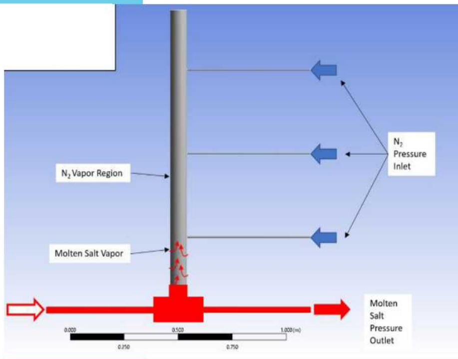
Sandia National Laboratories

SAND2020-10018C

Vapor Transport Analysis of a Chloride Molten Salt Flow Control Valve

SolarPACES 2020



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Agenda

Objectives

- Thermal-fluid flow phenomena investigation of proportional flow control valve (FCV) for 750 °C high-temperature transport.
- Computational Fluid Dynamics (CFD) model to accurately characterize salt vapor plating phenomena within valves.

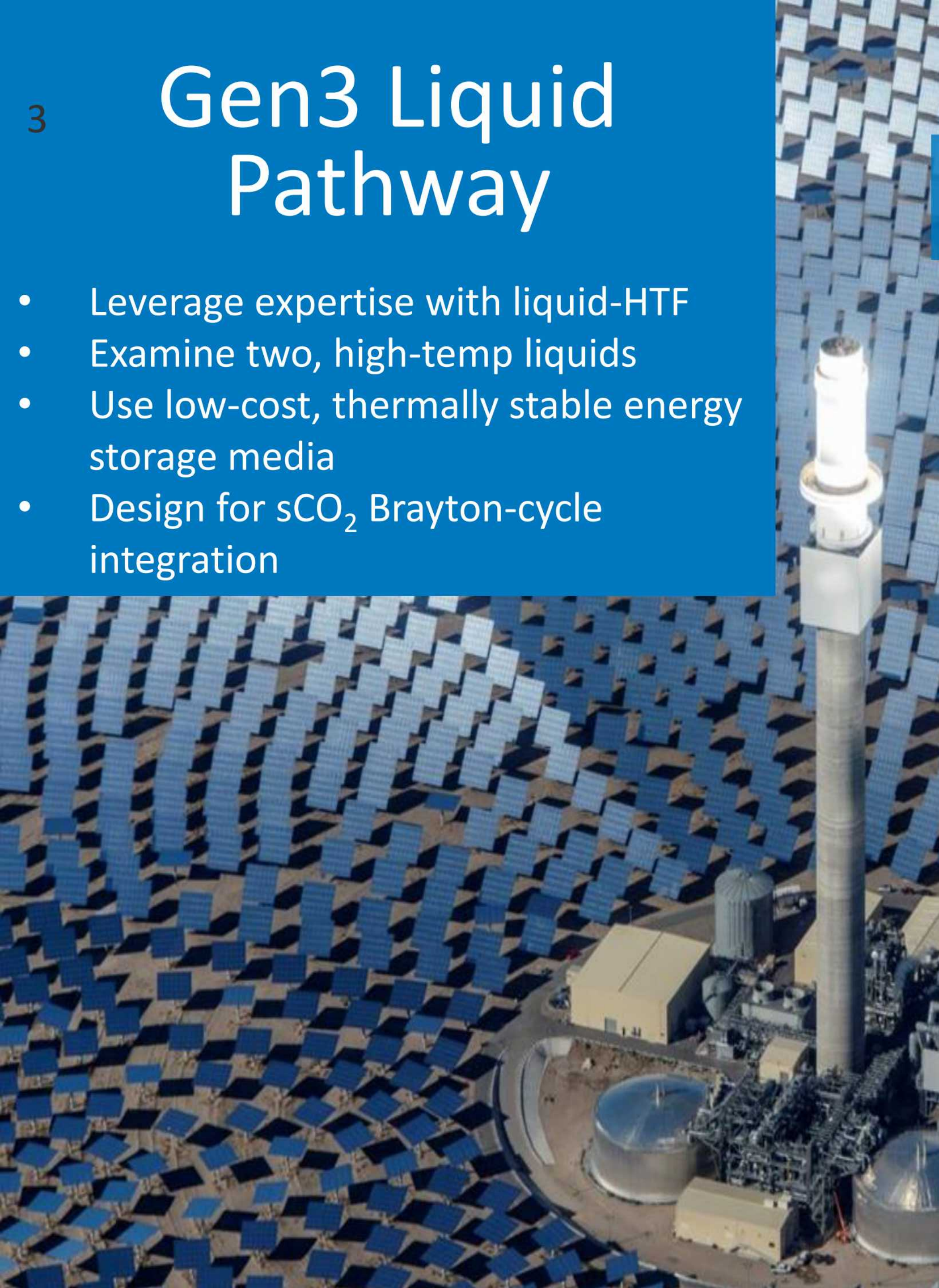
Overview

- Advanced valve for the DOE Gen 3 Liquid-Pathway program.
- Chloride molten salt vapor plating challenges related to valves.
- Model development.
- Modelling analysis results.

Conclusions & Future work

Gen3 Liquid Pathway

- Leverage expertise with liquid-HTF
- Examine two, high-temp liquids
- Use low-cost, thermally stable energy storage media
- Design for sCO_2 Brayton-cycle integration



