LHP: Loop Heat Pipes

ADVANCED MODELLING & SIMULATION – AMS –

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Loop Heat Pipes

Motivation and Background

— Background

- Interest in simulation of flow in LHP with a view to,
  - Analyze effect of geometry modification, filling quantity, etc.
  - Predict temperature, pressure, phase volume fraction, heat transport limits etc. to guide design

— Objectives

- Demonstrate capability of TransAT to simulate flow and heat/mass transfer in LHP
- Discuss current status and improvements if necessary

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Modelling

Evaporator

- Capillary Pressure Model
  - Capillary rise in grooved porous medium
  - Brings liquid into the porous wick
- Boiling model
  - Vapour is produced in the grooves

Condenser

- Condensation model
  - Wall condensation
  - Bulk condensation

Capillary Pressure Model Validation & Rise Velocity

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Evaporator: Capillary pressure model

- Capillary force depends on
  - pore size of wick,
  - surface tension,
  - contact angle (wettability of pores),
  - acts only within the wick object,
  - brings liquid into the porous wick.

$$\overline{\alpha} = (\alpha_2 - \alpha_1)/2$$

$$f_{cp,i} = \frac{4\sigma \cos(\theta)}{d_{cp}} \left(\frac{\partial \overline{\alpha}}{\partial x_i} \right)$$

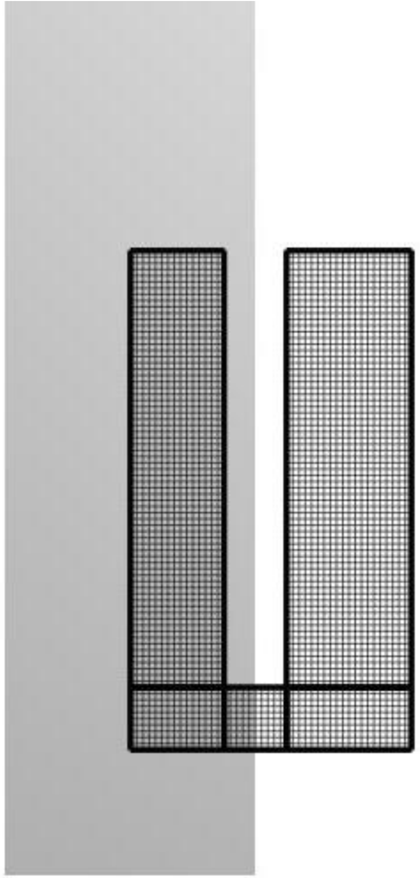
$$n_i = \nabla_i H$$

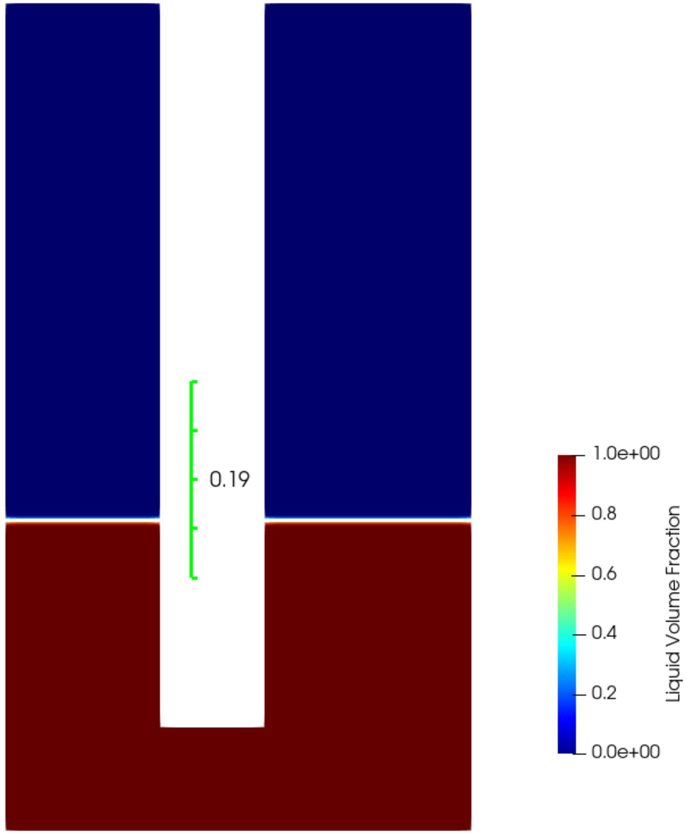
$$f^t_{cp,i} = f_{cp,i} - (f_{cp,j} \cdot n_j) n_i$$

