SAND2009-0911C

DOE Solar Energy Technologies Program Peer Review

Technical Track: Concentrating Solar Power (CSP)

Project Name: HTF/Thermal Storage Systems and Components

Principal Investigator: Nathan P. Siegel (SNL)

Denver, Colorado

March 9-10, 2009

TES R&D 10/2007-2/2009

- Heat transfer fluid development
  - New molten salt formulations and qualification
    - Enables higher performance, lower cost parabolic trough systems
- Storage systems and components
  - Pump and Valve upgrade design
    - Supports the development of salt-service components
  - Freeze/thaw testing of heat collection elements
    - Freeze recovery is an essential part of an advanced trough system
- Modeling
  - Investigated advanced parabolic trough concepts
    - Helps define the technology development needed to further reduce CSP costs
- FOA Support
  - Began working with Solar Millennium and Hamilton Sunstrand
- **Budget:**

Agreement Title	FY 2008 Budget ($K)
Storage components (freeze recovery, facility design)	93
Storage systems (modeling)	130
Advanced HT fluid development	56
FOA support	100

Thermal Storage R&D Team

- Team Members:
  - Nathan Siegel (SNL)
  - Bob Bradshaw (SNL)
  - Greg Kolb (SNL)
  - Rich Diver (SNL)
  - Joe Cordaro (SNL)
  - David Raymond (SNL)
  - Tim Moss (SNL)
  - Sai Jayaraman (U. Notre Dame)

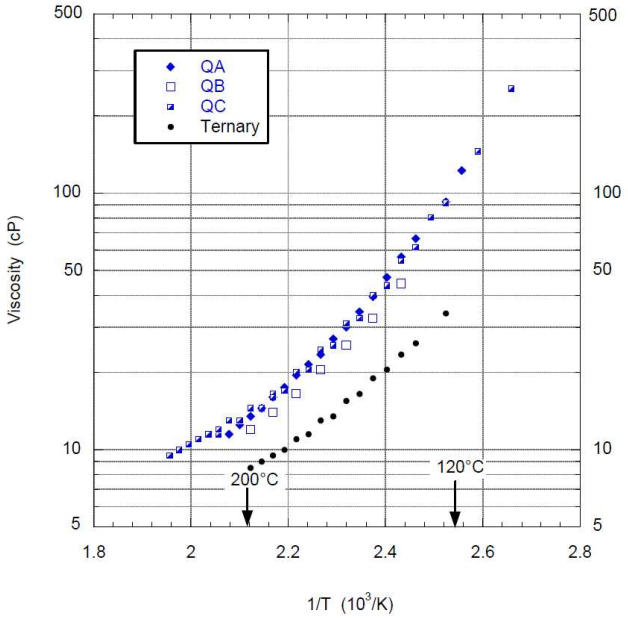
Patents:

Patent application S-112,575, Low-Melting Point Inorganic Nitrate Salt Heat Transfer Fluid, R. W. Bradshaw and D. A. Brosseau, filed May 12, 2008, in USPO review.

- Publications
  - *Improved Molten Salt Formulations for Heat Transfer Fluids in Parabolic Trough Solar Power Systems*, SolarPACES 2008, Las Vegas, NV, Mar. 4-7, 2008, R. W. Bradshaw and D. A. Brosseau
  - *Molten Nitrate Salt Development for Thermal Energy Storage in Parabolic Trough Solar Power Systems*, Paper ES2008-54174, ASME 2nd International Conference on Energy Sustainability, Jacksonville, FL, Aug. 10-14, 2008, R. W. Bradshaw and N. P. Siegel
  - *Conceptual Design of an Advanced Trough Utilizing a Molten Salt Working Fluid*, SolarPACES 2008, Las Vegas, NV, Mar. 4-7, 2008, G. J. Kolb and R. B. Diver

