Experiments for Modeling and Validation of Liquid-Metal Heat Pipe Simulation Tools for Micro-Reactor

NEUP Project 20-19735

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NEUP Program

Experiments for Modeling and Validation of Liquid-Metal Heat Pipe Simulation Tools for Micro-Reactors

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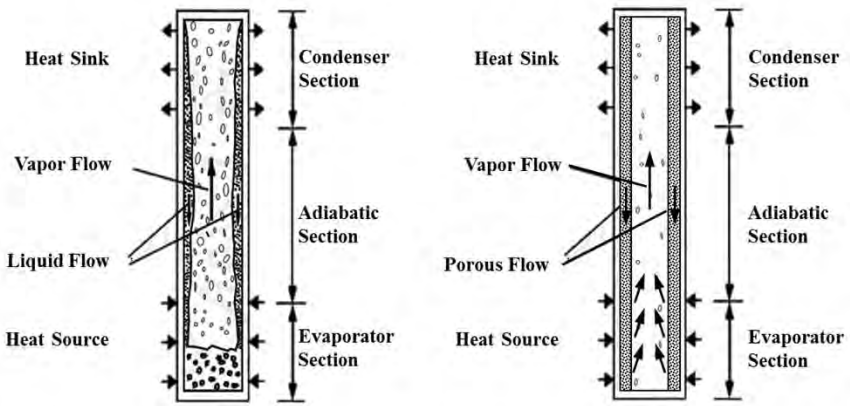
Overview of the Project



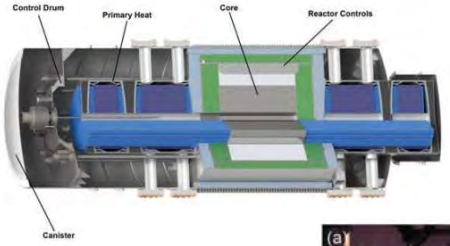
- The heat pipe is a device of very high conductance
- It works passively on the principle of evaporation and condensation of a working fluid so that it can transfer large amount of heat.
- Intensive studies to apply the heat pipe as a primary heat transfer system of the micro-reactor have been pursued.

Spacecraft

Computer

Pipeline

Spacecraft, heat pipes in computer, Alaska pipeline support legs cooled by heat pipe thermosyphons to keep permafrost frozen.
From: Heat pipe – Wikipedia and wall.alphacoders.com



Design of e-Vinci from Westinghouse

eBlock37, L.M. Gaspar et al., eBlock37 Microreactor Electrical Demonstration Unit, Nuclear Technology (2022)

Single heat pipe test facility (SPHERE) in the experimental station in INL.

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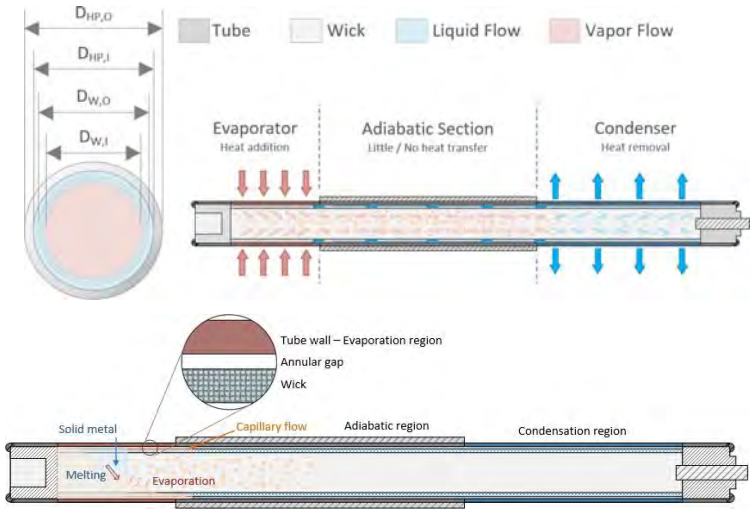
Overview of the Project

Purpose: The proposed work aims to produce high-fidelity liquid-metal heat-pipe experimental data for the validation of the simulation tool, Sockeye, through both single heat-pipe and integrated heat-pipe experiments.



Sodium heat pipe with targeted design

- Objectives:
  - Single Heat-Pipe Hydraulic Experiment
    - Measurements of the hydraulic resistance for validation / development of wall friction, wick friction/form loss models.
  - Single Liquid-Metal Heat-Pipe Experiment
    - Measurements of internal temperature, pressure, and phase distribution for validation/development of heat transfer and flow models in Sockeye.
  - Multiple Liquid-Metal Heat-Pipes Experiment in Hexagonal Arrangement
    - Investigate the integrated system performance under various operational scenarios such as partial failure of constituent heat pipes and non-uniform cooling/heating.

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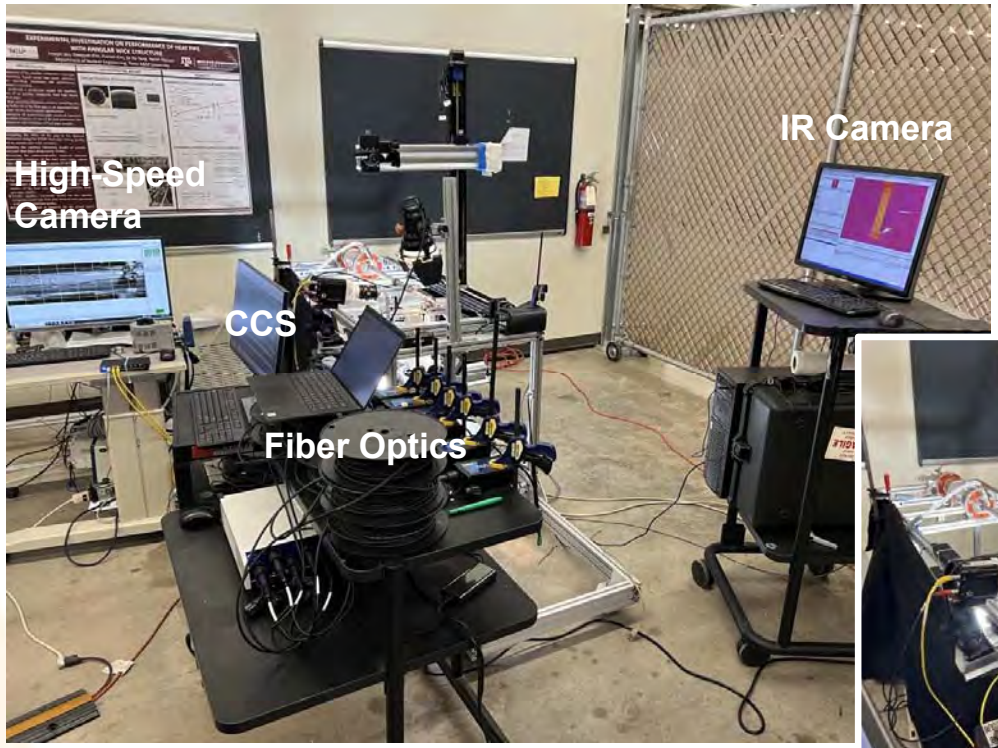
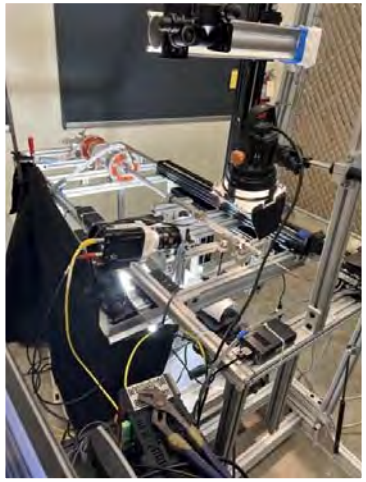
Heat Pipe Visualization Experimental Setup





- Visualization using high speed camera and IR camera is conducted.
- Temperature measurement using fiber optical sensor and IR camera is implemented.
- Confocal Chromatic Sensor (CCS) is applied to measure the liquid film behavior.
- 4 pneumatic cylinders were added to adjust inclination angle.

