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Internal Insulation and Corrosion Control of Molten Chloride Storage Tanks

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Project Objectives

- Develop molten chloride salt tank that meets target cost and performance values
- Select, evaluate, and validate materials compatible with molten chloride salt
- Design refractory liner for "cold wall" carbon steel tank
- Engineer system which inhibits the permeation of molten salt into refractory liner

Introduction and Approach

- Leverage industry knowledge regarding the containment of molten chloride salt
- Dead Sea Magnesium (Israel) uses refractory lined carbon steel tanks for magnesium production via molten chloride electrolysis
- Refractories are complex composites consisting of multiple ceramic phases, matrixes, and defects
- The excellent mechanical and thermal properties of refractories are leveraged to provide containment and insulation in many high temperature industrial applications
- The challenge is the design of a multi-layered liner that provides good chemical compatibility and thermal insulation over the lifetime of a typical CSP plant (>20 years)
    - Hot face layer to prevent salt permeation
    - Insulating layer
    - Refractory steel interface layer

Gen3 Liquid Pathway to SunShot

The U.S. Department of Energy Gen3 CSP program aims to develop integrated systems capable of delivering high temperature thermal energy to advanced power cycles [1]. The National Renewable Energy Laboratory (NREL) is leading a multi-national team to validate the potential of a chloride-based molten-salt system that uses a ternary blend of $MgCl_2$/KCl/NaCl to provide higher temperature thermal energy storage capability (Fig. 1a). The economic viability of this concept is dependent on internally insulating the hot and cold storage tanks to enable the use of low-cost steel shells (Fig. 1b).

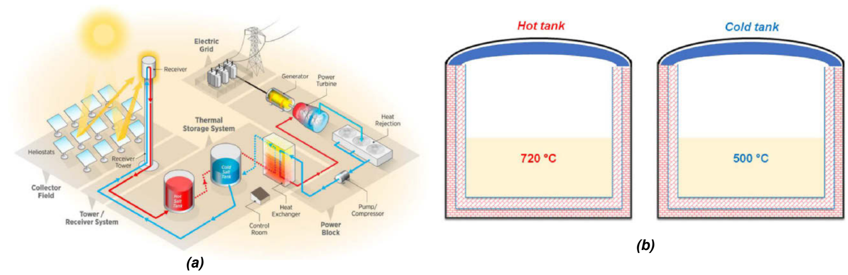
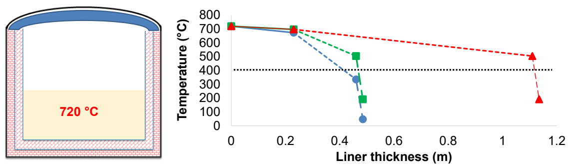


Fig. 1: Schematic of Gen3 Liquid Pathway CSP plant with power tower and two tank storage (a). Schematic of internal insulation of molten chloride hot and cold tanks. The refractory liner is proposed to consist of 3 layers: a hot face brick at the salt/refractory interface, insulating firebrick, and microporous insulation at the inner tank wall. The roof is insulated by ceramic wool blanket (b).

"Cold Walls" Design Basis



Hot Face Brick			Insulating Firebrick		
	K_e values (W/m*K)			K_e values (W/m*K)	
Temp. (°C)	dry	wetted	Temp. (°C)	dry	wetted
149	1.2	1.26	260	0.13	0.49
316	1.28	1.34	540	0.17	0.62
704	1.37	1.43	815	0.20	0.70
871	1.51	1.58	1100	0.24	0.83

- Dry insulation: carbon steel shell with <0.5 m liner (heat flux = 269 W/m²)
- Dry insulation that becomes wetted: allow heat loss exceeded, risk of tank failure (436 W/m²)
- Wetted insulation: stainless steel shell with >1 m liner (260 W/m²)

Fig. 2: 1-D heat transfer analysis through a dry refractory liner design when dry (dots), the same refractory liner configuration when wetted (squares), and a wetted liner design when wetted (triangles). The markers define the regions of the three liner materials: hot face, insulating firebrick, microporous insulation. The horizontal black dashed line denotes the temperature at which the chloride salt freezes (~400 °C). The table shows the thermal conductivity values for the hot face and insulating firebrick materials. The dry values are taken from the materials data sheets. Wetted values are calculated using known two-system thermal conductivity equations [2,3].

