STEALS (Solar Thermoelectricity via Advanced Latent Heat Storage)

Task 2: PCM Heat Storage & Corrosion Research

Kirk Smith | Dr. Corey Hardin & Dr. Eric Toberer | Colorado School of Mines

Motivation

Lack of practical energy storage and dispatchability in conventional solar power systems currently limit wide-scale adoption of these renewable technologies. This project aims to address both issues in a small-scale CSP (concentrated solar power) system.

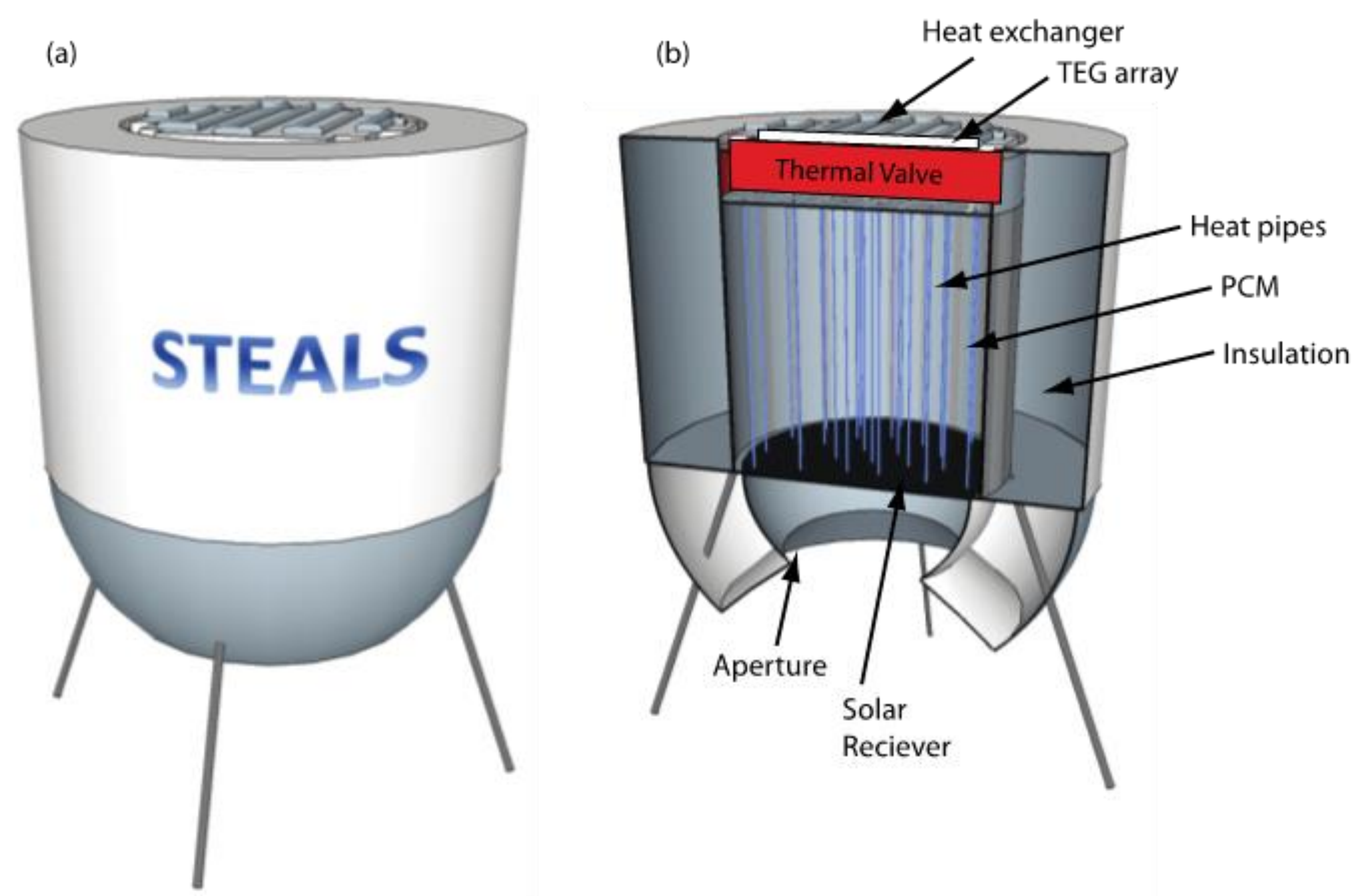


Figure 1: A conceptual STEALS unit (a) and its cross section (b). Concentrated sunlight enters through the solar receiver.

