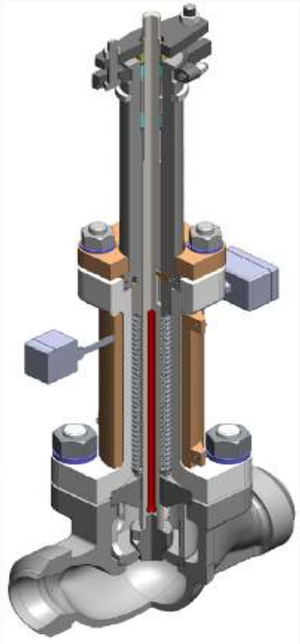
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

DOE Summit Molten Salt Components – Chloride Salt Valves



Gen3 CSP Summit
August 25, 2021

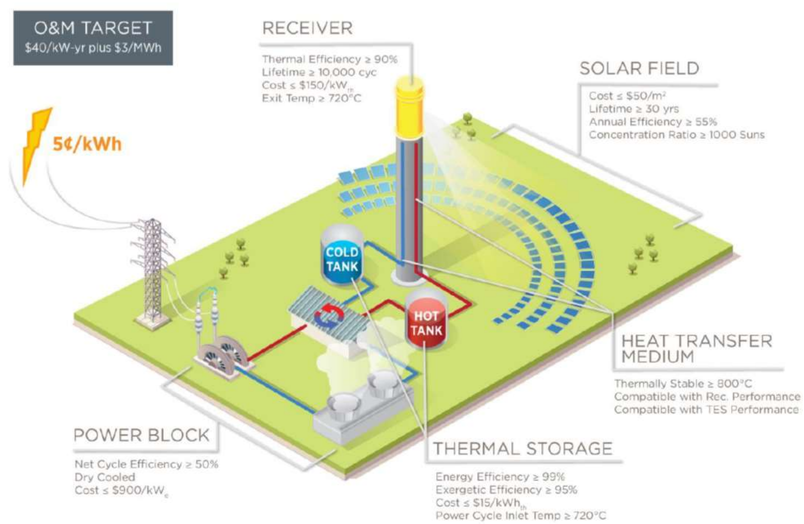
Ken Armijo
Principal Investigator
Sandia National Laboratories

Sandia National Laboratories FLOWSERVE Kairos Power

SNL Award # 36335 (Agreement Number)

750^{o}C Molten Salt Valve: Key Challenges

- DOE SETO focus of developing thermal transport systems capable of operating temperatures > 700°C and integration with advanced, high-efficiency power cycles.
- Materials and Manufacturing - Solutions to reduce the cost of manufacturing CSP components.
  - "Receiver & components: piping, pumps, tower structure, insulation, heat tracing, headers, and valves"
- To attain CSP capital reduction, need to improve performance of materials & reduce CSP component manufacturing costs.
- Materials compatibility up to 750°C
- Leak & Freeze Protection
- Proper Controls and Ullage Gas System Integration
- Higher-than-expected salt vapor pressure
- High salt vapor freezing phenomena

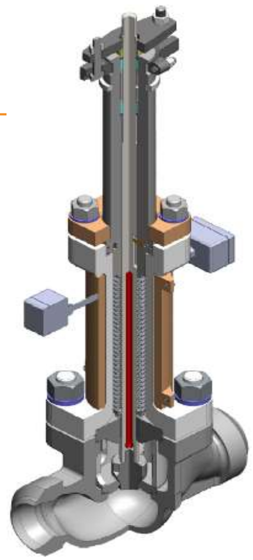


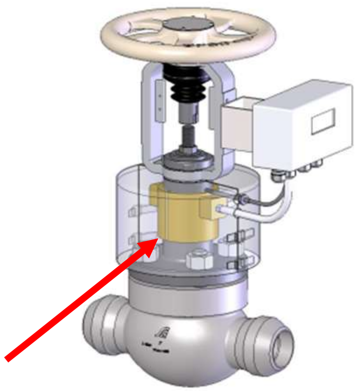
Project Objectives

- Design, prototype, and test 2-in. freeze-resistant, leak-reduction flow-control valve.
- Determine chloride salt compatible materials.
  - Down-selection of molten salt compatible materials at 750°C.
  - For “quick-change” packing, gaskets, bellows, seals and heat pipe alloys (e.g. H230 and Inconel 617).
- Design valving architectures to ensure freeze, leak-resistance & freeze resilience.
  - Thermal management valve design selected that achieves performance targets.
- Screening validation design tests of STM & heat pipe valve components.
  - Subsequent validation experiments of complete valve assembly with isothermal batch-processing flow test system.
- Techno-economic scalability & Translatability for valve to 6”-8” scale and to isolation and check valve.