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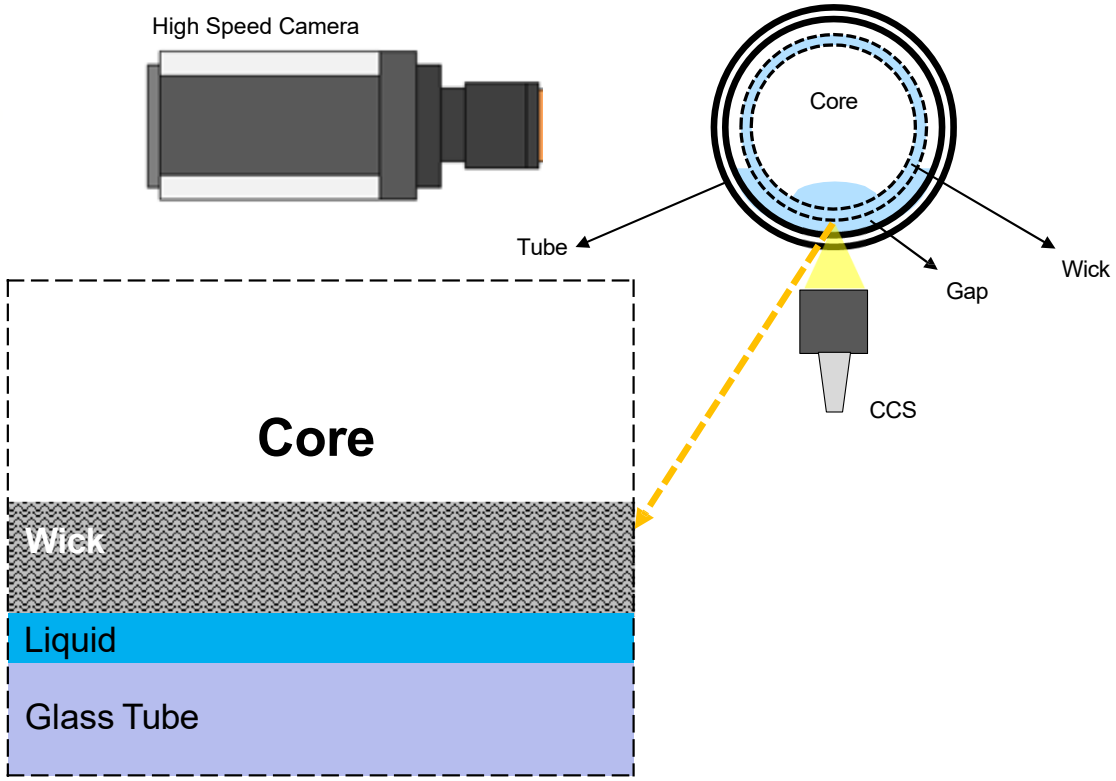
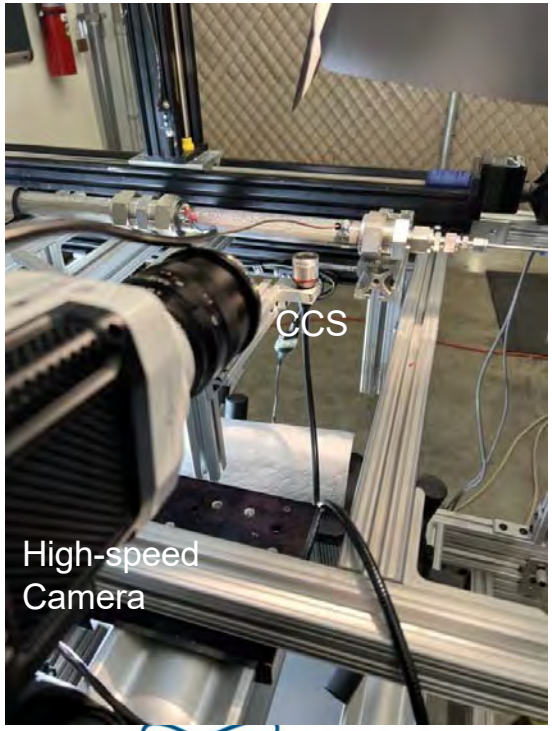
Confocal Chromatic Sensor Measurement





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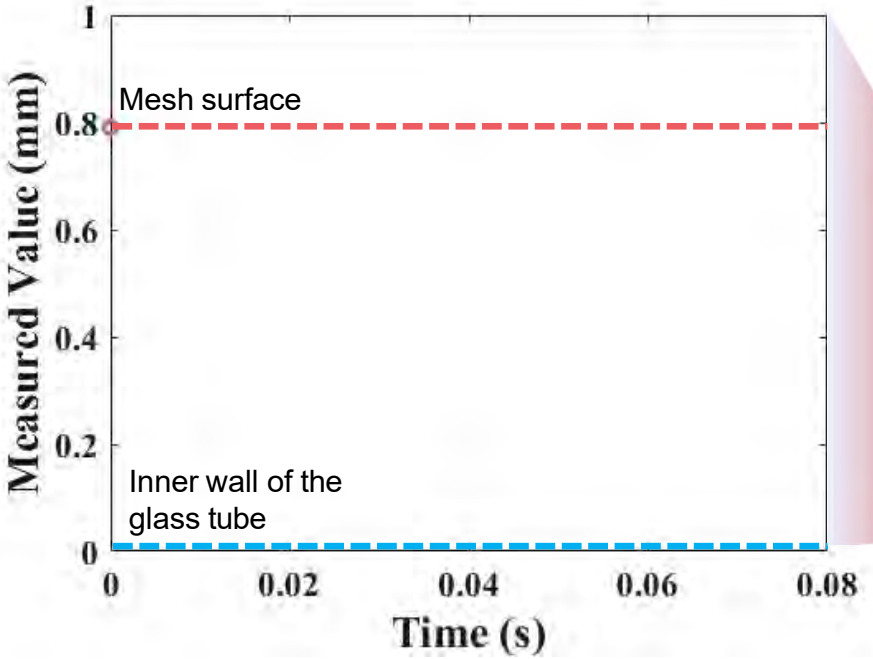
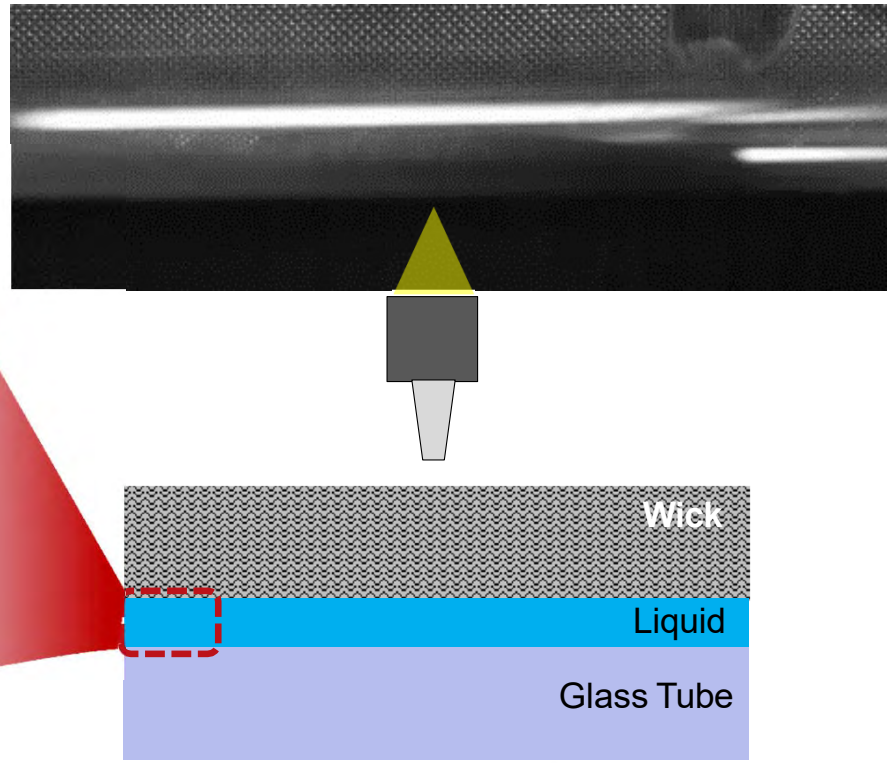
CCS Measurement & High-Speed Images