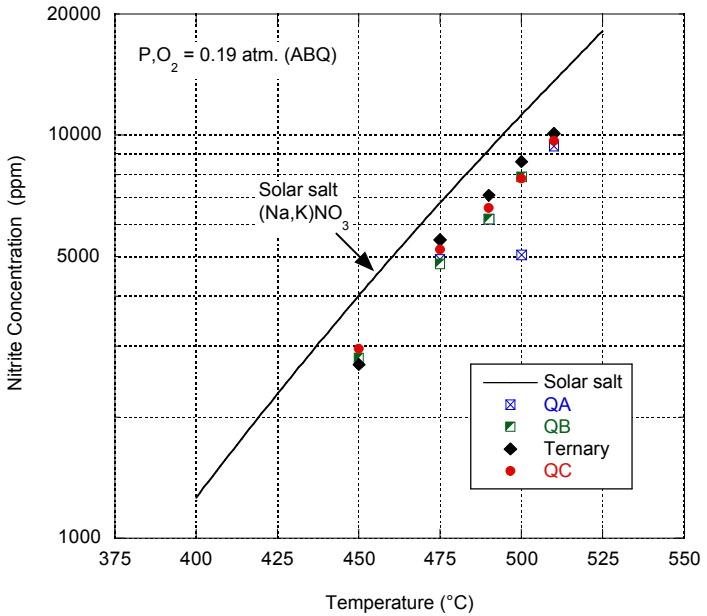
Heat Transfer Fluid Development

- Discovered several low melting point nitrate salts
  - Supports direct use of salt HTFs in troughs
  - Could help reduce parabolic trough LCOE
- Salt characterization is underway
  - Stability has been evaluated
  - Corrosion studies pending
  - Property evaluation near completion



Low MP salt viscosity

$$NO_3^- = NO_2^- + 1/2\ O_2$$



Low MP salt thermal stability

Heat Transfer Fluid Development

- Quaternary nitrates melt < 95 C
- Nitrate-Nitrite salts melt < 80 C
- To date, techniques are largely empirical
- Molecular dynamics will be used to aid materials discovery efforts

Na	K	Ca	Li	Liquidus Temp.	Notes
mol%	mol%	mol%	mol%	°C	
50	50			221	Na-K-NO_3 eutectic
21	49	30		133	Ca-Na-K-NO_3 eutectic
18	52		30	120	Li-Na-K-NO_3 eutectic
	58	11	31	117	Ca-Li-K-NO_3 eutectic
High	+	+	+	< 95	QA
Med.	+	+	+	< 95	QB
Low	+	+	+	< 95	QC

Melting points of nitrate salts

Materials Compatibility

- New salt formulations appear to be compatible with common engineering metals
  - Several samples (some with welds) of carbon, alloy, and stainless steels were tested for 3000 hours at 500 C and 350 C
  - Salt samples were taken at various intervals
  - Materials are now being evaluated:
    - Descaled weight loss
    - Microstructure

Compatibility Tests for New Salts

Material	Test Temperature, C
316H	500 C
321H	500 C
347H	500 C
304L	500 C
316L	500 C
Alloy: 2.25% Cr, 1% Mo	350 C
Alloy: 9% Cr, 1% Mo, 0.25% V	500 C, 350 C
A516 Gr.70	350 C

Test matrix for materials compatibility

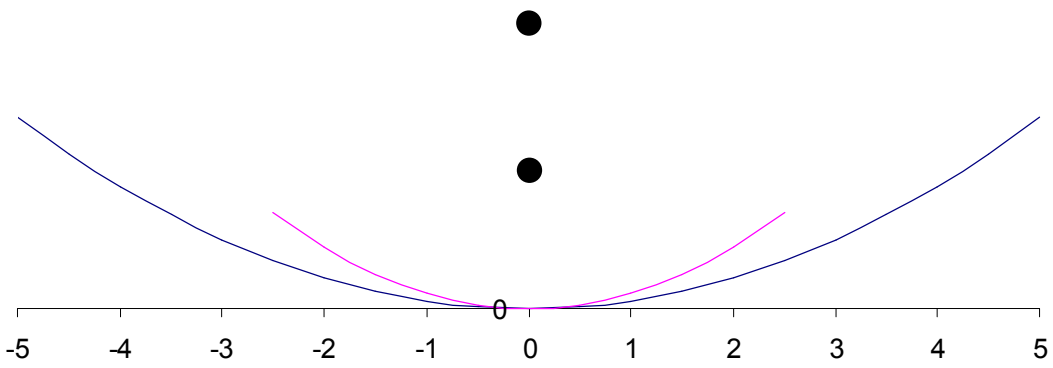
Freeze Recovery for Parabolic Troughs

- Using a molten salt HTF in parabolic troughs could enable lower cost operation
- Systems must be developed to recover from a freeze event
- We have begun studies involving freeze recovery via impedance heating of the HCE