Design Novelty & Approach

- **R&D approach to leverage passive & active thermal management for robust operation, to be translated across different valve types.**
- **Self-contained Thermal Management (STM)**
  - Develop Self-contained Thermal Management (STM) system integrated for consistent, repeatable alternative to heat tracing.
  - Unique extended bonnet design to accommodate "quick-change" packing configuration to reduce maintenance costs.
    - Serve as alternative or seal barrier for bellows, which rupture if actuated with frozen salt present and costly to maintain/replace.
  - Investigate incorporating temperature, pressure & flow sensing for overall system cost-reduction.
- **Heat Pipe Valve Stem**
  - Valve stem heat pipe allows for complete insulation and keeps valve hot as long as hot salt is present.
  - Thermal brake with heat pipe to maintain near-ambient actuator temperature.
  - Novel heat pipe valve stem to facilitate enhanced passive thermal management into valve assembly.
  - Valve stem heat pipe to facilitate natural circulation within bonnet during transient thermal operation.
  - Design integration with ACT & Flowserve for valve stem sealing approaches.





Representative STM System Design Approach

HT Salt Pot Materials Compatibility Studies

Components to be Studied

- Valve body, bonnet, gaskets, packing, bellows, welds, impellers.
- Gaskets and Seals

Materials being studied

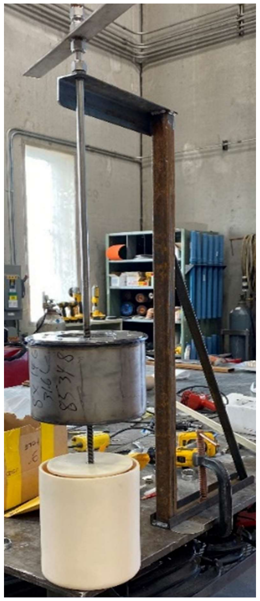
- Alloys: SS316H (CF8M), SS347H, Haynes 282, Haynes 230 (or Inconel N06230), C-276, SS304H Incoloy 800H, Inconel 617, Inconel 625, (potentially combined with nickel and cobalt based cladding such as Colmony 5, Alloy200, 740H.
- Seals: Ceramics, Mica, Thermiculite, graphite.
- Weldments

Salt Pot Work

- Nitrogen gas, vacuum pump, & gas condensation lines detachable via VCR fittings for lid removal
- Addition of a Liner or cladding
- Re-making lid out of $Al2O_3$/SiC
- Ullage Gas systems

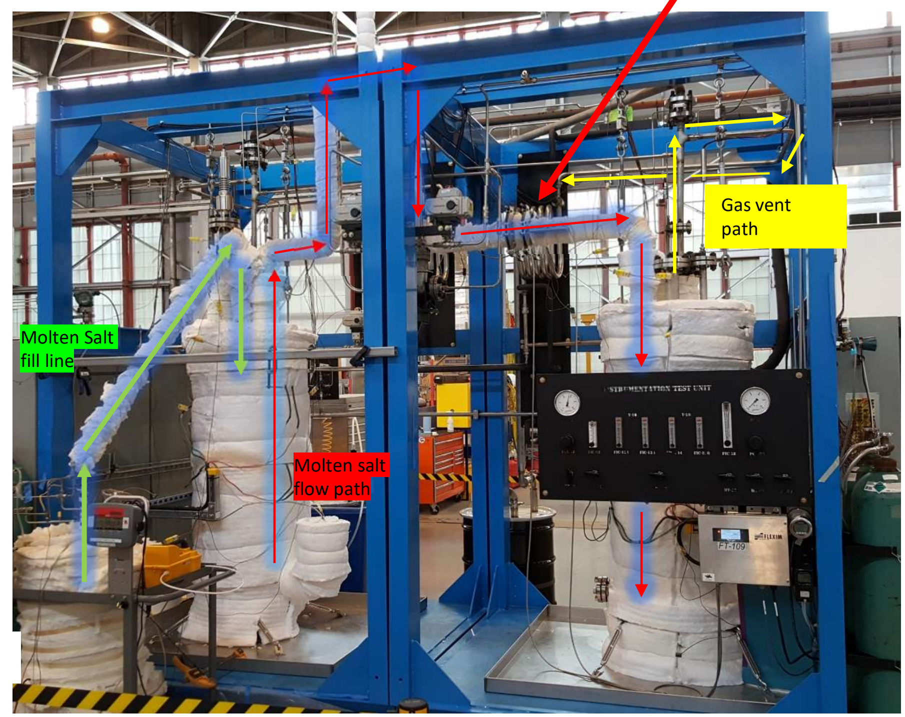
Post-Test Analysis

- Scanning Electron Microscopy/Energy Dispersive Spectroscopy (microscopic structural changes and elemental analysis, XPS)
- Mass loss measurements
- Corrosion analysis