Project Overview

Conventional CSP systems utilize a Rankine cycle with sensible heat storage for plants of >1 MWe. STEALS aims to develop a 100 kWe concentrated solar power plant with a thermoelectric generator (TEG) coupled with latent heat storage. Concentrated solar energy from a heliostat field is stored in a thermal battery (PCM tank) and directed to the TEG via a thermal valve. The project consists of four tasks:

1. System Modeling
2. **PCM Heat Storage & Corrosion Research**
3. Thermal Valve Development
4. Technoeconomic Analysis

PCM Heat Storage

Energy storage will be accomplished by utilizing a phase change material (PCM), such as molten salt or metal. Over the course of the solar day, the PCM (contained in a tank) will melt and store energy in the heat of fusion of the material in an isothermal process. When electricity is desired, the thermal valve opens and heat discharges from the PCM to the TEG via heat pipes, freezing the PCM.

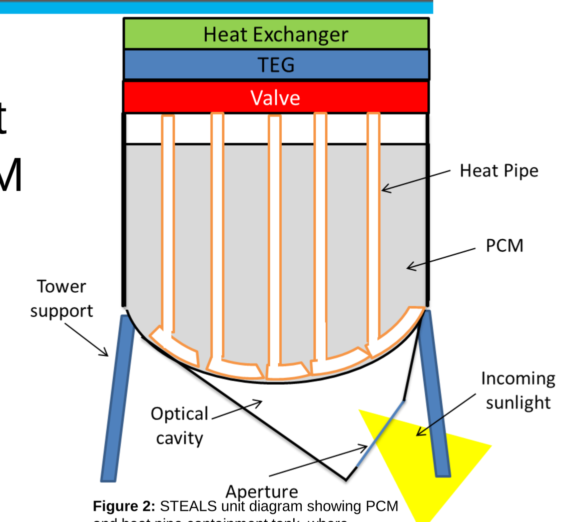


Figure 2: STEALS unit diagram showing PCM and heat pipe containment tank, where corrosion prevention is needed.

Corrosion Research

High temperature PCMs present a challenge in the form of corrosion on the inside of the PCM tank and on the heat pipes used to transfer heat to the TEG. This summer's research focused on minimizing tank and heat pipe corrosion from the PCM.

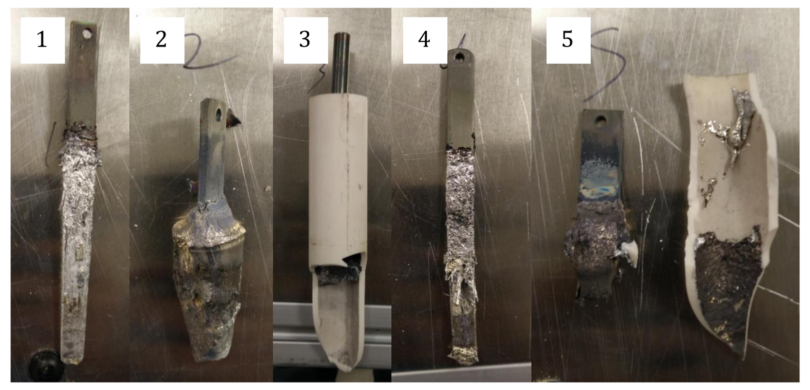


Figure 3: Various corrosion coupons tested in molten metals, all showing extreme failure

- Sample 1 – titanium coupon in pure molten aluminum
- Sample 2 – titanium coupon in aluminum with 0.2% titanium
- Sample 3 – titanium coupon in aluminum with 1% titanium
- Sample 4 – nickel coupon in aluminum-nickel eutectic
- Sample 5 – titanium coupon in aluminum-nickel eutectic

Figure 4: Left to right: virgin titanium, titanium exposed to N2 at 700 C for 200 hours, titanium exposed to molten aluminum at 700 C for 200 hours. The rightmost sample demonstrates the aggressive corrosion of molten aluminum.

