Quench front propagation measurement and comparison with inverted annular flow regime using infrared surface temperature profile and high-speed imaging

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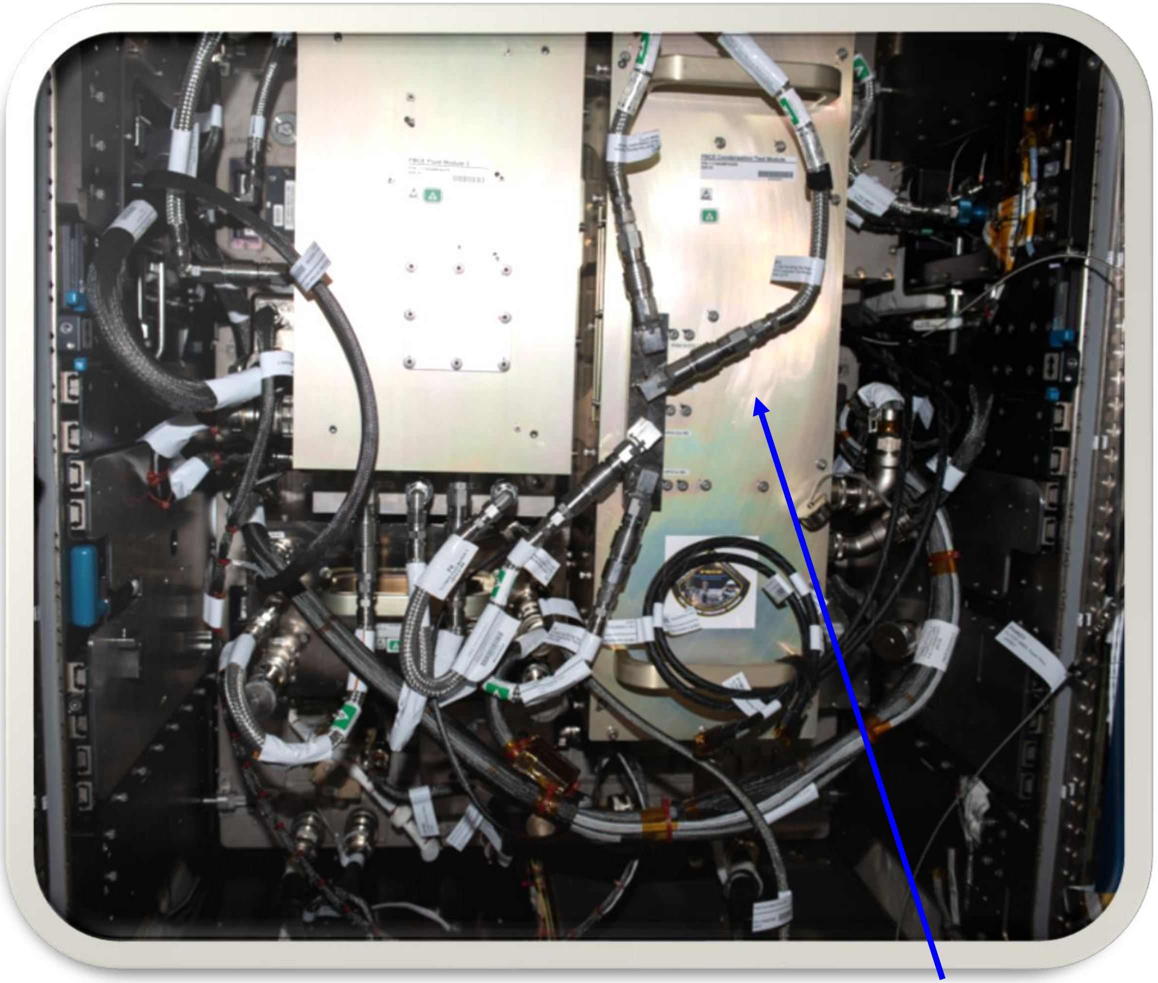
Overview

- Cryogenic Transfer Line (TL) study using non-cryogenic fluid (nPFH)
- Selected as International Space Station (ISS) flight experiment
- Expected launch in 2027
- Replace Condensation Module for Heat Transfer (CM-HT) in Flow Boiling and Condensation Experiment (FBCE) residing in the Fluids Integration Rack (FIR)
- TL consists of two different experiment modules – Heat Transfer & Flow Visualization



FBCE installed in the FIR aboard the ISS – TL installs here

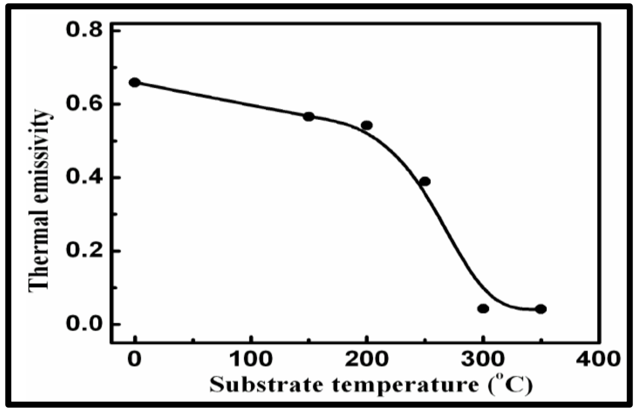
Transfer Line Experiment Objectives

Objectives			Science Data End Products
A	To study the effects of initial mass flow rates, initial inlet pressures, initial inlet subcoolings/qualities, and initial wall temperatures on transient flow boiling heat transfer during chilldown in microgravity.	1	Chilldown curve (internal wall temperature vs. time).
		2	Boiling curve (heat flux through the internal wall vs. internal wall temperature).
		3	The comparisons of heat transfer coefficient in each boiling.
		4	Pressure and differential pressure.
		5	The comparison of quench front velocity at different mass flow rates, inlet subcoolings/qualities, inlet pressures, as well as initial wall temperatures.
		6	Experimental correlations for average heat flux and heat transfer coefficient at each boiling regimes, rewetting temperature, critical heat flux, onset of nucleate boiling point, and rewetting velocity in microgravity.
B	To clarify the heat transfer mechanisms and interface dynamics of transient flow boiling during chilldown process in microgravity.	1	The analyses of flow patterns transition through flow visualization data from the high-speed camera
		2	The analyses of quench front propagation through wall temperature distribution images around the quench front.
C	To validate the 3D simulations developed by Raytheon Technologies based on the obtained heat transfer data and flow information in microgravity.	1	The quantified evolution of flow regime and nucleation dynamics and interactions therein under microgravity and its contrast to terrestrial conditions.
		2	Validation of the heat transfer and pressure drop predictions with data obtained on the FBCE on the ISS.