SolarReserve Crescent Dunes Molten-salt HTF plant (USA)

Vast Solar Jemalong
Sodium-HTF pilot facility (Australia)

Next Gen Chloride Salt

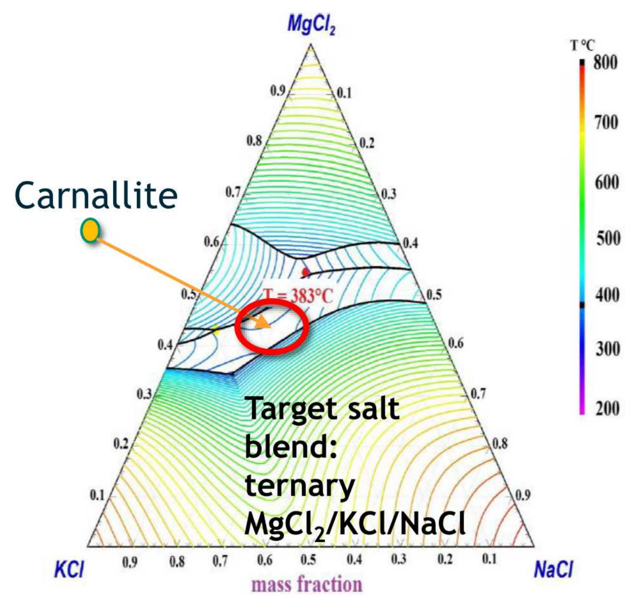
- Limit of traditional solar-salt thermal stability is ~600 °C with ambient air as cover gas.
- Nitrate salt concentrating solar power (CSP) systems currently deployed are considered state-of the art heat transfer fluids (HTFs)
- To achieve $15/kWh HTFs and LCOE of 6¢/kWh, need technologies at higher temperatures (e.g., 650 °C to 750 °C) with alternative salt chemistry composition.

Salt Vapor Composition

- Although salt vapor product melting temps are high, carnellite ($KMgCl_3$) is relatively low.

Gaseous Molecule	Molecular Mass [g/mol]	Melting Temperature [°C]	Diffusivity [m^2/s]	Reference
$KMgCl_3$	169.76	480	2.38E-05	TOMÁŠEK et al., 2017
NaCl	58.44	797	7.45E-05	ZHOU et al., 2020
KCl	74.55	768	4.62E-05	ZHOU et al., 2020
$MgCl_2$	95.211	714	6.85E-05	PENG et al., 2016

