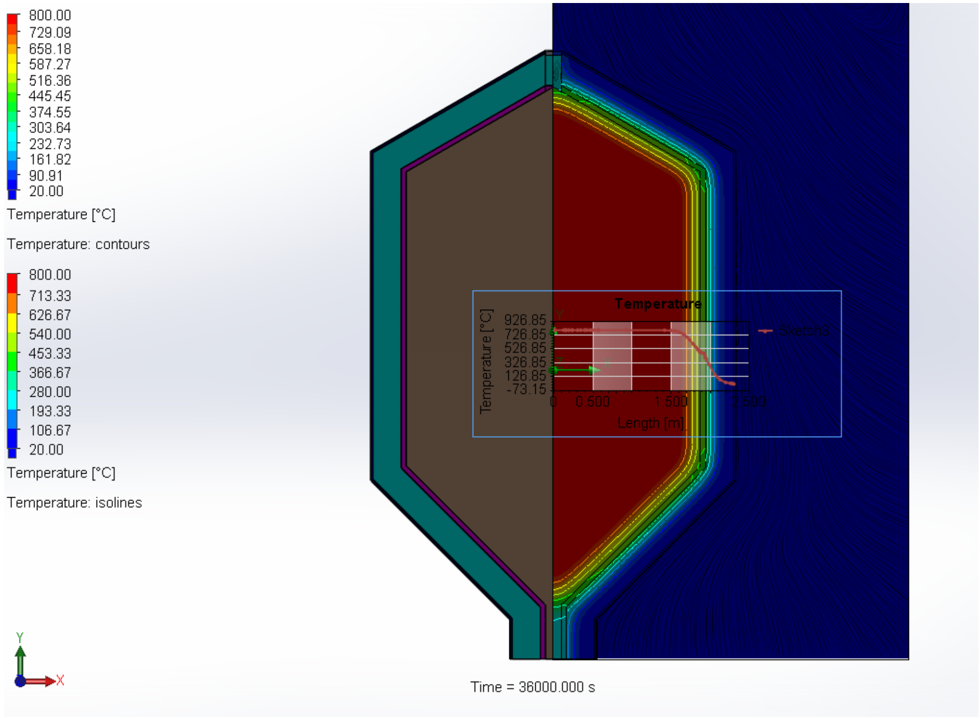
10 Hour Heat Loss in Initially Cold Tank

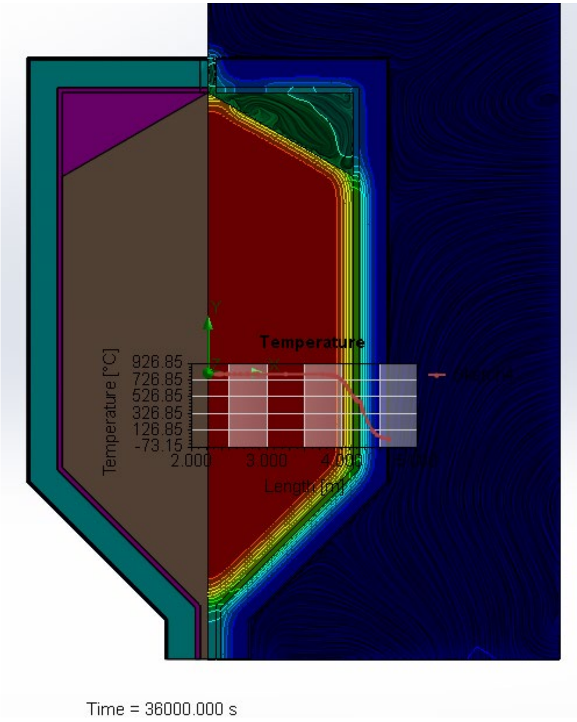
Time Dependent analysis was run to 10 hours