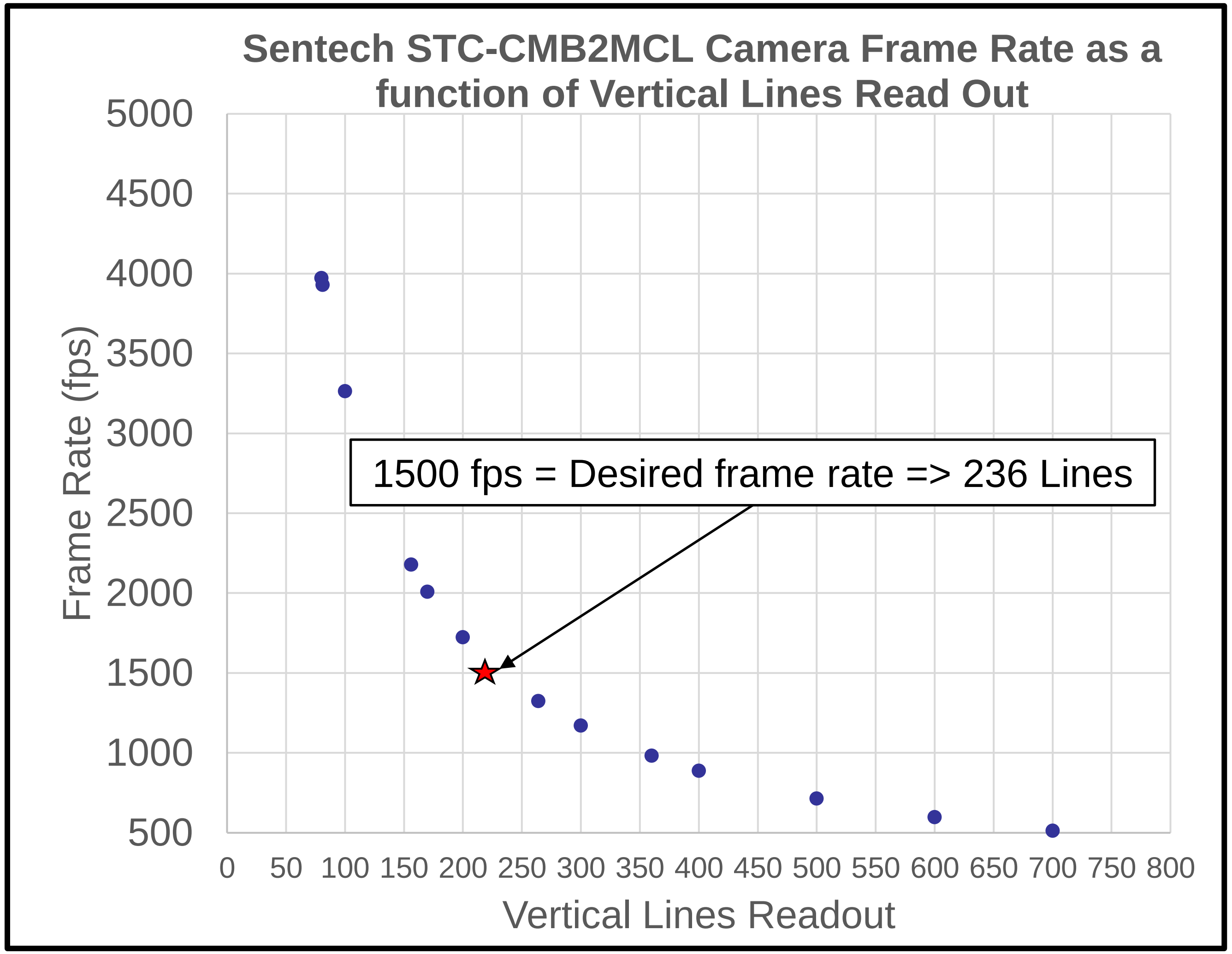
Focus of this talk

Imaging Needs

- High-Speed Imaging – plan on same camera-link system used on FBM
  - 1500 framed per second (fps)
  - 15 mm x 100 mm field of view (FOV)
  - 100-micron spatial resolution
  - Image flow regimes
- Infrared (IR) Imaging
  - 60 fps
  - 15 mm x 100 mm FOV
  - Thermal profile of Outer Wall to measure Quench Front Propagation and temperature
  - ITO Emissivity issue

