INL/CON-24-77280-Revision-0

A Sockeye Model of a Test at the Michigan Single Sodium Heat Pipe Facility

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Changing the World's Energy Future

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Motivation

- Microreactor designs such as eVinci™ are heat-pipe-cooled
- Sockeye (next slide) is an application developed to model heat pipes in microreactors
  - Requires more validation
- For high-temperature applications, heat pipes utilize liquid metals such as sodium
- High-resolution data on these heat pipes is sparse and lacking in detail
  - Experimental setup and conditions

Sockeye Introduction

- Sockeye is an *engineering-scale* application developed to model heat pipes in microreactors
  - Started in 2017
  - Funded by Nuclear Energy Advanced Modeling and Simulation (NEAMS)
- Based on the Multiphysics Object-Oriented Simulation Environment (MOOSE) framework:
  - Couples easily to other MOOSE applications (e.g., Griffin for neutronics and Bison for fuel performance) to facilitate multiphysics simulation of a microreactor
  - Builds from MOOSE's thermal hydraulics module (THM)
- Three main heat pipe models developed:
  - **Two-phase flow model**: 1D liquid and vapor flow
  - **Liquid Conduction, Vapor Flow model**: 1D vapor flow, 2D heat conduction for liquid
  - **Conduction model**: 2D heat conduction for liquid and vapor

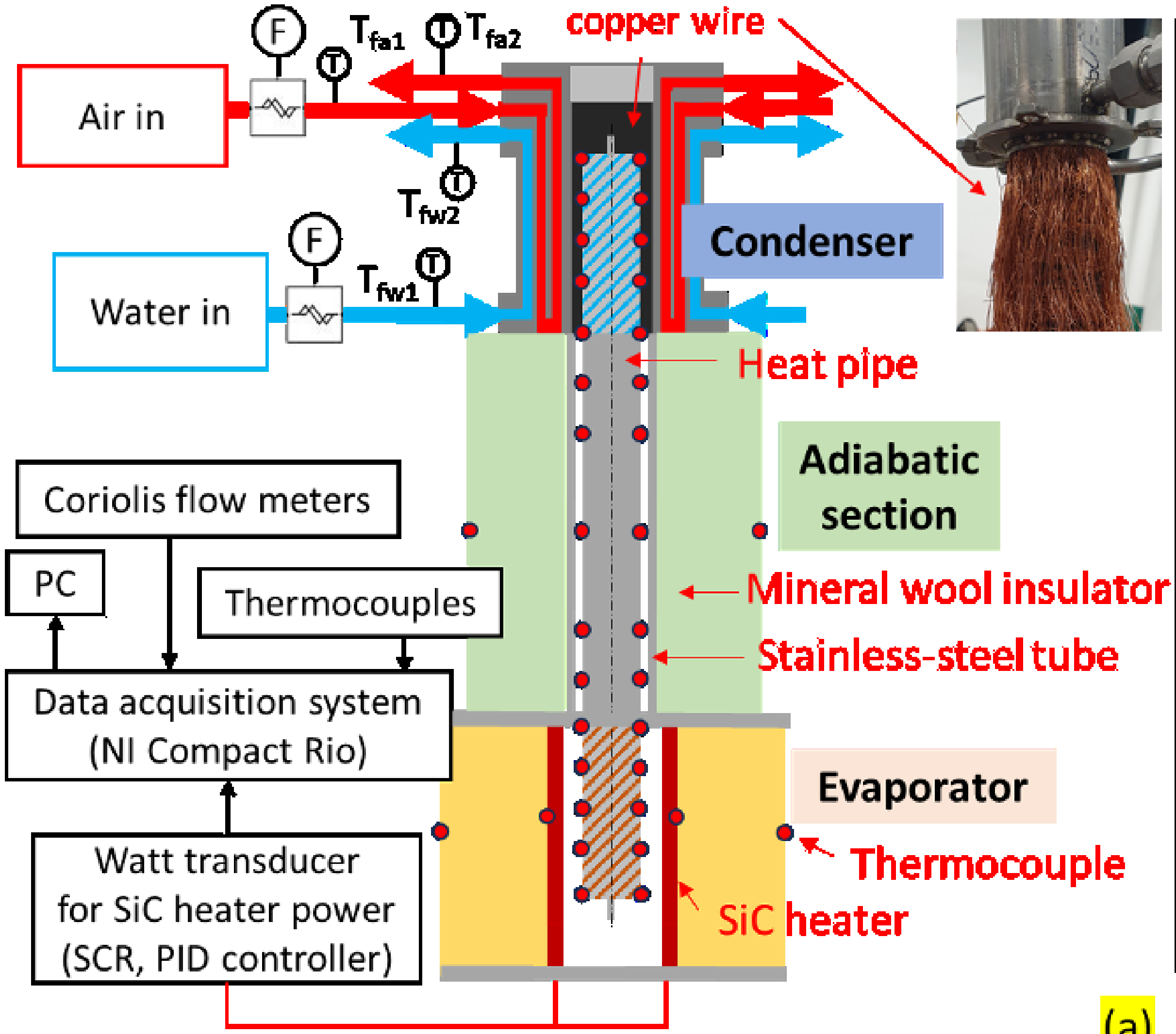
Conduction Model

- Models the whole heat pipe with 2D heat conduction
- Multiple radial regions:
  - Cladding
  - Wick/annulus (liquid)
  - Vapor
- Vapor region thermal conductivity is taken to be very high value
  - Controlled to obey analytic operational limits
- Model is very robust but at the expense of accuracy, since we approximate advection phenomena with diffusion

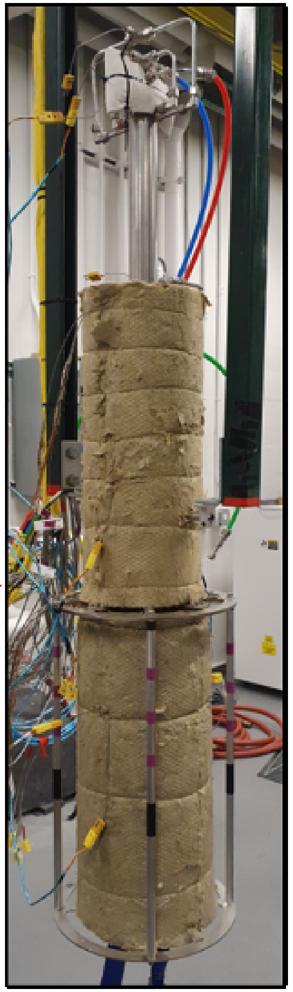
Liquid Conduction, Vapor Flow (LCVF) Model