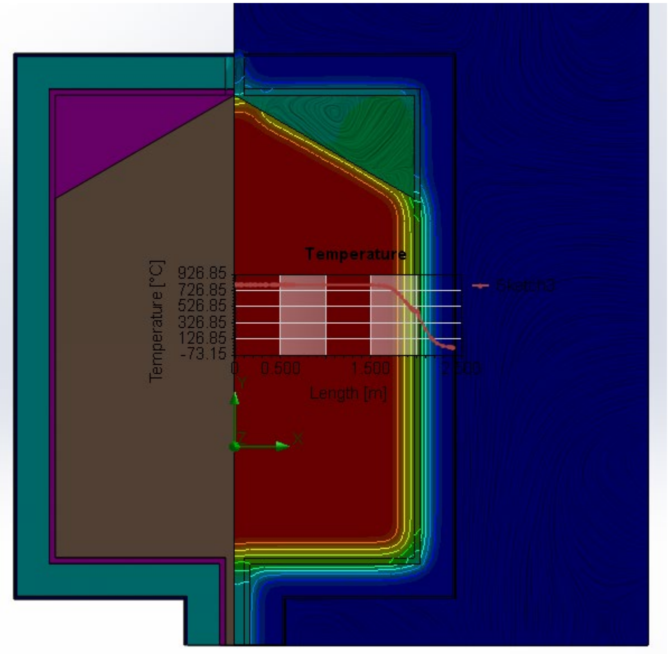
- Initially 20°C bin filled with 800°C particles
- Held for 10 hours where heat is transferred to refractory layers

Solid Filled (angled top) and Partially filled (flat top and flat bottom) designs were tested with buoyancy effects