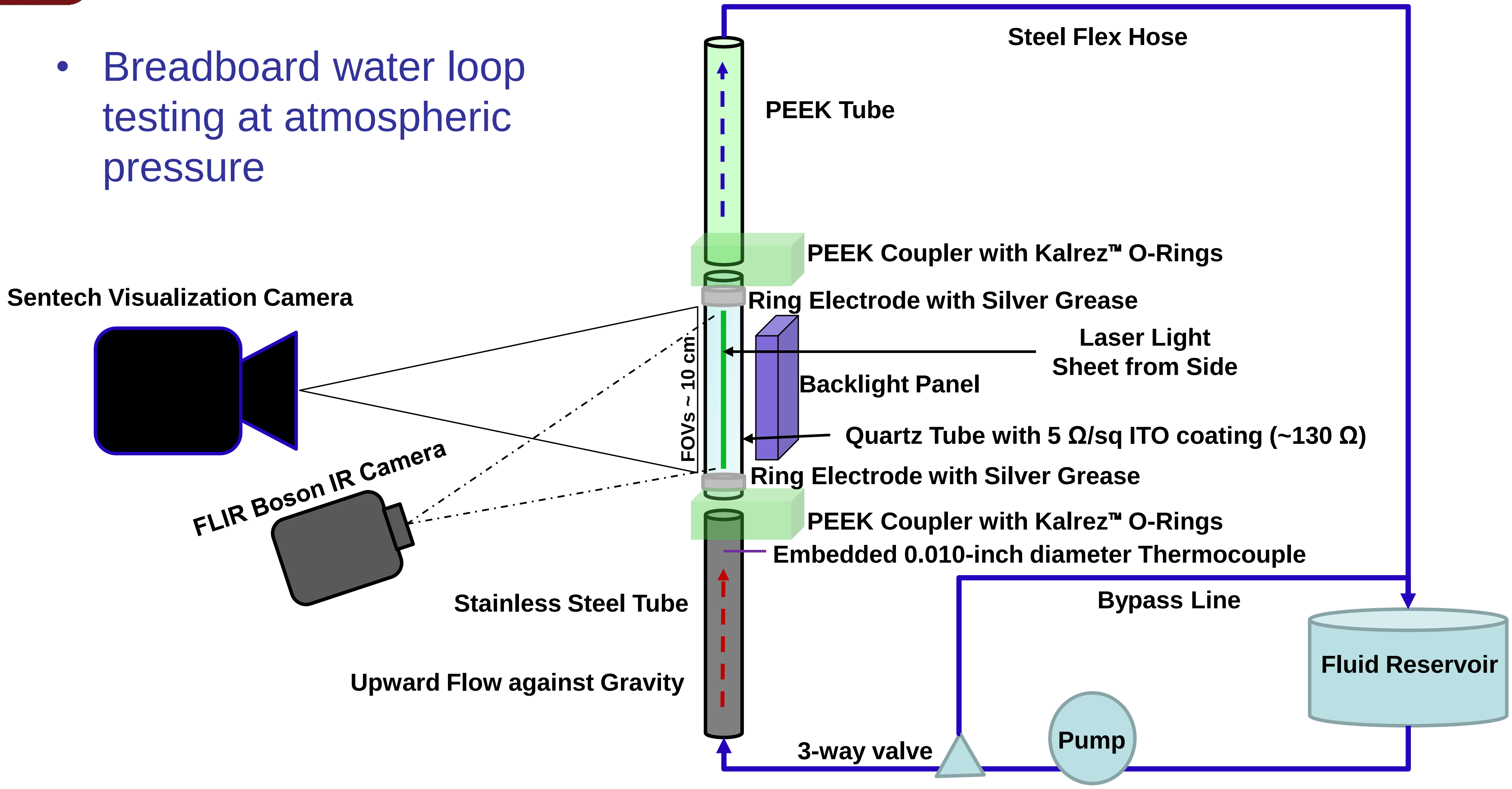


Source: International Journal of Physical Sciences Vol. 7(13), pp. 2102 - 2109

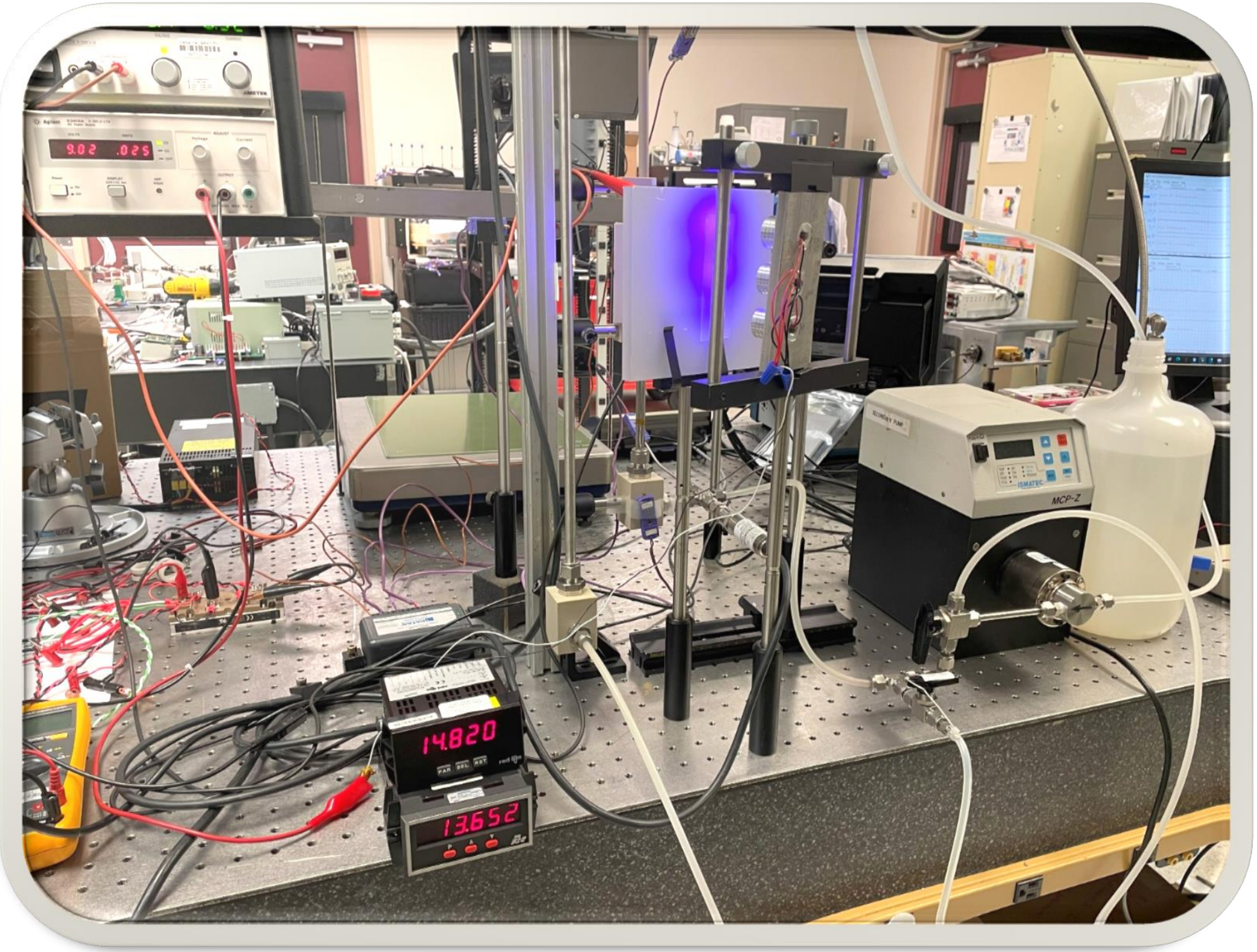


Test Configuration

- Breadboard water loop testing at atmospheric pressure

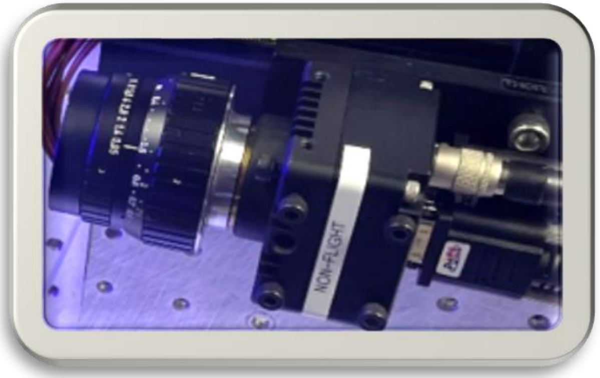


Water Loop Breadboard



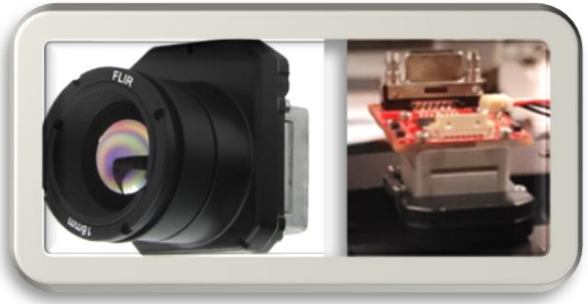
Instrumentation & Imaging Sensors

Ring Electrodes



High-Speed Camera

Thermocouples

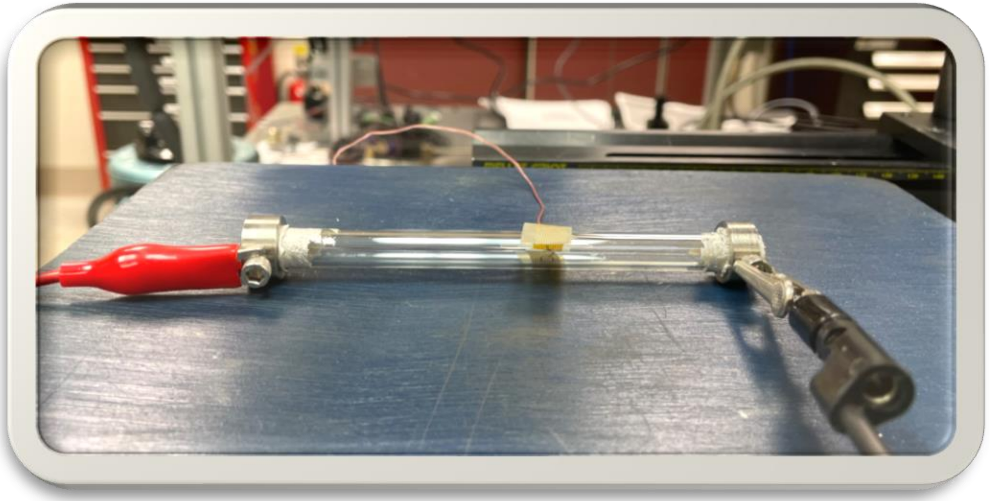