Capillary Rise

Validation test case

- Capillary rise into the porous object
- Porosity and pore size specified
- The height to which the liquid column rises depends on capillary force and gravity



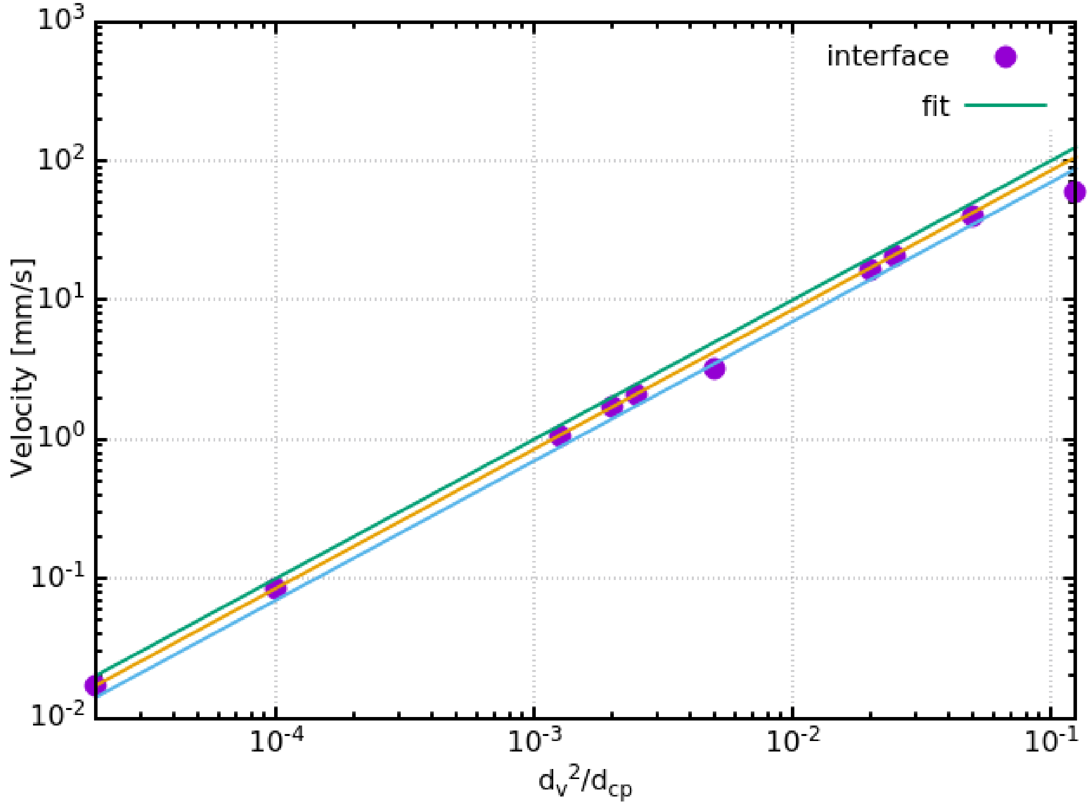


Capillary Rise: Fill velocity

$$v_{\text{fill}} = 0.85\left(\frac{d_v^2}{d_{cp}}\right)$$

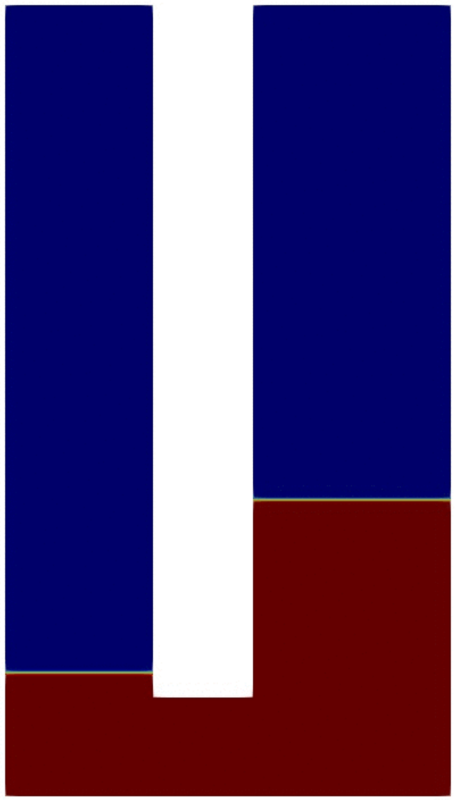
Several cases were run with different values for,