- Models the cladding and wick/annulus using 2D heat conduction
- Models the vapor using 1D flow equations
  - Compressible flow: Euler equations of gas dynamics:
    - Conservation of mass, momentum, energy
- Vapor and wick are coupled with interfacial heat and mass transfer terms
- Liquid energy advection approximated with steady assumptions
- Model is relatively robust without sacrificing too much accuracy

Michigan Single Sodium Heat Pipe (MISOH1) Facility

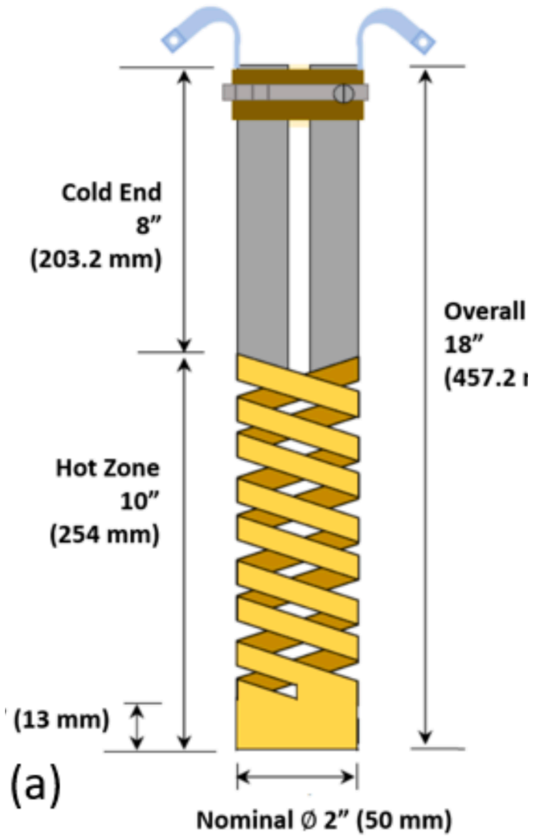


(a)



(b)

Heater:



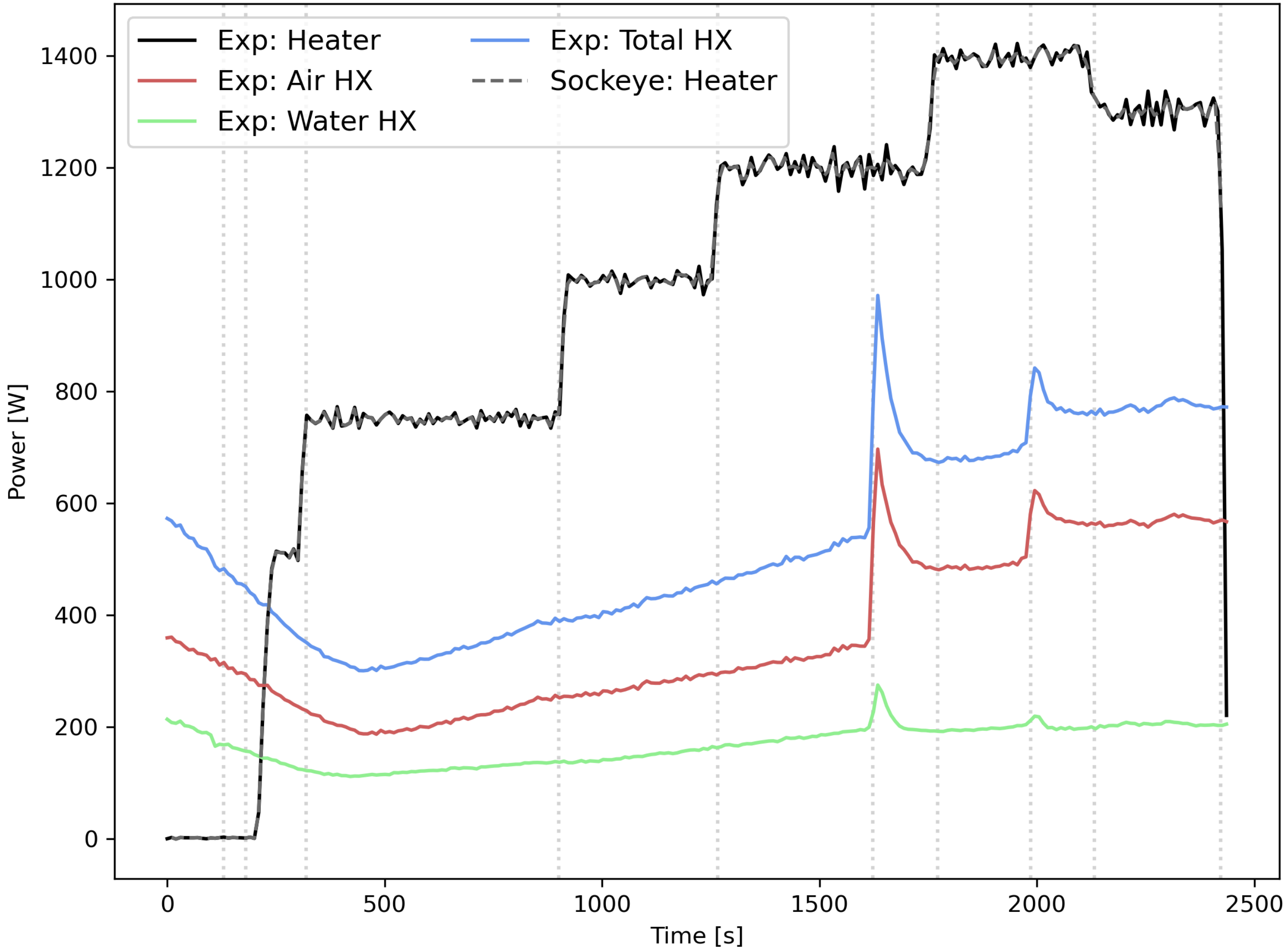
(a)

TEST-018 Description

- TEST-018 started in hot state shortly after conclusion of TEST-017
  - Rotated assembly from vertical (TEST-017) to horizontal (TEST-018)
- Transient events:
  - Heater power changes
  - HX air channel mass flow rate changes
  - HX water channel mass flow rate changes

Time [s]	Power [W]	Air [g/s]	Water [g/s]
0	0	3	50
130	...	...	32
181	500	...	...
320	750	...	...
900	1,000	...	...
1,266	1,200	...	...
1,623	...	5.9	...
1,772	1,400	...	...
1,986	...	7.4	...
2,132	1,300	...	...
2,423	...	...	...

