Addressing Failures in Molten Salt Thermal Energy Storage Tank for Central Receiver Concentrating Solar Power Plants

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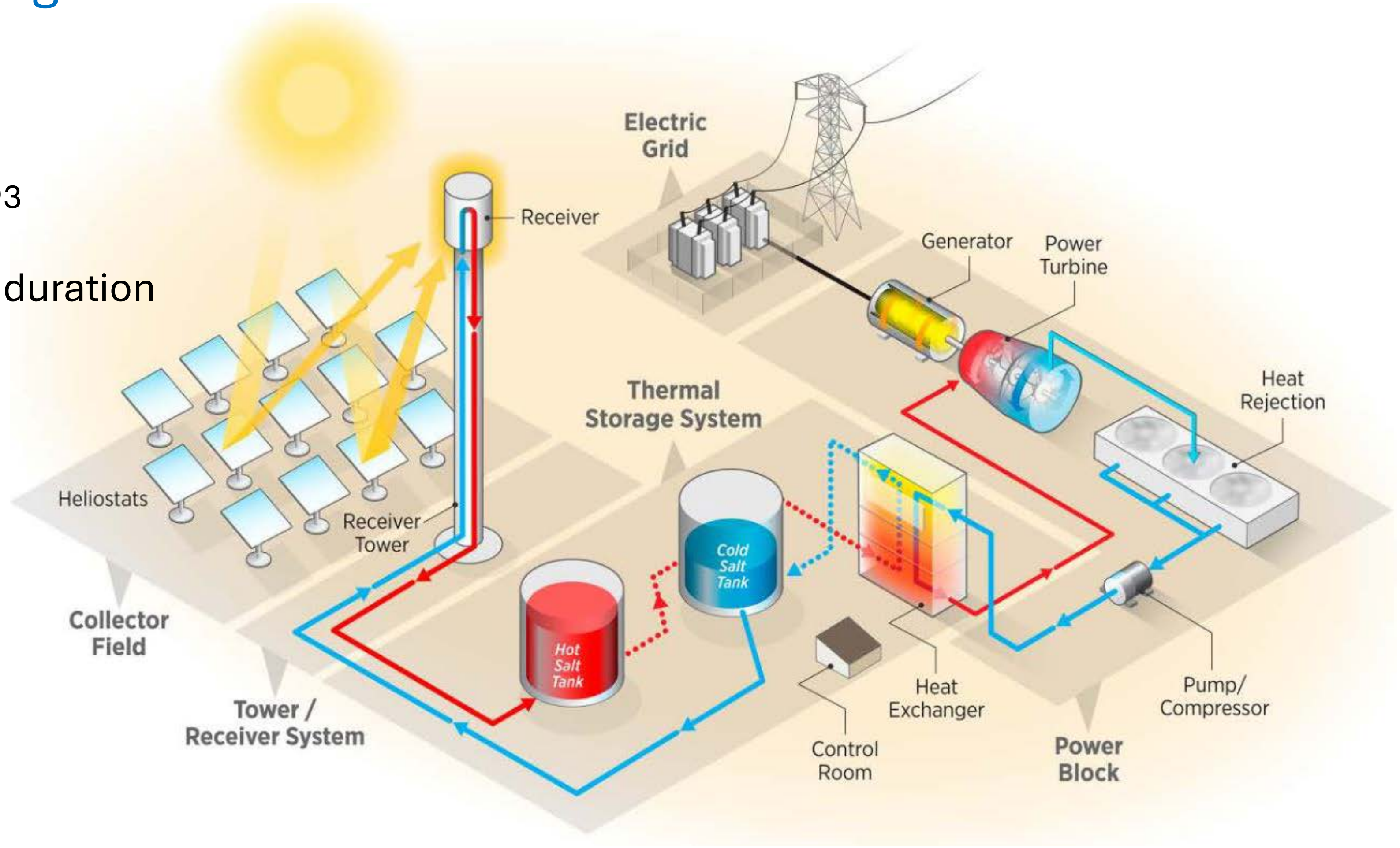
6th Thermal-Mechanical- Chemical Energy Storage Workshop
Charlotte, NC
July 31 - August 1, 2024
NREL/PR-5700-90714

Central receiver CPS Plants

Molten Salt Thermal Energy Storage

- Hot tank: 347H stainless steels, 565°C.
- Salt composition: 60% $NaNO_3$ – 40% KNO_3
- Commercial GWh energy storage at 10+ h duration
- Low capex
- Existing industry for valves and pumps
- Well-understood heat transfer properties
- Increase in capacity factors
- Levelized cost of Electricity
- Lower intermittent operation for the power cycle



[Gen2 CSP Plant. Central Receiver, two-tank molten salt thermal energy storage, steam-Rankine power generation cycle]

Problem Definition / Motivation

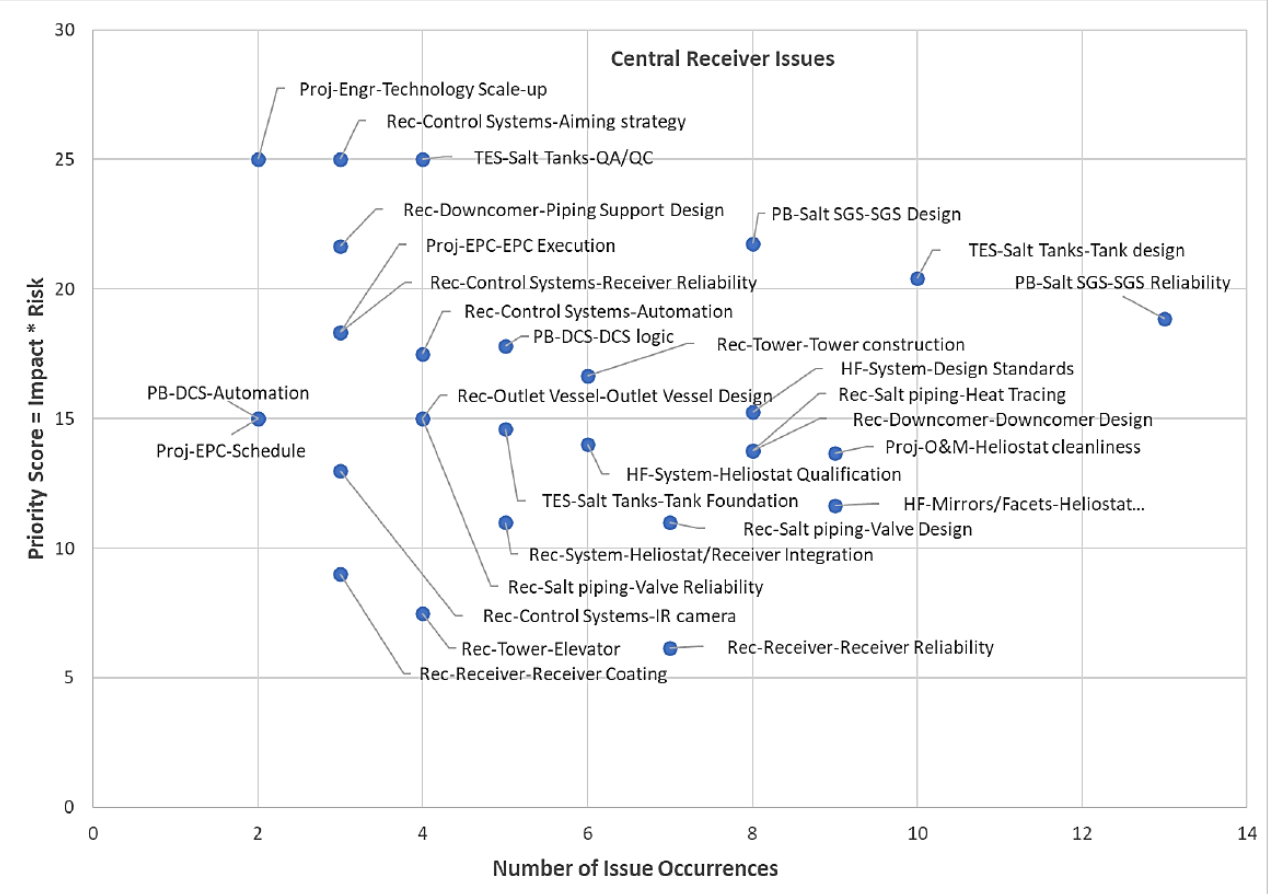
Several Failures have occurred in molten salt tanks in commercial CSP Plants around the world

[Crescent Dunes CSP Plant, Tonopah, NV]

In general, in-service hot tanks in the CSP industry have been generally designed based on American Petroleum Institute's (API) 650 and ASME BPVC Section II standards.

API 650 → Guidelines about dimensions and fabrication for oil storage tanks up to 260°C.