SNL/Kairos Power Isothermal Batch Flow Unit

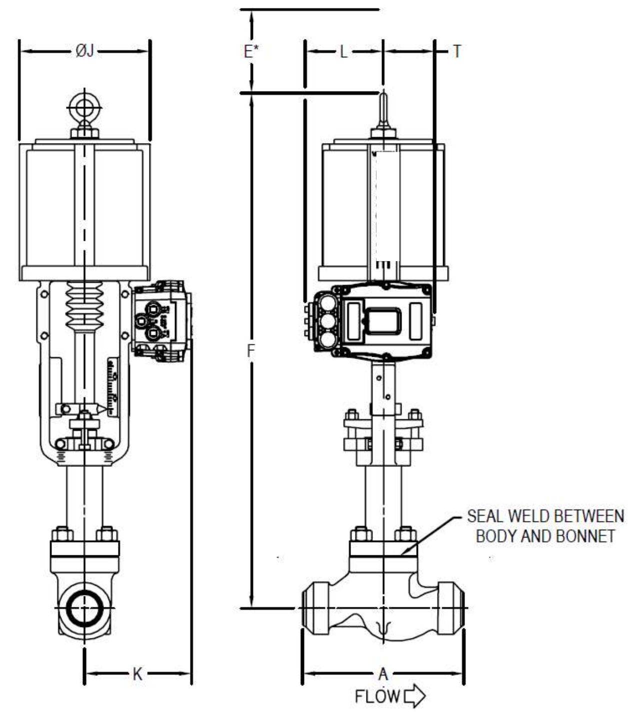
- Finalized designs for two designed prototypes tested within Kairos Power Isothermal-Batch flow test system.
- Investigations of valve performance and reliability up to 750 °C operational temperature.
  - Throttle valve C_v validation
  - Leak and thaw capabilities
  - STM & Heat Pipe valve stem validation
  - Ceramic Fiber (CF) heating validation
- Cold commissioning completed.
  - Leak checks
  - Heater run-ins, Vessel bake-out
- Hot Commissioning completed.
  - Ramped heaters up to 600C
  - Verification of system operations
  - Completed transfer from vessel V10 to vessel V20
  - Commissioning utilizing orifice plates to simulate C_v & pre-operations



Valve Flow Testing: ORNL FASTR / Kairos Power Flow Systems

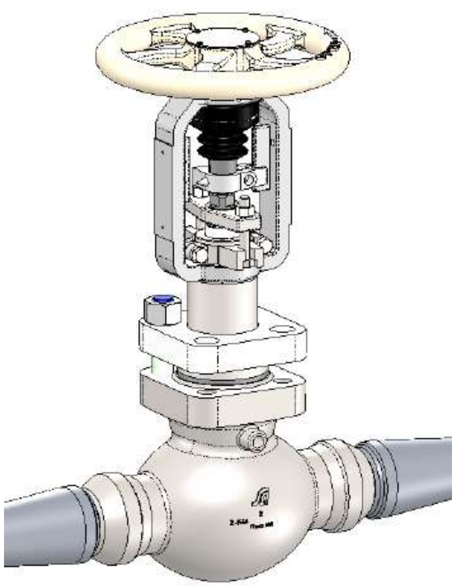
Developing Effort

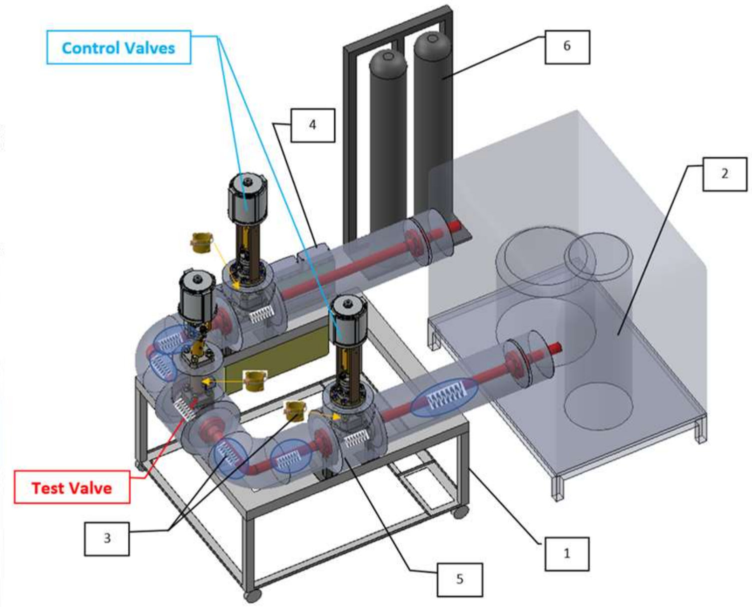
- Valve Type: Globe Valve, proportional flow control
- Overview: Test in flowing ternary chloride salt; assess actuation, isolation, C_v, leak mitigation with packing and possibly freeze-recovery
- Globe valves are most recommended for molten salt application
- Alloy: Forged Hastelloy C-276
- Coating Material: Colmonoy 5
- Seal: Two graphite packing sets, no bellows
- Flanges: Raised-faced flanges
- Actuation: Automated
- Temp Range: 500-720 °C



