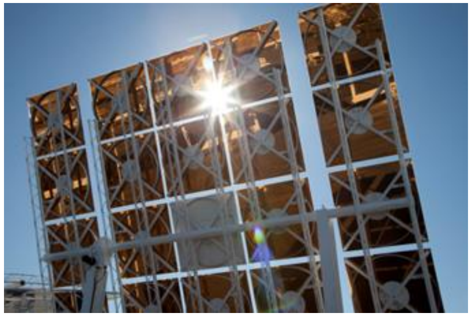
SAND2015-8576C

Exceptional service in the national interest

Sandia National Laboratories

solar.sandia.gov



High Performance Felt-Metal-Wick Heat Pipe for Solar Receivers

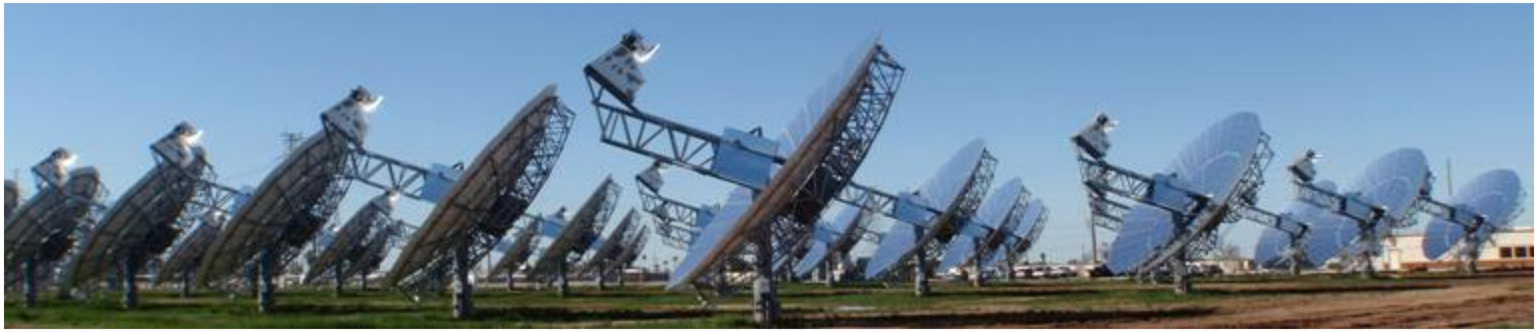
SolarPACES 2015

Chuck Andraka, Timothy Moss, Volodymyr Baturkin, Vladlen Zaripov, Oleksandr Nishchyk