ASME BPVC Section II → Allowable stress values for various materials at a range of temperatures and conditions

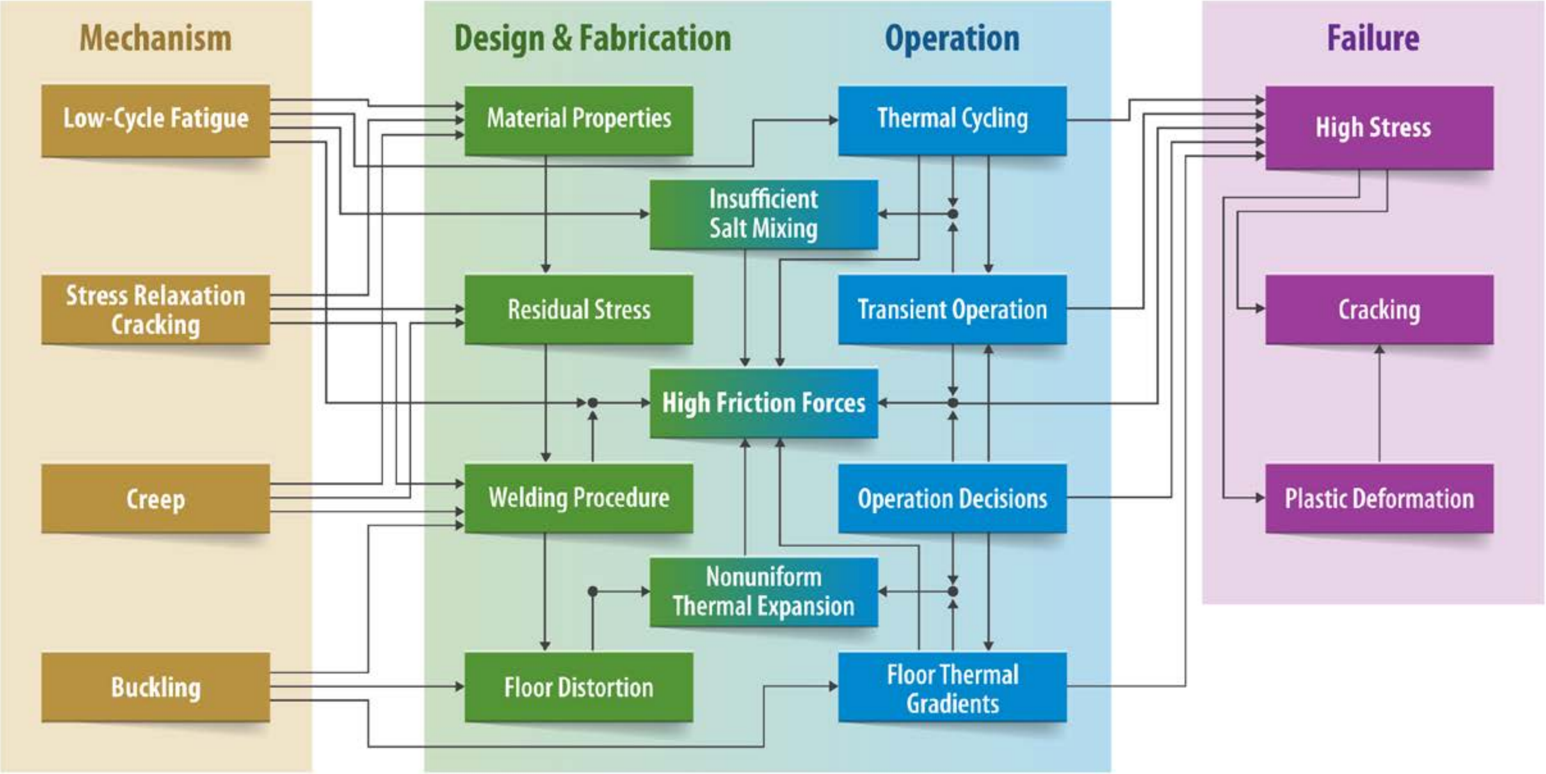


[Mehos et al. 2020. Concentrating Solar Power Best Practices Study. NREL/TP-5500-75763]

API 650 and ASME BPVC Section II seem to be limited for hot tanks design where high temperatures, thermal cycling, and transient conditions are expected!

Problem Definition / Motivation

Project 38475 – “Failure Analysis of Molten salt Thermal energy storage tanks for in-service CSP plant”



Failure Analysis for Molten Salt Thermal Energy Storage Tanks for In-Service CSP Plants

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2 Solar Dynamics LLC
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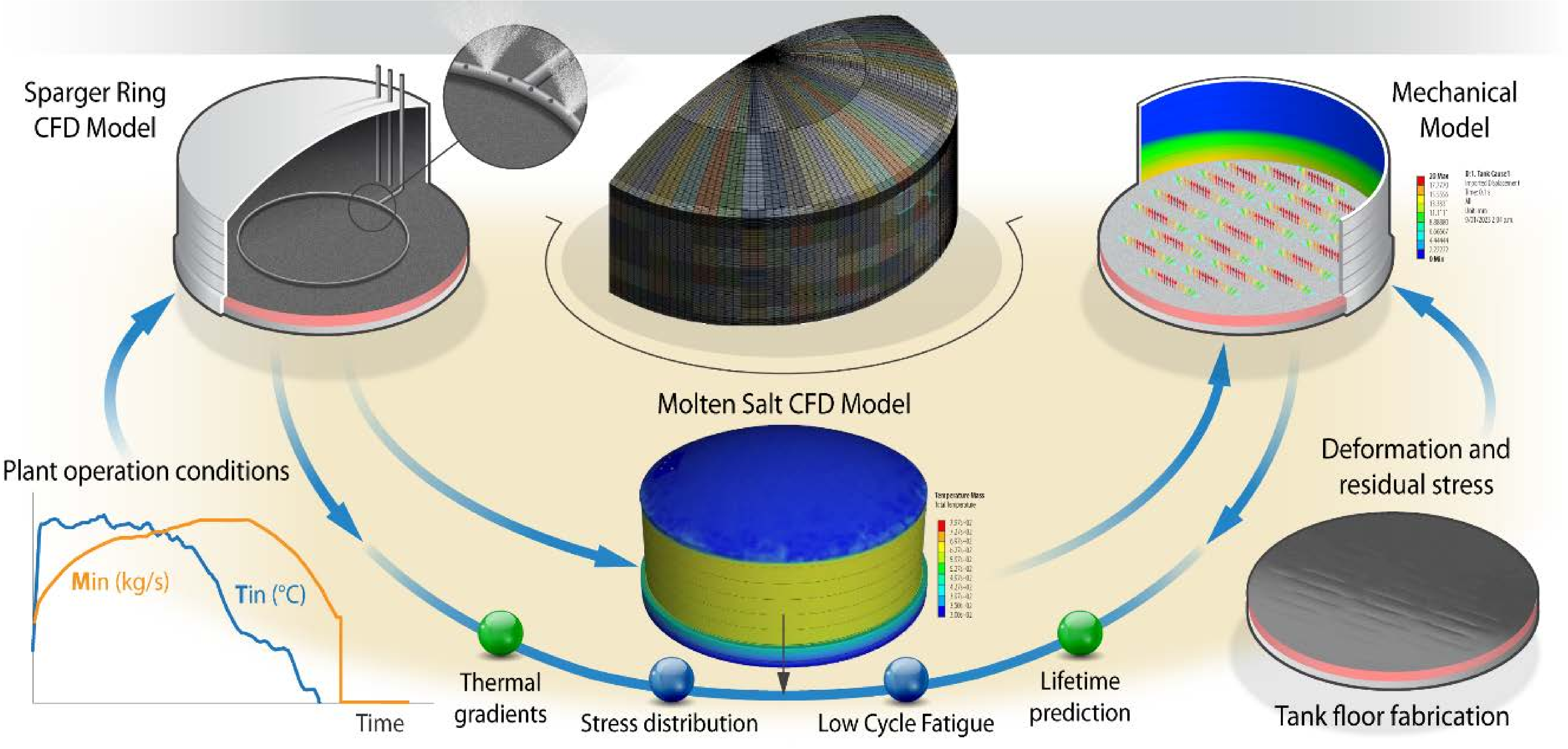
4 Universidad Pontificia Bolivariana
5 Colorado School of Mines