Form factor varied with height to diameter ratios of 0.5, 1, and 2



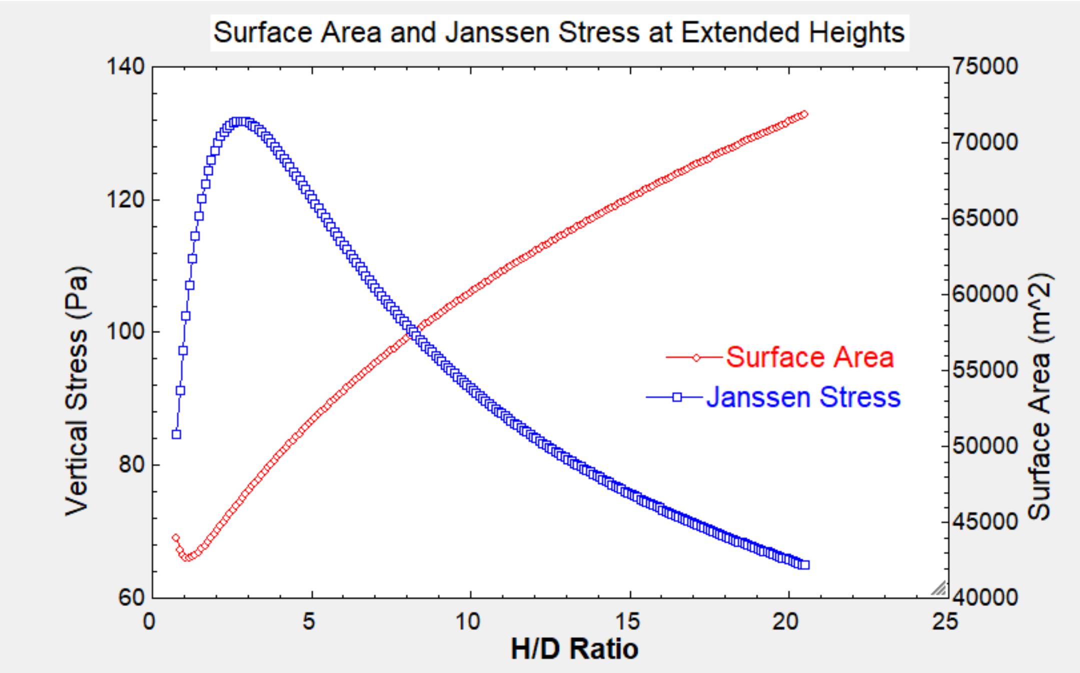


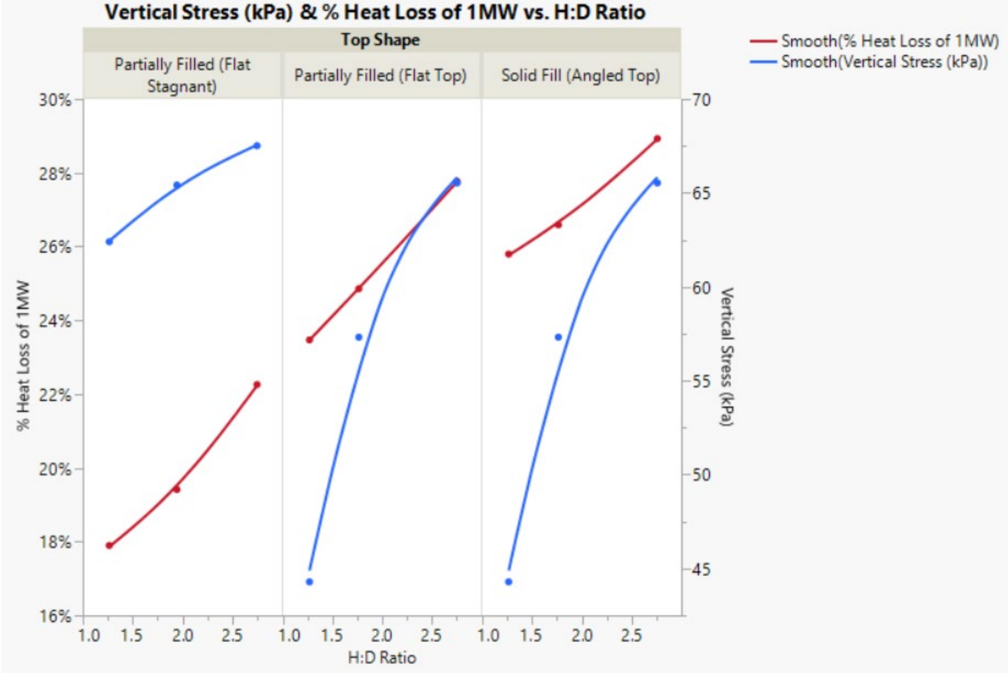


Optimization of Stress vs. Heat Loss: Results

Stress decreases with elongation due to the Janssen effect but heat loss also increases with elongation as surface area increases.

- Both factors are near minimum with minimum surface area geometry
- Reduction of floor area is a dominant factor over Janssen effect in size regime of 1MW_t bin.
- Partial fill vs Solid filled storage may be a significant consideration as solid fill loses slightly more heat to refractory ceiling material than air in the top of the tank.
- Surface area increase is nearly linear in 1MW size regime. Model of heat loss follows surface area curve.
- Heat loss may be less in flat bottom bins due to the insulative effects of the stagnant floor particles. Higher stress due in part to additional mass from stagnant particles on floor.

