Degradation Mechanisms and Development of Protective Coatings for TES and HTF Containment Materials

NREL

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SunShot U.S. Department of Energy

NREL NATIONAL RENEWABLE ENERGY LABORATORY

PROJECT OBJECTIVES

Goal:

- To extend the lifetime of containment materials and thus reduce capital and maintenance costs of future solar power plants.
- Advanced protective coatings and surface modification techniques will be developed and evaluated to have degradation rates lower than 30 µm/year.
- The fundamental understanding of CSP components degradation in the presence of high temperature TES and HTF such as molten salts, liquid aluminum alloys and supercritical carbon dioxide (S-CO_2) will be addressed.

Innovation: The novelty of the proposed research is the development of protective coatings and working conditions for materials in contact with high temperature TES and HTF. Current state-of-the-art materials and protection methods are non-existent for CSP applications.

Milestones: There are no milestones for this quarter

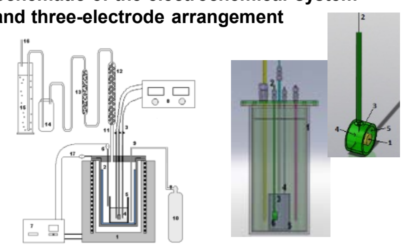
APPROACH

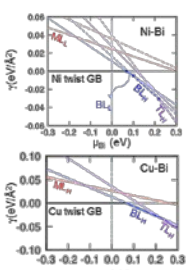
- The selection of the fluids was performed using FactSage modeling, laboratory testing and the report “Advanced Fluids Milestone: Candidate Materials for Sensible and Phase Change Thermal Energy Storage”. The selection of the coating candidates was done after evaluating current technologies applied to turbine blades working under thin film molten salt corrosion over 700°C and containment materials protection to contain liquid aluminum.
- The design of the electrochemical cell for molten salt corrosion evaluations was performed based on our previous experience with similar electrochemical systems. The contact angle measurement instrument was designed after evaluating current technologies.
- In the density-functional theory (DFT) simulations for liquid metal embrittlement, the total energies of grain boundaries (GBs) and GB-stabilized impurity phases were calculated within the generalized gradient approximation (GGA-PBE). Our DFT calculations employed the projector augmented wave method.
- The University of Wisconsin-Madison conducted autoclave corrosion tests on various commercial iron-based and nickel-based alloys in contact with research and industrial CO_2 grades at 650°C and 20MPa during 200 hrs.

KEY RESULTS AND OUTCOMES

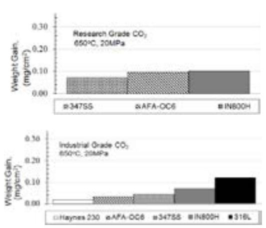
Proposed fluids: pure B_2O_3 and eutectics of K_2CO_3–Na_2CO_3, NaCl–LiCl, Na_2CO_3–NaCl, Al–Si, and Al–Mg.
Proposed alloys: 310SS, 347SS, Incoloy800H, Inconel625, AFA-OC6.
Proposed coatings: bond coat of Ni–Cr or NiCoCrAlY, outer layer of aluminum with an aluminosilicate top coat.

Schematic of the electrochemical system and three-electrode arrangement





- The calculated formation energies of various impurity phases in Ni and Cu grain boundaries (GBs) showed that the Bi bilayer (BL) phase is the most stable and thus the dominant interfacial phase in the Bi-rich condition in which the Bi chemical potential is close to zero.



- Industrial CO_2 gas may be less corrosive than the pure version due to some impurities acting as corrosion inhibitors similar from oil and gas research.[1,2]
- Longer exposure times and metallography are needed to determine which alloy is performing better overall.

[1]Ko, M. et al. *Corrosion 2012*. Salt Lake City, UT, March 11–15, 2012.
[2]Mustafa, A.H. et al.(2012). *Journal of Materials Engineering and Performance*, Dec 2012: 1-8.

NEXT MILESTONES

- **Milestone (Task 1.1):** Identify and synthesize candidate protective coatings for particular molten salts and liquid metal alloys. (09/30/13)
- **Milestone (Task 1.2):** The selection of the substrates for further evaluation using coatings or cathodic/anodic protection will be based on the 30 µm/year metric for a lifetime of at least 30 years or more. (09/30/13)
- **Milestone (Task 1.3):** Document corrosion data of three alloys (800H, 347SS, and AFA-OC6) exposed to different commercial CO_2 gas grades and impurity concentrations. Model corrosion rate as a function of impurity concentration and time and identify conditions estimated to provide a corrosion rate of less than 30µm/year, i.e., a material lifetime of 30 years. (09/30/13)

Risks and their mitigation for next quarter activities:

- Low temperature deposition of crystalline alpha (α) alumina (Al_2O_3) top coat. Mitigation: Preliminary tests will be performed to define deposition conditions of α-Al_2O_3 or annealing conditions to transform deposited coating.
- Identification of the impurity species in industrial CO_2 that reduce corrosion. Mitigation: Analysis of incoming and outgoing CO_2 and SEM analysis of the corrosion layer need to be performed to identify changes in the corrosion layer between pure and industrial CO_2.