nrel.gov/docs/fy24osti/89036.pdf

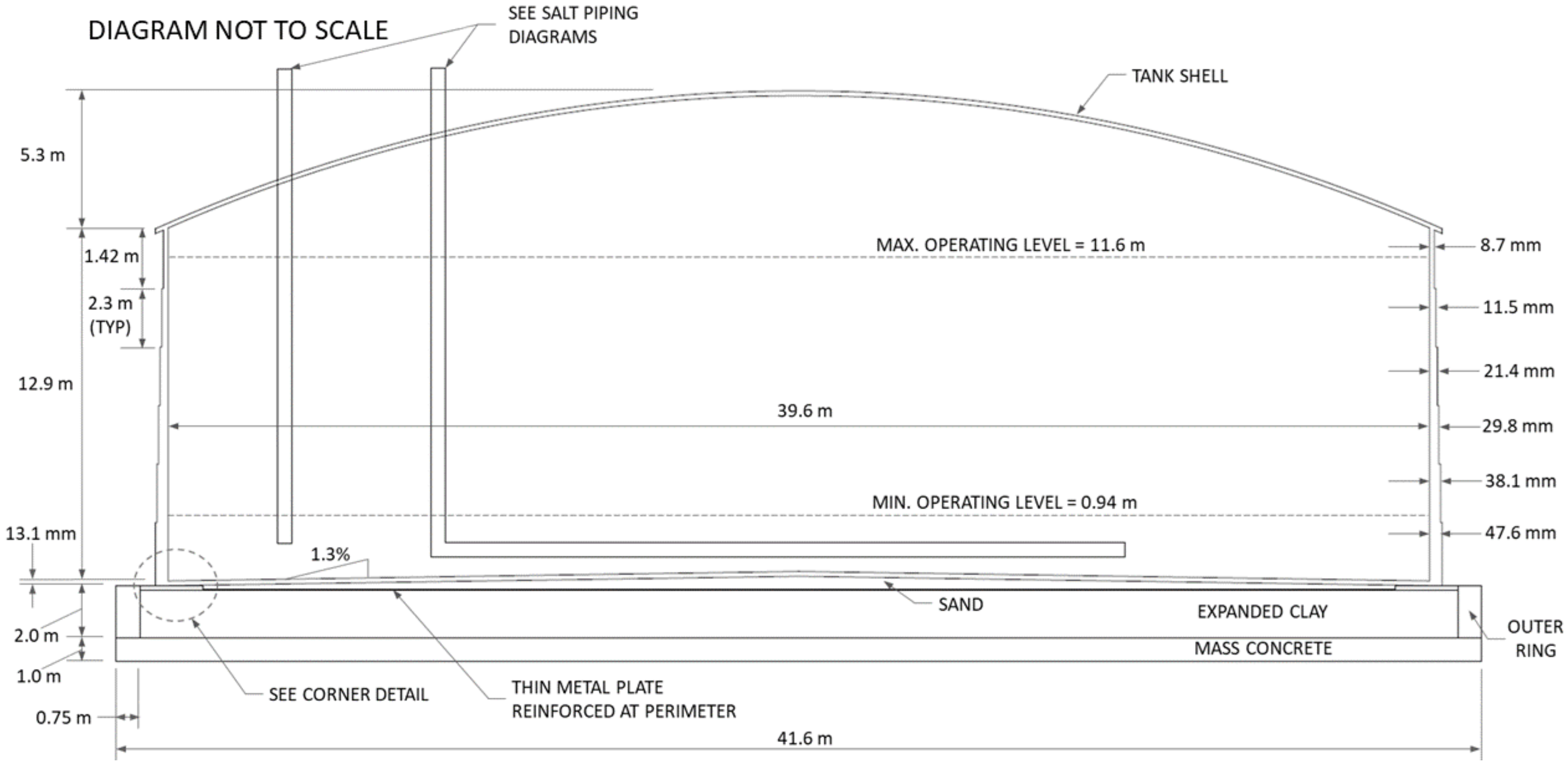
Most tank **failures** have **occurred in the tank floor** and are mainly associated with **improper design** and **fabrication procedures** of the floor, leading to **high residual stresses** after welding fabrication, **high stress** during operation, stress relaxation cracking (SRC), buckling, and creep

Molten Salt Hot Tank Modeling



The hot tank model has been validated. It incorporates computational fluid dynamics (CFD) models for the sparger ring and molten salt and a mechanical model for the tank shell and floor.

Representative Tank Design



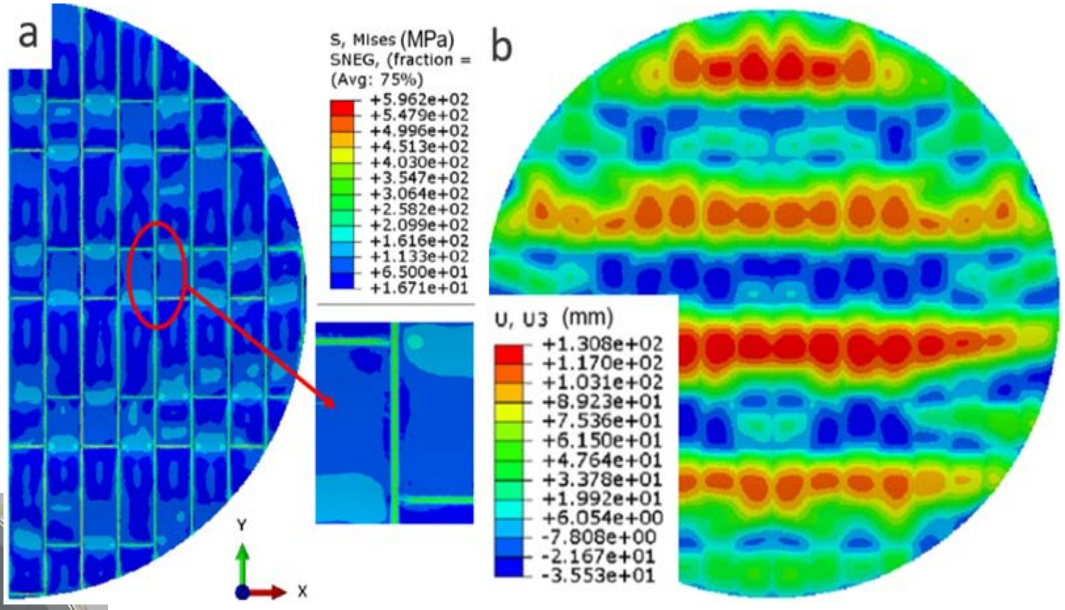
Dimensions are representative several existing hot tank designs

Tank Floor Fabrication Modeling

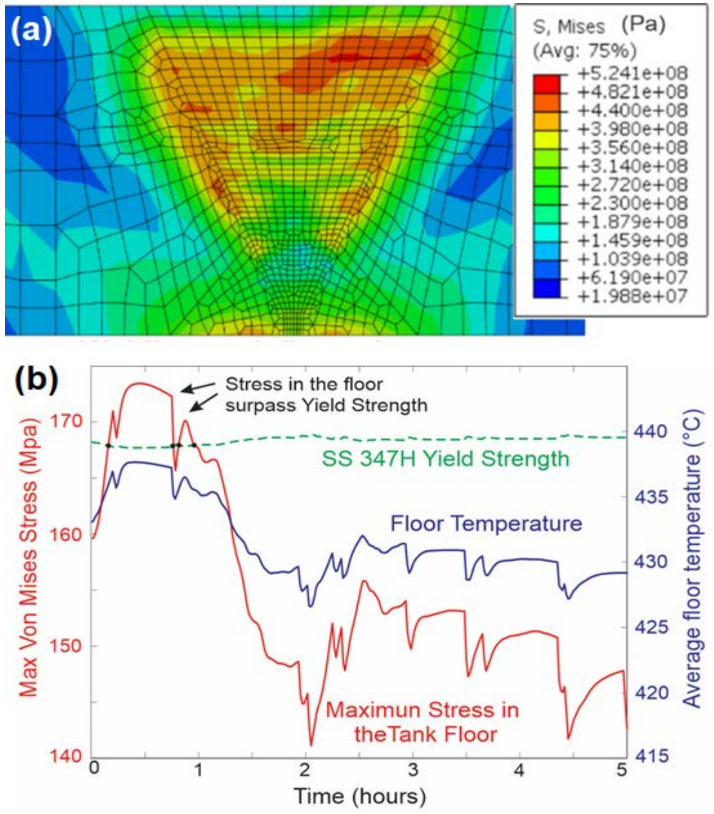
The tank floor is the most critical component due to the large loads and friction forces between floor and foundation during cycle operation.

High stresses have a negative impact on the tank lifetime.

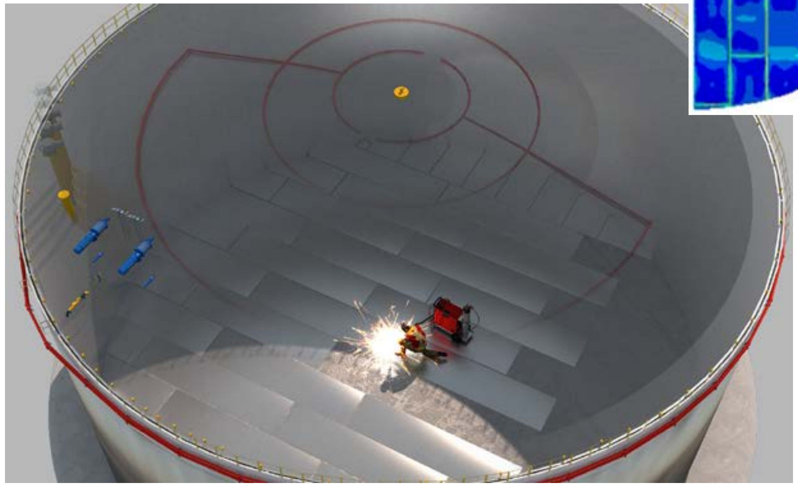
Under current fabrication procedures and implementation practices followed by industry, the floor fabrication and tank commissioning usually result in plastic deformations and high residual stresses



a) Von Mises stress (half floor),
b) floor plastic deformation



(a) Residual stresses in the floor after fabrication;
(b) Maximum stress in the floor during operation.