Flowserve Molten Salt Test Rig

- Valve prototype qualification (Flowserve Screening Tests)
- Test loop to test the functionality, fatigue strength, corrosion resistance, temperature profile and heat losses at the valve should to be measured.
- Salt tank with filter: D = 168mm; L = 735 mm), Material 1.4301
- Pump: Max. T 400°C, 26,000 l/min, Gasket: Inconel, (New: 750°C; 11 ba
- Test Valve: 2 in. ID, Bonnet bellows seal special design





1. Mobile support frame
2. Flow system (salt tank, pump, valves, pipes)
3. Electrical heating system
4. Control and safety system.
5. Insulation
6. Nitrogen gas supply

Note: Control Valves are MK1 with extended bonnet (quick change packing)

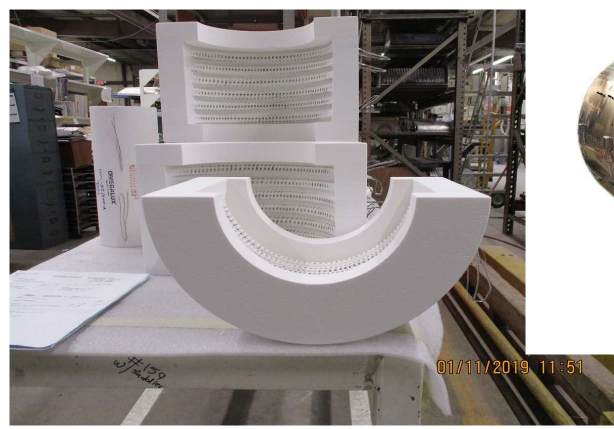
Back-Up Slides

Piping, Heat Trace and System Layout

Five types of pipe preheating systems, of which three: Mineral insulated (MI) cable, heat tape, and ceramic fiber heaters, were found to be viable for parts of the project need.

- Only one system, the ceramic fiber (CF) heater can be exposed continuously at >720 °C hot salt temperatures and not reduce the service life of the pipe preheating system.

MI cable installation for MSTL at Sandia.



Thermcraft CF heaters

Piping, Heat Trace and System Layout

Ceramic fiber heaters (from Thermcraft) operate off of radiant heat principle

- Heater contains multiple electrical heating elements at the internal surface of the heater with a small air gap (~1”) between the pipe OD and heater ID.
- Heaters are capable of preheating pipe to 1200°C and could be utilized to raise salt fluid temperature or offset temperature loss if desired.
- With an operating temperature of 704°C, the outer surface of the ceramic heater would be 173°C.

MI cable versus clamshell CF heater installed cost.

Pipe Heating System	Heater Initial Cost	Heater Installation Cost	Insulation Installation Cost	Contractor Markup	Total Installed Cost (Full Contractor Markup)
Ceramic Fiber	$400-$700 / ft.	$75 / ft.	$190 / ft.	1.3	$865 - $1255 / ft.
MI Cable	$150 / ft.	$170 / ft.	$388 / ft.	1.3	$920 / ft.

Coupon Test Series #1

Coupon holder design finalized to hold 33 coupons, including the AlO spacers.

Alloy Type	Sample 1 Mass (grams)	Sample 2 Mass (grams)	Sample 3 Mass (grams)	Sample 4 Mass (grams)	Sample 5 Mass (grams)
Inconel 625	35.9586	35.1802	35.6901	N/A	N/A
Welded Inconel 625	36.623	36.6217	37.5742	N/A	N/A
Inconel 600	34.8192	33.4425	34.1997	N/A	N/A
Hastelloy C276	40.4855	40.8965	40.5005	N/A	N/A
Inconel 800H	35.2656	34.2379	35.0777	N/A	N/A
Welded Inconel 800H	33.0834	34.4234	34.3691	N/A	N/A
Inconel 617	37.0879	37.149	36.4142	N/A	N/A
Haynes 230	18.0427	17.7475	18.4035	N/A	N/A
Welded Haynes 230	19.6826	18.9591	17.9698	N/A	N/A
Inconel 740H	36.7177	35.729	35.956	N/A	N/A
Haynes 282	12.7779	11.8516	17.2241	N/A	N/A
Wrought Haynes 282	4.3807	5.2237	5.0157	4.0015	5.5156