SAND2007-1417C

Improved Molten Salt Heat Transfer Fluid Development

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ABSTRACT

Integration of thermal energy storage in parabolic trough plants is a logical development that increases value and enhances the dispatchability of solar-generated power. One option to significantly reduce costs is to implement direct thermal energy storage systems that utilize a single molten nitrate salt heat transfer fluid for collection and storage. A focused R&D effort is required to address key issues related to use of molten salt in trough solar fields and related thermal energy storage components. Of particular importance is the development of improved molten salt formulations with reduced freezing points useful to advanced solar power plant applications.

1. Objectives

The long-term goals of thermal energy storage (TES) development include lower freeze temperatures and higher operating temperatures in order to increase parabolic trough plant capacity factor, enhance dispatchability of solar-only operation, and increase the value of power delivered. Substantial cost reduction can be achieved by using molten salt as both the storage medium and solar field heat transfer fluid (HTF) in direct storage systems. Commercial salt formulations that are currently available include properties, such as high freezing points, that are detrimental to use in large solar fields. As such, the key objective of this activity is to develop new and improved molten salt formulations that exhibit usable properties and are low in cost relative to alternative HTF options. These TES goals and objectives are addressed in Section 3.2 of the current DOE Solar Energy Technologies Program Multi-Year Program Plan (see www.eere.energy.gov/solar/about.html).

2. Technical Approach

Evaluation of TES system configurations for tower and trough plants has been the subject of relatively intensive effort under the DOE CSP program for a number of years. SunLab studies[1,2] and R&D efforts focused on the integration of solar thermal energy storage, and evaluated the option of using inorganic molten salts as both the solar field HTF and TES media in trough power plants. These systems studies have shown that direct storage configurations may offer the least cost TES option.

Over the past 7 years, studies and experiments have been conducted at the Sandia National Laboratories National Solar Thermal Test Facility in Albuquerque, New Mexico. Pacheco[3] and Brosseau[4] conducted a series of design studies and experiments that evaluated molten salt formulations, salt-oil and salt-metal interactions, and demonstrated a large laboratory-scale thermocline system and the durability of thermocline filler materials in molten nitrate salt. Recommendations were made during these testing campaigns and a TES R&D Plan[5] was issued responsive to the recommendations that provided a roadmap for the next sequence of R&D activities.

The TES R&D Plan addressed a suite of activities needed to demonstrate the direct molten salt concept. The primary focus for TES development in FY06 and FY07 has been initial investigations of new molten salt formulations, based on inorganic nitrates and nitrites, as well as the need to address salt freeze events and freeze recovery systems.

New formulations are being considered to optimize the following desired properties:

- Reduced freeze point (relative to other salts)
- Low cost (relative to Therminol VP-1 now used)
- Chemical stability at ≥ 500°C
- Environmentally friendly (relative to VP-1)
- Very low vapor pressure (for TES tanks)
- Compatible with materials of construction
- Excellent HTF fluid properties

Task Plans[6] were developed in FY06 and updated in FY07 to guide the molten salt development activities.

3. Results and Accomplishments

FY06 activities focused on literature review and evaluation of published phase diagrams of binary and ternary nitrate and nitrite salt mixtures. These reviews helped establish a baseline for formulating multi-component mixtures. Molten salt furnaces and melting point apparatus were procured to prepare and evaluate a matrix of multi-component molten salt formulations, focusing on freeze point determination. Preliminary cost data were also collected from the open literature.

FY07 activities were focused on identifying starting compositions and adding soluble constituents in an effort to depress the solidification or melting point. Since no data on the phase change behavior of targeted salt mixtures was found in the literature, we devised simple experiments to closely control salt temperature in test tubes to determine onset of solid phase formation with a variety of salt mixtures (Fig. 1).

This approach led to identification of a small number of candidate formulations that warranted further evaluation. Targeted nitrate mixtures that are liquid at temperatures below 100°C have been observed. This freeze point is substantially below that measured for salt mixtures studied or commercialized to date and indicates the potential for reaching program goals.

Figure 1. 10-Tube Test Apparatus.

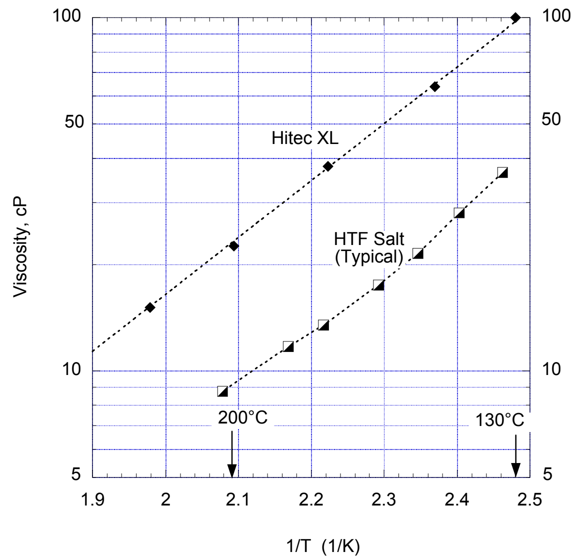

Figure 2. Viscosity of molten nitrate salt HTF

Thermal stability of a molten salt mixture is also an important characteristic. Many current nitrate and nitrite salt mixtures exhibit maximum upper temperatures (thermal stability) between 500°C and 600°C. Though more work is required to demonstrate this, the thermal stability of mixtures under evaluation is anticipated to be at least 500°C.

Viscosity is also an important property, particularly near the salt freeze point. Viscosity of molten salt mixtures was determined using a Brookfield digital viscometer over a range of temperatures. Figure 2 shows an Arrhenius plot of viscosity data for Hitec XL®, a commercial molten nitrate salt mixture, and a candidate mixture. Measurements to date of the candidate mixtures have shown viscosities of less than 100 cP near the freeze point. Viscosities over the range of operating temperatures are comparable to binary solar salt.

Finally, commercial cost of these salts will be very important to determine. The candidate mixtures can be optimized to include less of the higher cost ingredients. While more work is required, cost targets for this new HTF formulation should be achievable and will be less than organic HTF.

4. Conclusions

In order to meet the long-term goal to deploy commercially viable direct TES systems utilizing nitrate salt HTF, SunLab is poised to make significant progress with the development of a new HTF formulation that will improve the economics of TES system implementation in parabolic troughs. Research and development activities are in progress that will identify molten salt formulations that provide optimal properties. The exact details of the molten salt compositions and the type of additives are protected as intellectual property at this time.

ACKNOWLEDGEMENTS

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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