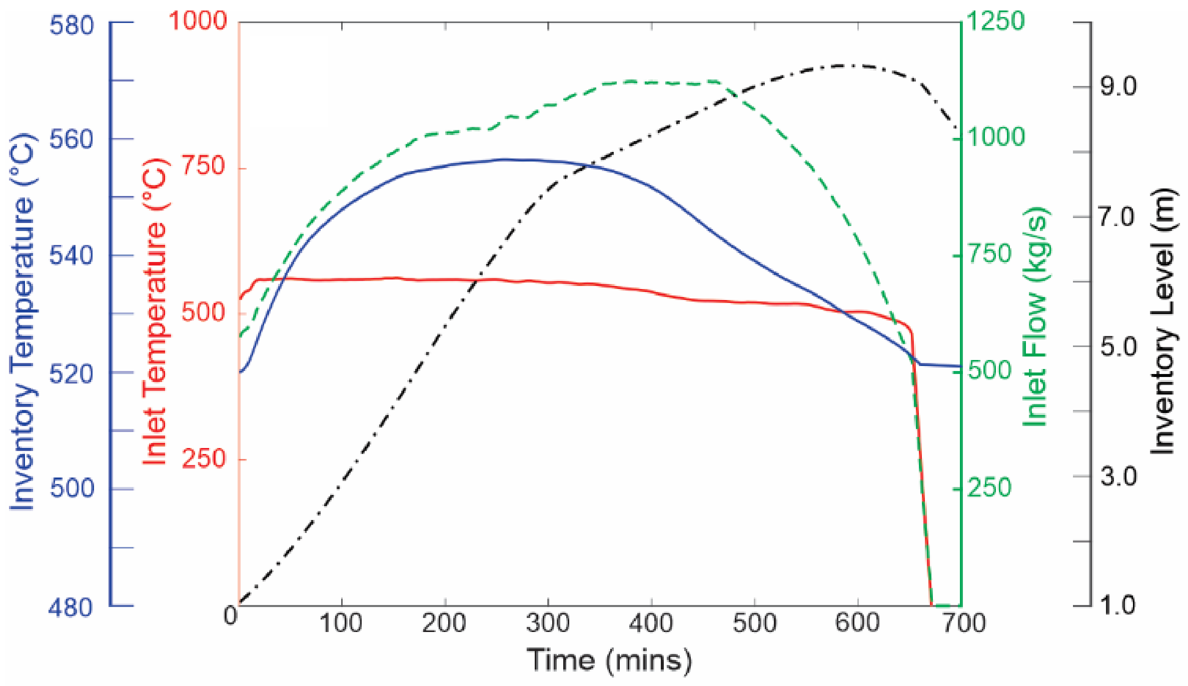
The floor is typically fabricated from several thin rectangular plates that are welded together.

Under current floor design, fabrication, and operation **our model predicts a lifetime lower than 3 years!**

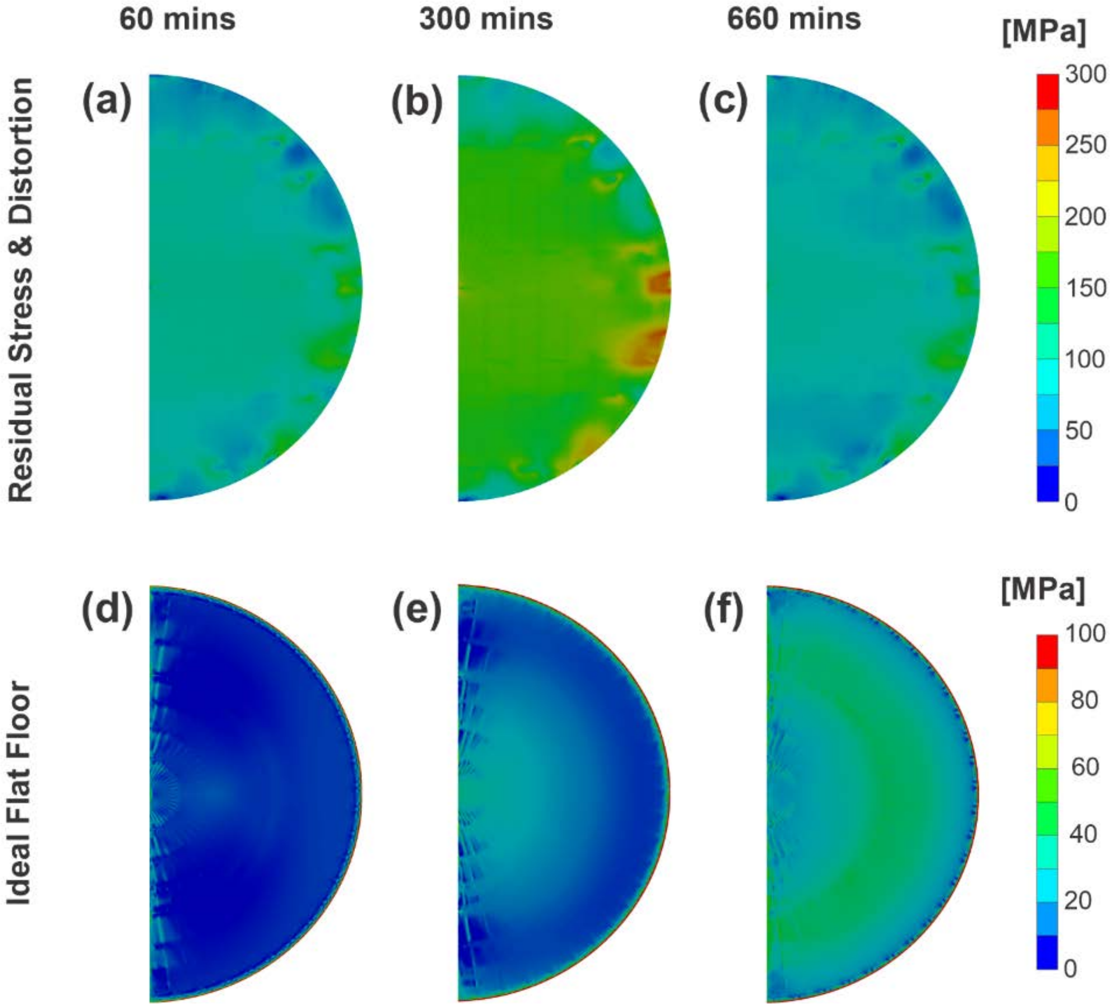
Failures in current plants have occurred in less than 3 years of operation!!

Stress Distribution in the Tank Floor

Comparison in stress in the tank floor. (a-c) Residual stress & distortion considered. (d-f) Flat floor



Boundary conditions: Inlet salt mass flow rate and inlet molten salt temperature. Molten salt inventory level and temperature.