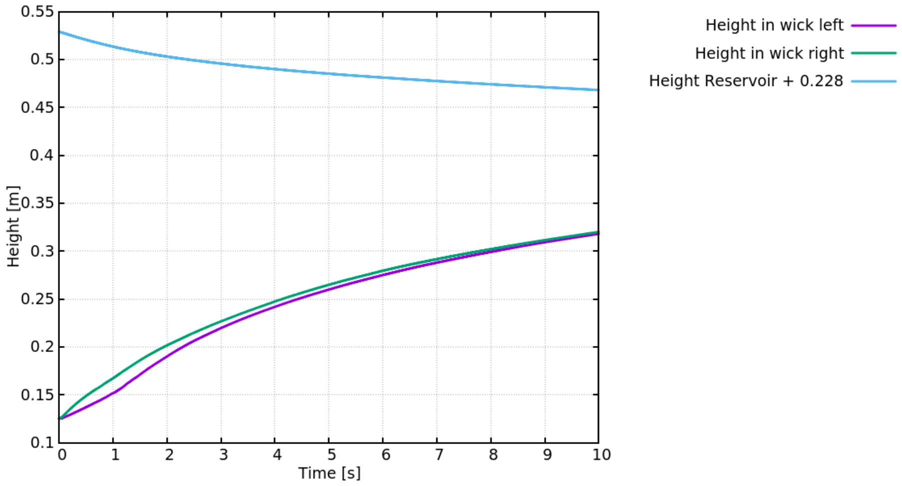
- Depends on viscous resistance and capillary force giving rise to two model parameters
  - Capillary pressure pore size (d_{cp})
  - Permeability pore size (d_v)



Capillary Rise: Grooved wick

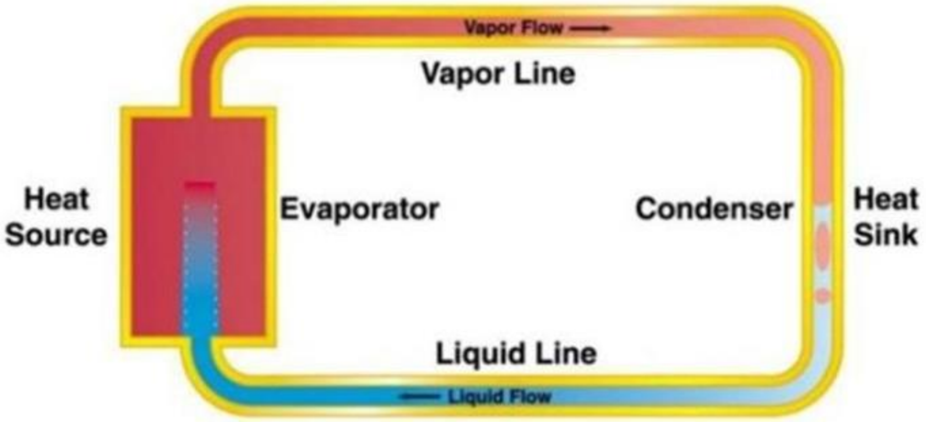
- Model works well for a simple grooved wick