Impedance heating system at SNL

Modeling – 2X Trough

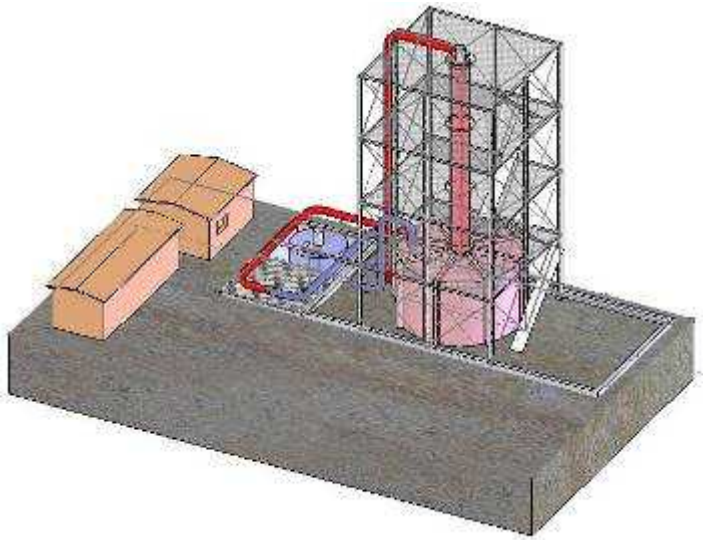
- A modeling effort was undertaken to define an advanced trough that enables a reduced LCOE (25% versus current technology)
  - This trough has a 10 m aperture with a 7 cm receiver, or twice the concentration of conventional systems (LS-2)
  - It operates at 500 C outlet temperature with low melting point salt and thermal storage
  - Requires an error budget of 2.5 mrad versus 5 mrad
  - Closed loop tracking
  - Requires a low emissivity coating
  - ~7% low ε coating
- Provides benefits even if operating with an oil HTF