October 13-16, 2015

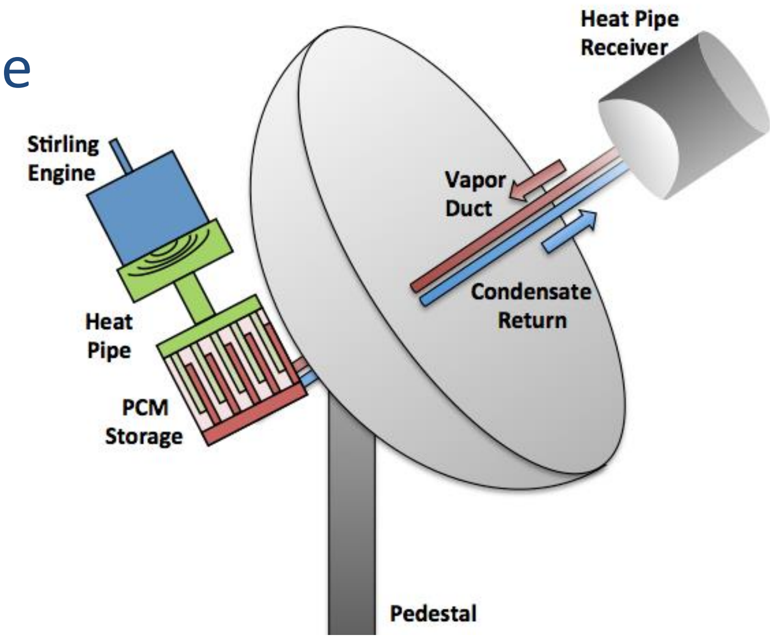
Dish Stirling Technology

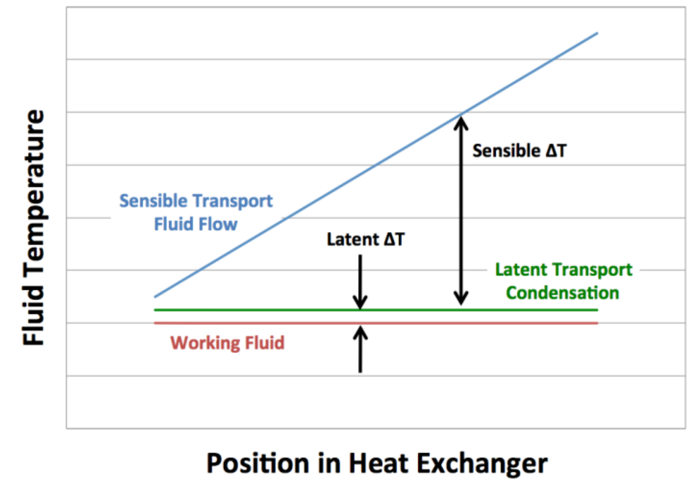
- High performance systems
  - Over 31% sunlight to grid efficiency
  - Over 26% annual efficiency
  - High temperature
  - High concentration
- Typically 3-30kWe
  - Potentially off-grid
  - Large power parks proposed for low cost
- Best technology to meet SunShot goal
  - $0.06/kWh attainable
    - Deployment
    - Supply chain development
    - Design for manufacture
- <u>Needs storage</u>
  - Match demand curves
  - Utilities/PUC's need to "value" evening generation
  - Differentiation from PV



Dish Storage Concept

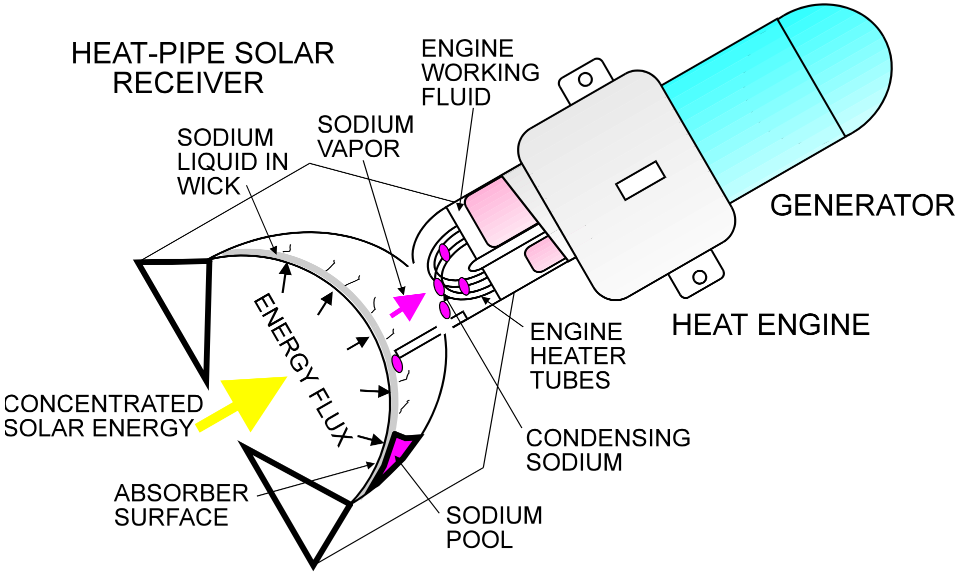
- Phase Change Material (PCM) storage
  - Heat pipe transport to storage and to engine
  - Latent transport and storage ideal for Stirling input
  - Condensate return via pump
- Rear dish mount
  - Rebalances system
  - Allows heavy storage
  - Closes pedestal gap
- Isothermal input to engine
  - Sensible heat input results in large exergy loss
  - Latent input matches engine needs





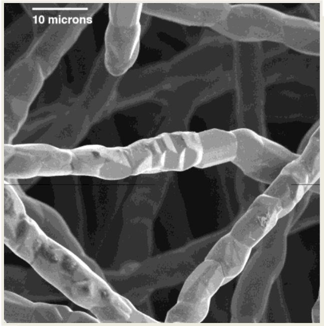
Heat Pipe Receiver System

- Thermal transport through liquid-vapor phase change
- Gravity- or pump-assisted liquid return
- Wick (sponge) to distribute working fluid over heated surface
- Sodium working fluid
- Nearly isothermal end-to-end