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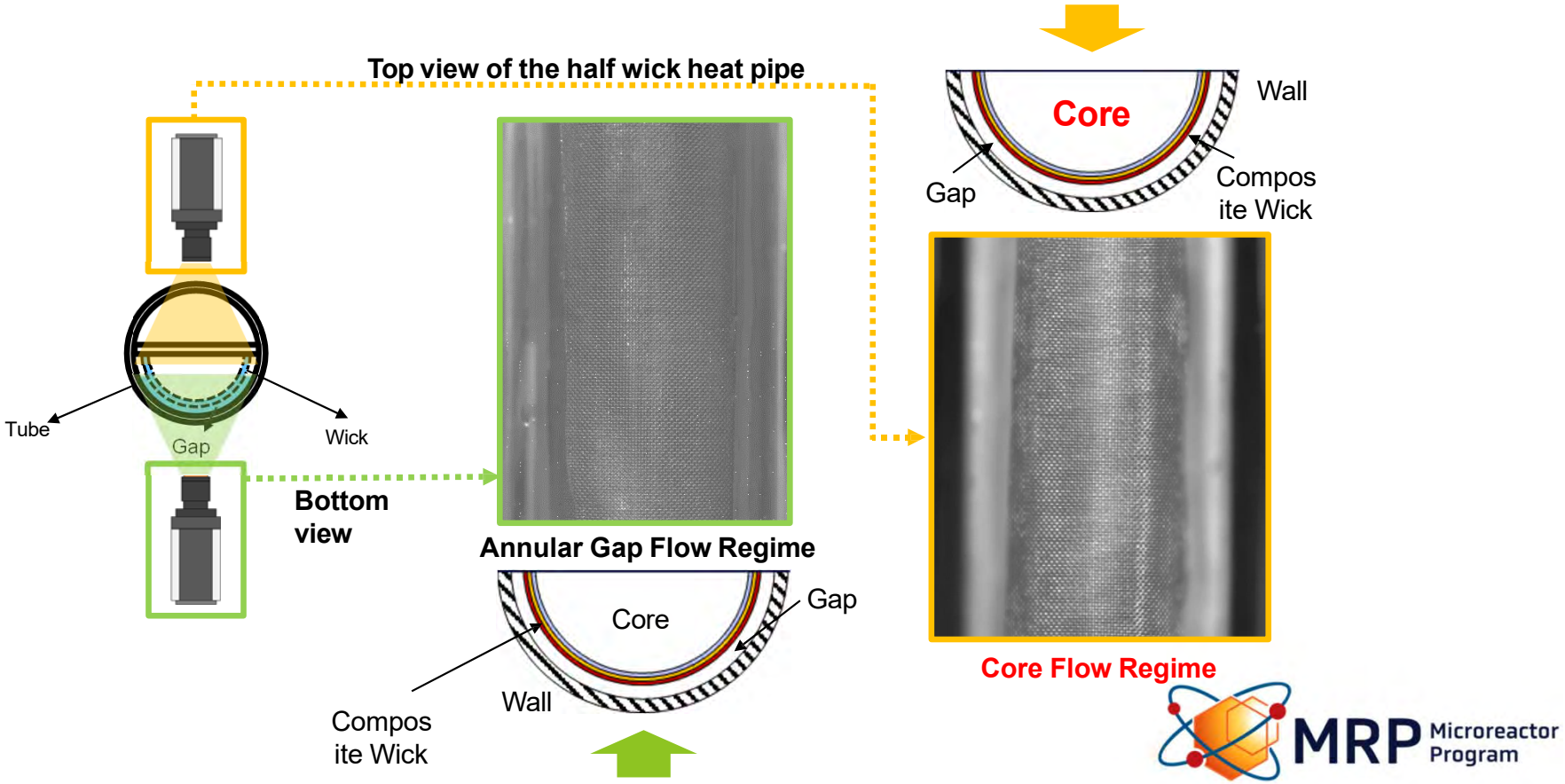
Boiling Pattern Inside Heat Pipe – Half Wick Exp



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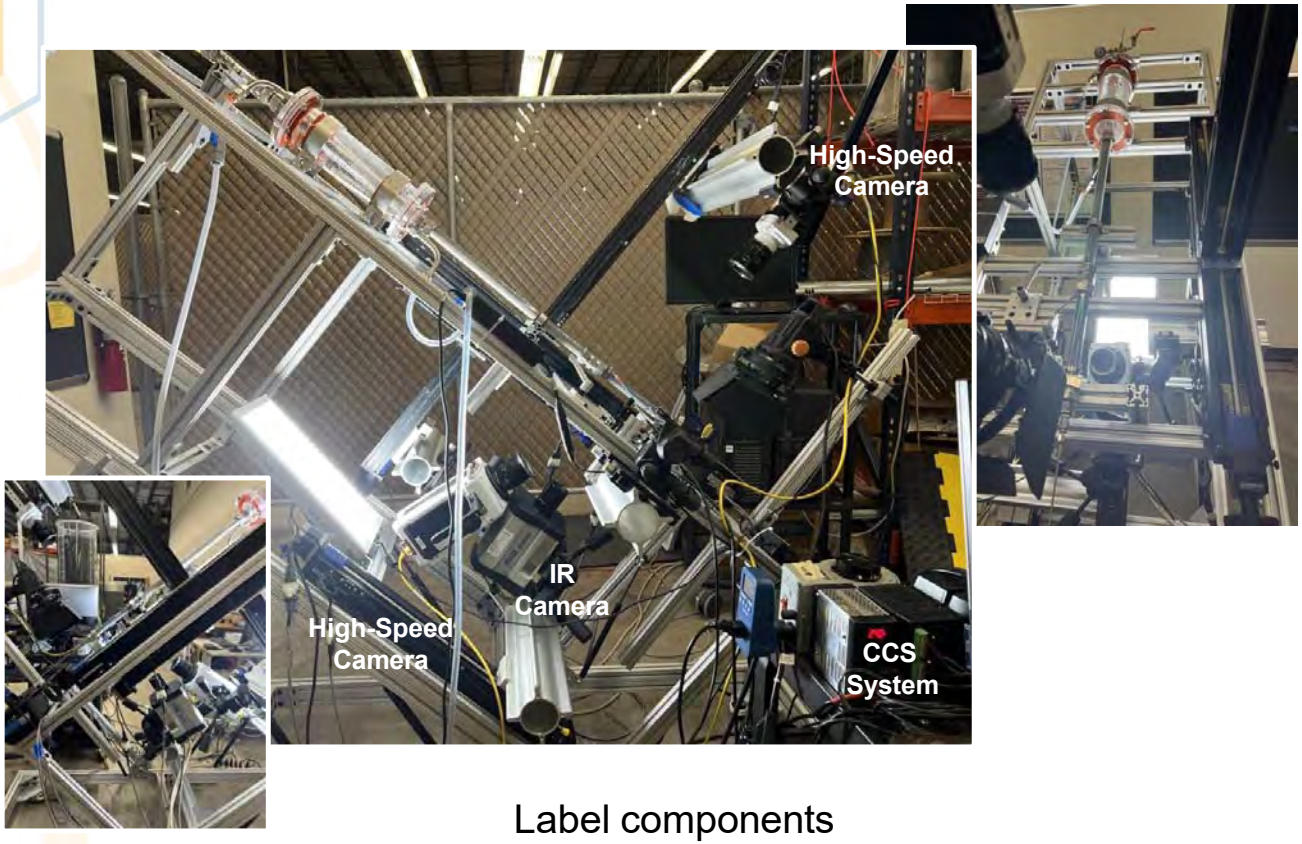
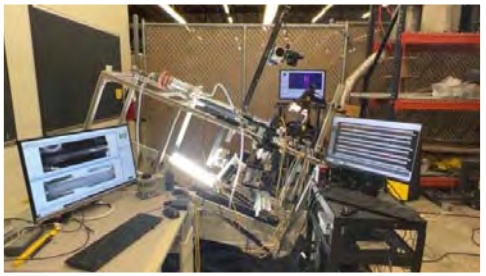
Heat Pipe Visualization with Inclination Angle



Label components

- Visualization of the heat pipe with different inclination angle.
- Temperature measurement using fiber optical sensor and IR camera is implemented.
- Two high-speed camera was set (bottom side and top side)



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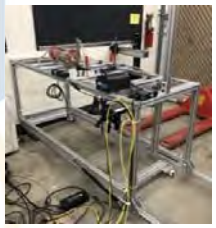
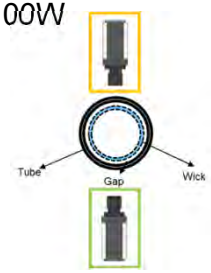
Heat Pipe Visualization Results – Inclination Effect

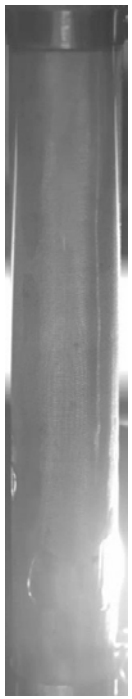


0-degree
(Horizontal)
100W



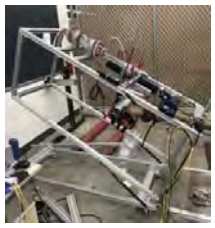
Cond. Evap.

g



Bottom

Top

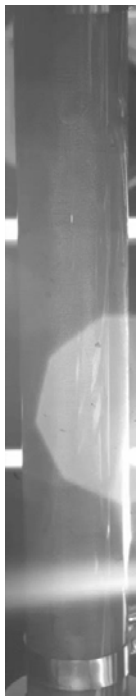


45-degree
200W

Cond.

Evap.

g



Bottom

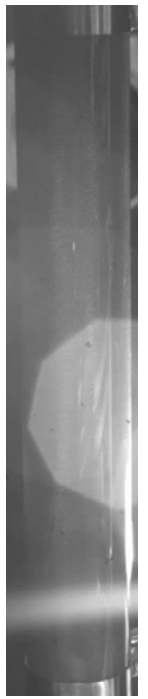
Top

90-degree
(Vertical)
200W

Cond.

g

Evap.