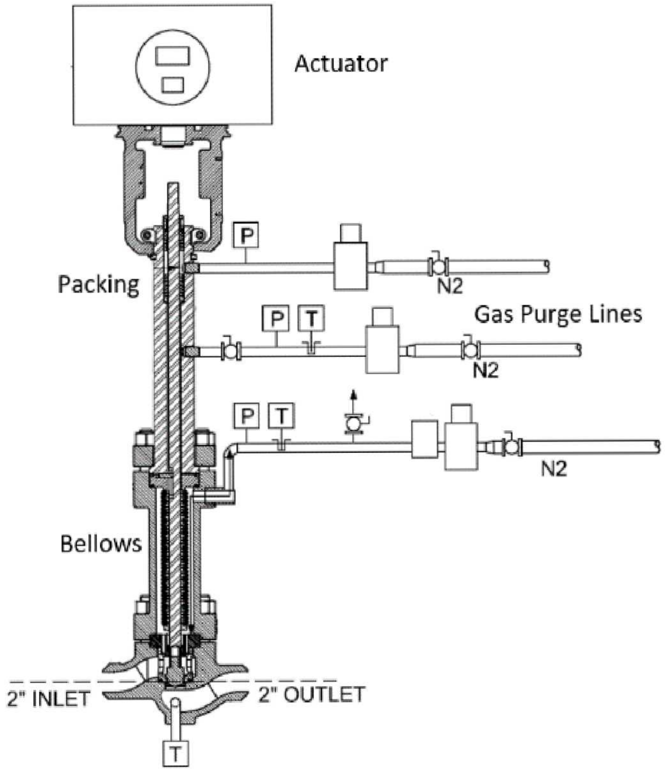
Carnallite:
$MgKCl_3 \cdot 6H_2O$

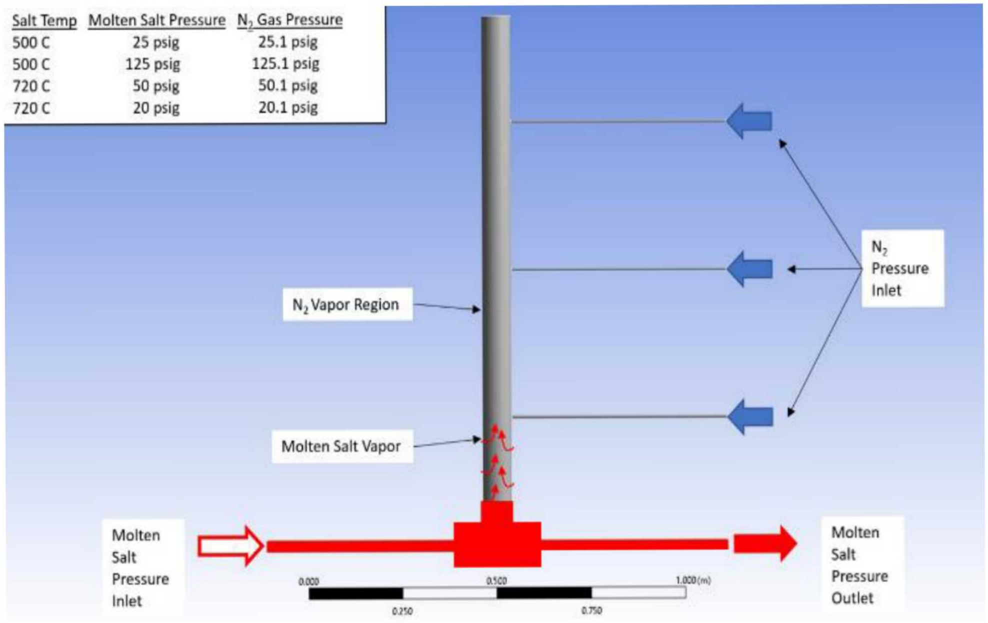


Mohan et al., Energy Conversion and Management 167 (2018)

Proportional Control Valve Design

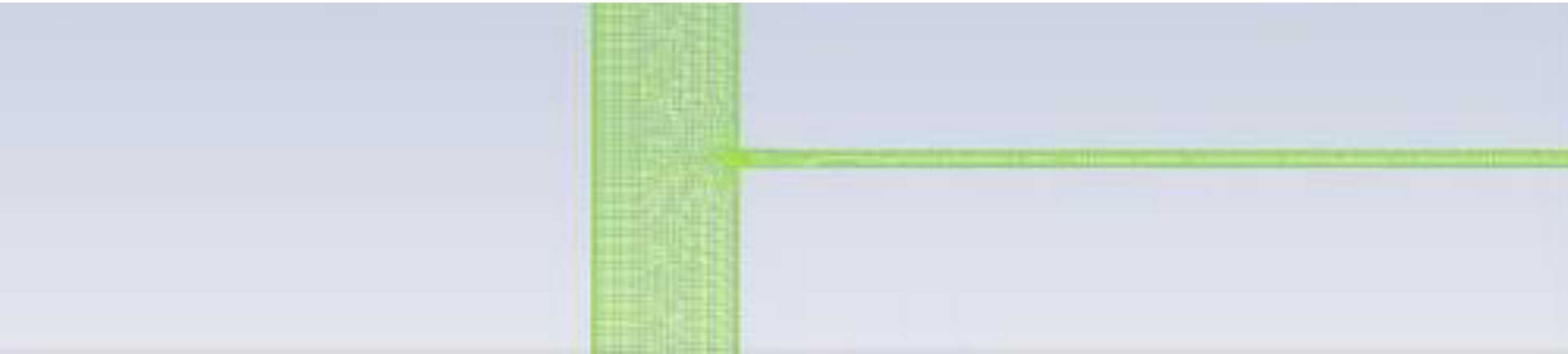
- FCV's required to modulate flow through CSP systems to facilitate transient (e.g. receiver preheating & drain-back) and steady operations (e.g. TES charging/discharging).
- FCV plug design offers a target *Cv* curve for nominal flow control.
- Proper flow control is critical for flow management when operating pumps, attemporation and rapid drain-back operations.
- Chloride salt valves require ullage gas input to mitigate air ingress, reduce liq./vap. salt transport.
- Challenge: salt vapors may penetrate beyond bellows seal to narrow areas and facilitate plating.