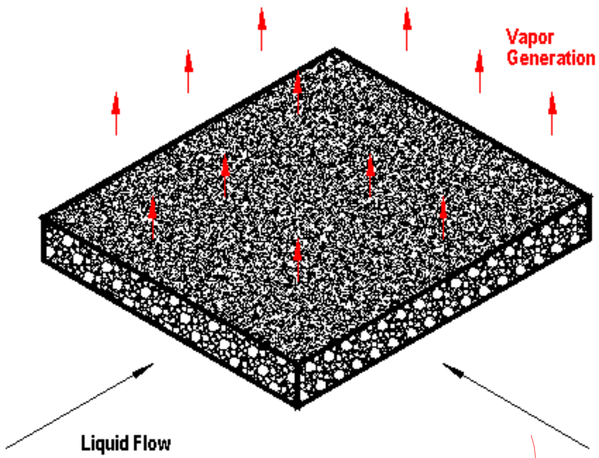
Heat Pipe Wick options

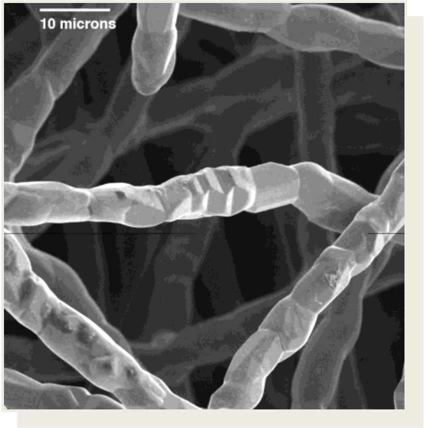
- Screens/Grooves
  - Robust
  - Low throughput
- Sintered powder
  - Mid-performance
  - Proven, commercial
- Felt metal wick
  - Demonstrated high performance
  - Durability issues: Wick compression
- Need:
  - $80kW_{th}$ throughput
  - $100\ W/cm^2$
  - Durability

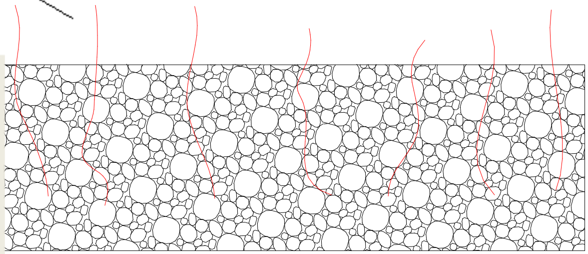


Felt Wick Benefits

- High porosity (>90%)
- High permeability
- Small effective pore diameter
- Pore diameter distribution allows vapor transport
- Demonstrated performance
  - High flux
  - High throughput
- Thicker wires attempted
  - Durable
  - Significantly lower performance







Robust Wick Development Approach

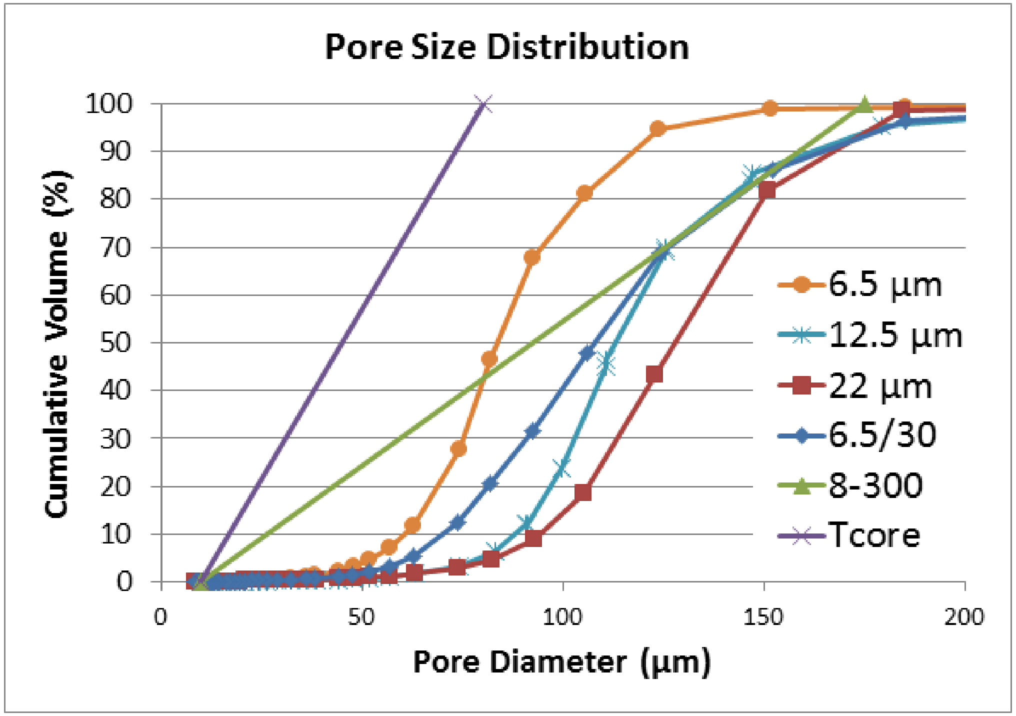
- Leverage past felt wick experience
  - Maintain performance
  - Add features to improve robustness
  - Full-scale models
  - Bench-scale durability testing
- Felt wick variations
  - Large fibers: 22µm and 12µm
    - 30µm previously tested did not perform
  - Small fiber with reinforcement
  - Blended fiber
- Test wick parameters
- Test performance
- Test durability