Bottom

Top

Inclination [°]	0	45	90
Maximum Power Input [W]	~100	~400	~550
Operating Pressure [bar]	~0.3	~0.3	~0.3

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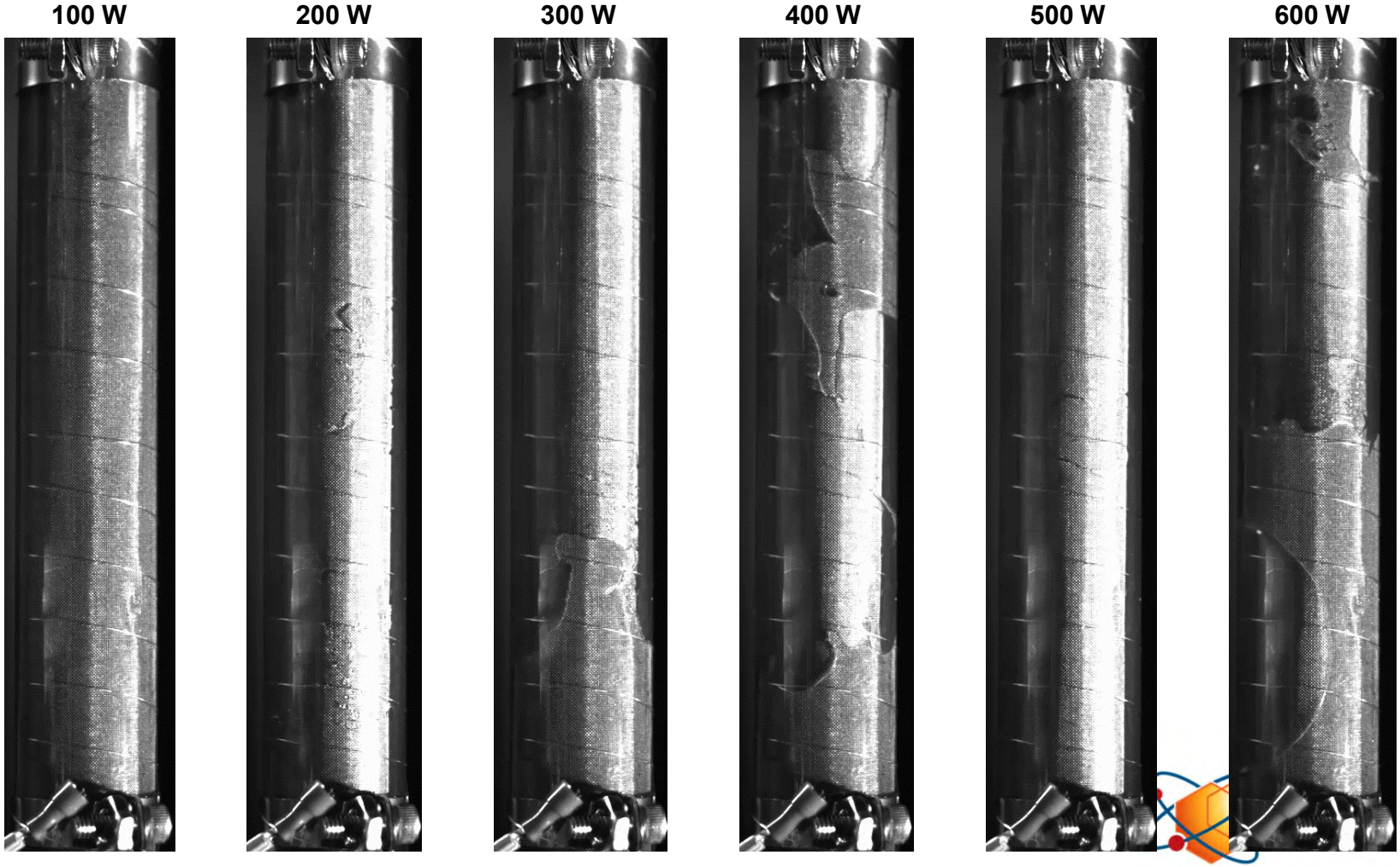
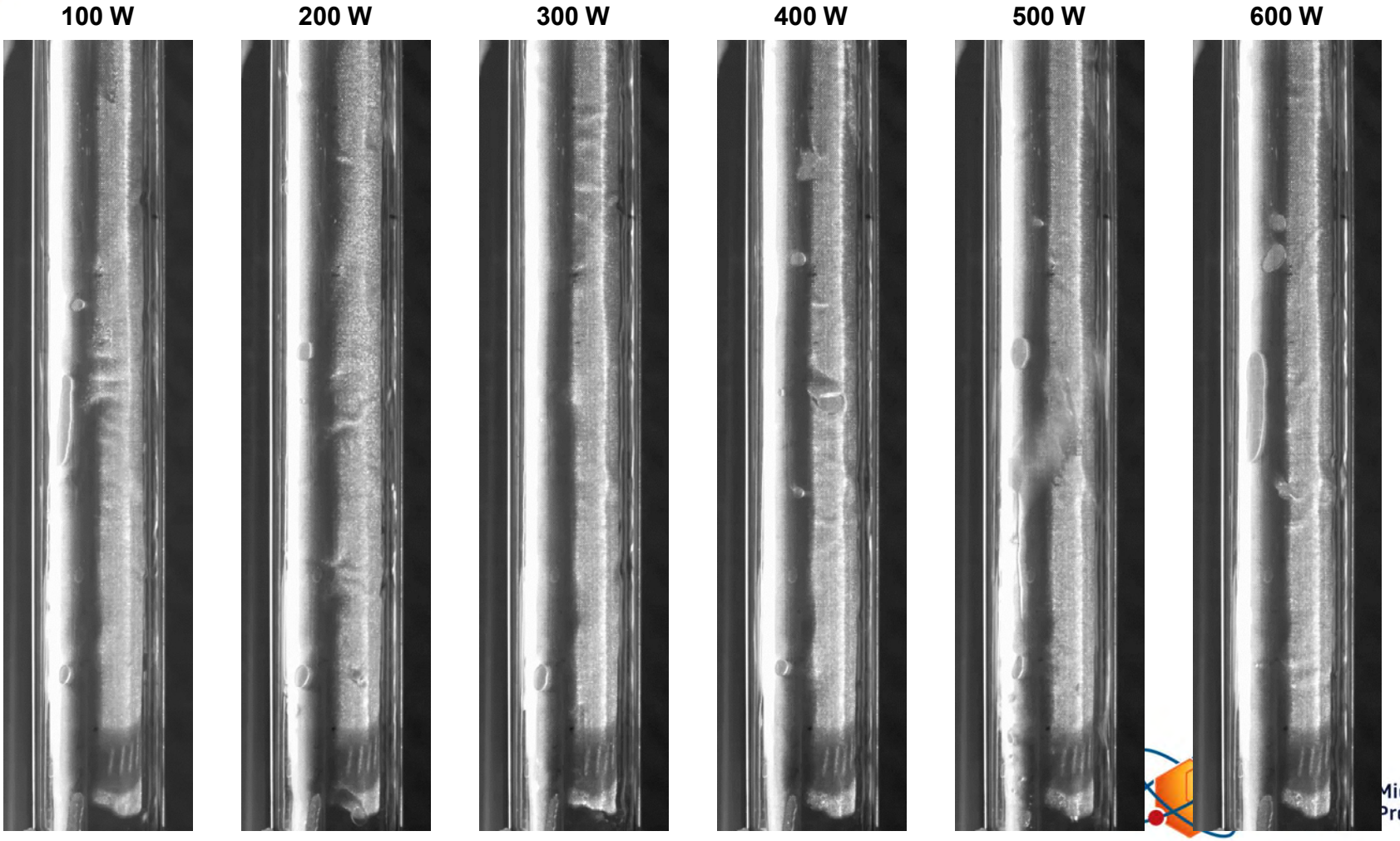
Heat Pipe Visualization (Vertical with Varying Power) - Evaporator