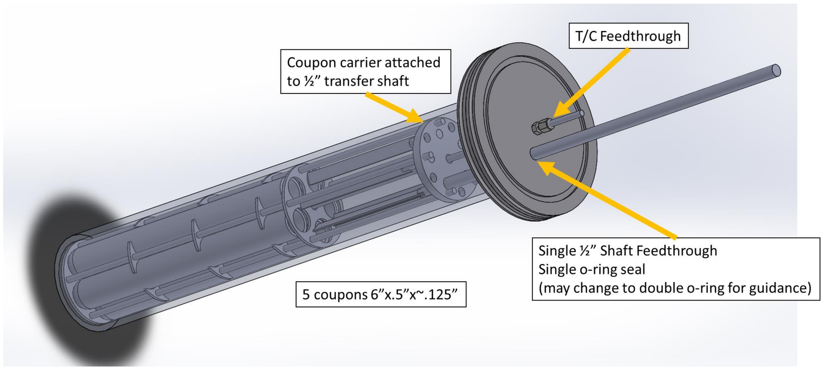
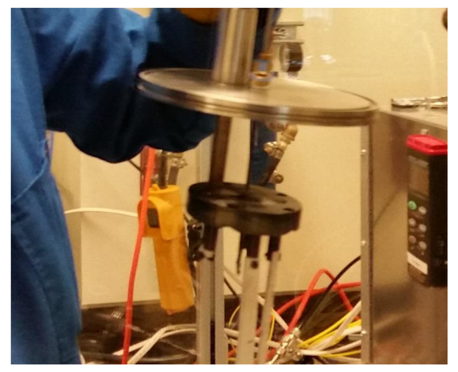


Figure 5: Coupon holder schematic. Coupons are fastened to this device before being placed into furnaces in **Figure 6**.

Figure 6: Custom-built furnaces used for molten PCM corrosion testing. Coupon holders are placed into the flanges and then coupons lowered into molten PCM.

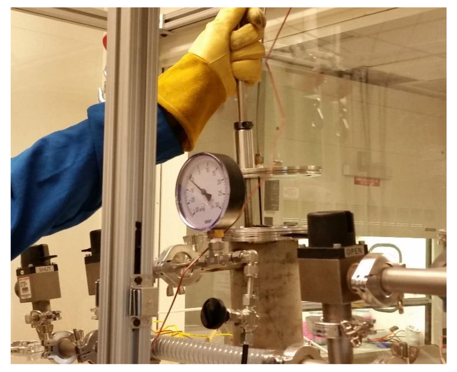
Procedure

Prepare Test Coupons



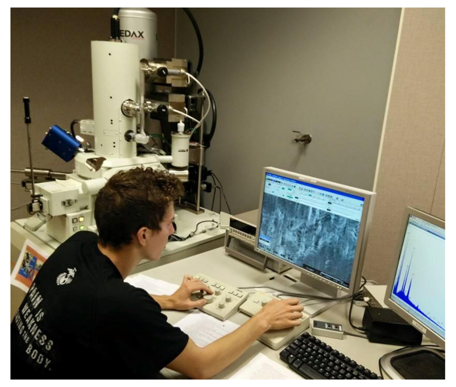
Sample materials are machined into test coupons that will be corroded. Coatings are applied as necessary. Sample materials included stainless steel (316L), titanium, nickel, Inconel 625, silicon carbide, boron nitride, and aluminum oxide, with various ceramic coatings.

Corrode Coupons



Coupons are dropped in molten PCM for 200-3000 hours. Candidate salt PCMs tested include Ca K Cl, Al K F, and Mg Na K SO_4. Metal PCMs included pure aluminum and aluminum 4047 alloy.