Experimental Power Transient



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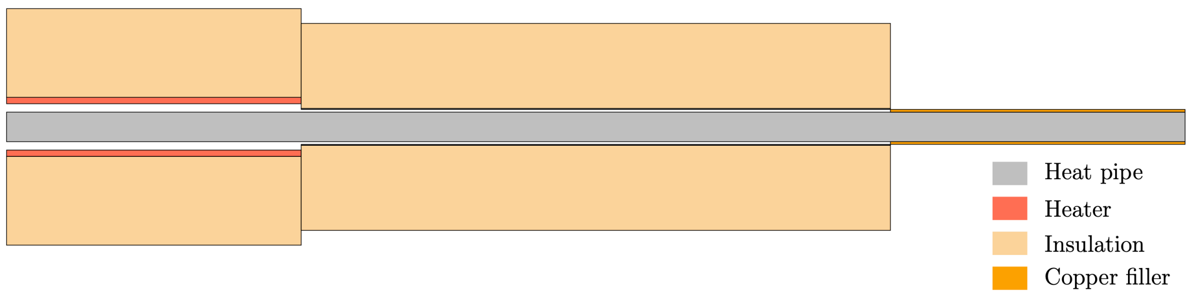
2,132	1,300	...	...
2,423	...	...	...

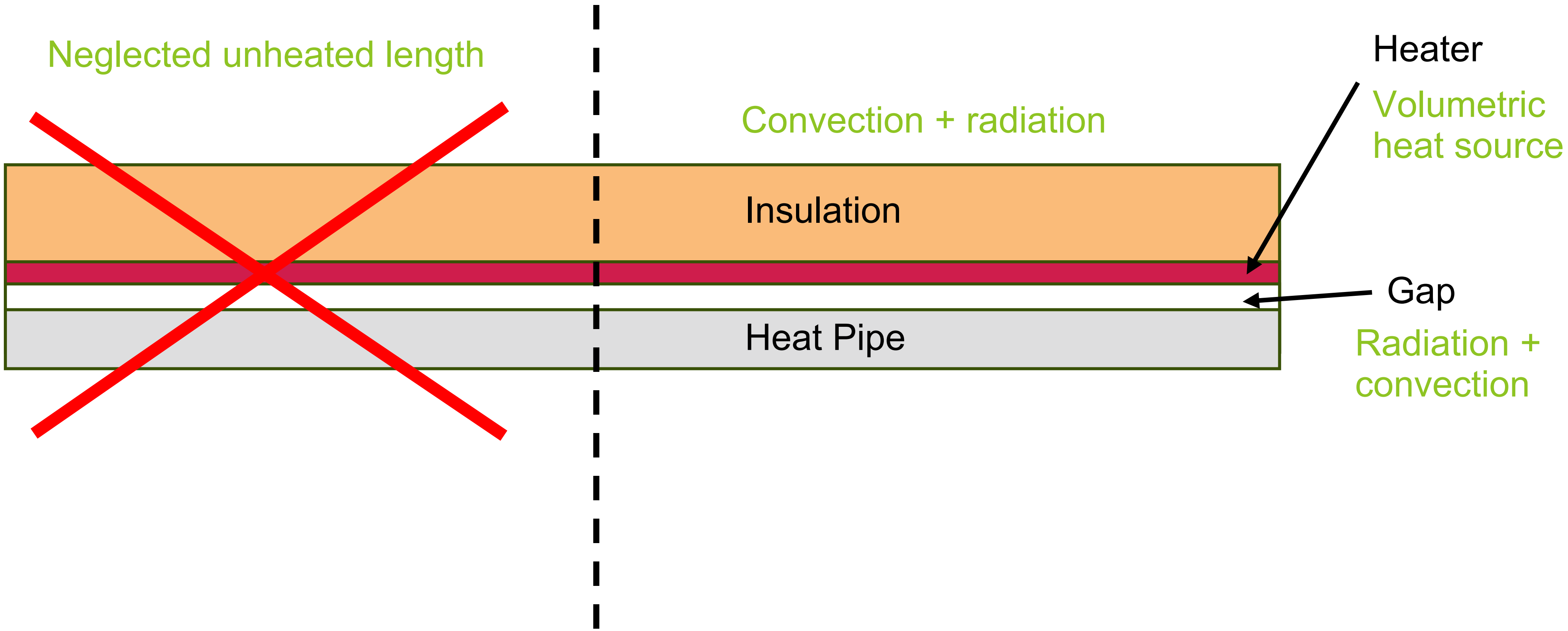
Experiment Model Description

- Approximated as 2D problem
- Evaporator section:
  - Heater region with volumetric heat source
  - Insulation
- Adiabatic section:
  - Support tube
  - Insulation
- Condenser section:
  - Filler
  - Heat exchanger (if modeled explicitly)

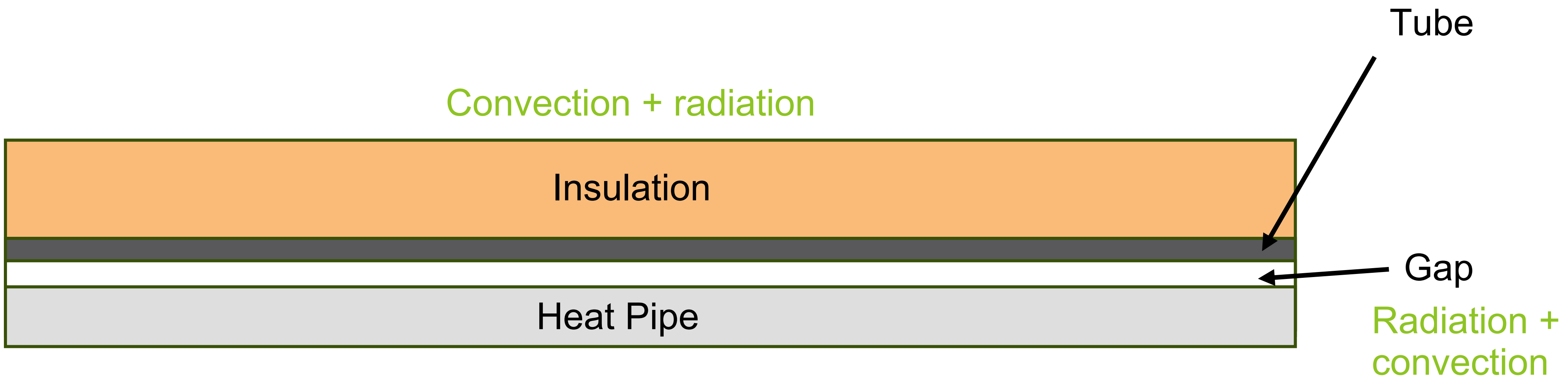


- Convection and radiation BCs
- Convection and radiation gap interface conditions
- Heat exchanger approximated via uniform heat flux from data