Hot Face Materials Evaluation

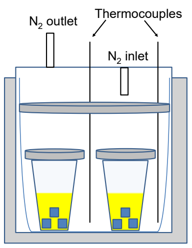


Fig 3. Refractory coupons are cut and immersed in molten salt at 720 °C. The reaction vessel is swept with 100 sccm N_2.

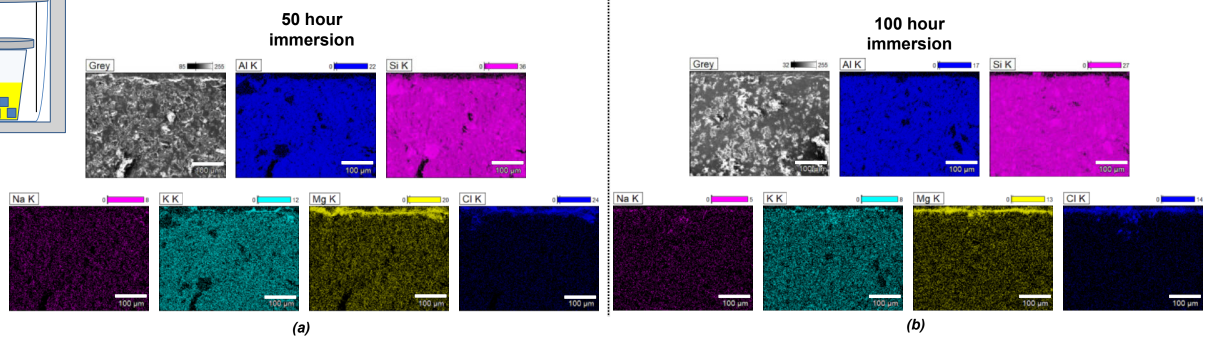
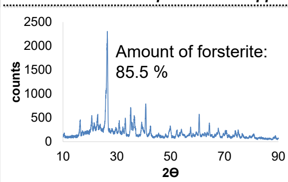


Fig. 4: Energy dispersive X-ray spectroscopy (EDS) maps of cross sectioned hot face coupons immersed in salt for 50 hours (a) and 100 hours (b). Magnesium is more highly concentrated on the upper surface of the coupon than the other salt constituents (Na and K). The penetration depth of magnesium in both experiments is approximately 20 µm.



$$(1)\quad 2Fe_2O_3 + 6MgCl_2\,(xcs) + 3SiO_2\,(xcs) \xrightarrow[740\ ^\circ C]{1.5\text{-}3hr} a(FeCl_2 + 1.5Cl_2) + bFeCl_3 + 3Mg_2SiO_4$$

$$(2)\quad MgO + SiO_2 \xrightarrow{1hr,\ 740\ ^\circ C} Mg_2SiO_4$$

XRD analysis shows the formation of a secondary phase (forsterite, Mg_2SiO_4), which may create a barrier to further salt penetration.

Fig. 5: X-ray diffraction (XRD) of hot face material after 100 hours of salt immersion indicates formation of forsterite where none existed in the native material. Forsterite formation in silica-containing refractory in the presence of molten magnesium chloride has been reported in the literature (Equations 1 and 2) [4].

Conclusions

- An internal refractory liner is necessary for thermal and corrosion protection to enable the use of low-cost steels for molten chloride salt storage tanks
- A "cold walls" design follows design practice in magnesium production industry where multi-layered refractories protect a carbon steel tank
- Preliminary design has been developed based on low-porosity, acid brick protecting low thermal conductivity insulating layers
- Salt exposure testing indicates limited penetration of chloride salt into the hot face brick with potential formation of a forsterite barrier phase
- Future work includes evaluation of mortars, refractory liner construction, and overall costs

References

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