INL/MIS-21-61754-Revision-0

Sockeye Experimental Validation - MRP Feb 2021

February 2021

Changing the World's Energy Future

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Sockeye

Experimental Validation

February 2021

NEAMS
NUCLEAR ENERGY ADVANCED MODELING & SIMULATION PROGRAM

V&V Status

- **Validation:**
  - No additional validation performed since last update (November 2020); we have the following:
    - Comparison to SAFE-30 experimental data (see backup slide)
- **Verification:**
  - Unlike validation, verification is a continuous part of development process
    - Code changes accompanied by regression tests, most of which do some verification through unit-testing
  - Additionally, can perform holistic verification using analytic solutions.
  - Again, no update on these comparisons since last update; we have the following:
    - Comparison to analytic velocity profiles (see backup slide)
    - Comparison to analytic pressure drop profiles (see backup slide)
    - Verification of spatial convergence order (see backup slide)
- **Next V&V efforts will be performed Summer 2021 (but some possibly sooner).**

V&V Timeline

- Summer 2021: Hired ISU student intern to perform V&V.
- Summer 2021: (If proposal accepted) CAES collaboration with ISU to perform literature review and build heat pipe modeling and simulation database.
- 2021 (sometime): Obtain data from NEUP Project 19-17416.
- 2022 (sometime): Obtain data from NEUP Project 20-19735.

Existing Experiments

- **Potential Validation Data:**
  - SAFE-30
  - SAFE-100/SAFE-100a
  - Cao & Faghri
  - Advanced Cooling Technologies (ACT)
    - Provided heat pipe for SPHERE and MAGNET facilities at INL
    - External thermocouple data for startup and normal operation transients
  - SPHERE
    - Performed their own startup with the ACT heat pipe
- **Ongoing Experiments:**
  - Texas A&M University (TAMU): NEUP Project 20-19735 (see next slide)
  - University of Michigan (UM): NEUP Project 19-17416 (see next next slide)
  - Idaho State University (ISU): Various heat pipe experiments, such as wetting behavior

NEUP Project 20-19735

- **Experiments for Modeling and Validation of Liquid-Metal Heat Pipe Simulation Tools for Micro-Reactors**
  - Texas A&M University: Yassin Hassan
  - Normal operation, frozen startup, shutdown, and restart
  - Measurements:
    - Temperature distribution in the core, wick, annular gap, and external wall surface measured by fiber-optic distributed temperature sensor (FO-DTS) and thermocouples
    - Pressure measured by pressure-transfer-liquid techniques
    - Phase distribution measured by X-ray systems
    - Wick characteristics: capillary rise, wall friction, pressure drop form factor

NEUP Project 19-17416

- **Experiments and computations to address the safety case of heat pipe failures in Special Purpose Reactors**
  - University of Michigan: Victor Petrov, Annalisa Manera
  - Normal operation, frozen startup, and shutdown
  - Various inclinations
  - Fiber optics and thermocouples on external cladding surface
  - High-resolution X-ray imaging to measure void fraction
  - Thermomechanical stresses on core structure after multiple heat pipe failures

Thoughts on Future Experiments

- **Ideal data characteristics:**
  - Internal to the heat pipe cladding, but not invasive
    - ACT heat pipe has a central thermowell; Sockeye cannot model this without significant approximation
  - High resolution (spatial and temporal)
    - Want to capture phenomena that occur across smaller scales
- **Information on the experimental environment is crucial for accurate modeling:**
  - Identity of surrounding gas, if any
  - Temperature of surroundings, ideally not just initial value
  - Material composition, size, and location of any neighboring bodies
- **Ideally, future experiments should include:**
  - Characterization of wick parameters (porosity, permeability, capillary pressure)
    - These are Sockeye inputs, as they cannot be accurately predicted.
    - Important for modeling capillary pressure and limit.
  - Identity and mass of non-condensable gases (NCGs) inside heat pipe
    - Important for heat transfer predictions (NCGs effectively shorten active length of heat pipe)