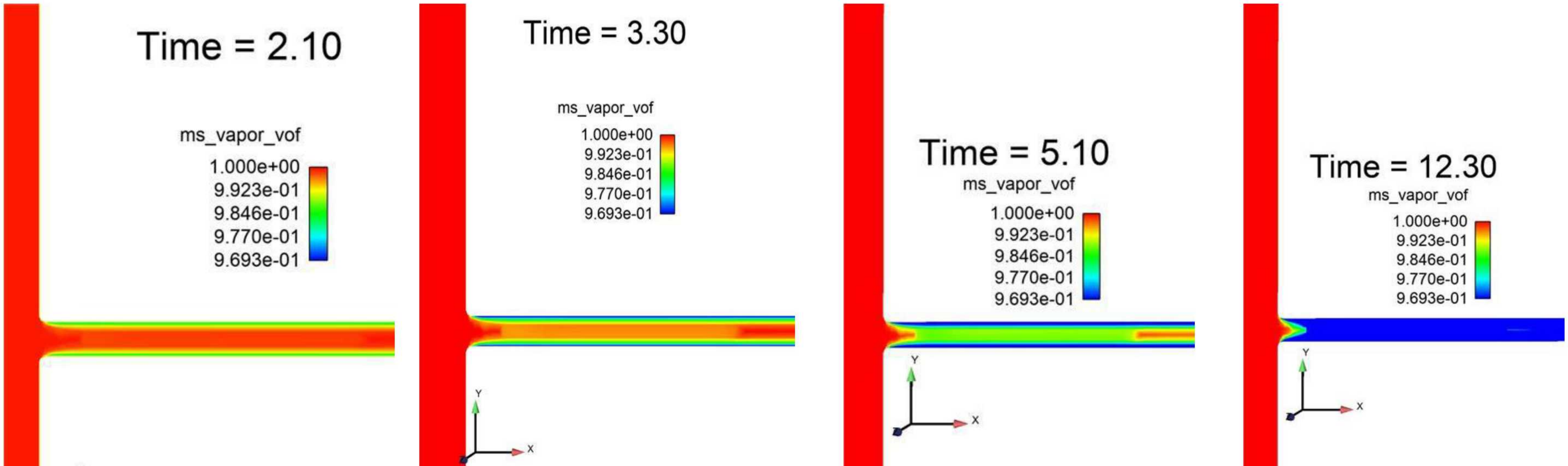
Model Setup

- Two-part phase change model: Gas/Liquid Multiphase Volume of Fluid Model & & Liquid/Solid Solidification Model
  - Considering vapor condensing and plating in ullage lines during a contingency (N_2 gas reduction less than salt vapor pressure).
  - **Four Submodels:** 1. Energy, 2. Laminar Fluid dynamics, 3. Multiphase Volume of Fluid (2 Eularian Phases) & 4. Solidification & Melting Model.
- Heat losses allowed on the N_2 lines (1/4" ID) to simulate contingency power loss.
- Inlet saturated salt vapor condition ~0.01 m/s (to approximate Laminar BC) and adiabatic wall valve boundary conditions, and no-slip BC at the walls.
- Inflation layers added to Mesh to capture boundary layer flow dynamics within valve.
- Transient Simulation with a fixed 0.3 sec. therefore Courant Number <1 (CFD flow dynamics convergence criteria).