Designation	Fiber diameter	Fiber Length	Goal porosity	Purpose
CS-22/3	22µm	3mm	0.905	Large fibers provide strength, push performance limits
CS-12/2	12µm	2mm	0.955	Compromise fiber size
CS-6.5/3	6.5µm	3mm	0.98	Small fibers favor wicking performance
CS-30/9+6.5/2	30µm + 6.5µm	9mm + 2mm	Maximize	Gain strength of large fibers and wicking of small fibers in blended configuration

Bulk Wick Measurements

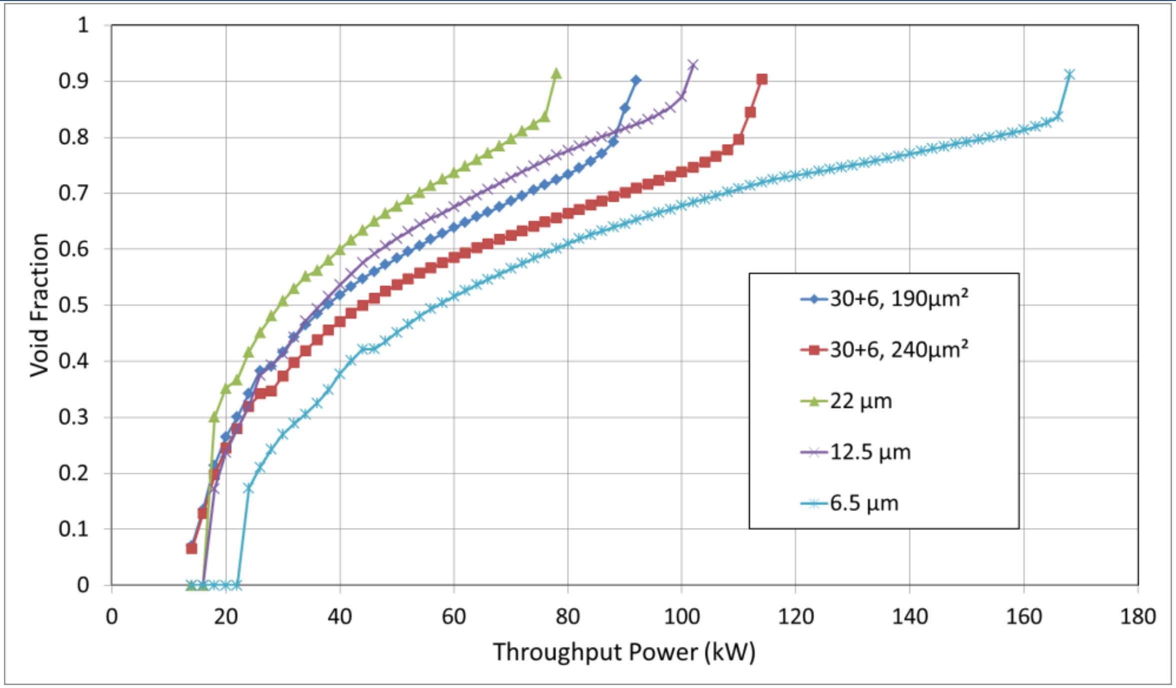
- Permeability
  - Apparatus to flow alcohol at room temperature
- Pore size distribution
  - Mercury intrusion
  - Distributed pore size important to performance

Felt Fiber Diameter (μm)	Porosity measured by saturation (%)	Liquid Permeability measured (μm²)
22	93	210
12	91	250
6.5	95	302
Mixture 30+6.5	88	240
Mixture 30+6.5	95	190



Wick Performance Model

- 2-phase flow
  - Liquid in-plane
  - Vapor perpendicular
  - Coupled
- Model full receiver
  - Realistic flux distribution
  - Fluid return points
- Model operation
  - Increase power until dryout
  - Dries out sharply at 80% void
- Results
  - Blended fiber acceptable over range of permeability
  - Two fixed fiber sizes acceptable