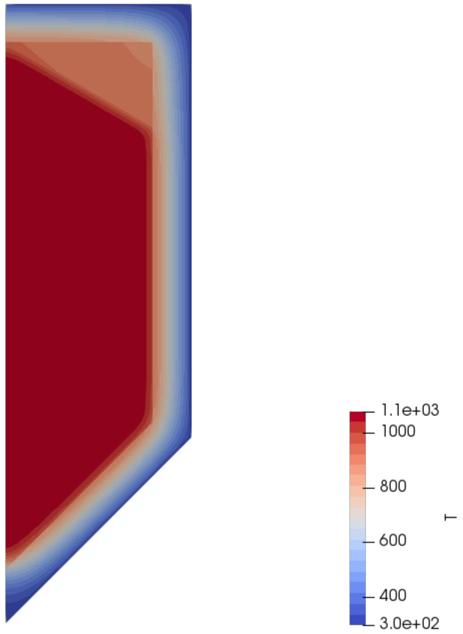


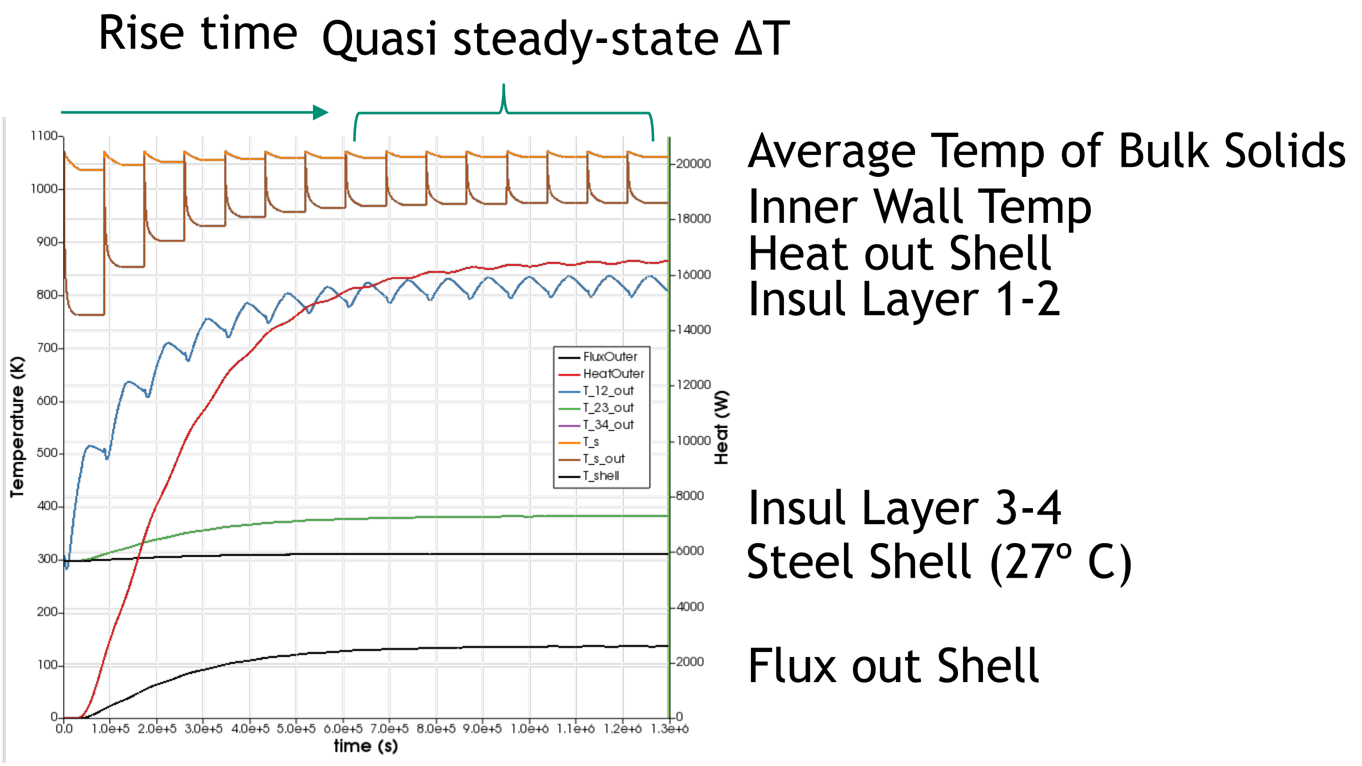


Cyclic Analysis

Cyclic analysis was run to quasi-steady-state conditions (model by Kevin Albrecht)

- Initially cold bin filled instantly with 800°C particles
- Held for 10 hours where heat is transferred to refractory layers
- Discharged instantly and held empty for 14 hours
- Repeated daily until heat loss reaches quasi-steady-state
- Form factor varied with height to diameter ratios of 1, 2, and 4 (6.58m, 8.47m, 9.79m heights respectively)