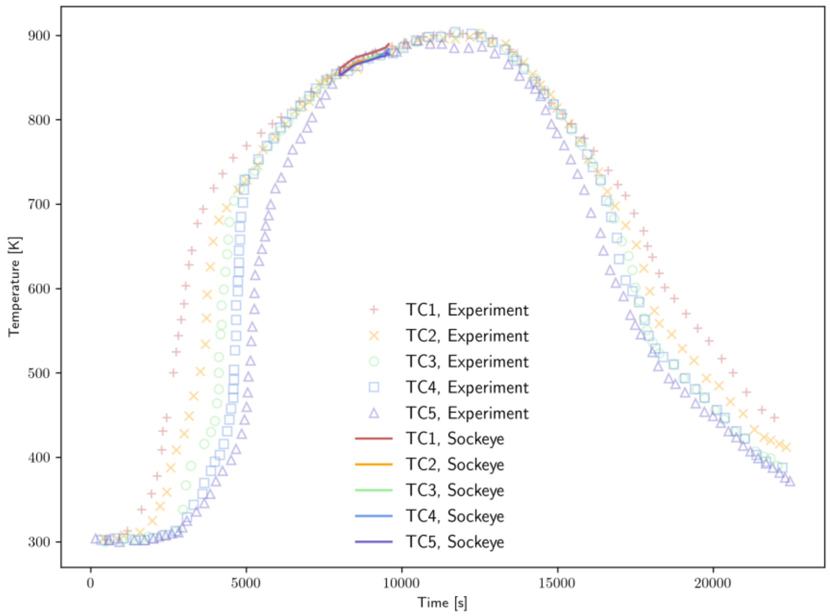
Possible Future Experiments

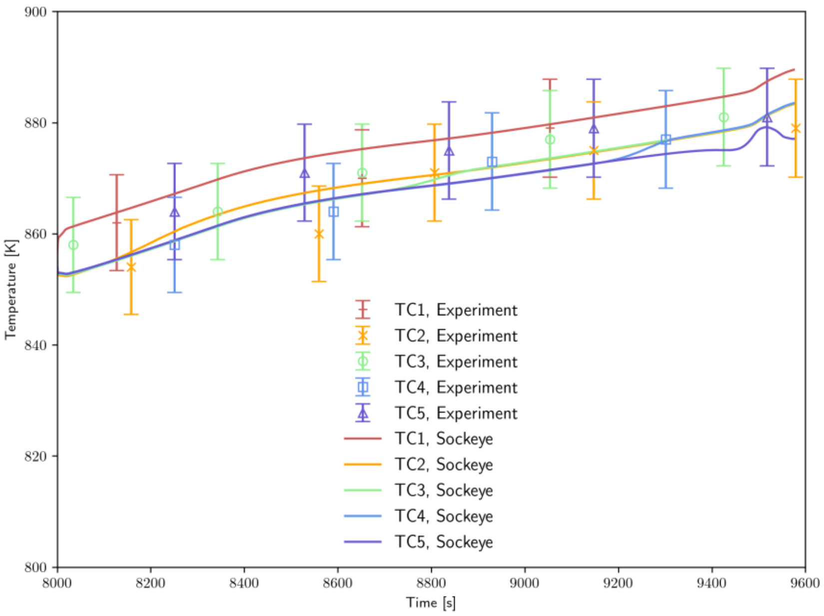
- **Capillary limit study**
  - Gradually increase power until dryout occurs
  - Do several runs at different operating temperatures
    - How to control operating temperature? Force air over heat pipe at different speeds?
- **Dryout recovery study**
  - Maybe combine with previous study
  - After dryout occurs, try to recover by lowering power
- **Shutdown study**
  - Observe working fluid distribution after shutdown
  - Use different gravity orientations
- **Fundamental studies:**
  - Capillary pressure vs. wick saturation
  - Capillary pressure vs. temperature

Questions/Discussion

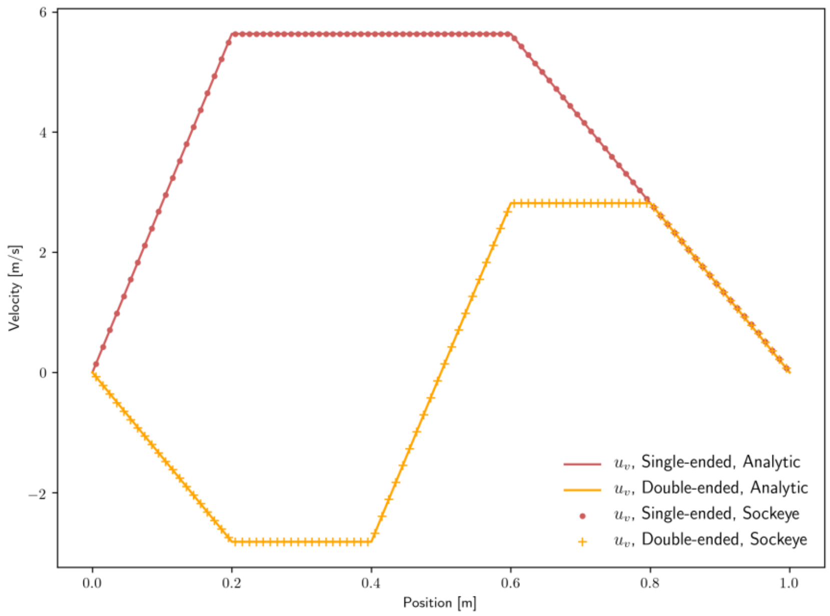
- **What types of measurements are possible?**
  - Obviously, we have the option of externally-mounted thermocouples.
  - Is it possible to measure internal pressures?
  - Some have suggested fiber-optic temperature sensors for internal measurements – is this possible?
  - Some have planned to use X-rays to get void fraction – what resolution is reasonable here? Just enough to determine if wick is saturated/dry or if there is a pool? Or enough to see level within wick or even interface curvature?
  - Any way to measure velocities inside the heat pipe?
  - Any other measurements that could be of interest?
- **What experiments are currently planned?**
  - What heat pipes are being used?