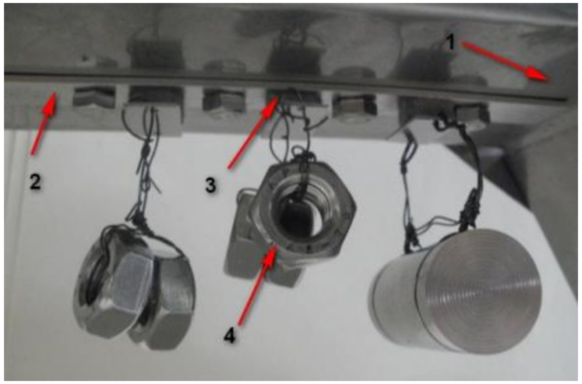


C. E. Andraka, "Solar Heat-Pipe Receiver Wick Modeling", in *Solar Engineering 1999, Proceedings of the ASME Solar Energy Division* (ASME Solar Energy Division, Maui, HI, 1999)

Wick Durability

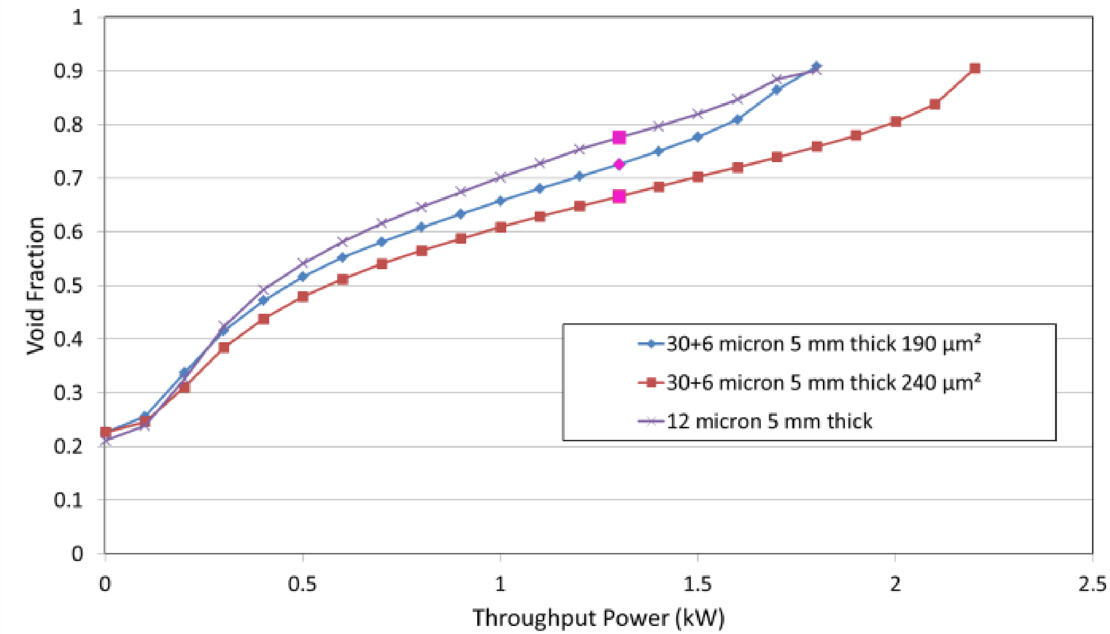
- Creep load at 800° C
  - Surrogate for wick compression
  - Tensile loading simpler to evaluate impact
  - Inert environment
- Wick pin reinforcement option
- Peel test for wall-wick bond
- Results
  - Pin reinforcement provides 2-4x enhancement
  - Over 10 kPa deemed desirable based on prior 30µm tests