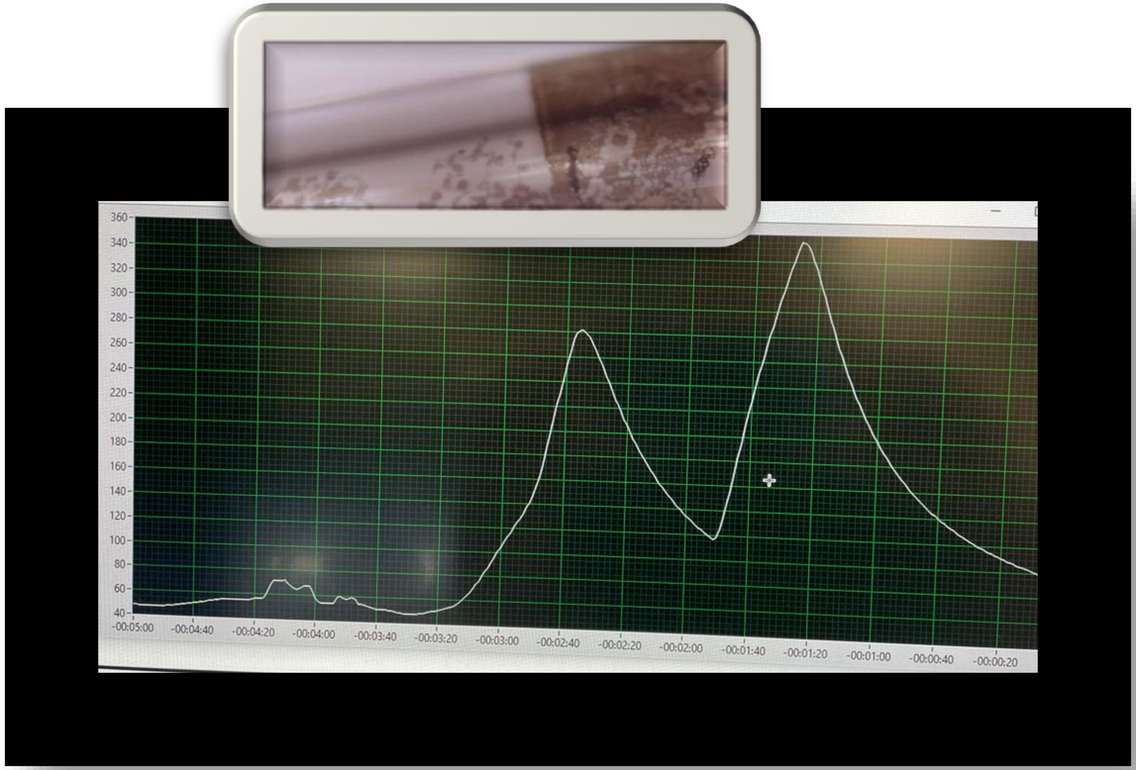
Infrared Camera

Pressure Transducers

Joule Heating ITO Coatings

- Fabricated custom ring electrodes from 316 stainless steel tubing
- Must anneal ITO coating to 400 C or temperature non-uniformity
- Silver conductive grease used to eliminate galvanic corrosion
- Able to increase temperature by 240 C in 30 s with no fluid in tube

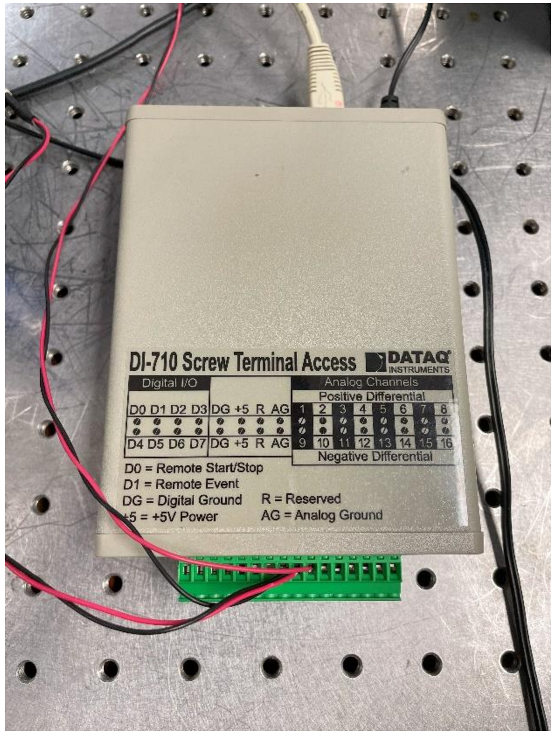




- What about using sapphire tubes?