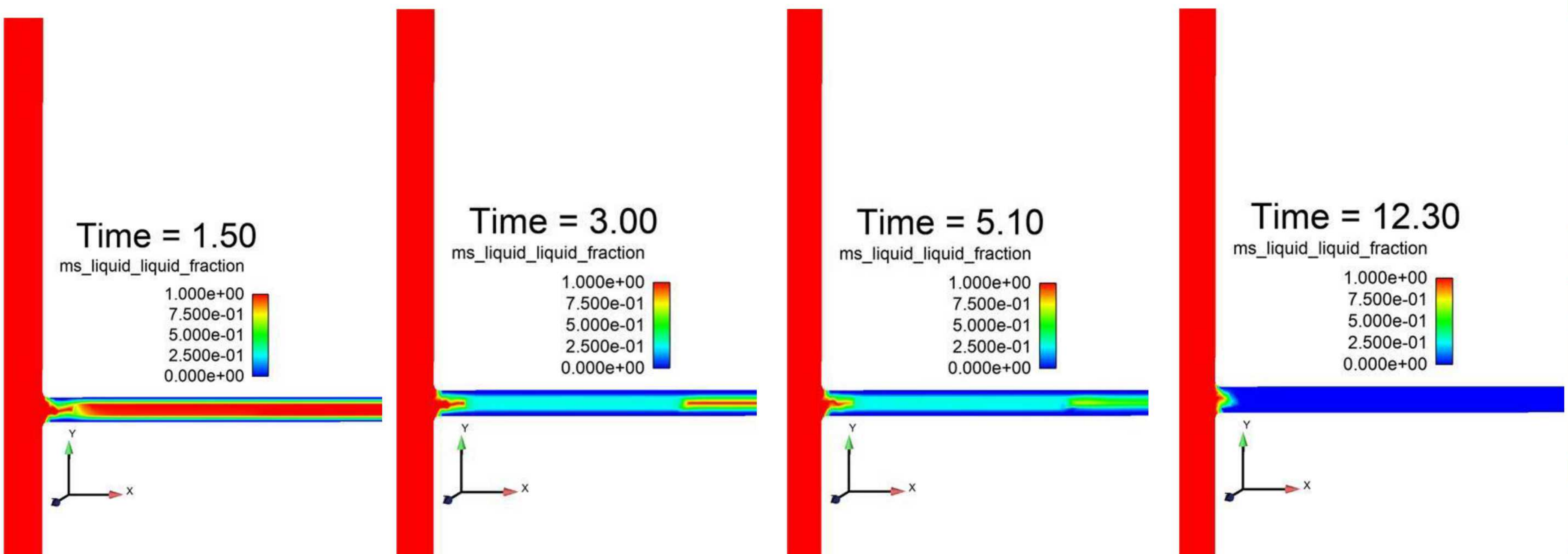
System Results (Vapor/Liquid)

- Fully developed flow indicated by constant steady velocity flow profile.
- With reduction in temperature placed on N_2 gas line boundary, gas (red) / liquid (blue) phase change observed with VOF model.
- Vapor to liqud phase change found to begin completely occupying gas line at 3.3 sec.
- As phase change occurs vapor velocity reduces at gas line interface ~1 in. from piping intersection.
- Molten salt vapor would only occupy small volume fraction because of small partial pressure within total gas mixture.



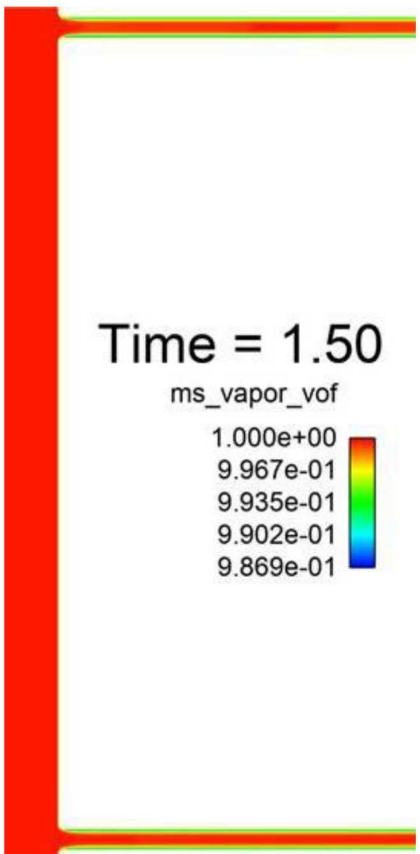
System Results (Liquid/Solid)