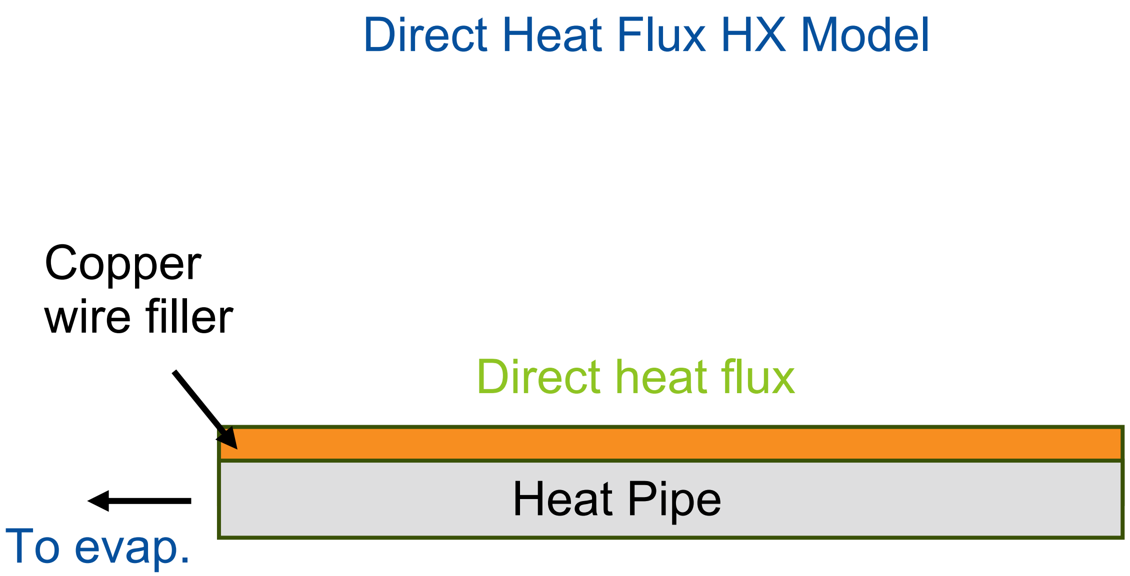
Evaporator Section Model Setup

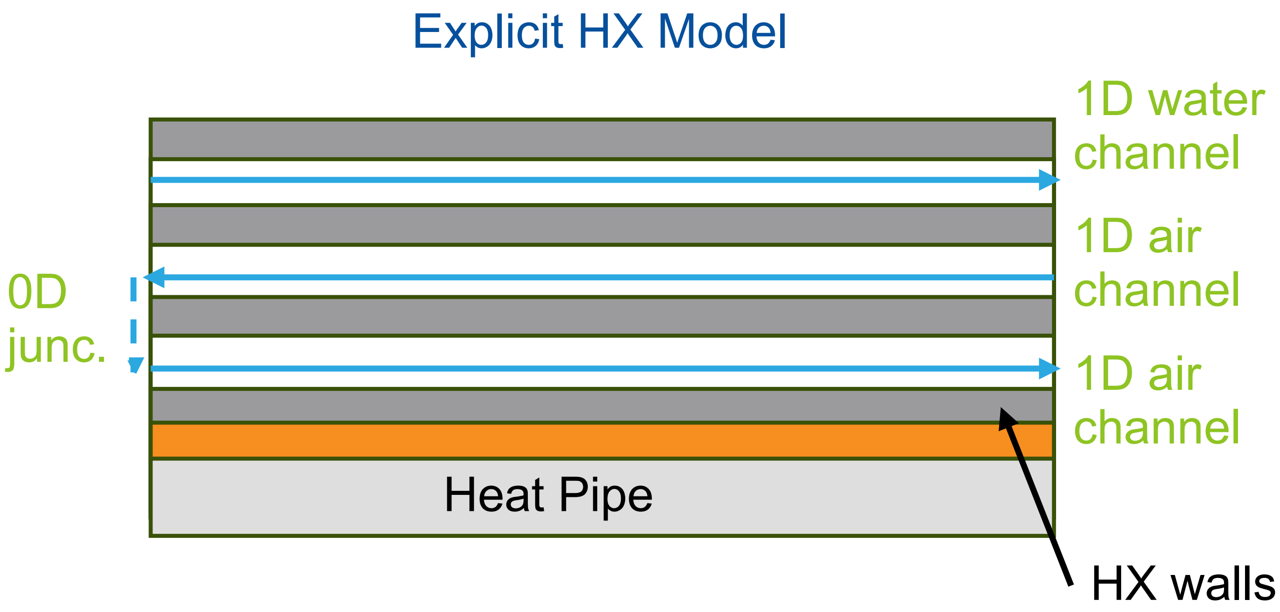


Adiabatic Section Model Setup



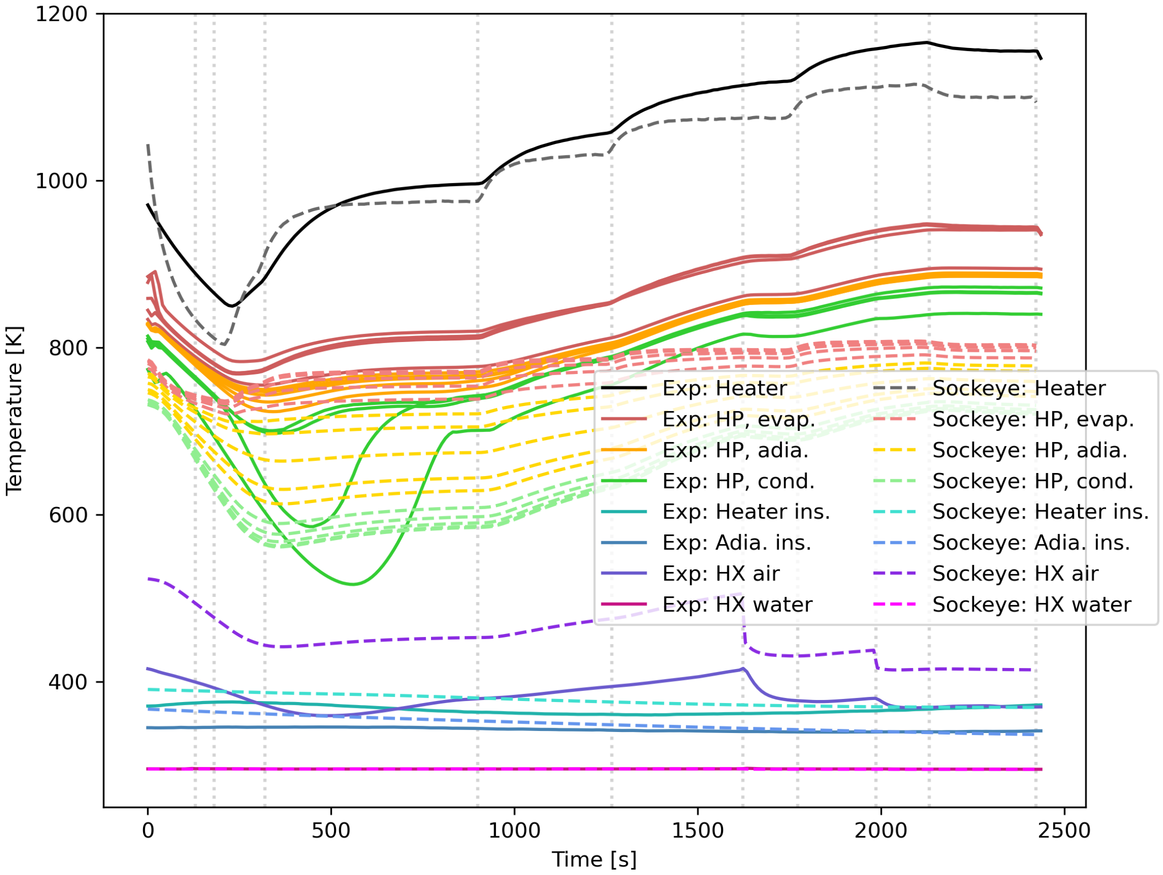
Condenser Section Model Setup



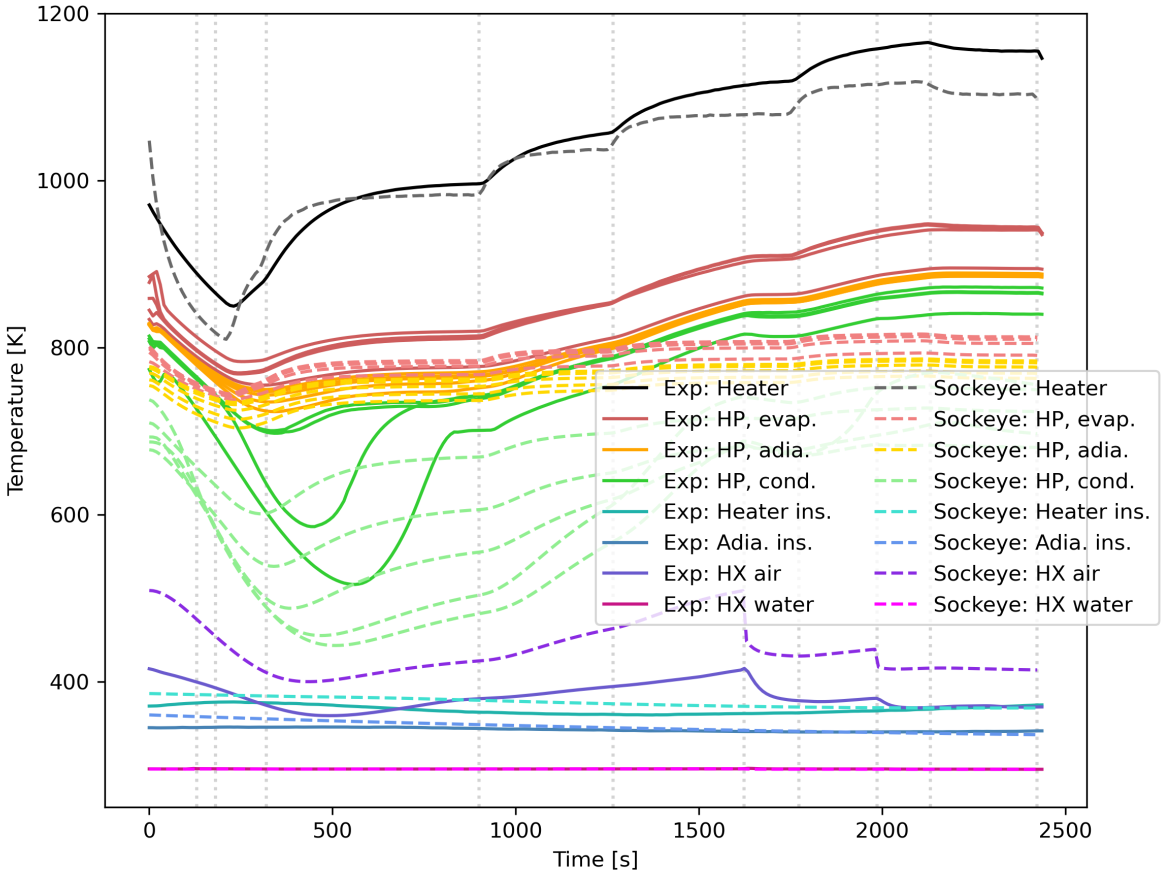


Transient Temperature Results, Explicit HX Model

Conduction Model

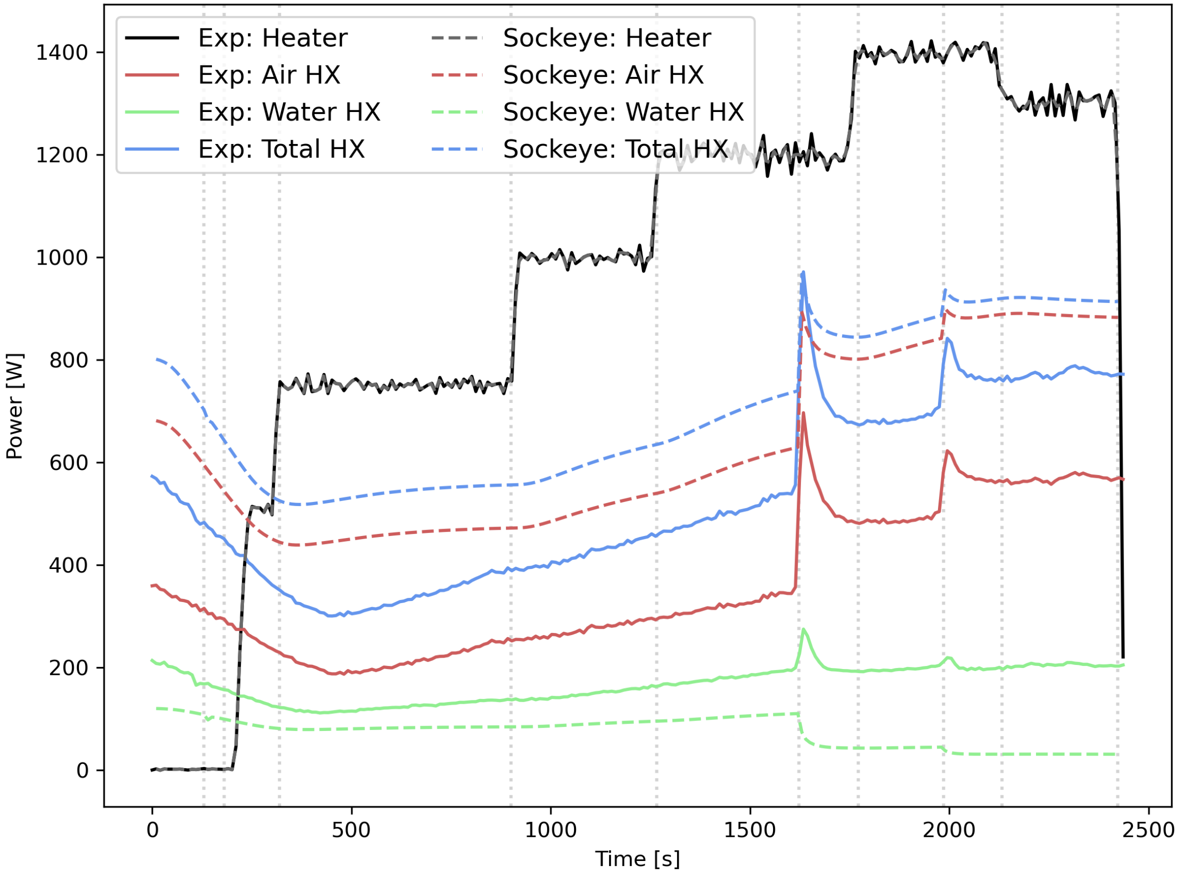


LCVF Model