Microreactor Program

Heat Pipe Visualization (Vertical with Varying Power) – Adiabatic Region



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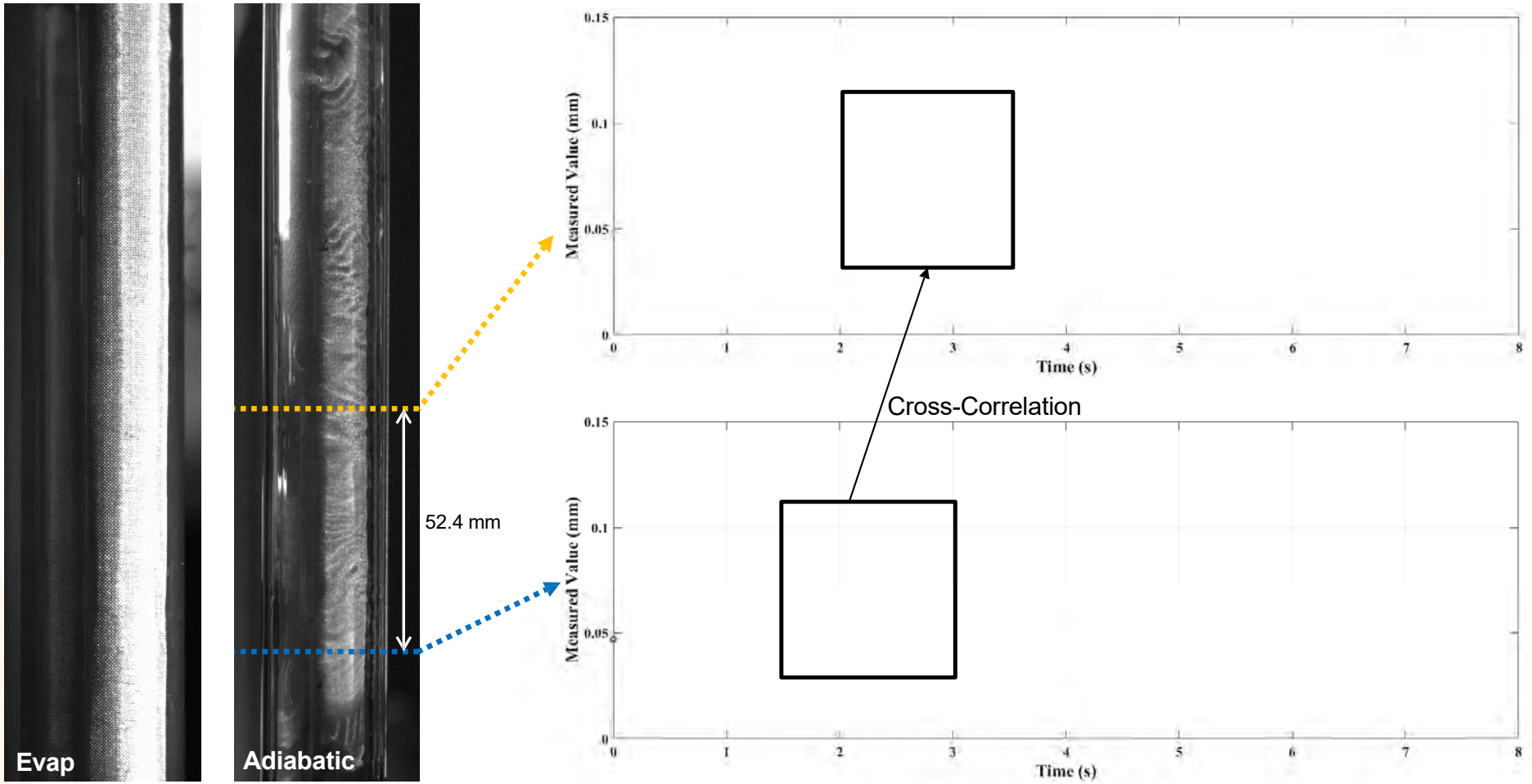
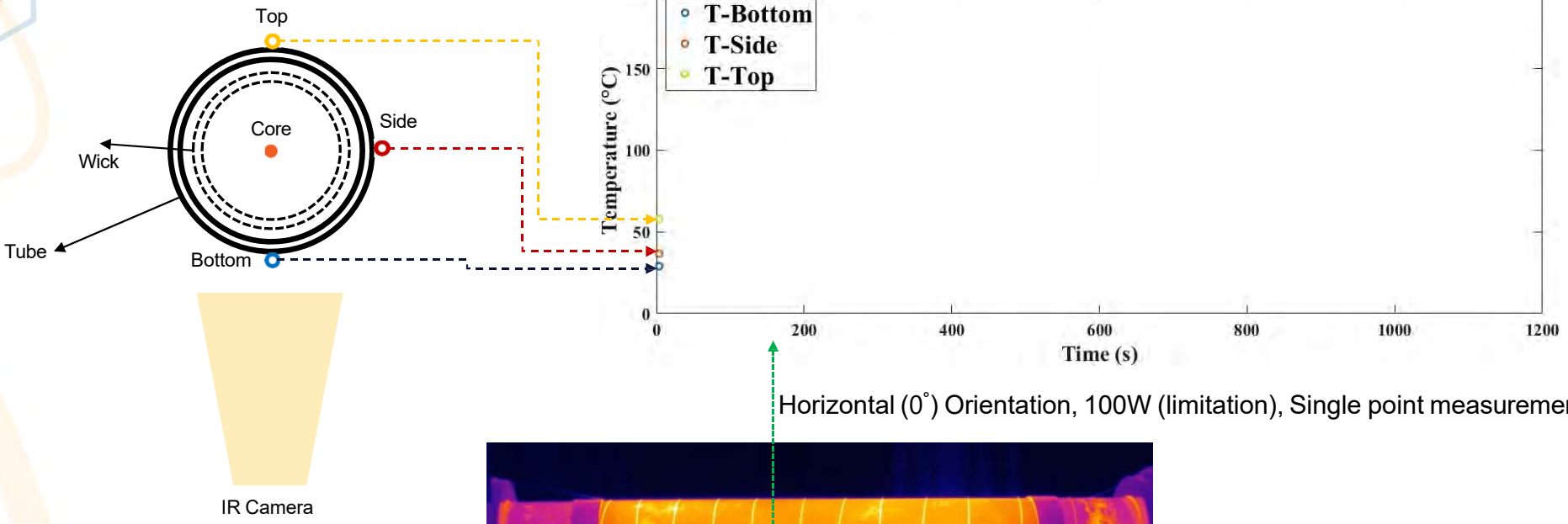
Film Thickness Measurement

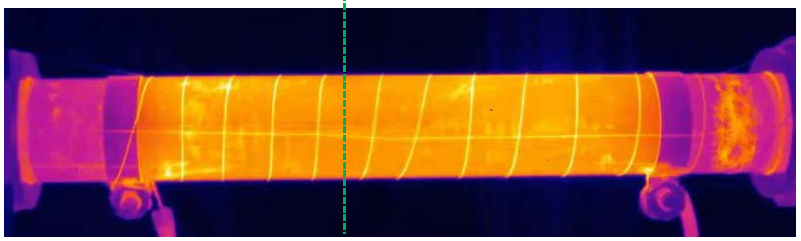
500 W



Heat Pipe Visualization Results – Horizontal Effect (Gravity)



Horizontal (0˚) Orientation, 100W (limitation), Single point measurement



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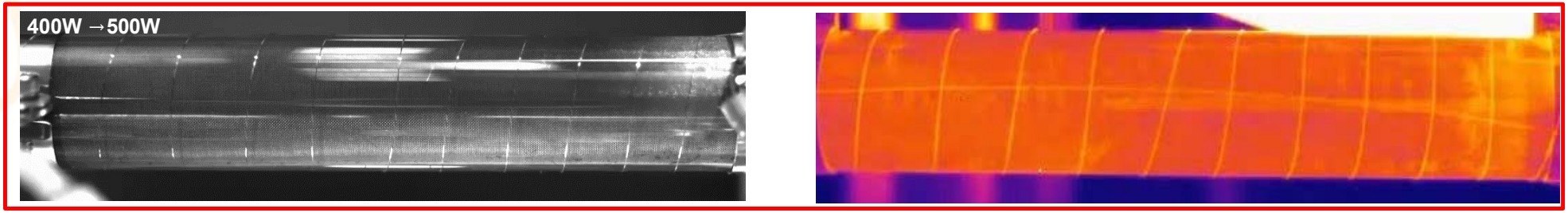
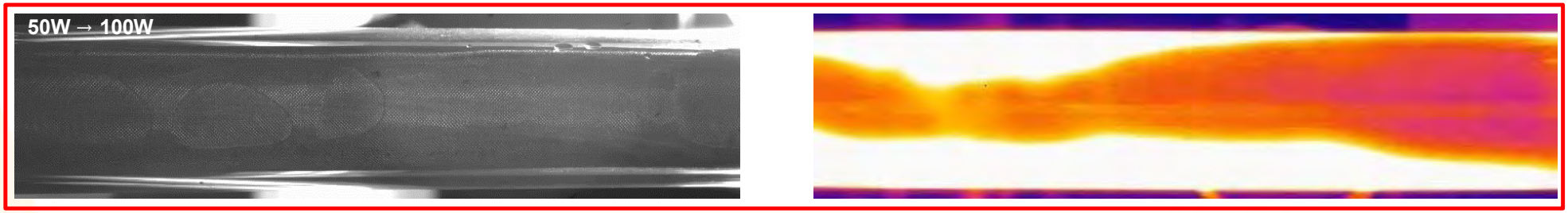
Heat Pipe Visualization Results – Operating Limitation

45°inclination angle *Operating limitation achieved after sudden increase of power from 400W to 500W (~15s after the power increase)*