Data Acquisition Components

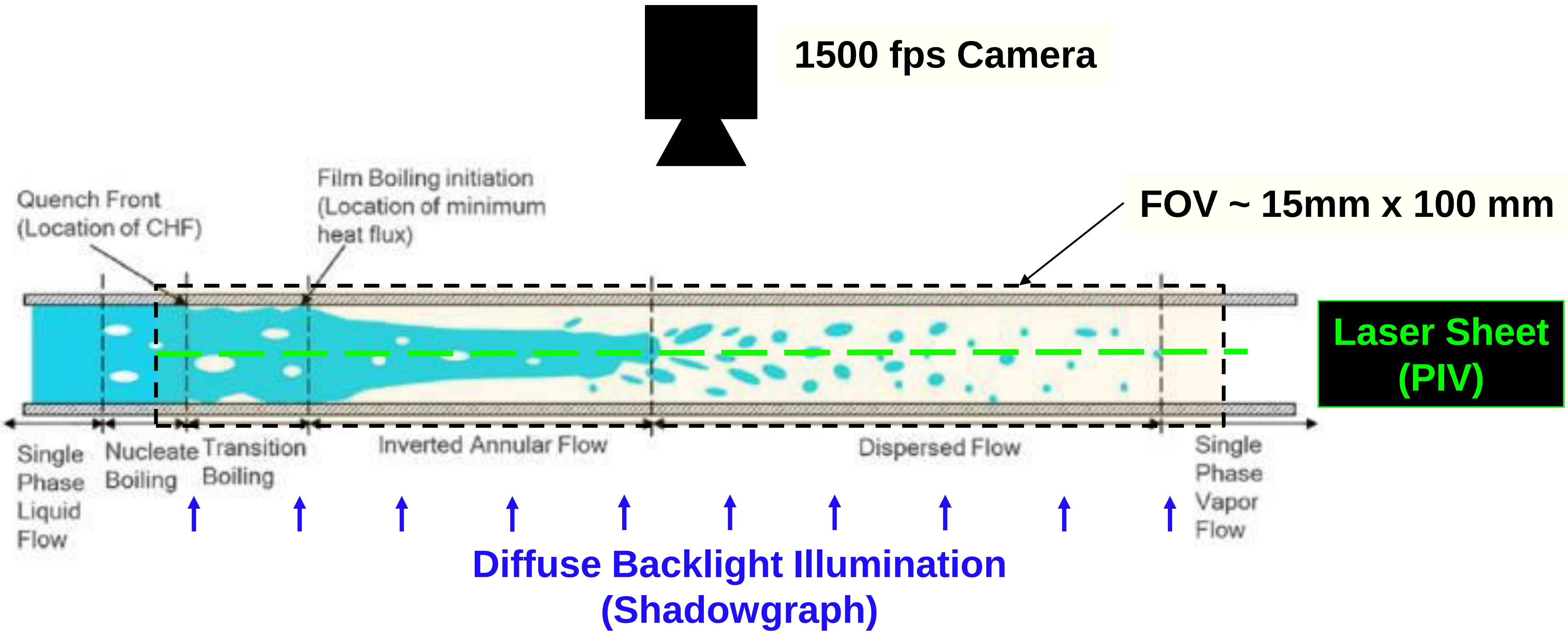
Thermocouple Reader



Pressure Transducer DAQ

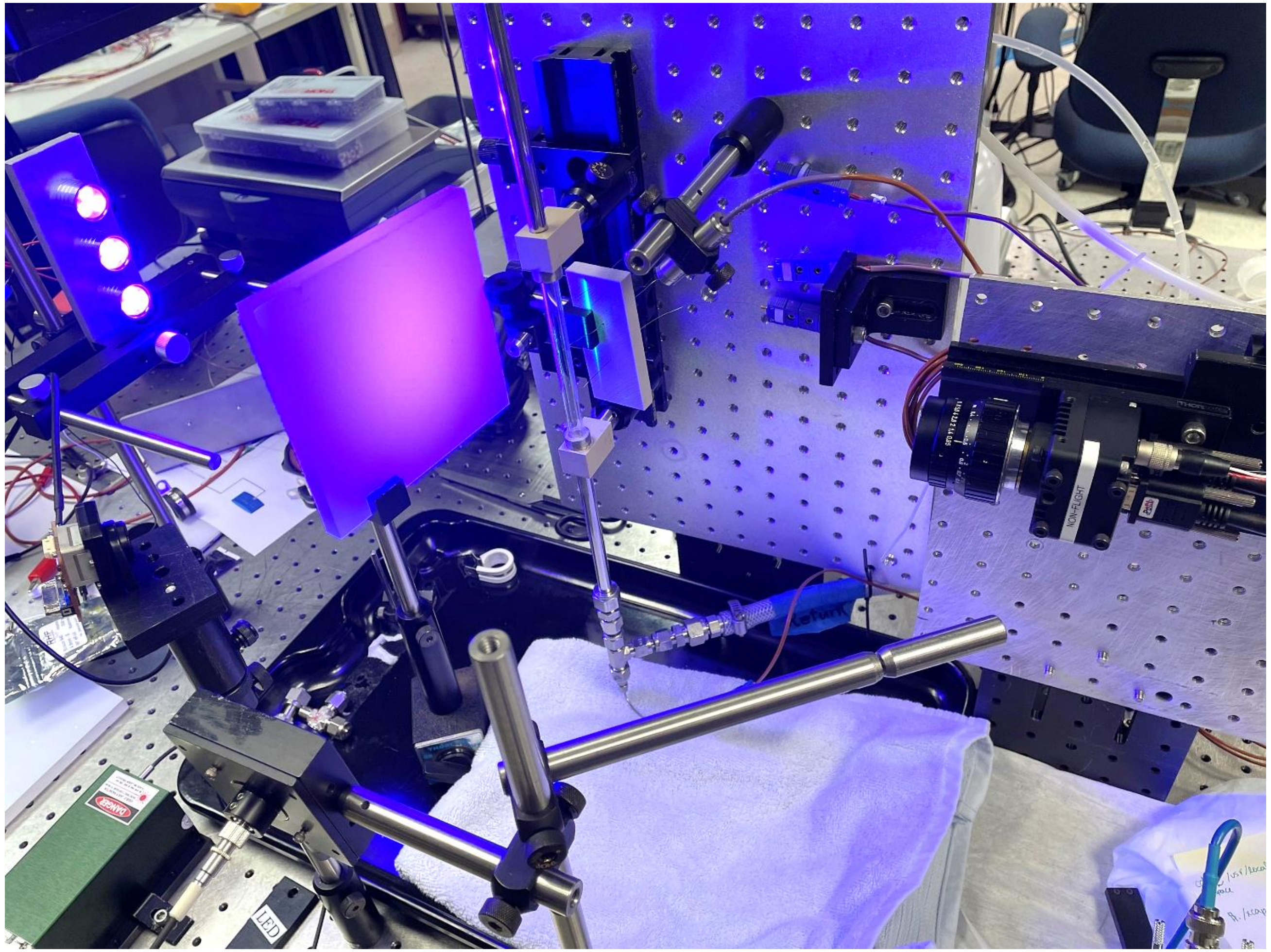
Instrumentation Charting (left), HS & IR Imaging (right)