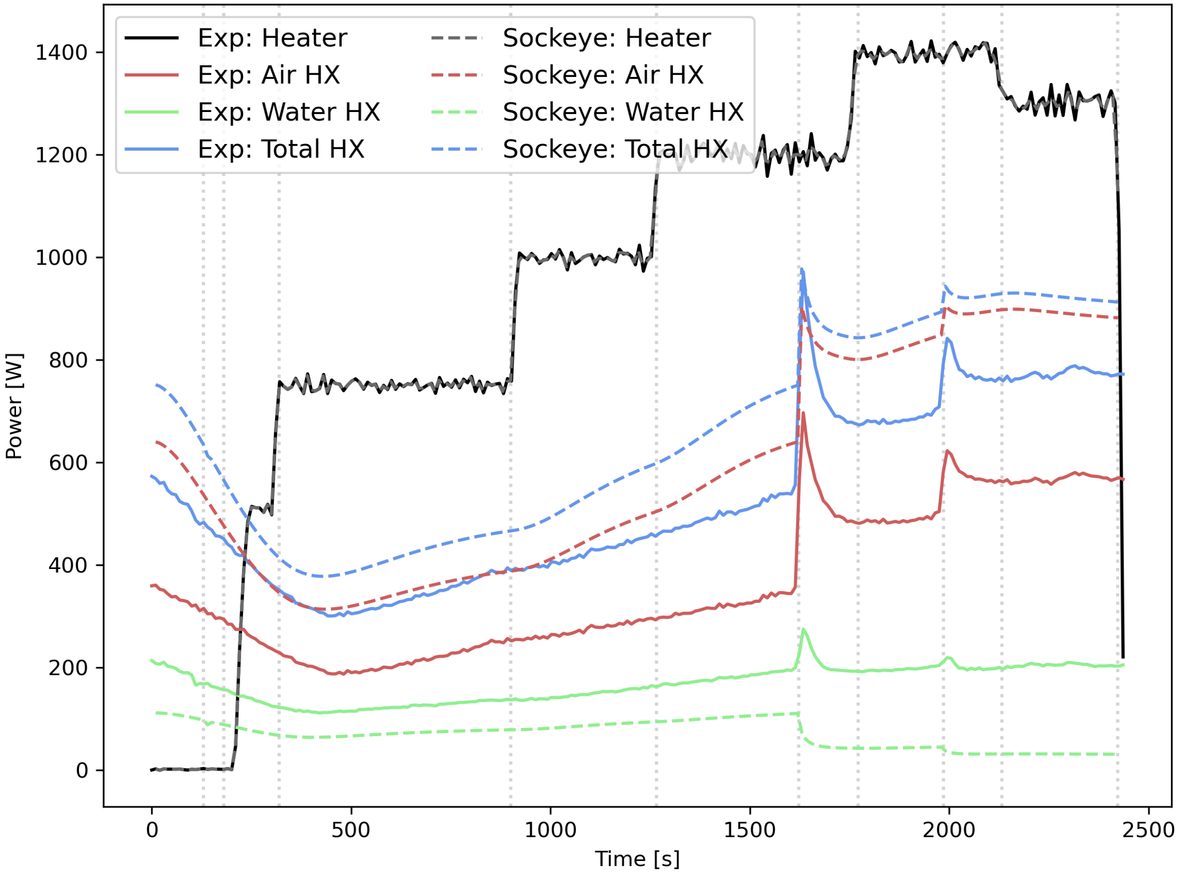


Transient Power Results, Explicit HX Model

Conduction Model

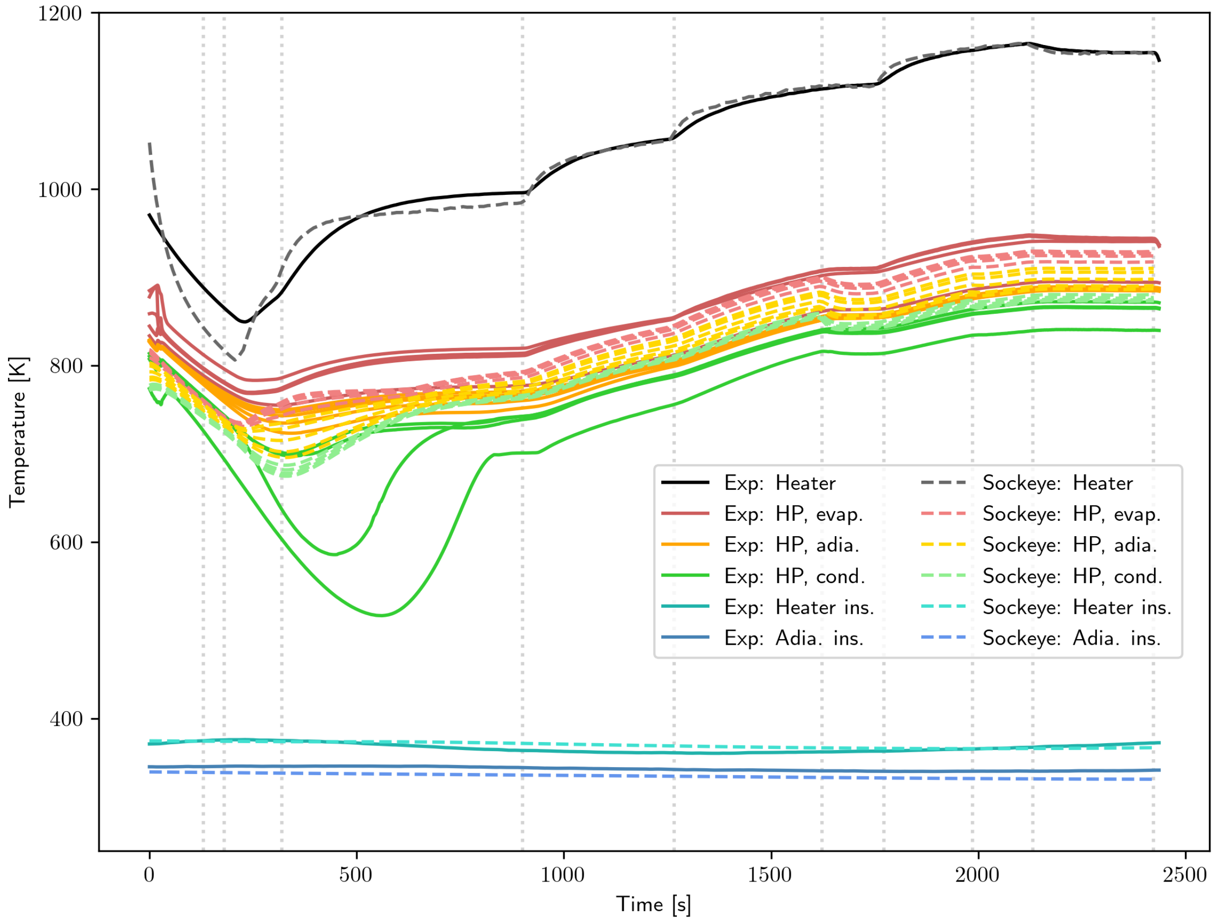


LCVF Model

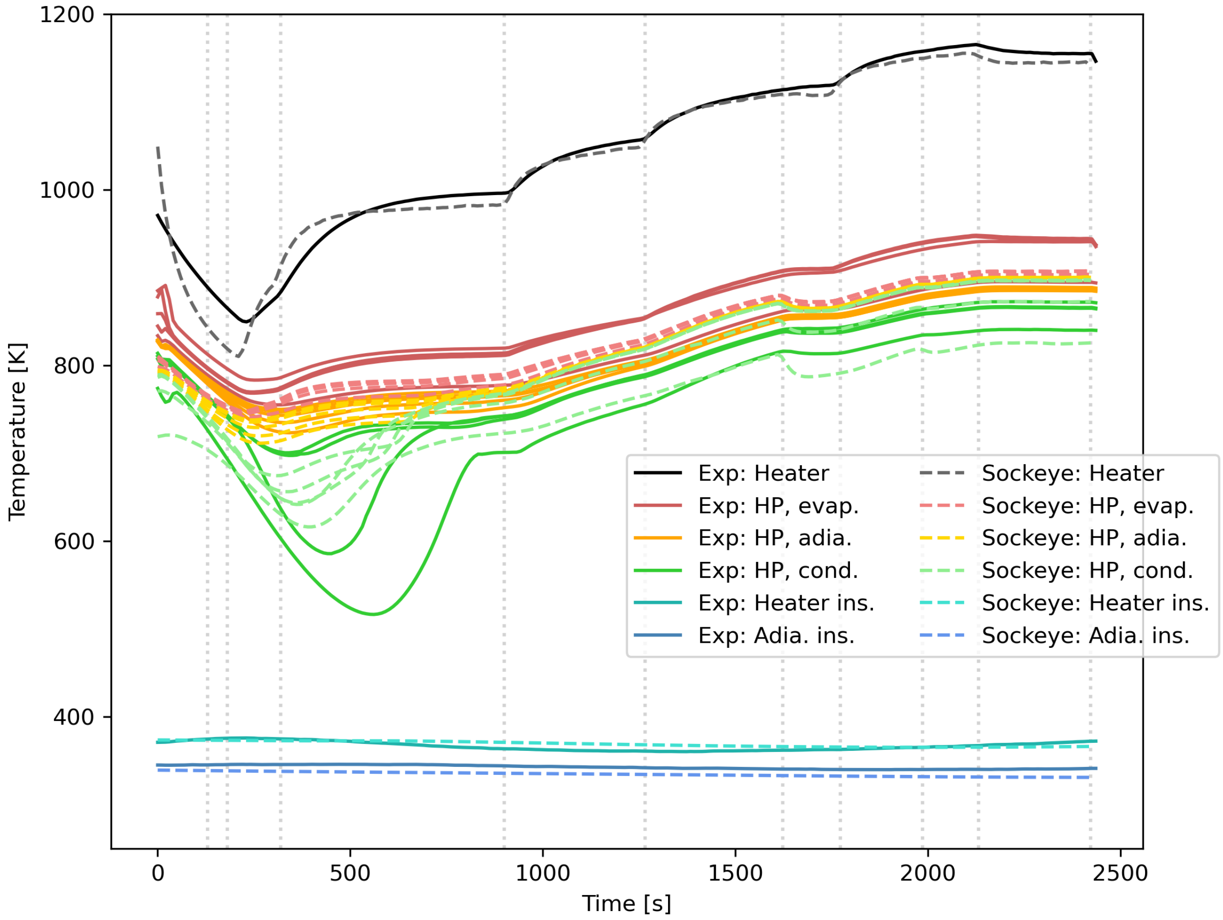


Transient Temperature Results, Direct Heat Flux HX Model

Conduction Model

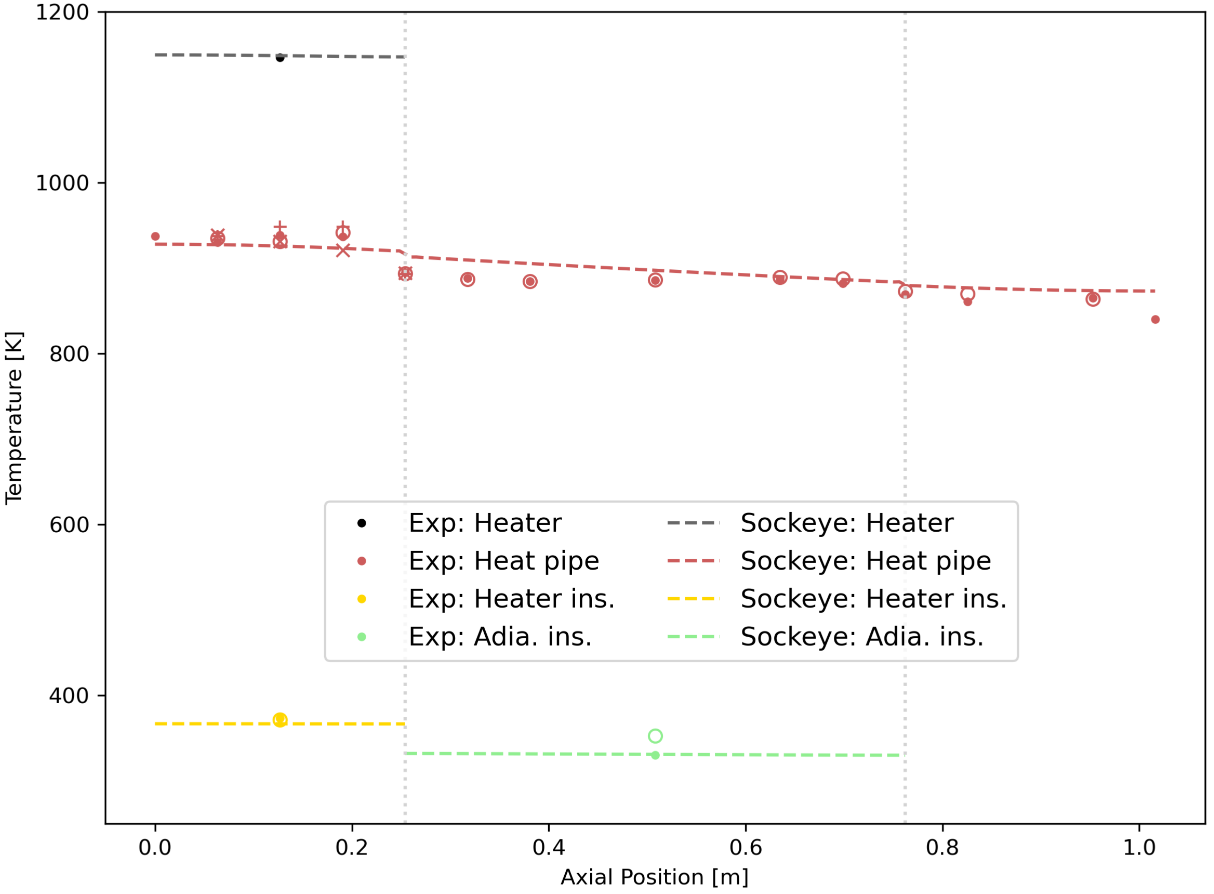


LCVF Model

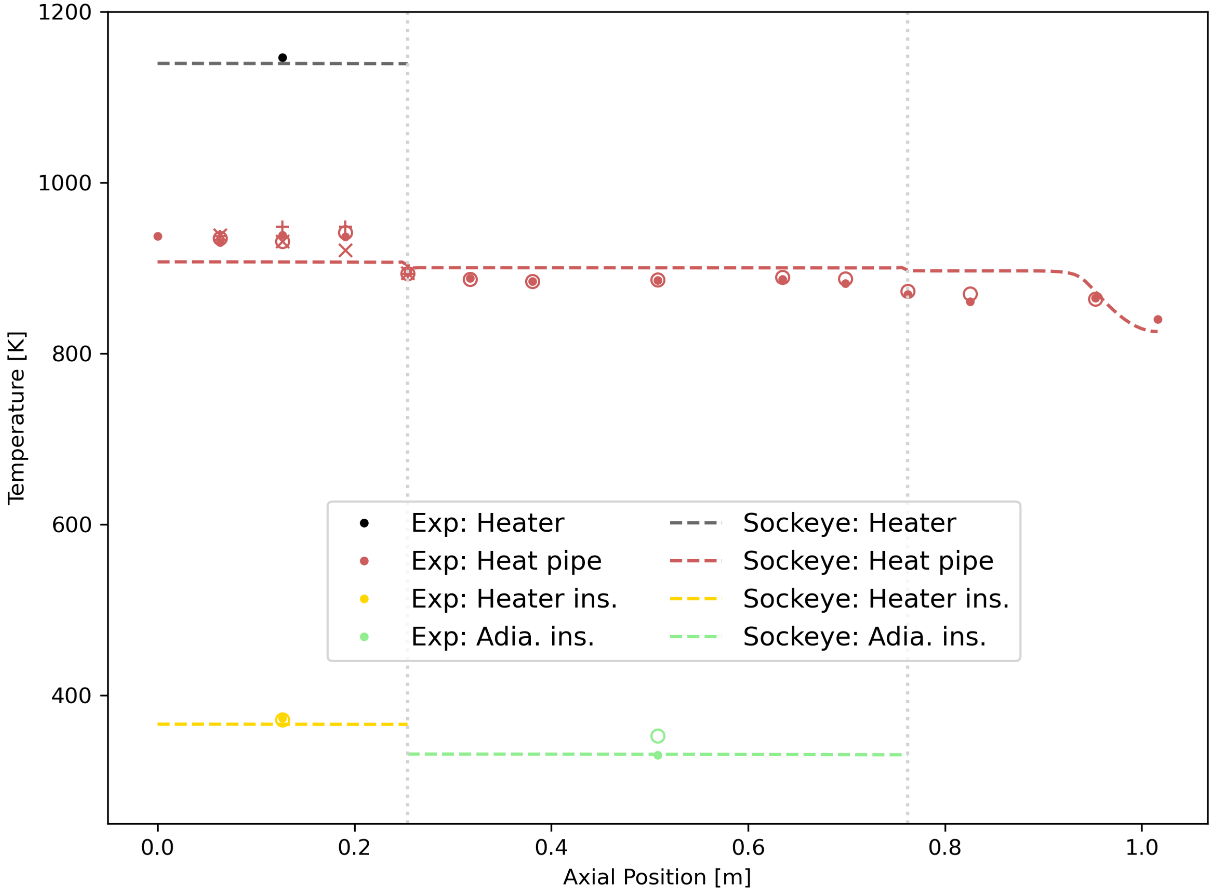


Steady Results, Direct Heat Flux HX Model

Conduction Model



LCVF Model



Conclusions

- Sockeye model captures transient
  - Basic heating and heat pipe performance matched well
  - Conduction model underestimated transient impact of sonic limit
- Many unknowns that impacted comparison:
  - Heat pipe internals details, like working fluid mass
  - Emissivities of surfaces
  - Thermal properties of insulation
- Accurate approximations of external system layers crucial
  - Heat losses in evaporator and adiabatic section important
  - Heat exchanger is particularly difficult to model
  - Explicit model of the heat exchanger gave unsatisfactory results

Future Work

- More experimental data
  - Ideally with heat pipes that do not have proprietary design information
  - Internal, distributed temperature measurements
  - Virtual elimination of heat losses by radiation shielding
- Test model improvement:
  - Decrease geometrical approximations
  - More sophisticated interface models
- Sockeye heat pipe models improvement:
  - Frozen startup
  - Condenser pool
  - Non-condensable gases

Idaho National Laboratory

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