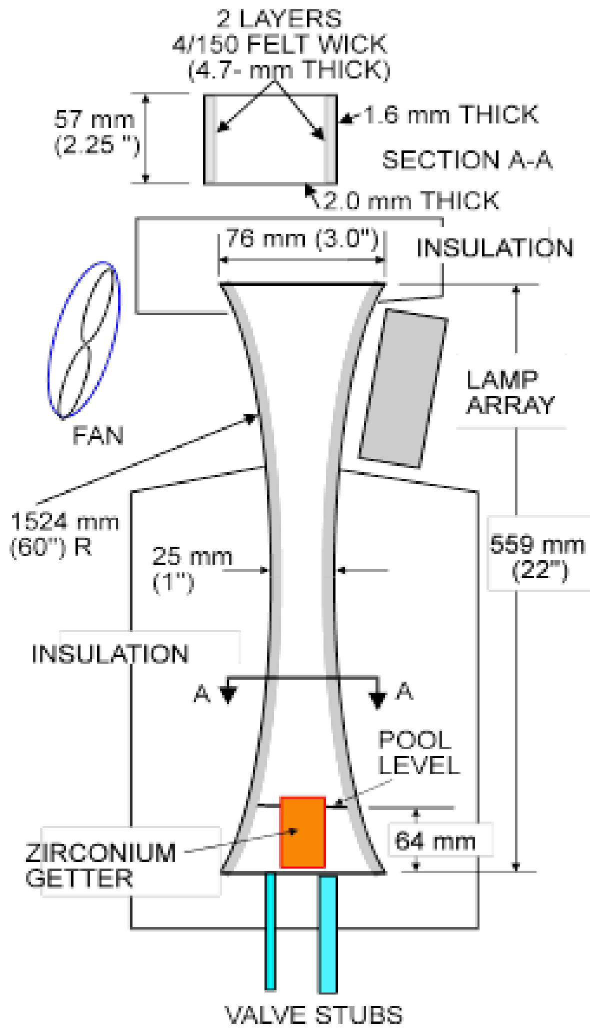
Type of felt Dia. (µm) / length (mm)	T (°C)	Pins	σ_{lim}, kPa
6.5/3	800	no	1.0
12/3	800	no	4.0
22/3	800	no	8
30/9+6.5/2	800	no	12.5
6.5/3	800	yes	6.5
12/3	800	yes	15
22/3	800	yes	20.5
30	20	no	320
30	750	no	30
8	20	no	50
8	750	no	< 5 (estimate)
30	800	No	11 (extrapolation)
30	800	Yes	25 (extrapolation)
30/9+6.5/2	800	Yes	28 (extrapolation)



Bench Test

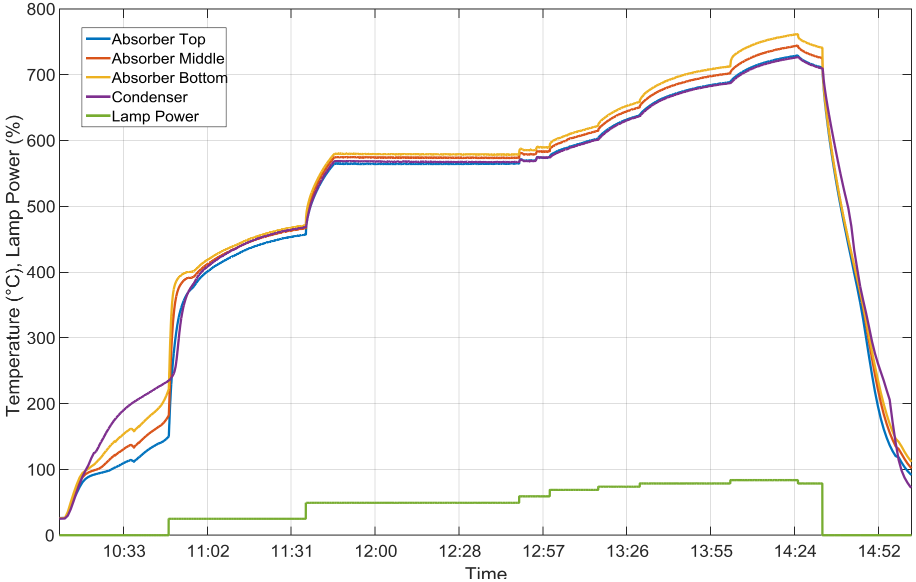
- Lamp heated for round-the clock testing
- Test correlates to $80kW_{th}$ receiver
  - Test throughput $2kW_{th}$
- Long-term passive test: 20,000 hour goal
  - Prior wicks crushed in first 500 hours