Friction coefficient = 0.5

Stress Distribution in the Tank Floor

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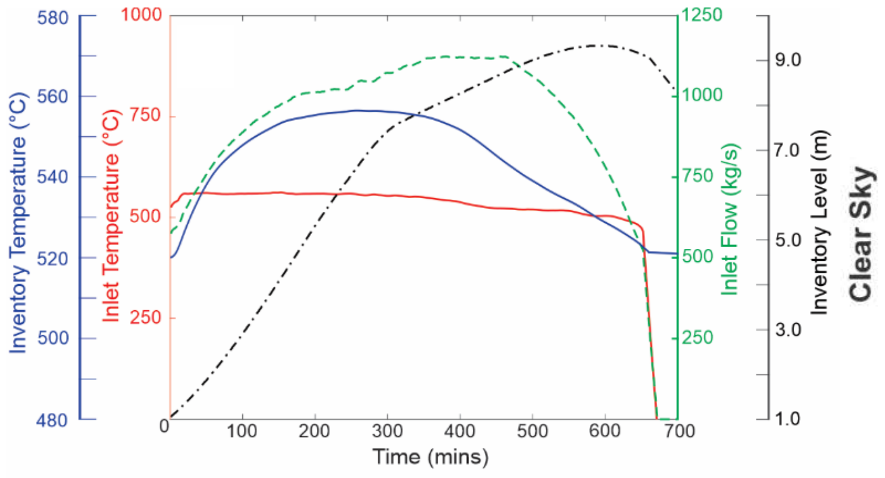
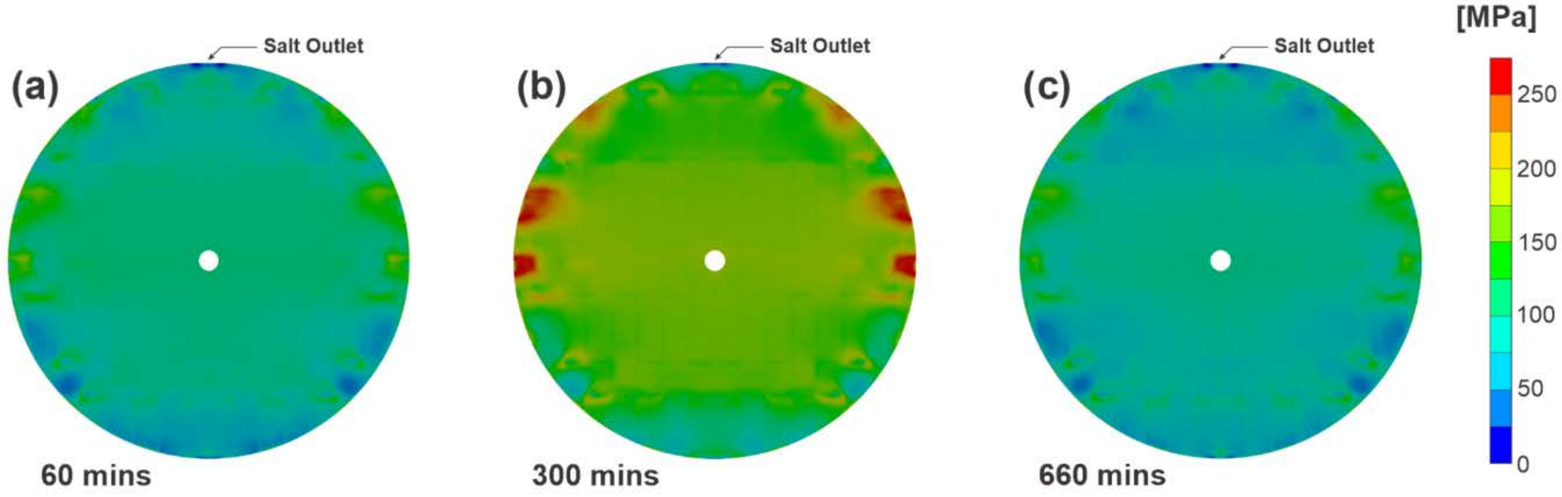
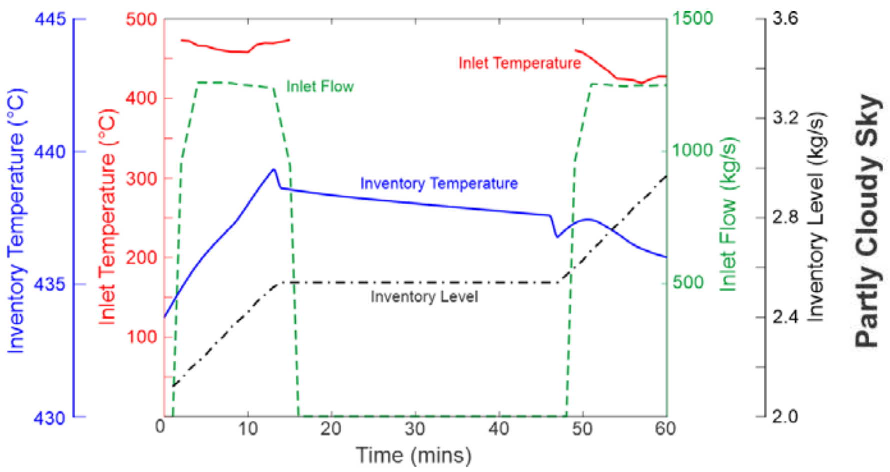
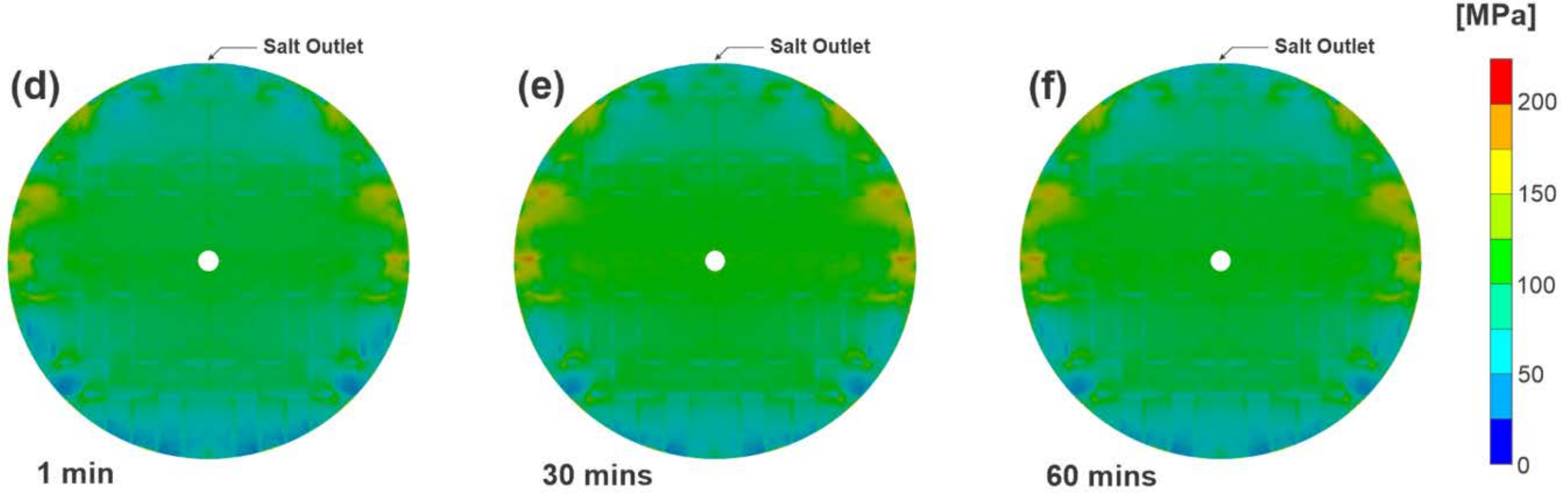
Von Mises Stress contours. (a-c) Clear sky and (d-f) Partly cloudy sky operation conditions