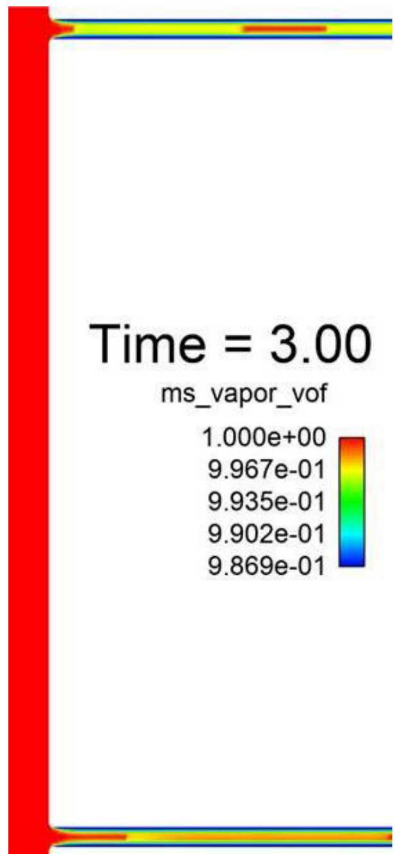
- Red region indicates non-solid (either gas or liquid)
- Molten salt vapor would only occupy a small volume fraction, because of the small partial pressure within the gas mixture.
- Partial pressure of salt vapors (based on concentrations) determine the phase it can be stable at.
- From the solidification model results, one can see confirmed velocity reduction to zero corresponding to solidification of the previous VOF liquid phase, indicating plating phenomena.

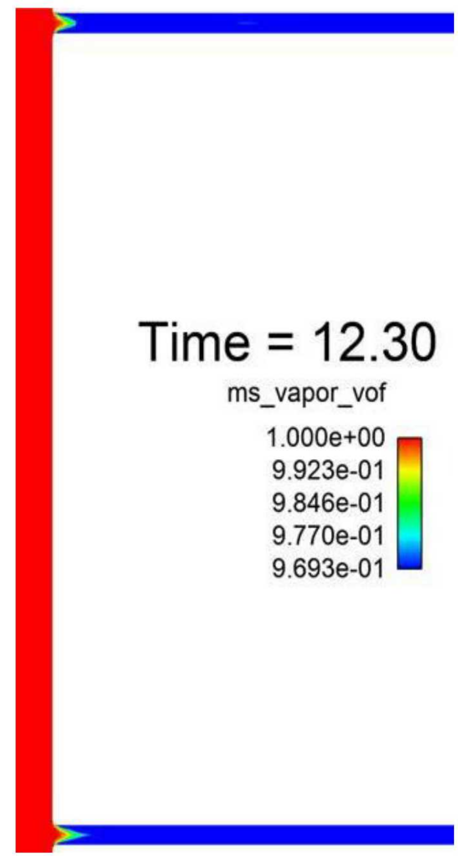


System Results

- Slightly higher velocity found on bottom N_2 line than with top line due to friction losses.
- Higher velocities indicate lower solidification potential.
- N_2 gas velocity (even slight) would increase the salt vapor velocities further reducing the potential for plating.
- Overall loss of N_2 ullage gas pressure and heating power would result in near-immediate plating/plugging of lines with salt vapor.







Conclusions & Future Work

- Worst case, 1st Order CFD model of loss in N_2 ullage gas in valve system.
- Analysis considers volume fractions to assess plating phenomena.
  - If a particular salt vapor product has high concentration then its particular partial pressure can be higher, which encourages higher plating phenomena.
- Overall loss of N_2 ullage gas pressure and heating power would result in near-immediate plating/plugging of lines with salt vapor
- N_2 gas velocity (even slight) would increase the salt vapor velocities further reducing the potential for plating.
- If vapors reach a point that they slow down, then plating potential increases.
- Future work to consider partial N_2 gas loss due to fouling.
- Classical thermodynamics model evaluating macroscopic gas dynamics and phase change.
- Statistical thermodynamics is needed to capture species interactions between product salt vapors and N_2 gas to fully understand psychometric properties and gas/phase change dynamics.

Acknowledgements

This work is funded in part or whole by the U.S. Department of Energy Solar Energy Technologies Office under DOE-EE0002064-2260.

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Thank you.