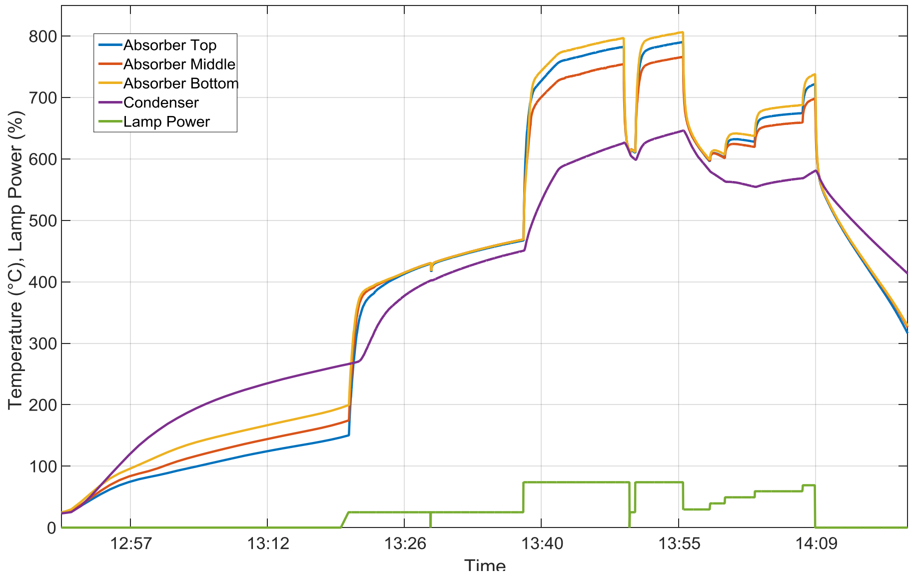




Bench Test Results

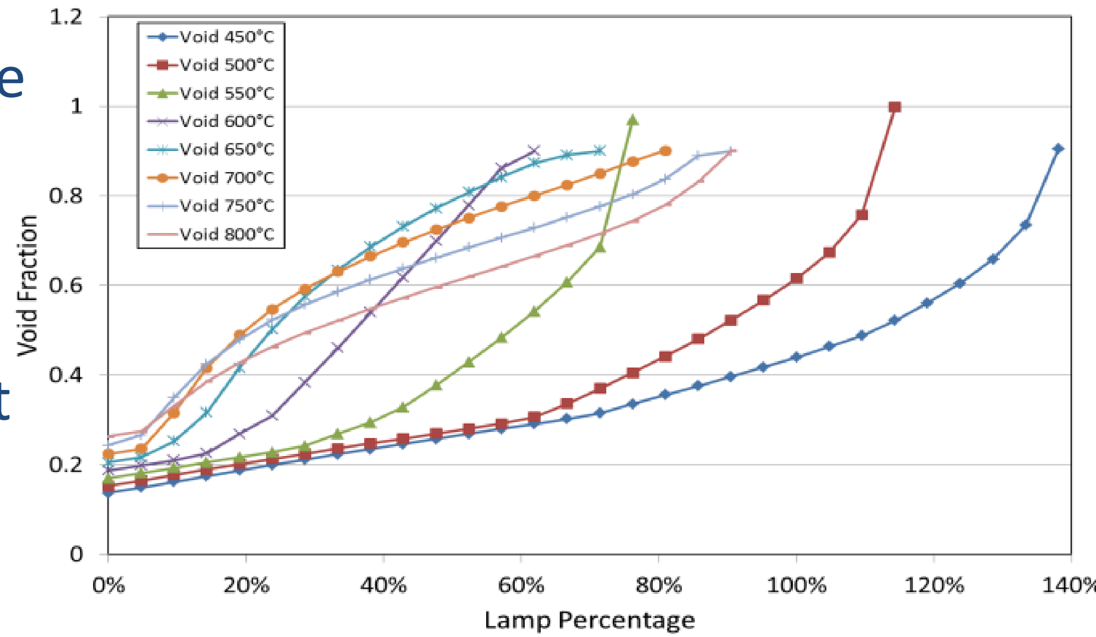
- 12µm wick dried out just over 80kW_{th} equivalent
- 30+6µm wick successful on manual start
  - Rapid automated start fails
  - Dryout leads to overtemp
  - Irrecoverable
- Rewetting successful
  - Lay pipe down and heat to 600°C
  - Slow start protocol developed and repeatable