Horizontal orientation (0°inclination angle) *Operating limitation achieved after sudden increase of power from 50W to 100W (~ 30s after the power increase)*



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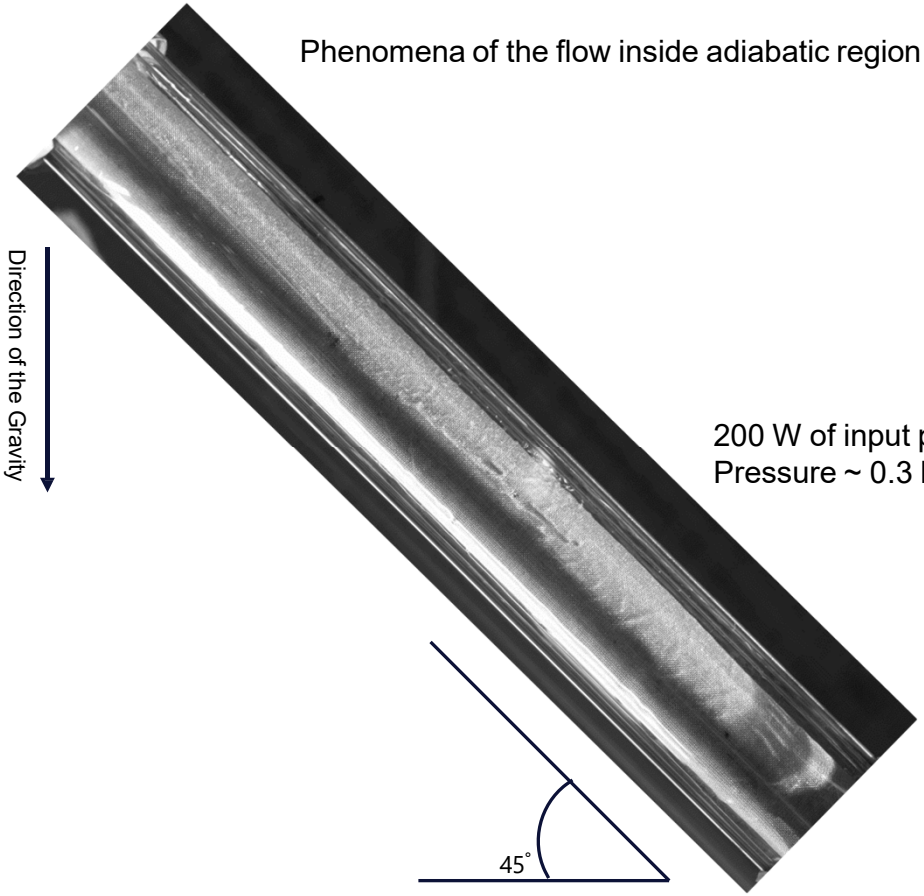
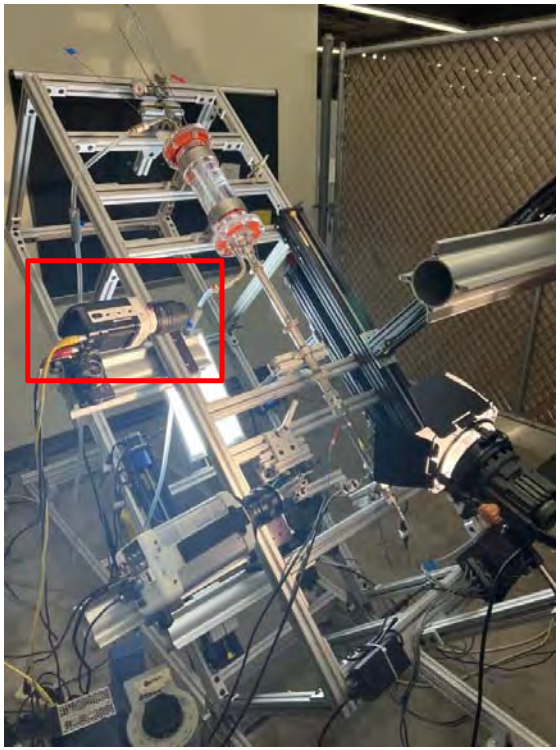
Heat Pipe Visualization Results – Adiabatic Region

Phenomena of the flow inside adiabatic region



200 W of input power
Pressure ~ 0.3 bar



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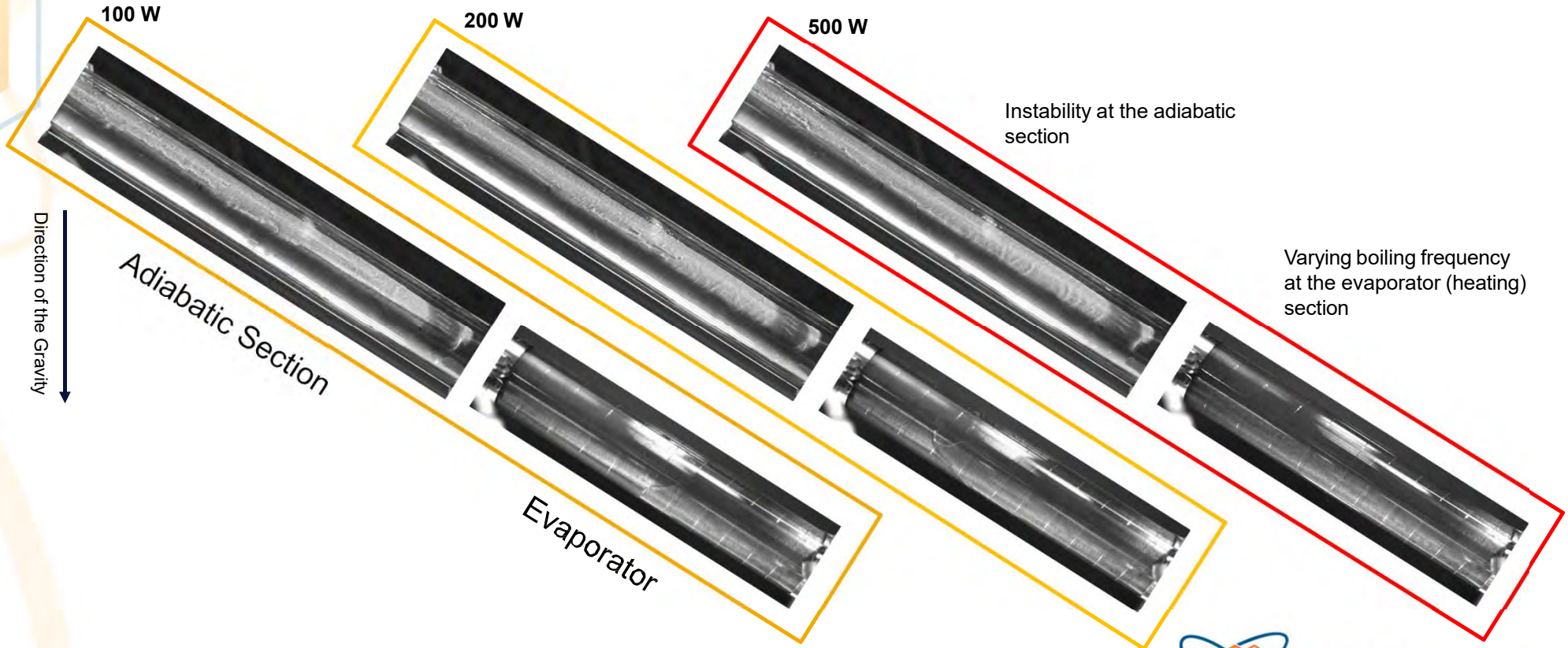
Visualization with Different Power at the Inclination of 45°