Analyze Coupons



Coupons are removed from molten PCM and corrosion layers analyzed to determine performance. Analysis included visual inspection, mass loss/gain, surface and cross section SEM.

Results

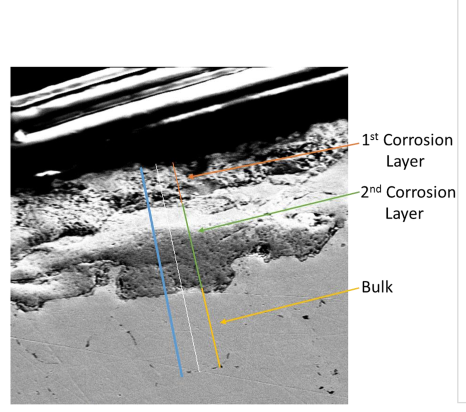


Figure 7: Image taken from cross section SEM of 316L in Ca K Cl. An EDS linescan was taken across the different corrosion layers.

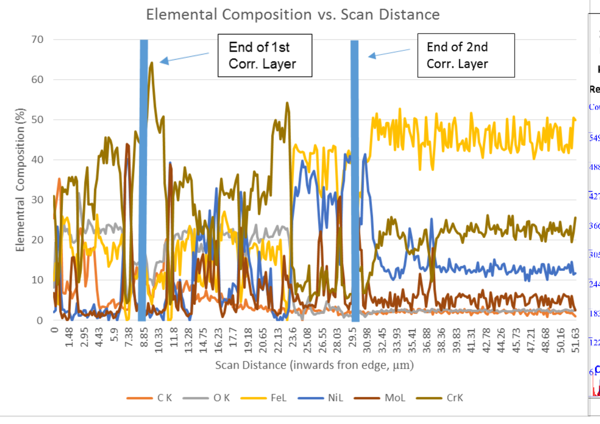


Figure 8: Graph showing elemental composition of different corrosion layers of sample from linescan in **Figure 2**.

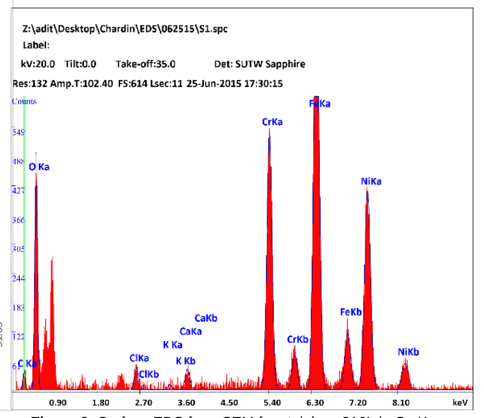


Figure 9: Surface EDS from SEM for stainless 316L in Ca K Cl showing elemental composition of surface.

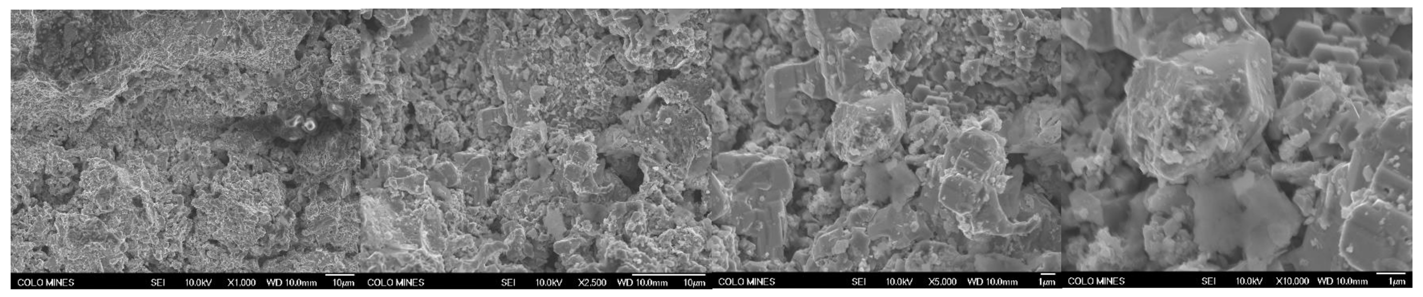


Figure 10: SEM photos of surface of stainless 316L in Ca K Cl at magnifications of x1,000, x2,500, x5,000 and x10,000, respectively