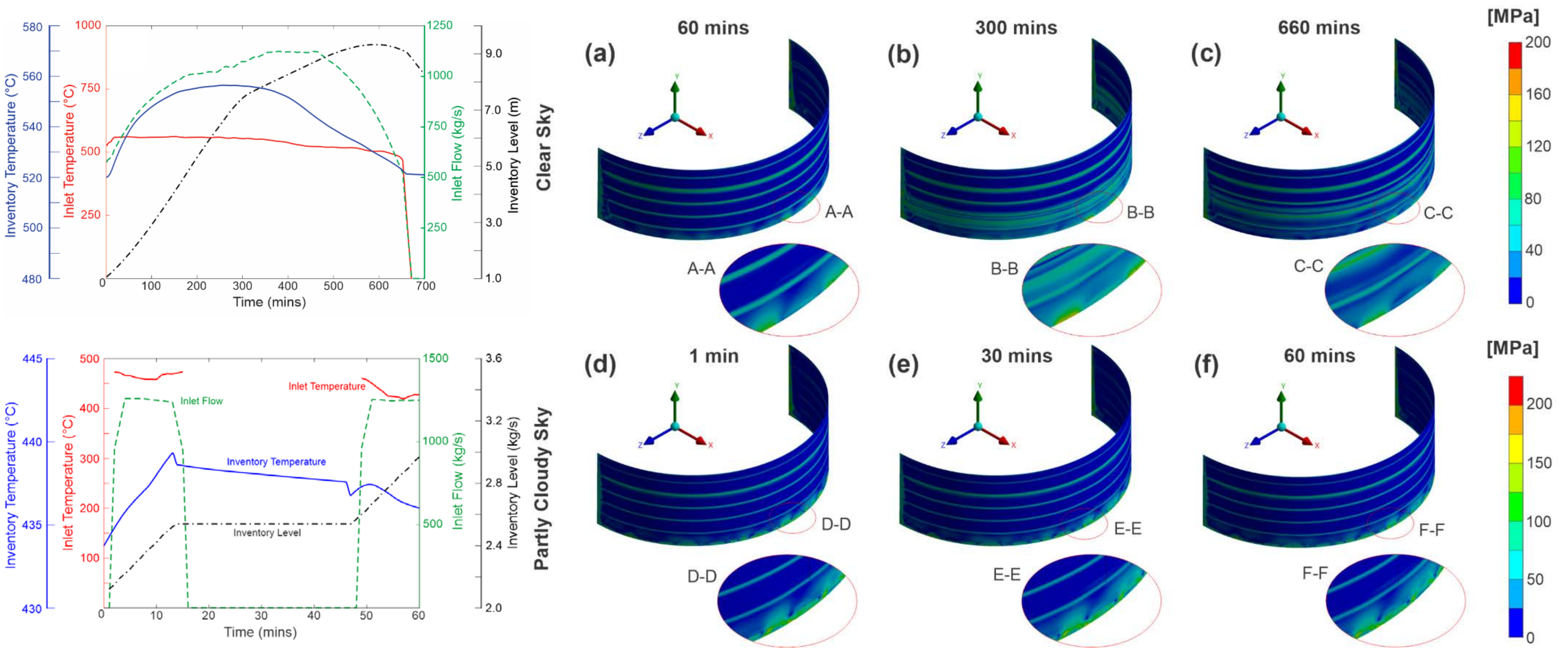




Friction coefficient = 0.5

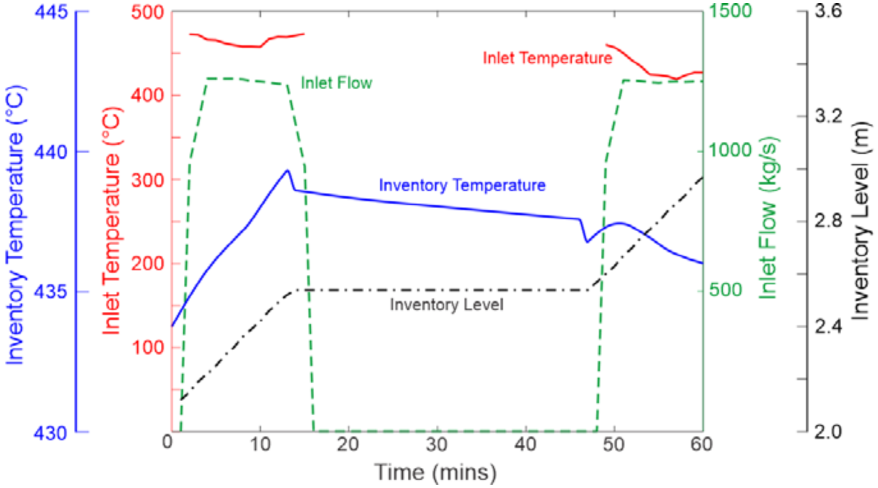
Stress Distribution in the Tank Shell

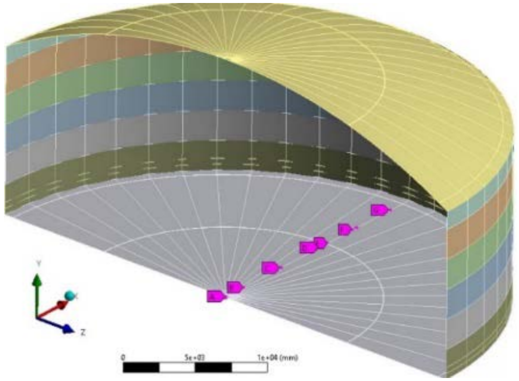
Von Mises Stress contours. (a-c) Clear sky and (d-f) Partly cloudy sky operation conditions

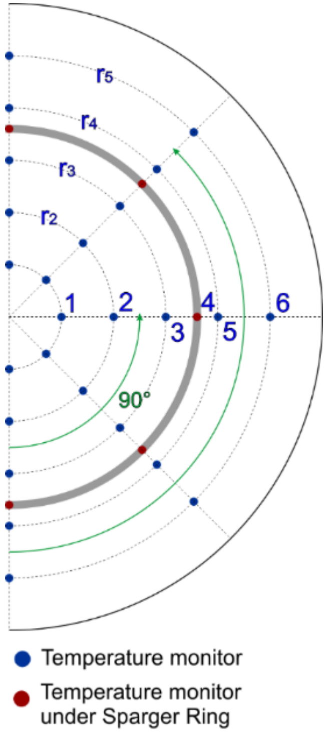


Friction coefficient = 0.5

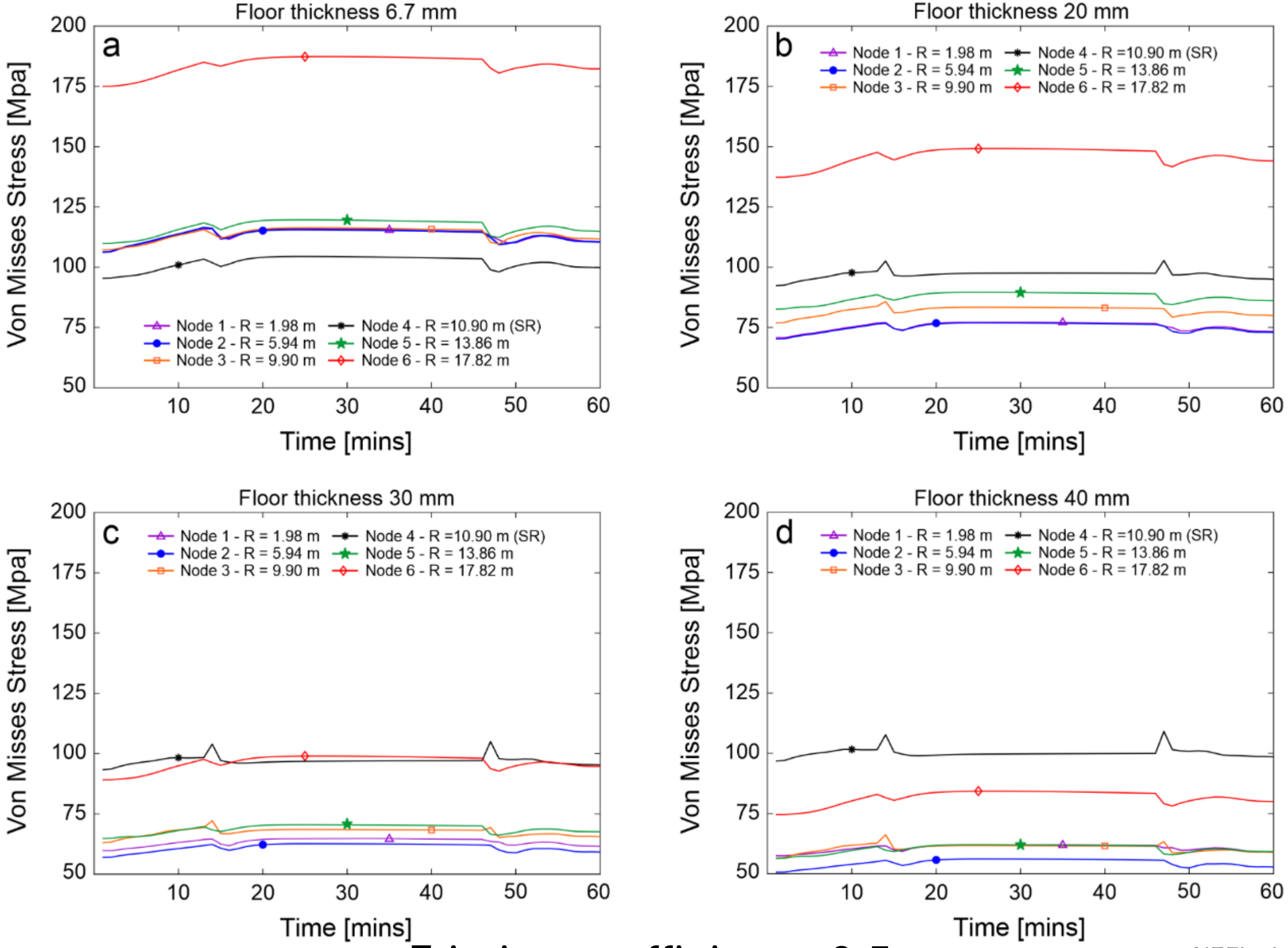
Stress Distribution in the Tank Floor





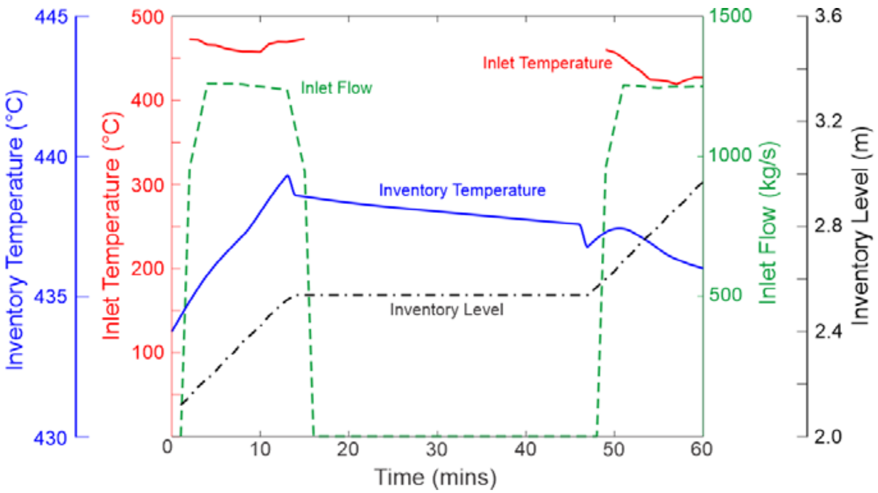


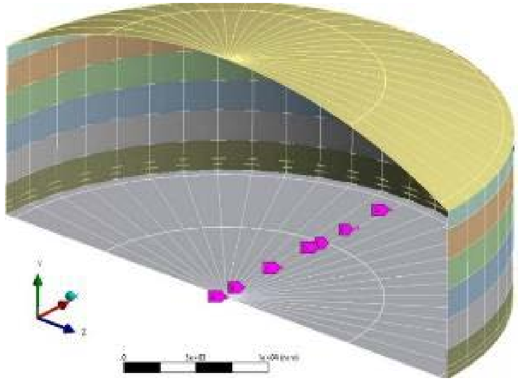
Stress evolution in the tank floor for different floor thicknesses