Experiment

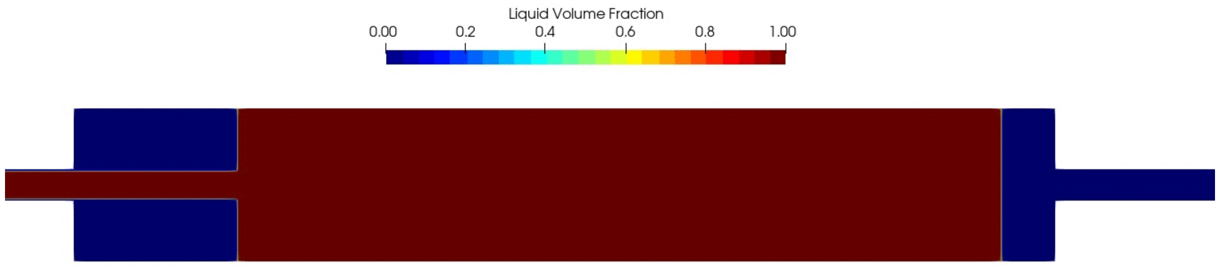
— EXP LHP
- Propylene as medium
- Copper tube with filling 15.061 g
- Gas pipe: 800 mm
- Liquid pipe: 605 mm
- Condenser coil: 538 mm
- Pipeline: o.d. 6 mm, thickness 1.5 mm

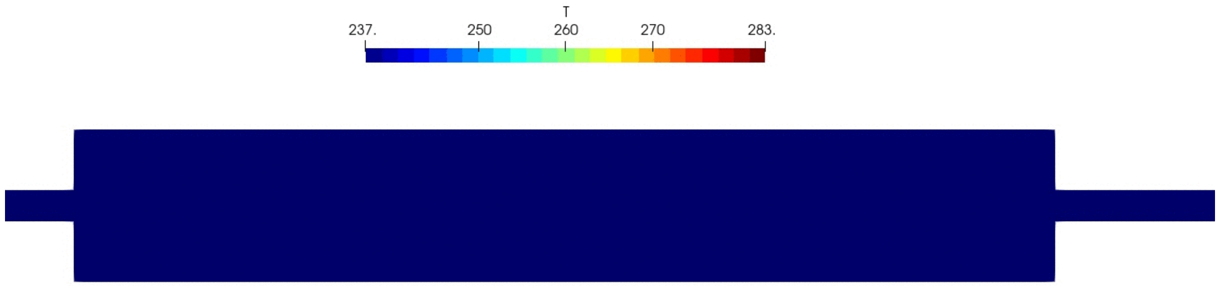


Evaporator: Propylene – 30W

Permeability pore size: 20 micron
Capillary pore size: 20 micron

- In the animation, which lasts for a total of 30+ seconds, the wick is saturated with liquid
- Grooves are filled with vapour and a steady-state conditions is reached