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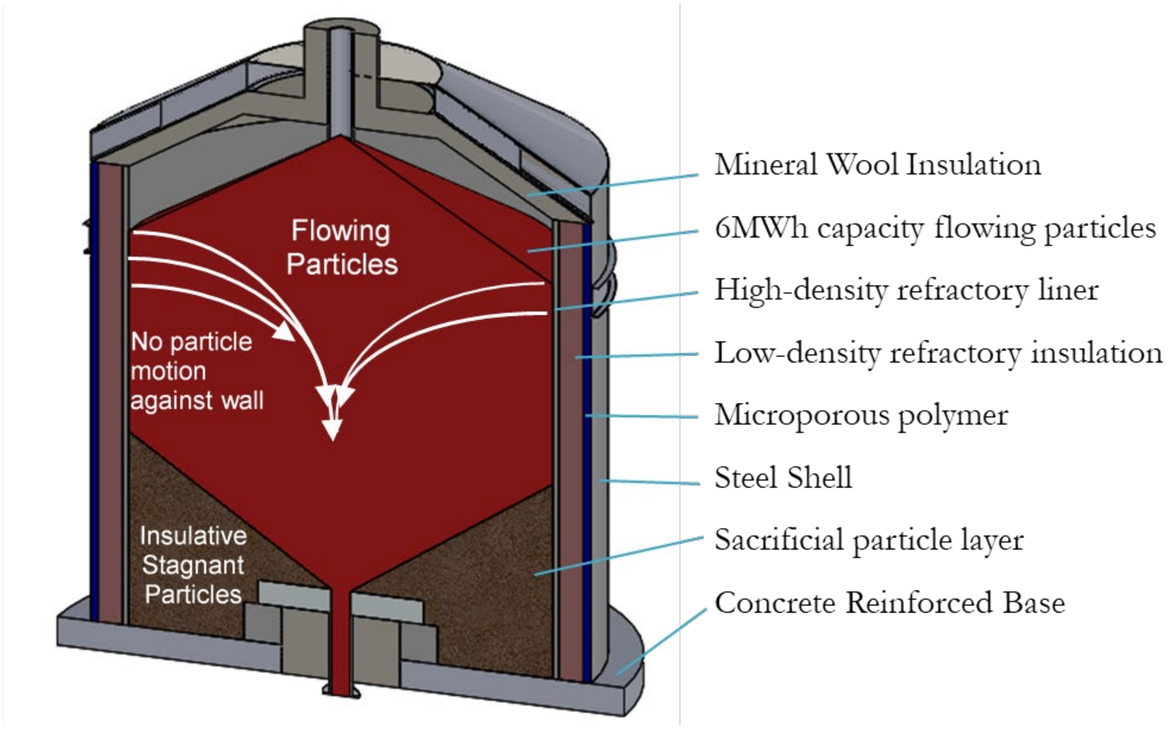
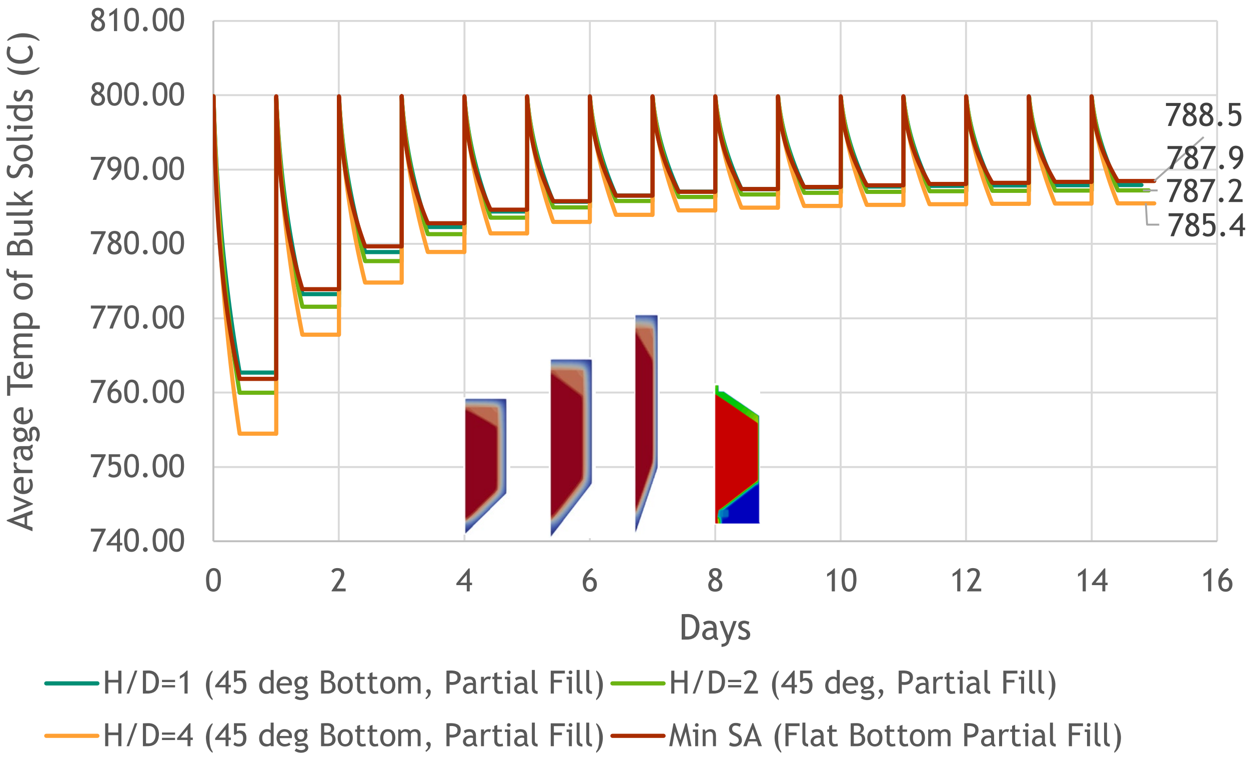
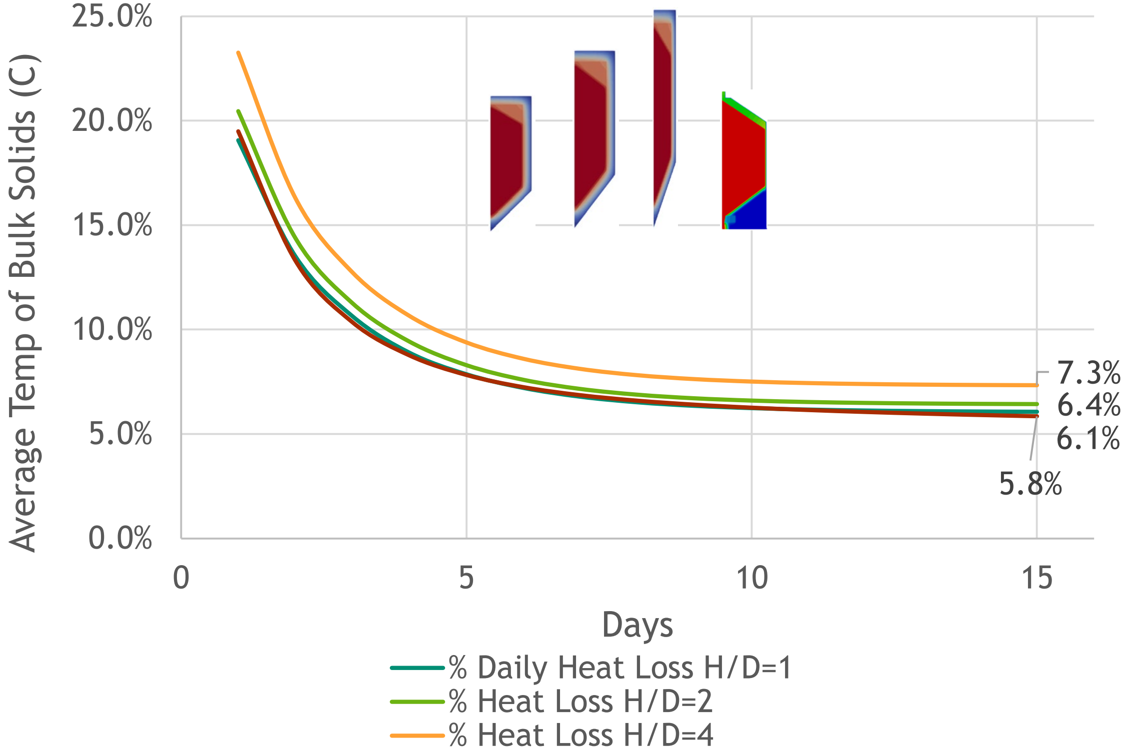
- Form factor varied with height to diameter ratios of 1, 2, and 4
- Modeled initial G3P3 design: Min SA, Flat bottom, without bottom insulation