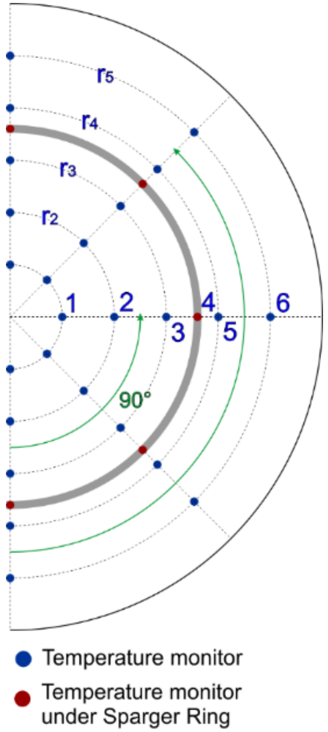


Friction coefficient = 0.5

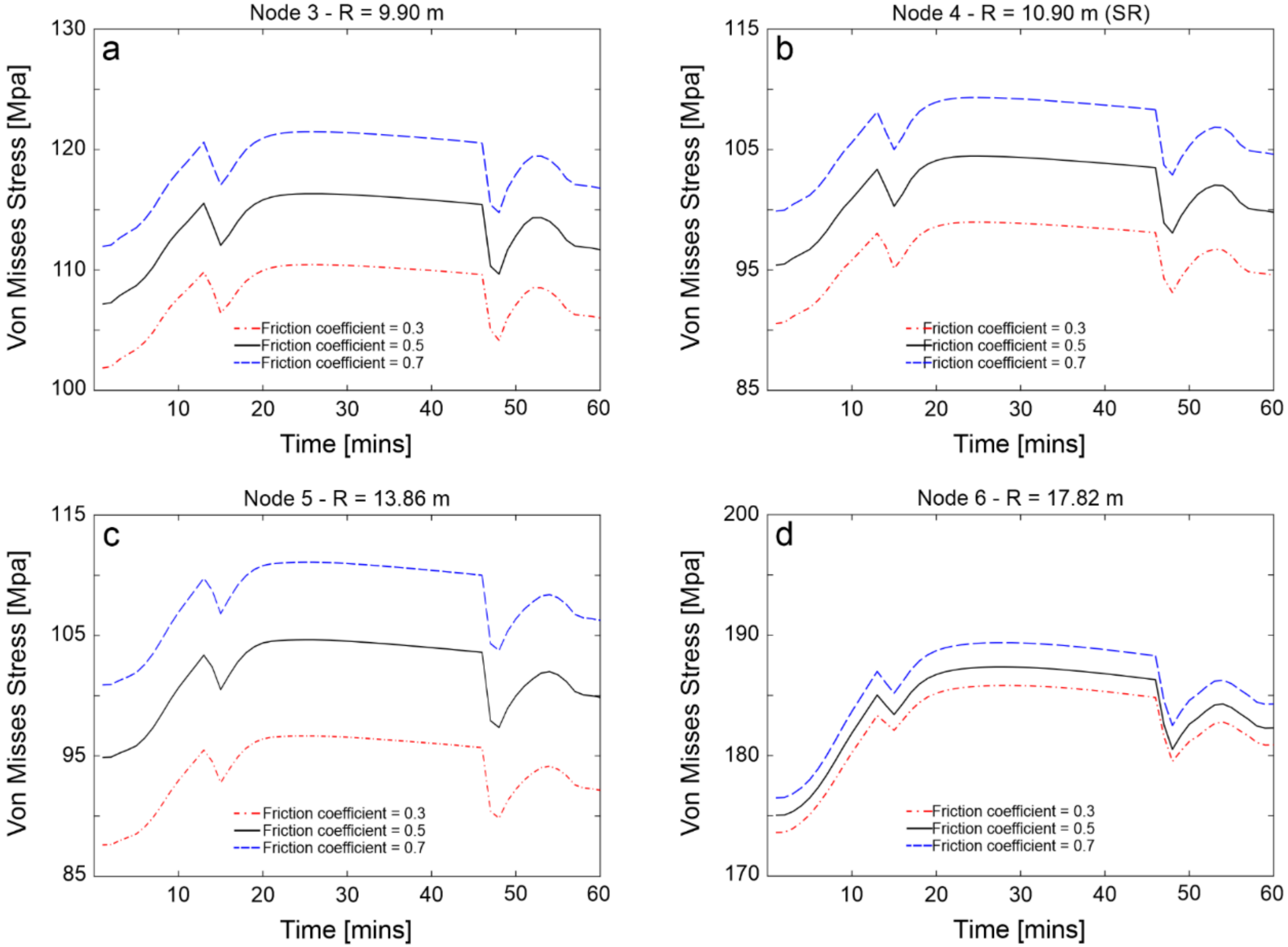
Stress Distribution in the Tank Floor







Stress evolution in the tank floor for different friction coefficients



Floor thickness = 6.7 mm

Sparger Ring Position

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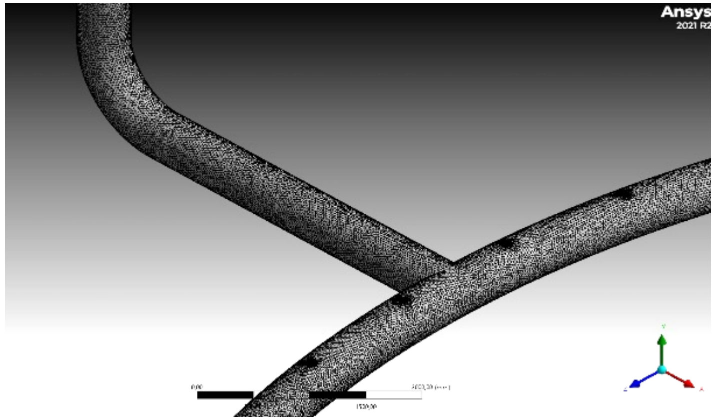
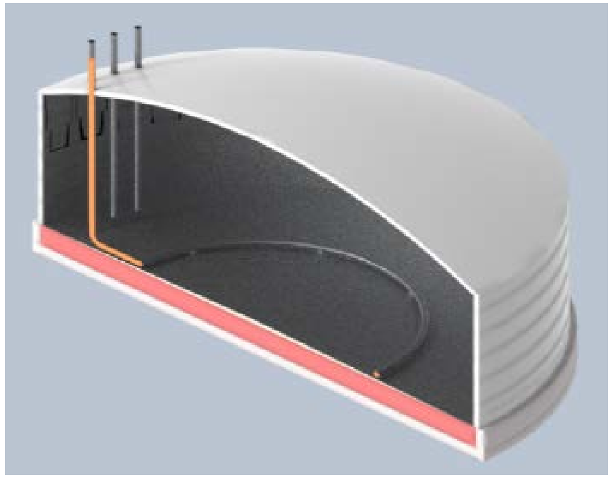
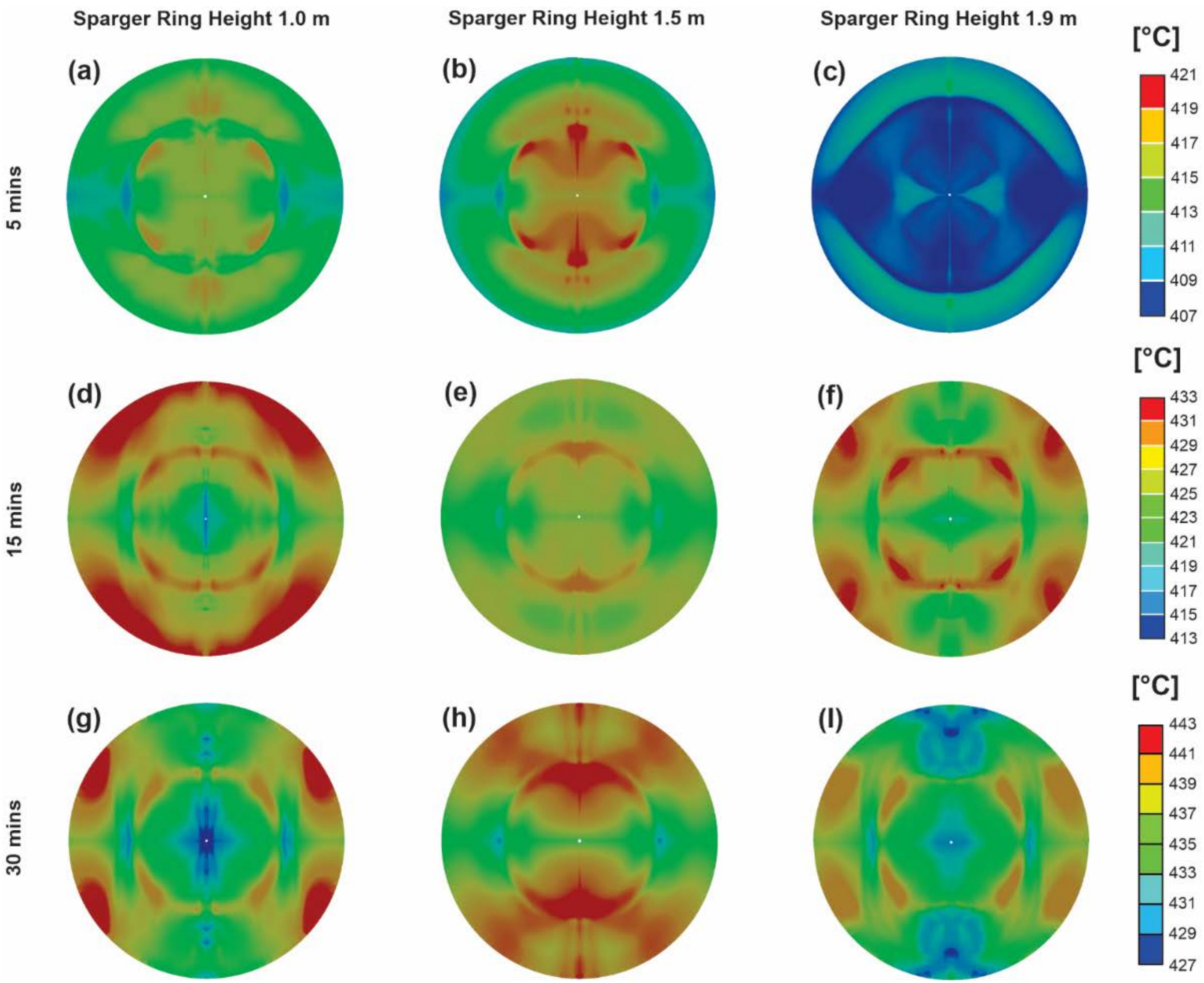