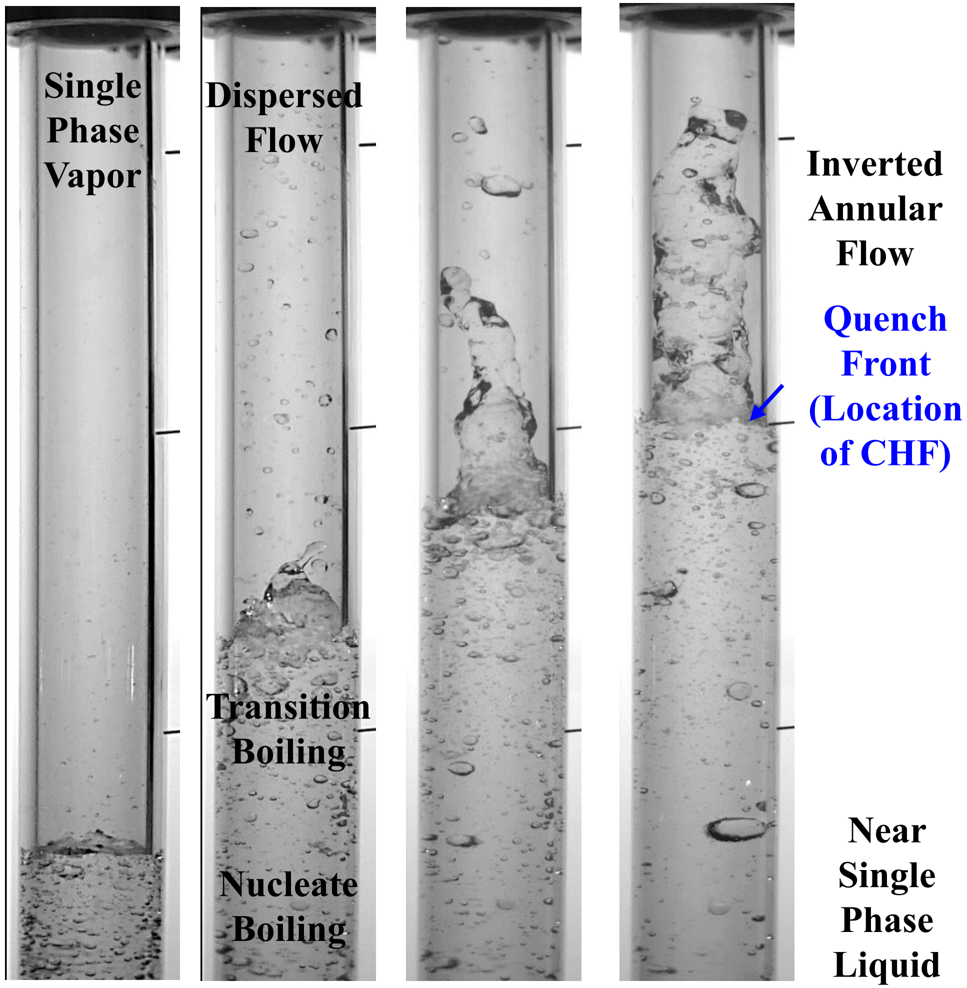
Flow Regimes & High-Speed Imaging



High-Speed Imaging Results

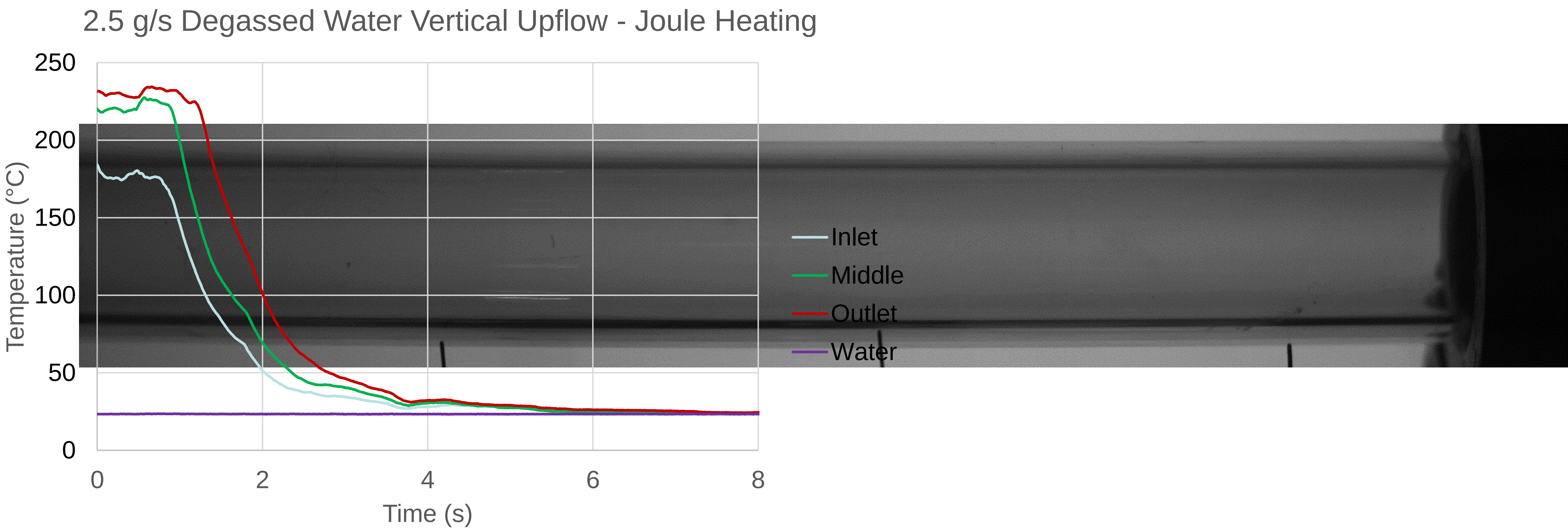
- High-Speed Imaging preliminary results for vertical upflow using water