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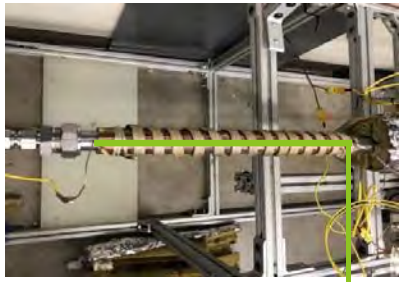
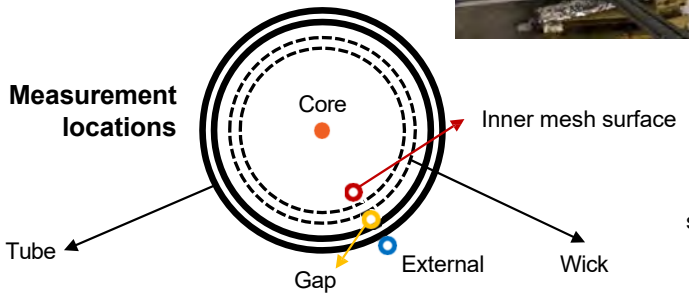
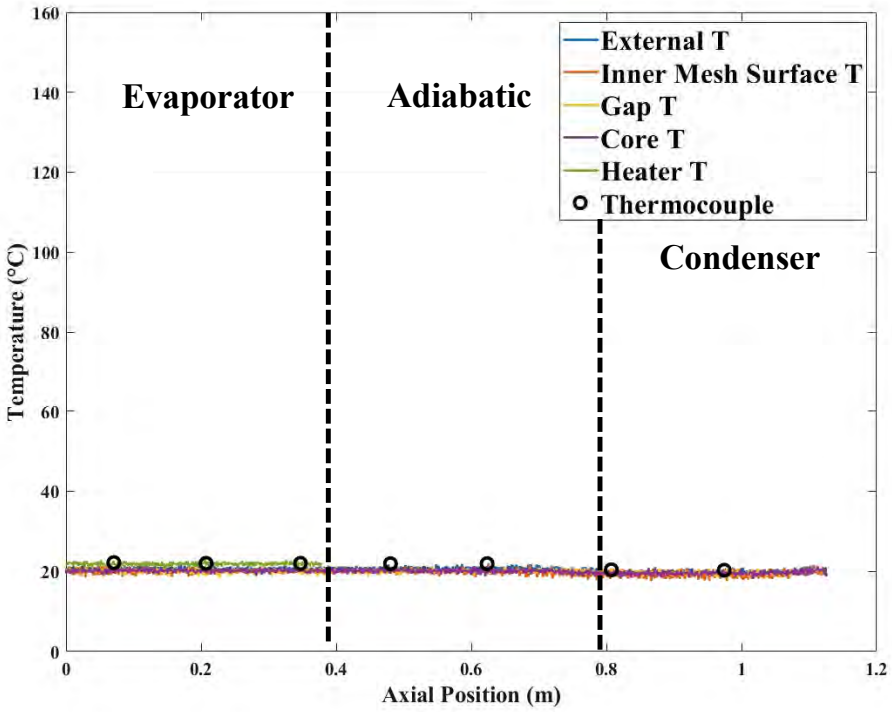
Distributed Temperature Sensing (DTS)

Heater was wrapped on the copper tube for uniform heat transfer to the heat pipe.

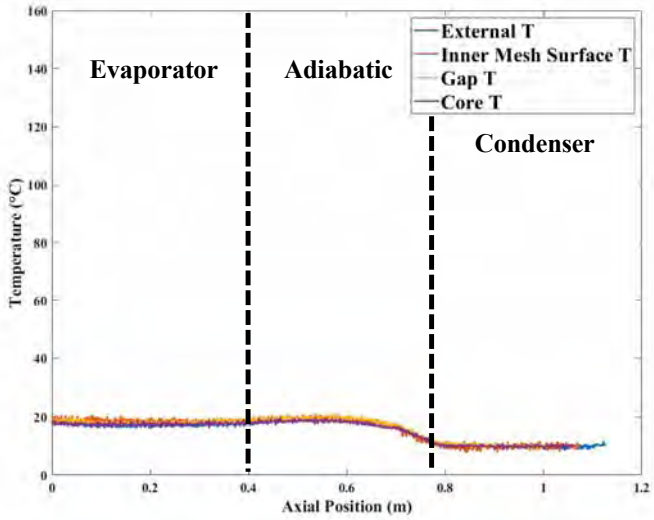




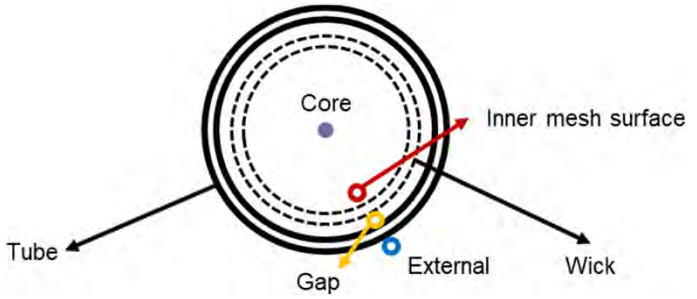
Slow start (30W, ~60 mins) of the heat pipe



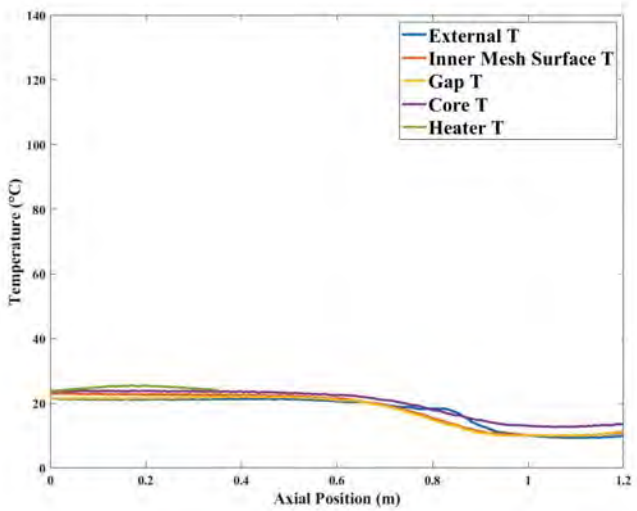
Rapid start (75W, ~60 mins) of the heat pipe



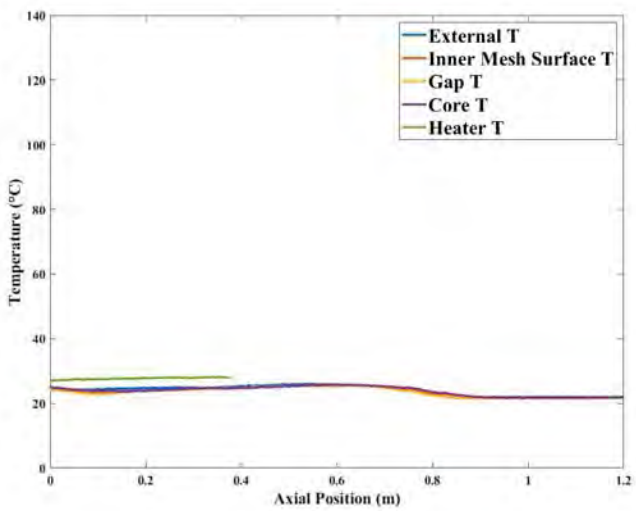
Distributed Temperature Sensing (DTS)



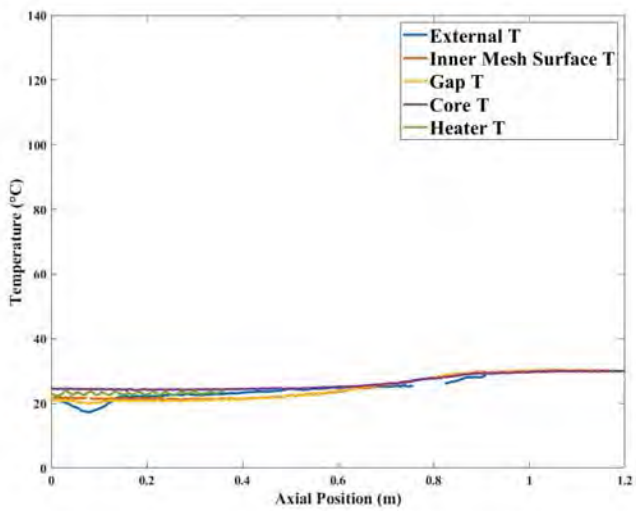
10℃ Cooling Condition



22℃ Cooling Condition



30℃ Cooling Condition

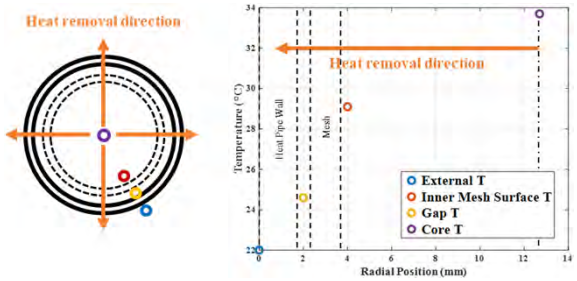


Distributed Temperature Sensing (DTS)

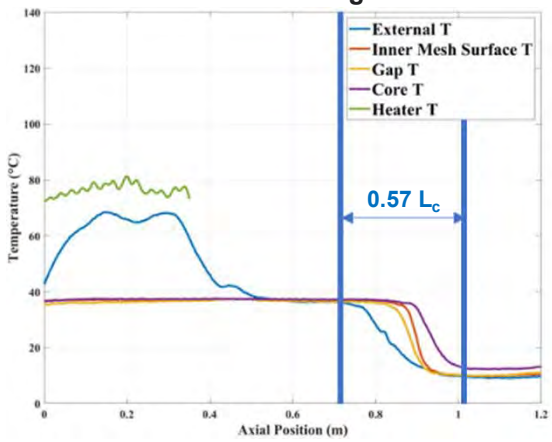
Effective Condenser Length

$L_{eff} = 0.5L_E + L_A + 0.5L_C$

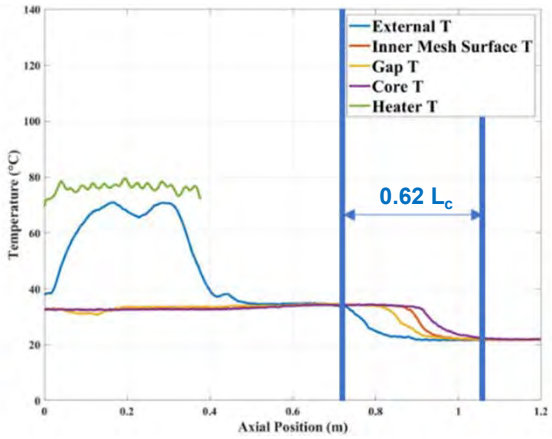
The dependency of the effective condenser length on the cooling condition was investigated by leveraging DTS.