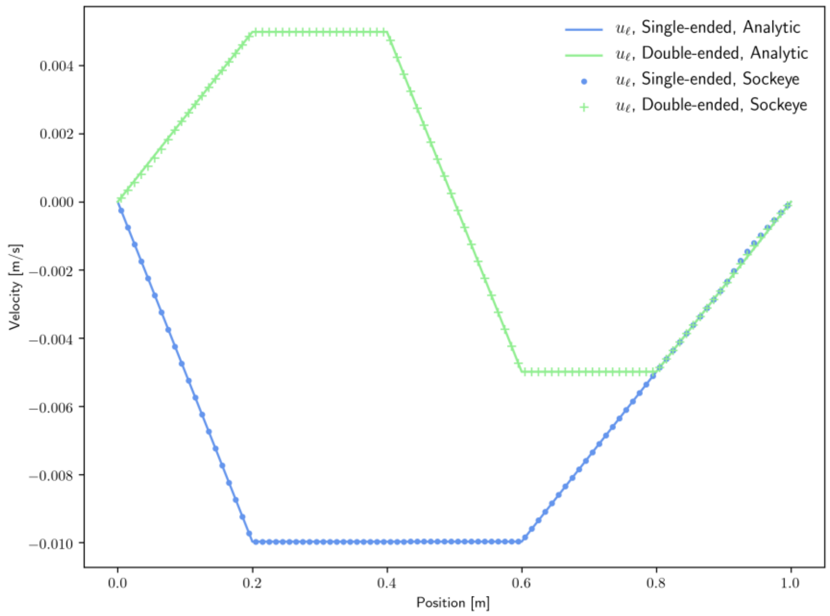
SAFE-30 Comparison



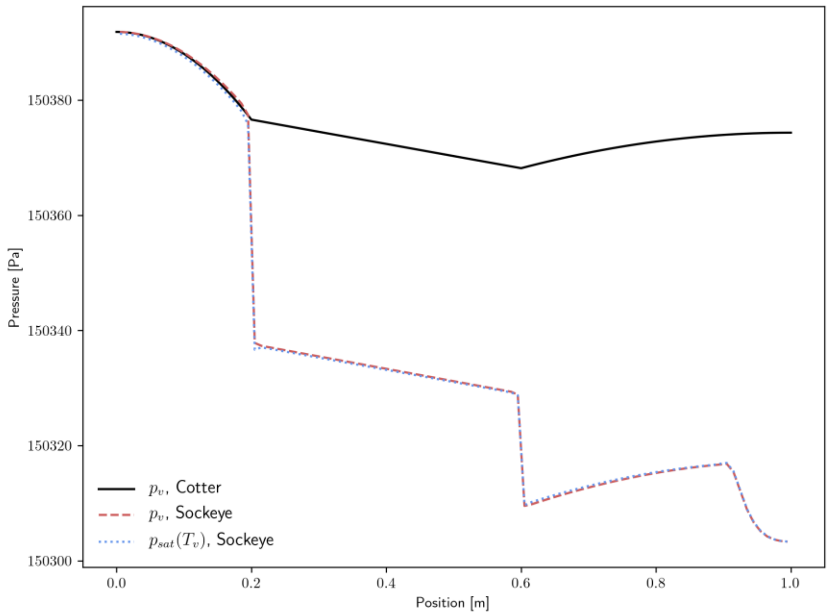


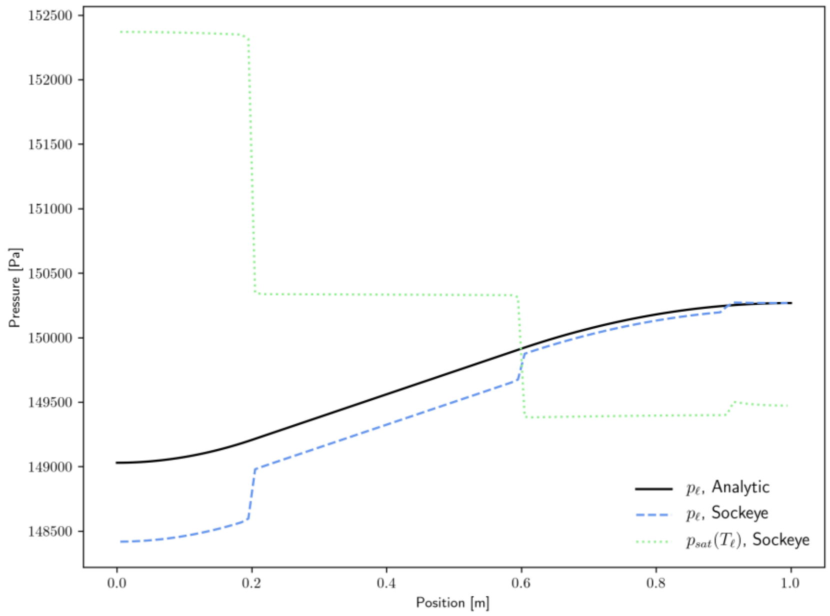
Analytic Velocity Solutions





Analytic Pressure Drop Solutions





Spatial Convergence