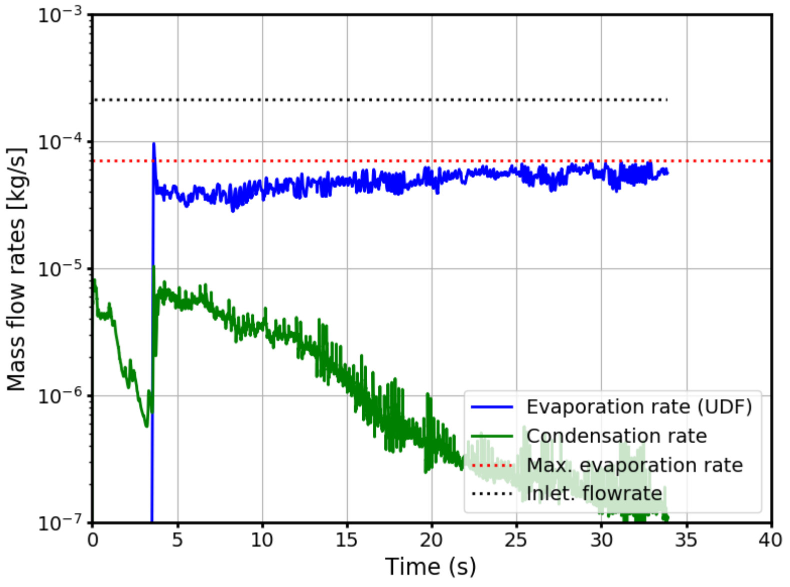


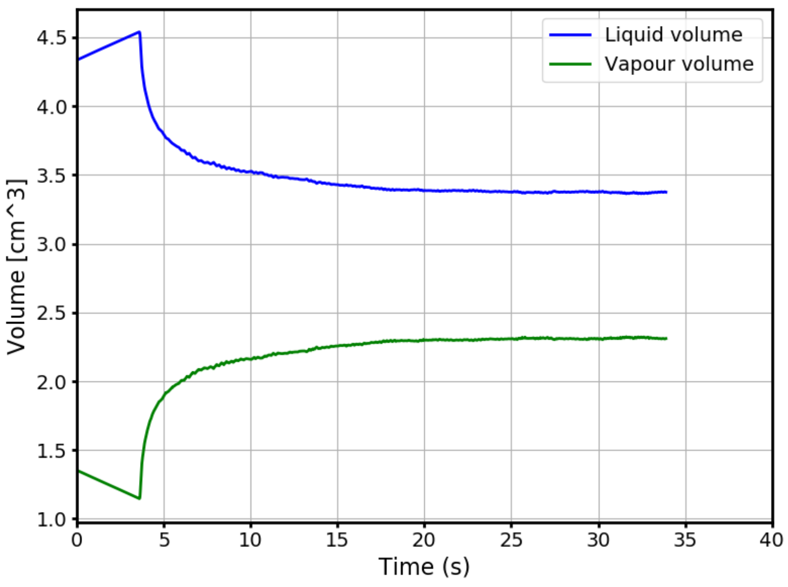


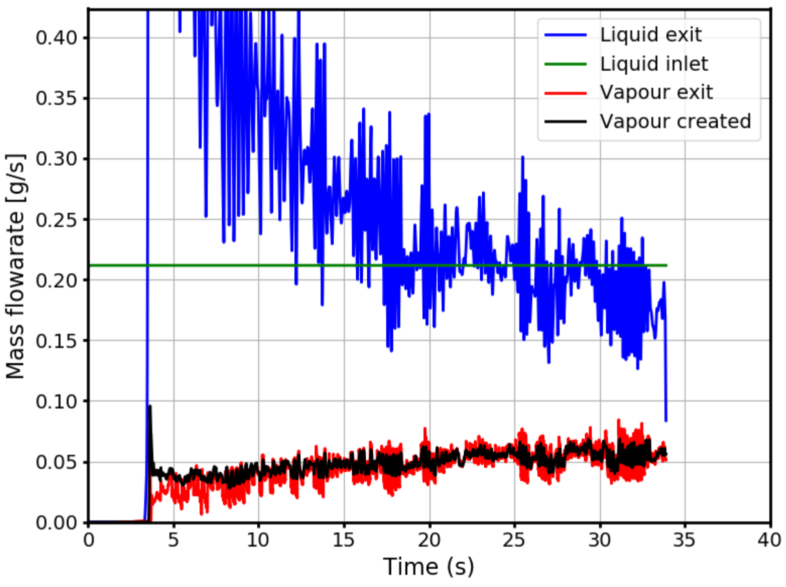
Evaporator: Propylene – 30W

- Mass transfer rate is as expected
- Volumes of both phases reach steady state