Large radial and circumferential temperature gradients in the floor

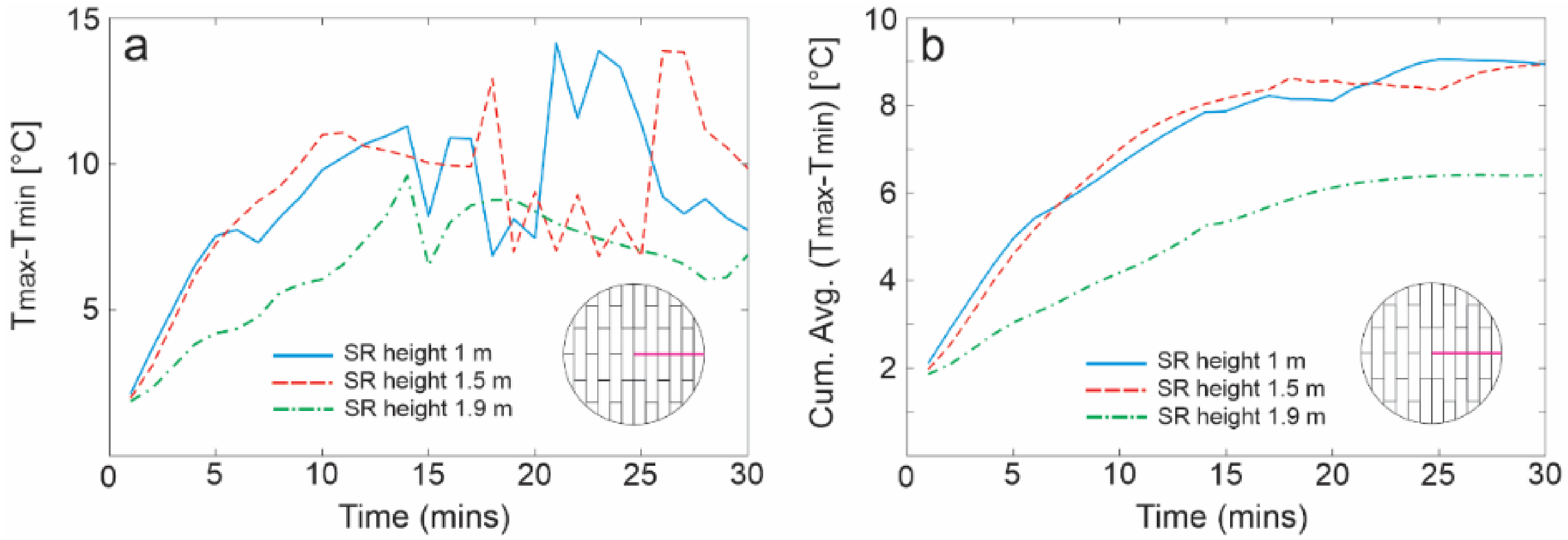


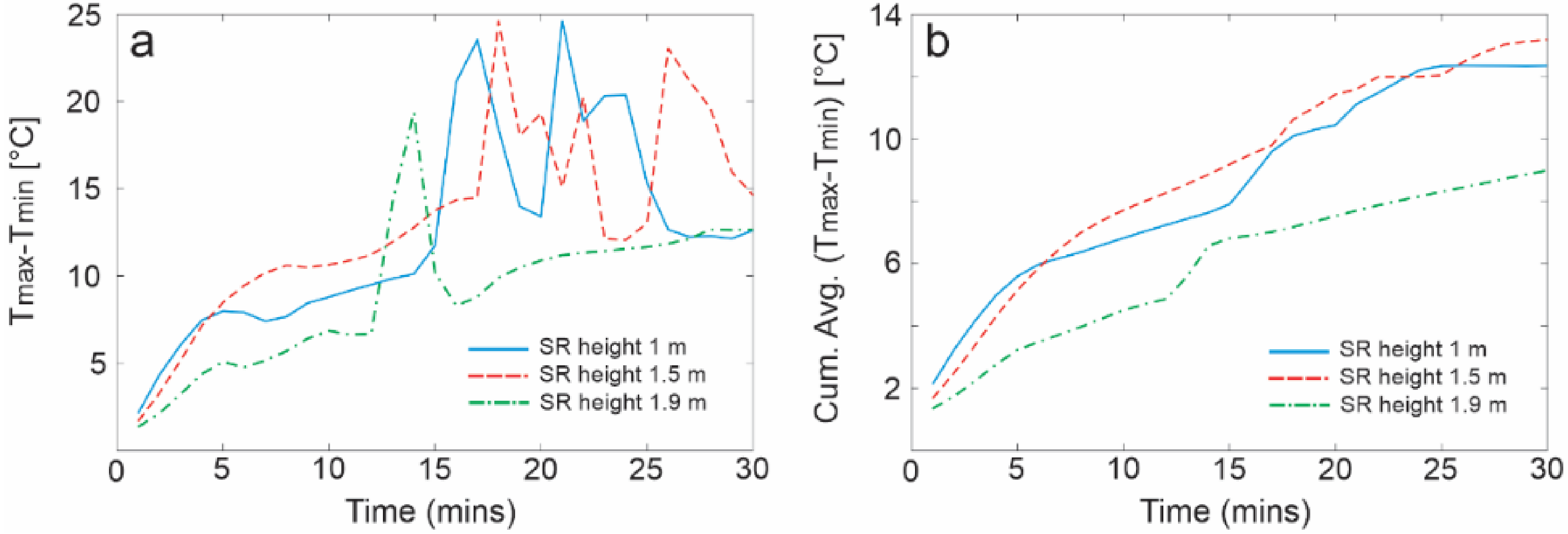
Inventory level = 2m, Tinv. = 400°C, Tin = 560°C, inflow = 1200 kg/s

Sparger Ring Position

Tmax – Tmin radial line

A significant reduction in the temperature difference is observed for a sparger ring located at 1.90 m above the floor

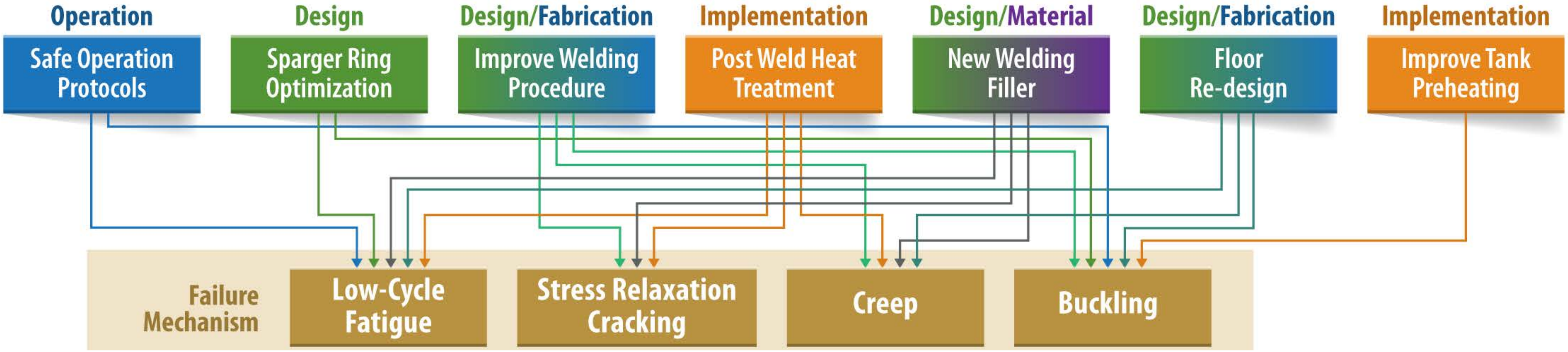




The Sparger Ring should be optimized to reduce temperature variations

Tmax – Tmin tank floor

Final Remarks



- Failures in hot tanks can be attributed to multiple mechanisms, including low cycle fatigue, stress relaxation cracking, excessive deformation (buckling), and creep.
- Current failures in hot tanks are strongly influenced by their design, fabrication procedures, material characteristics, and challenging operating conditions.
    - The residual stresses and distortion of the tank floor after welding fabrication exert a strong impact on the stress levels developed during operation.

Final Remarks

- Design changes such as floor thickness and sparger ring location (height) could be improved to reduce stresses.
- A definitive solution to tank failures requires addressing multiple issues during tank design, fabrication, implementation, and operation.

Take a picture to **download** the **final report**

https://www.nrel.gov/docs/fy24osti/89036.pdf

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.