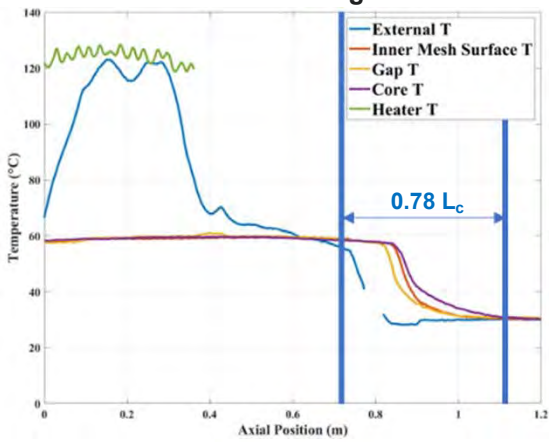
10 C Cooling



20 C Cooling



30 C Cooling



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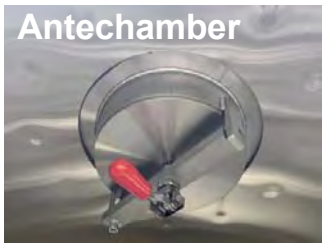
Construction of Sodium Heat Pipe



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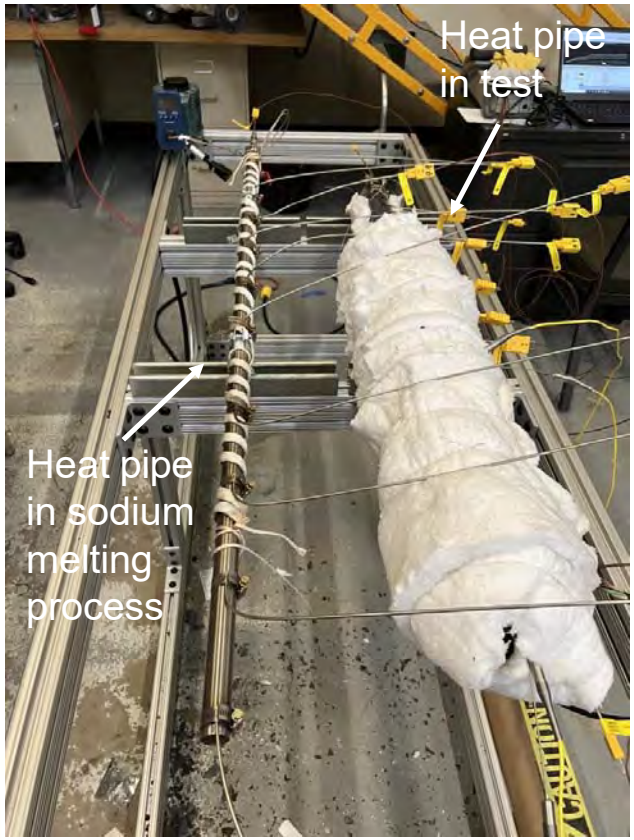
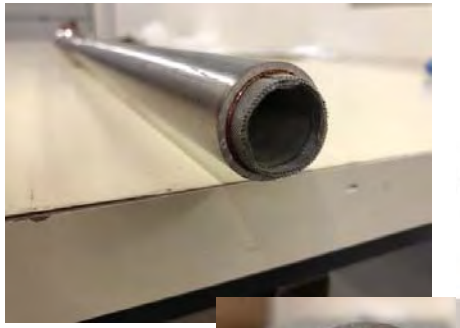
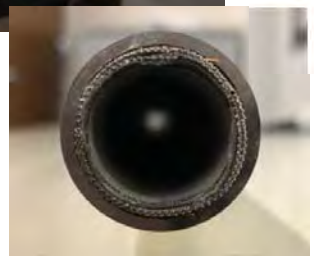
Sodium Heat Pipe Preliminary Experimental Facility

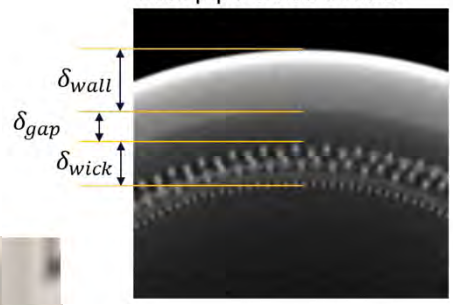


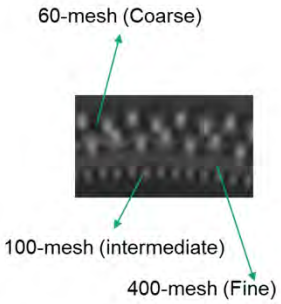


Multi-layered composite screen wick mesh was fabricated.



Micro CT scanning of the heat pipe cross-section





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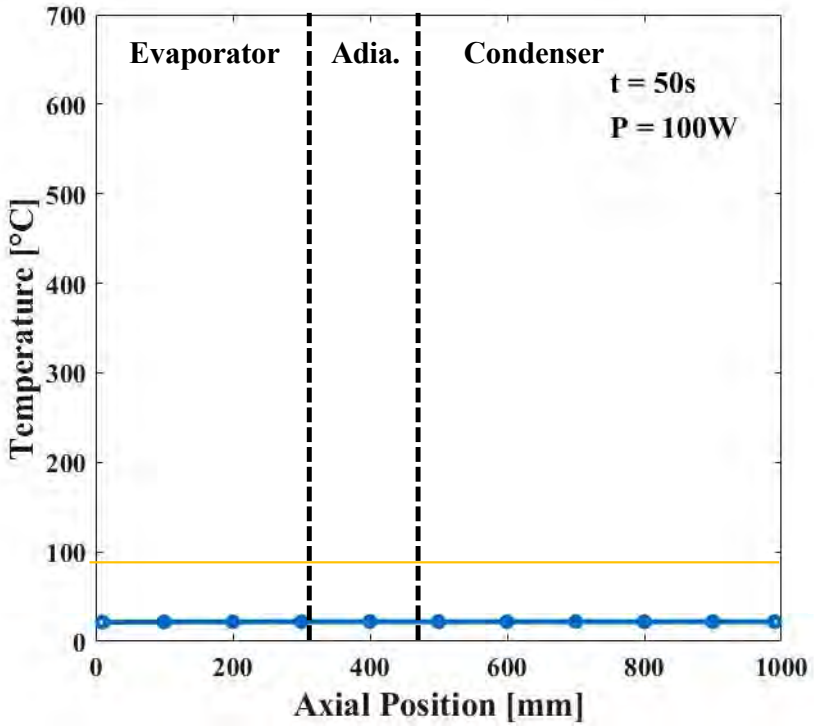
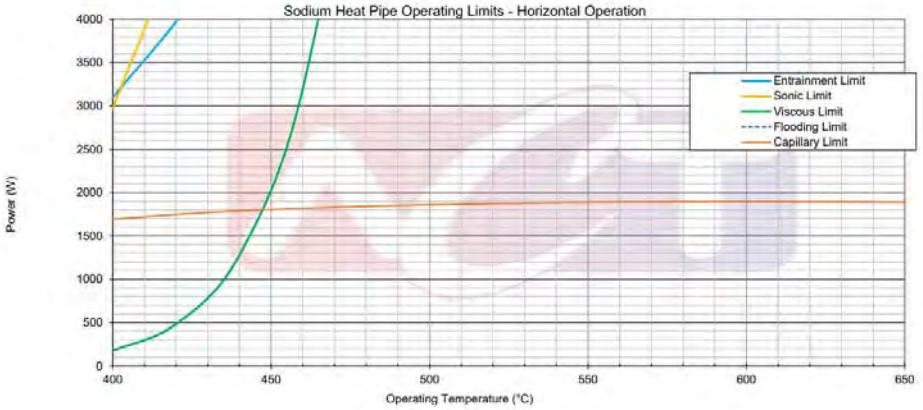
Sodium Heat Pipe Preliminary Experiments





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Thank you

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