Conventional trough vs. 2X trough

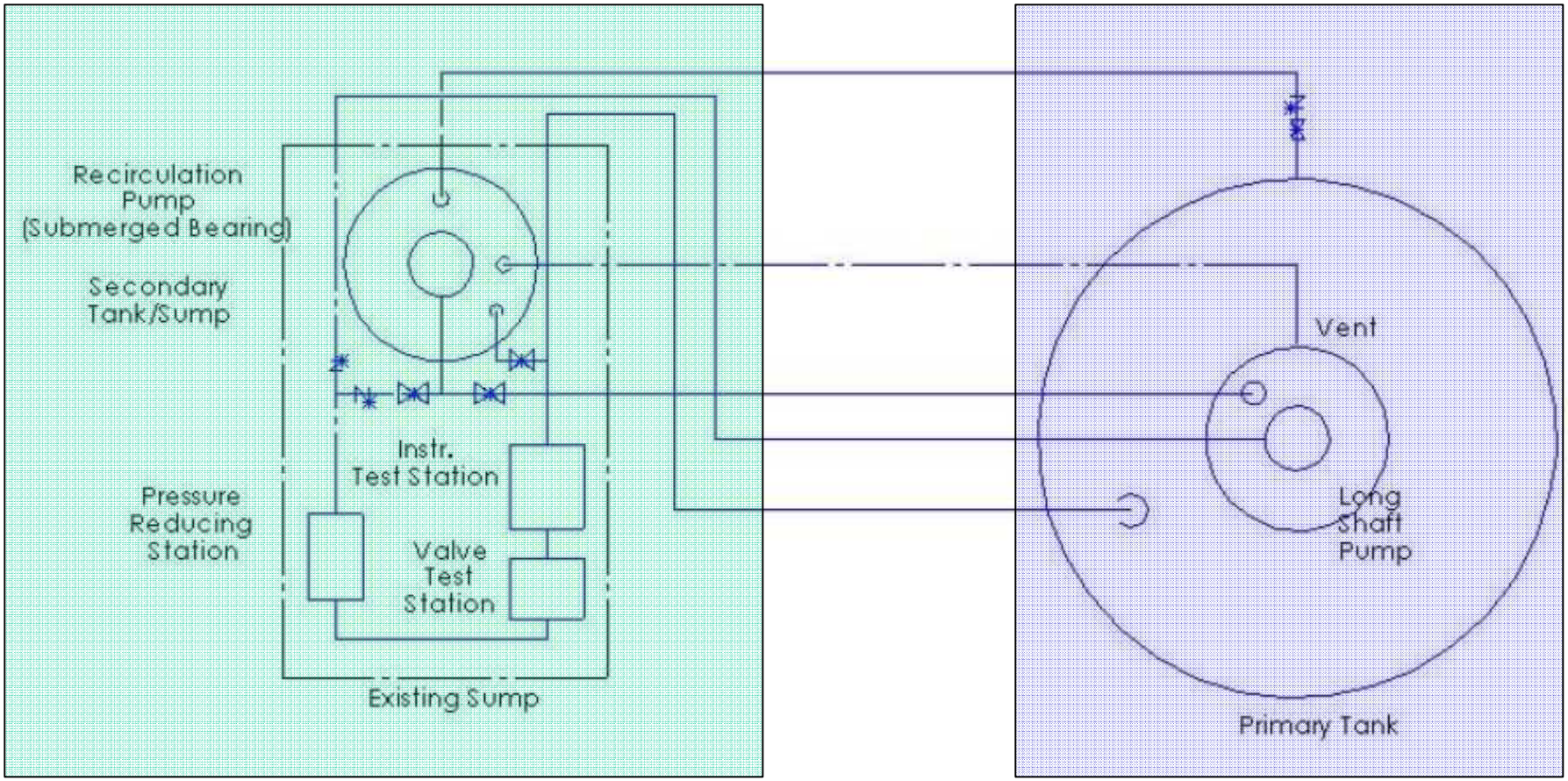
Molten Salt Test Facility Design

- The existing Pump and Valve facility will be upgraded to support the testing of CSP storage components
- Conceptual design is complete
- Upgraded Facility Capabilities
  - Stage 1:
    - Valve development and evaluation
    - Data acquisition and controls evaluation
  - Stage 2:
    - Possible support of central receiver development at the power tower
    - Long shafted pump testing at full flow and variable pressure/head conditions



An Upgraded Pump and Valve Test Facility

Molten Salt Test Facility Layout



Phase 1: Instrumentation and component testing

Phase 2: 15 m long shafted pump testing

Molten Salt Test Facility Capabilities

- **Accommodate prototypic pumps and component testing**
  - **Pumps**
    - **Specifications**
      - **high temperature, low head prototypic pump for trough and tower applications**
      - **52 ft long-shaft pump, tank-mounted**
      - **6000-11,000 gpm at 200-250 psi**
    - **Pump Testing**
      - **Variable head/flow rates (HQ line)**
      - **Variable flow temperatures (full range)**
      - **Variable tank height (25%-100% of pump shaft length)**
      - **6 ft stand-off from suction-bell to tank wall**
  - **Other components**
    - **Valves (packing seal)**
    - **Instrumentation (flow meters, pressure transducers)**
    - **Expansion joint(s)**
    - **Ball-swivel connection(s)**
    - **Instrumentation**

Future Directions

- Heat transfer fluids
  - Continue low melting point fluid discovery/characterization
  - Begin investigating higher temperature fluids for central receiver applications
  - Expand computational materials discovery efforts
- Systems and Components
  - Proceed with construction of salt test facility upgrade
  - Begin to upgrade central receiver test capability
  - Continue and possibly expand freeze recovery test and development
  - Continue developing 2X trough concept
- FOA support and associated facility upgrades