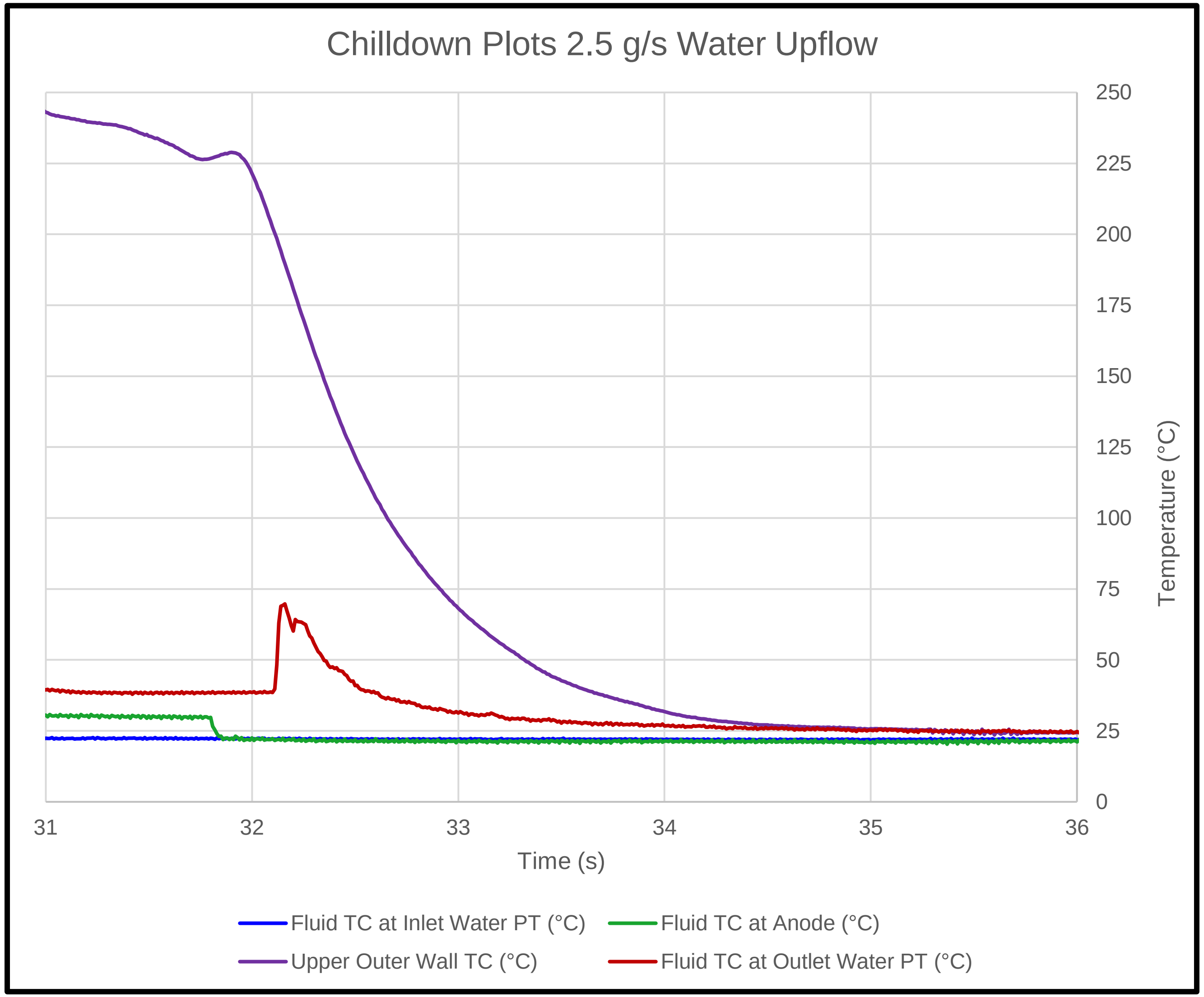


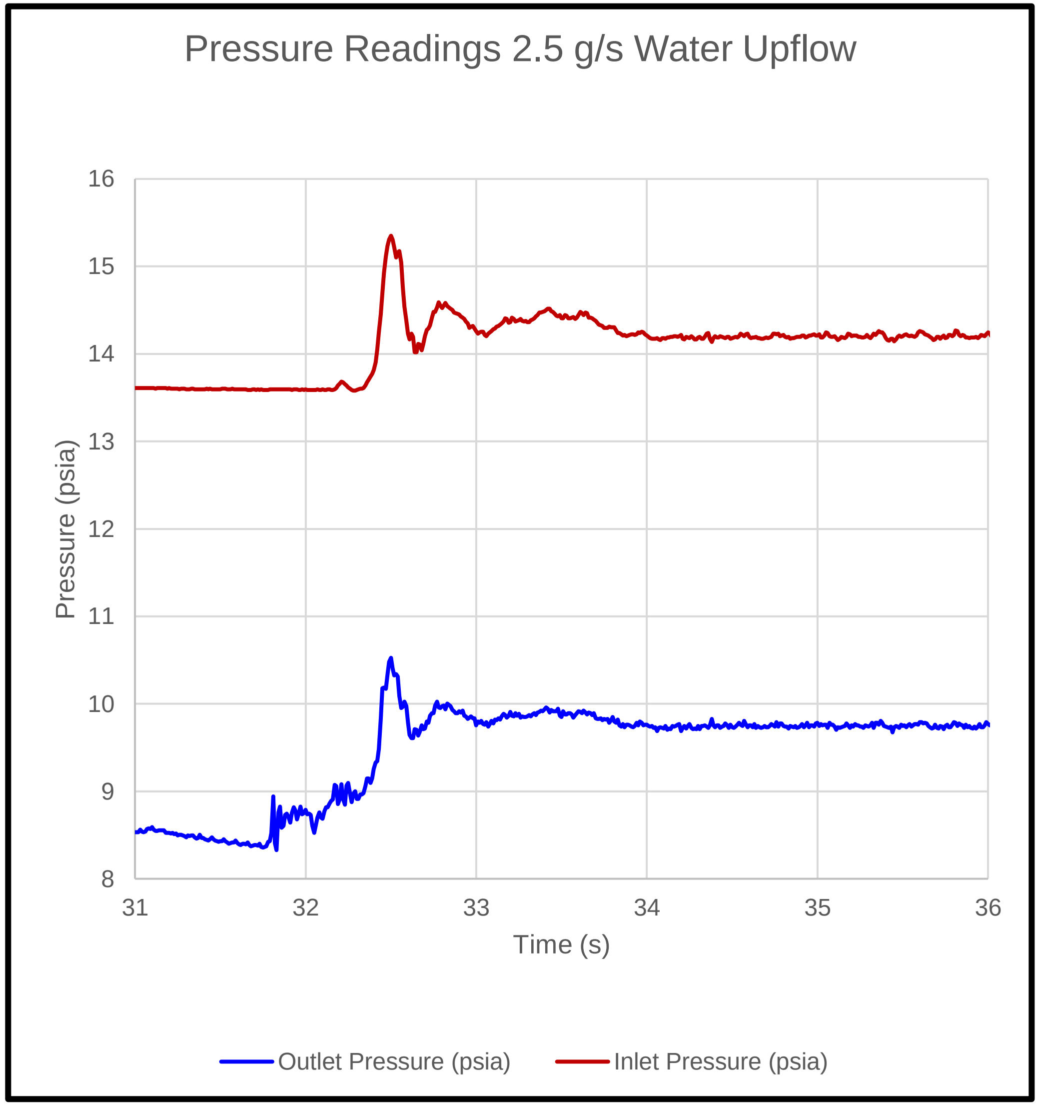
High-Speed Imaging Video Vertical Upflow

- 1500 fps played back at 30 fps
- Distilled water in fused quartz tube coated with ITO on outer surface
- Flow rate = 2.5 g/s

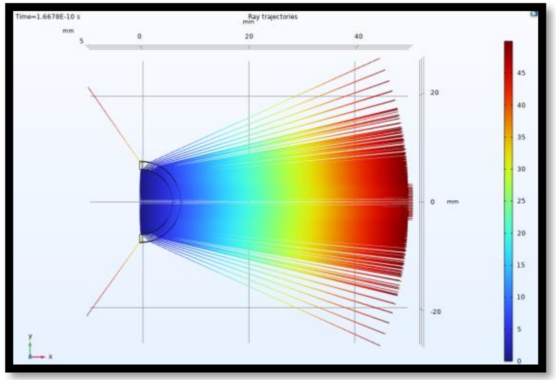


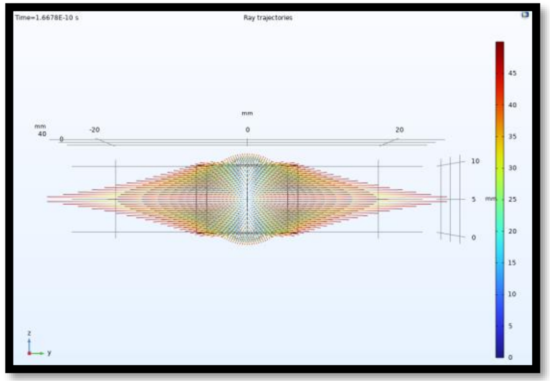
Chilldown Plots – Water Vertical Upflow



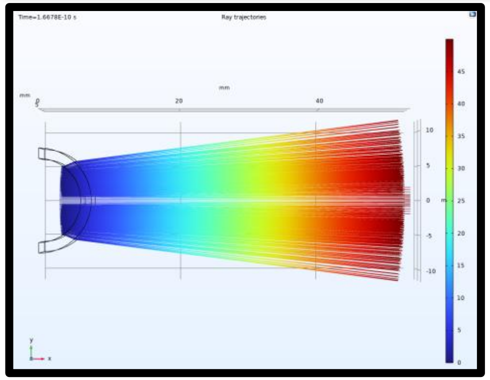


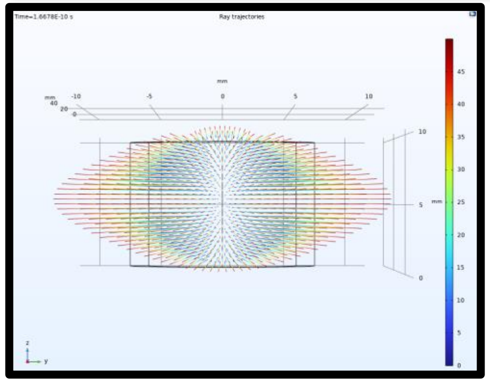
Imaging through Cylindrical Geometry



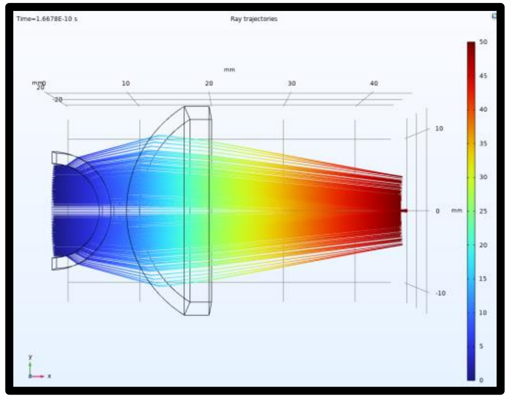


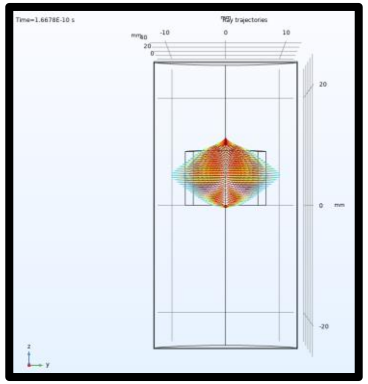
460 nm rays from middle of plane radially bisecting cylinder in plane orthogonal to visual camera field of view.