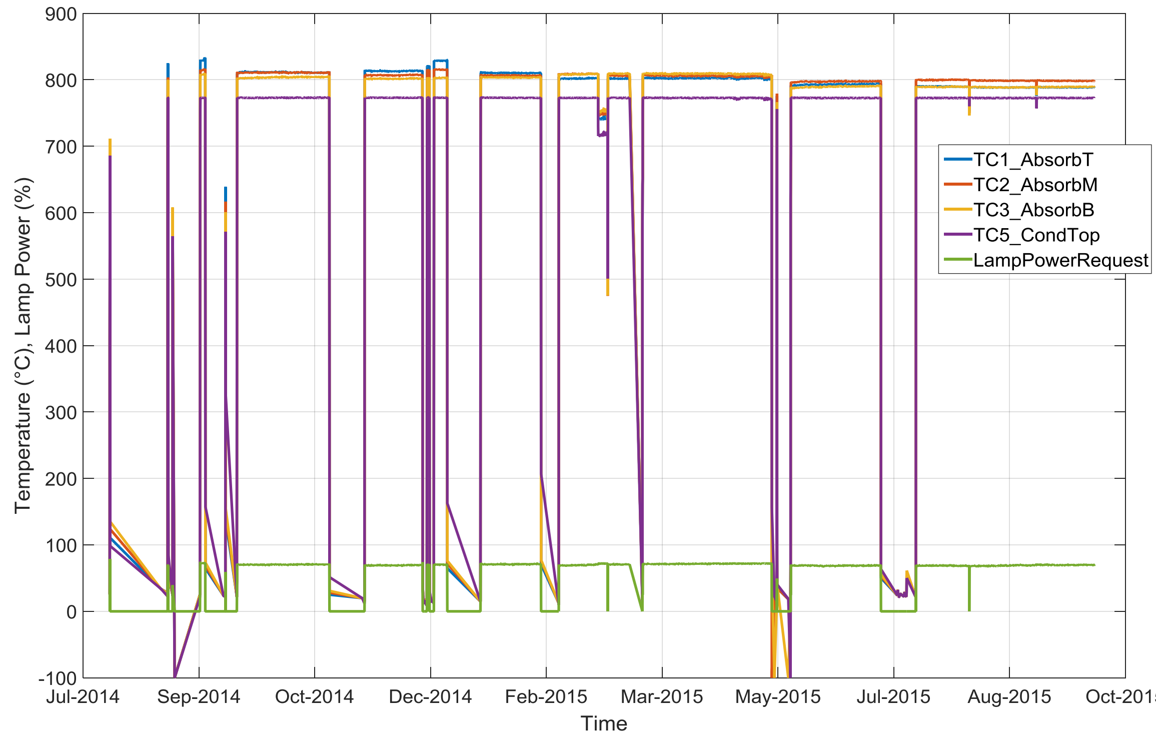
Bench Test Temperature Dependence

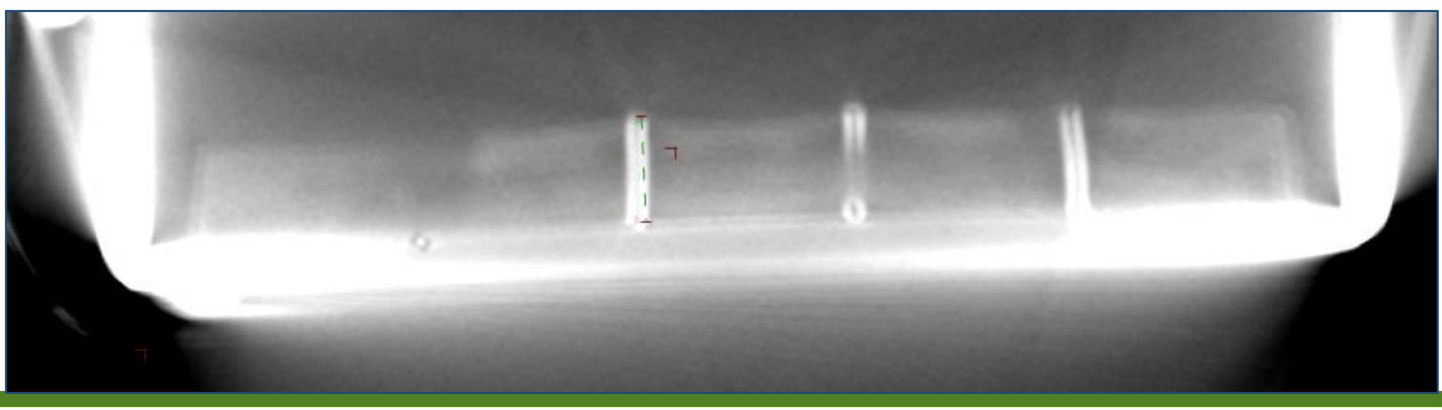
- Model modified to explore throughput at various temperatures
  - Explore rapid start issues
- Minima in performance at 600 to 700° C
- Combination of sodium properties impact performance
- Slow start to 700° C prescribed
- Increased margin would help



Current Operational Results

- 7400 hours and counting
- 13 cold starts
- No significant wick compression
  - X-Ray Computed Tomography
  - Periodic inspection





Conclusions and Next Steps

- Heat pipes are a critical element of a dish Stirling storage system due to isothermal input.
- Blended felt wick with pin supports appears to meet performance and durability goals, still under test
  - Over a factor of 10 increase in durability demonstrated
- Further work can optimize blended felt
  - Ratios of fiber mass
  - Fiber diameters
  - Co-felting methods
  - Extend performance to avoid startup shortfall