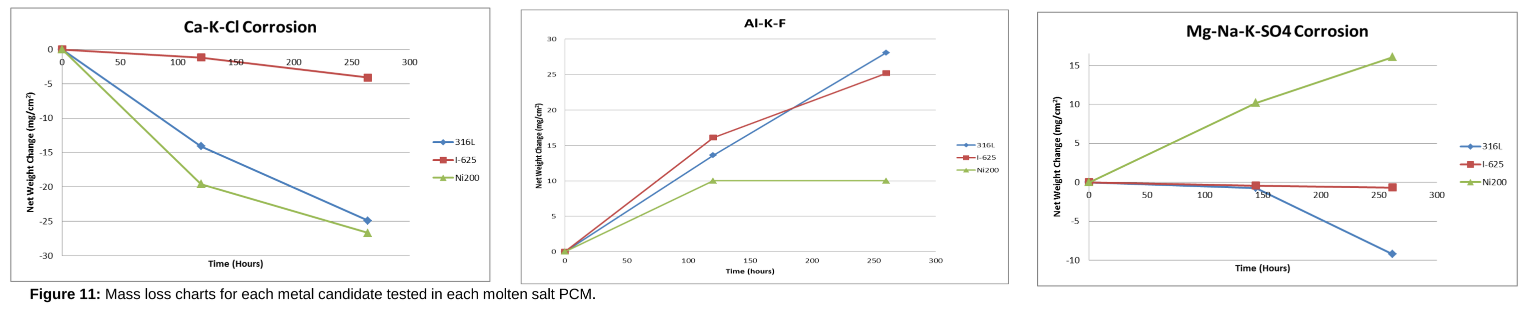


Figure 11: Mass loss charts for each metal candidate tested in each molten salt PCM.

Table 1: Results of testing summarized, table identifies compatible wall materials of possible PCM materials

PCM Material	Cost of Receiver/ Storage ($)	Effective Thermal Conductivity (W/mK)	Compatible Wall Materials	Energy Density (MJ/m^3)	Comments
Pure Al	175,000	~800	Al_2O_3, BN, SiC	1053	Melting point may be too high for current TEG materials, meets all milestones
4047 Al	166,000	~800	Al_2O_3, BN, SiC	1200	Meets all milestones
K-Ca-Cl	465,000	~160	I625, Al_2O_3	240	Low energy density
Mg-Na-K-SO4	492,000	~160	316L, I625, Al_2O_3	314	Low energy density, Shows stability issues in DSC
Al-K-F	658,000	~160	I625, Ni200, Al_2O_3	658	Cost is high due to high salt cost

Figure 12: Virgin monolithic aluminum oxide on left and monolithic aluminum oxide on right after 650 hours in molten aluminum 4047 alloy. This combination is currently the most promising candidate and work is currently underway to test stainless steel coated with aluminum oxide.

Conclusion

The STEALS team has developed a promising concentrated solar power system for off-sun electricity production via thermoelectric generators utilizing latent heat storage. Initial modeling shows molten aluminum PCMs as exciting candidates for further development despite their extreme corrosive properties. Molten salts showed to be less corrosive than metals, but their low thermal conductivity and energy density compromise other components of the STEALS system model, resulting in a higher estimated cost as seen in **Table 1**. With the corrosion test furnaces designed and built at CSM, a reliable testing procedure for PCM and wall material candidates was used to gather crucial data to assess the materials' performance. Monolithic ceramics (such as aluminum oxide) in molten metal PCMs show early signs of promise and further work will be dedicated to testing various ceramic coatings in similar PCMs.

Acknowledgements

Special thanks to Dr. Eric Toberer, Dr. Corey Hardin, Dr. Chris Oshman, & Jonathan Rea at CSM.

National Science Foundation award DMR-1461275, *REU Site: Research Experiences for Undergraduates in Renewable Energy*