460 nm rays from plane orthogonal to visual camera field of view. Plane moved 3 mm toward the camera.

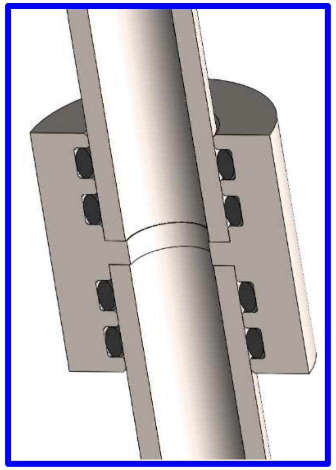


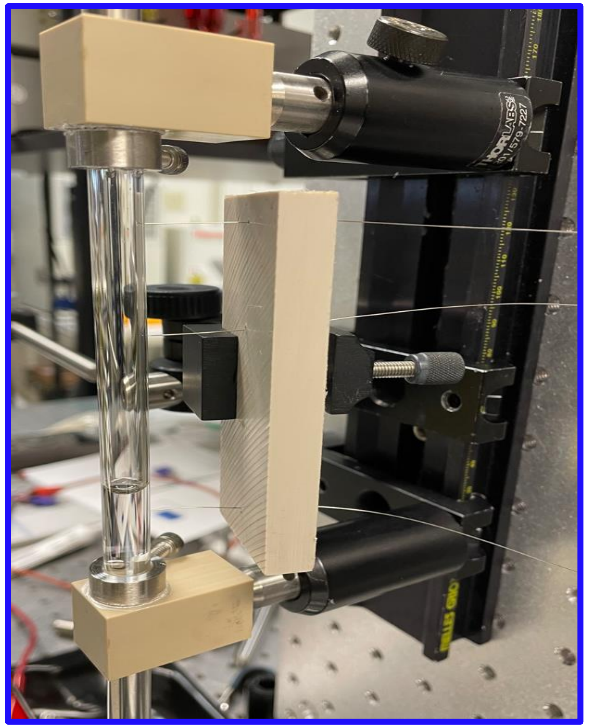


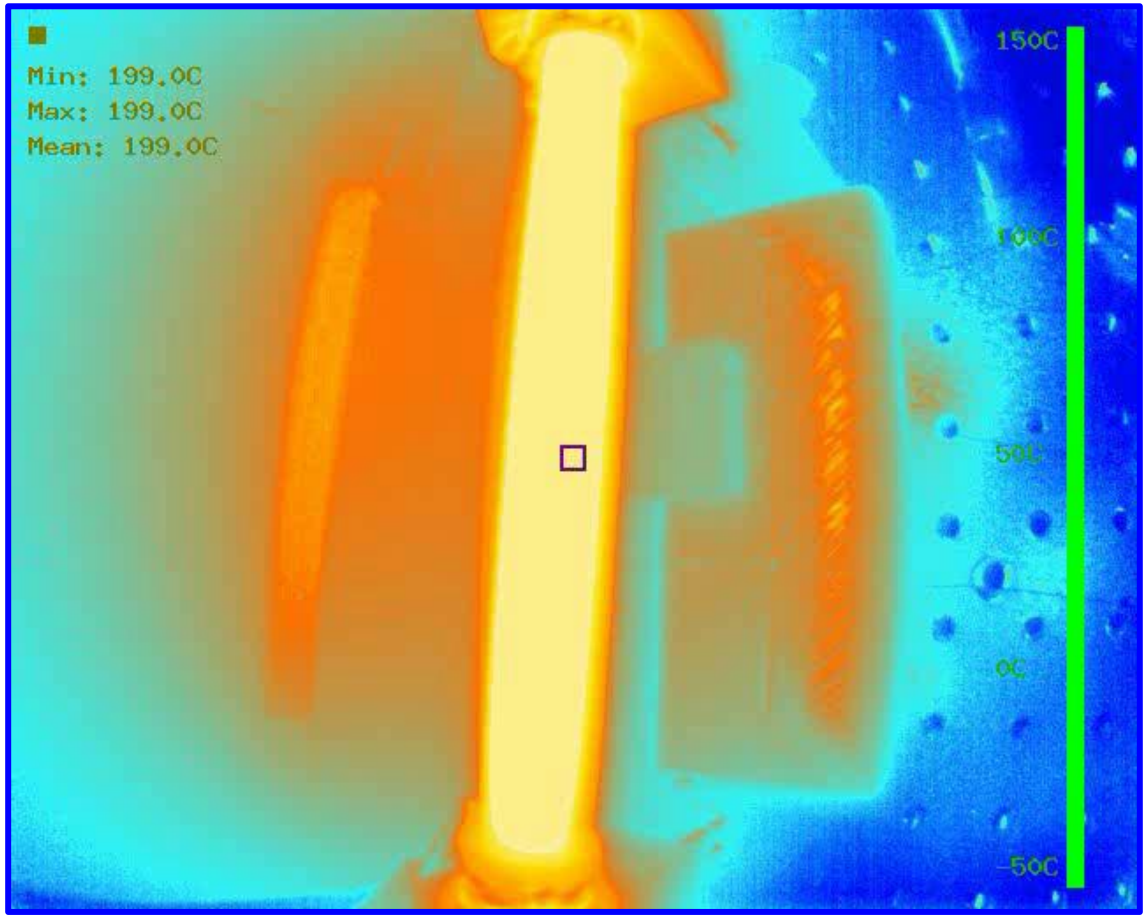
460 nm rays Compensated using cylindrical lens.

Infrared Imaging Video Vertical Upflow

- 60 fps played back at 30 fps
- Distilled water in fused quartz tube coated with ITO on outer surface
- Flow rate = 2.5 g/s
- No emissivity compensation







IR Emissivity Compensation

- IR imaging with black stripe used as emissivity calibration reference

Constant Emissivity over Temperature range of interest

Conclusions

- High-speed imaging possible at 1500 fps
- Requires cylindrical lens to fit image within 236 vertical lines on image array
- Quench front position on tube wall can be tracked
- Quench from temperature can be accurately measured using thermal mask over ITO coating in IR region of interest

Future Development

Future Optical and Infrared Imaging Work:

- Compensate for ITO emissivity in IR imaging using black coating – also provides in-situ IR calibration method
- Illumination as Fiber-coupled backlights from FIR White Light Source
- Light Sheet as Fiber-coupled laser light from FIR Nd:YAG Laser
- Enclosure with ZnSe windows and coatings – quantify heat loss
- Camera-link operation of IR camera – partially accomplished
- Test with nPFH flight fluid – scheduled for December 2014
- Cylindrical lensing effect compensation/re-mapping
- Full-length tubes sent to UK for ITO coating – anneal & test at GRC

Acknowledgement:

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