Cyclic Analysis

- The temperature differences shown for the first 10 hours were significantly less (~1%) from shortest to tallest ratio after coming to quasi steady state
- Cycle time to steady state was similar for all geometries (~10 days).
- Dynamic filling and discharging is expected to increase heat loss, models are being developed.





Conclusions

Heat loss and container stress were used as metrics to inform decisions on hot particle storage geometry.

- Heat losses are significant and proportional to surface area (SA) in the first 10 hours as the refractory absorbs heat from the particles, however, cyclic models show that these losses diminish significantly after about 10 days of cycles and the thermal losses in elongated tanks may be practically comparable to those with minimal SA.
- As bins elongate, stresses decrease due to the reduction of the repose heap and the Janssen effect, but in the size regime of minimal SA, floor stress is dominated by the reduction of floor area more than the Janssen effect.
- Since there is minimal benefit to elongation as a means of reducing floor stress in the min SA size regime, the G3P3 storage design uses a geometry that minimizes the flowing surface area.
- Stress and heat loss measurements were significant factors in the choice of floor and roof angle. The G3P3 storage min minimizes surface area and stress and utilizes stagnant particles on the flat bottom to gain addition insulative performance.

Next Steps

- Thermal Analysis During Dynamic Flow
- Analysis at Commercial Scale

Acknowledgments

SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

This work is funded in part or whole by the U.S. Department of Energy Solar Energy Technologies Office under Award Number 33869

- DOE Project Managers: Matthew Bauer, Andru Prescod


Questions

Thank you!