Permeability pore size: 20 micron
Capillary pore size: 20 micron







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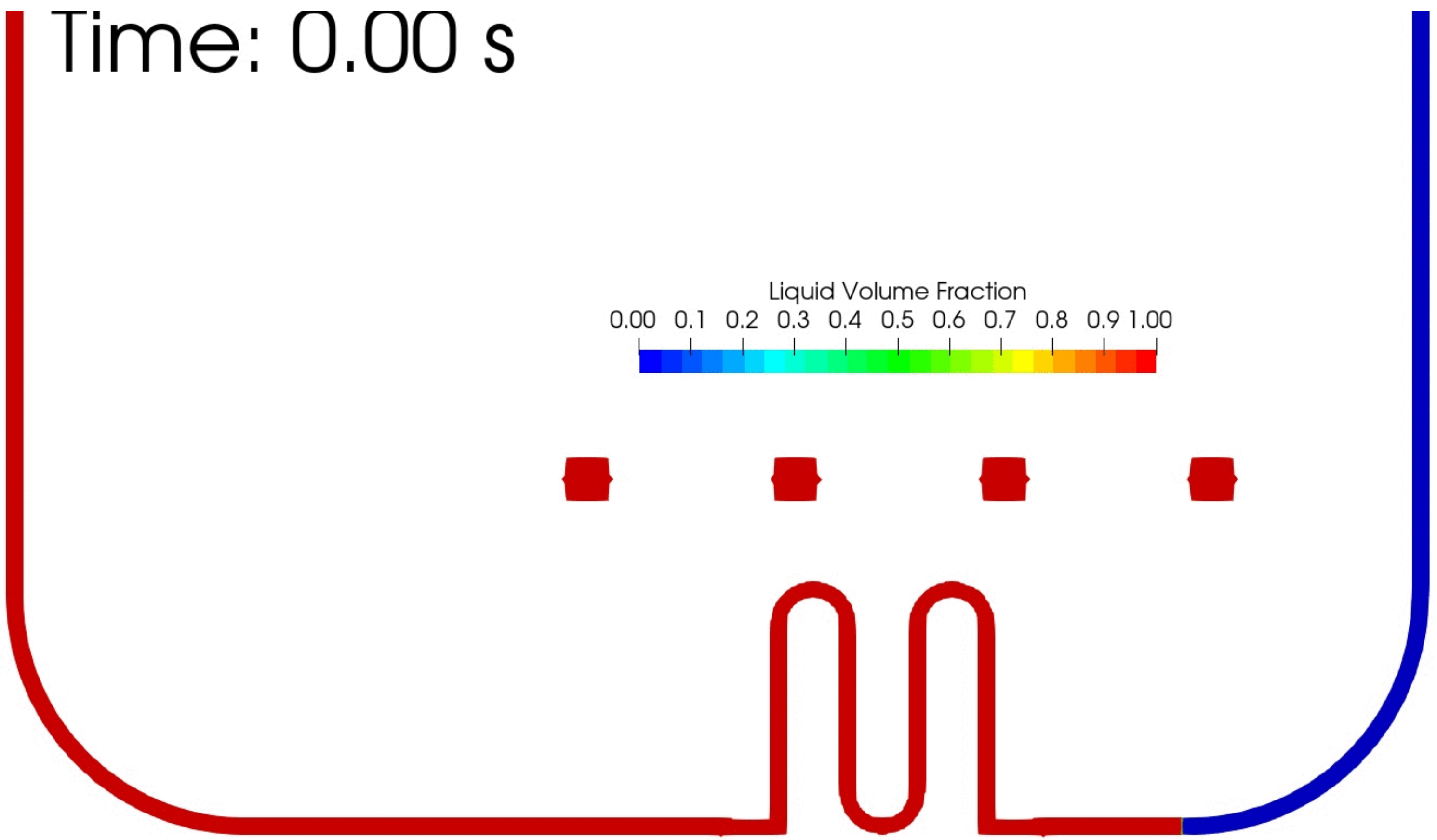
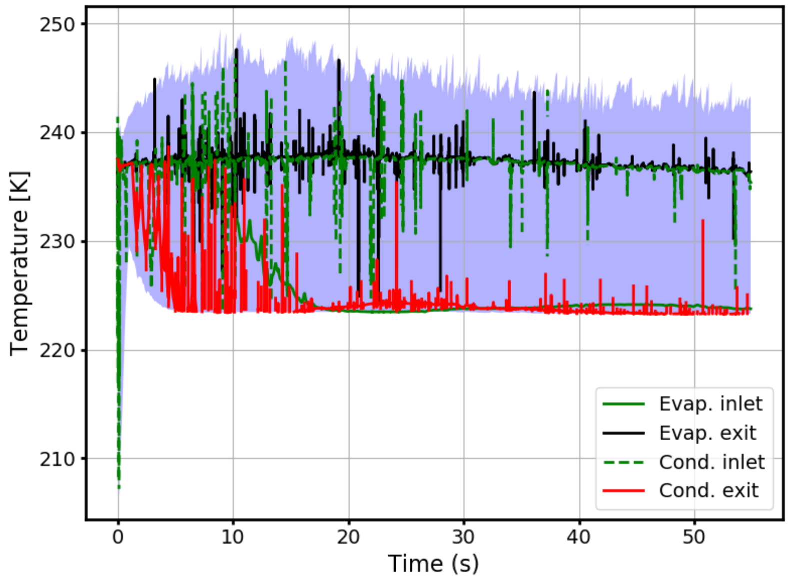
Condenser: Propylene 30W case

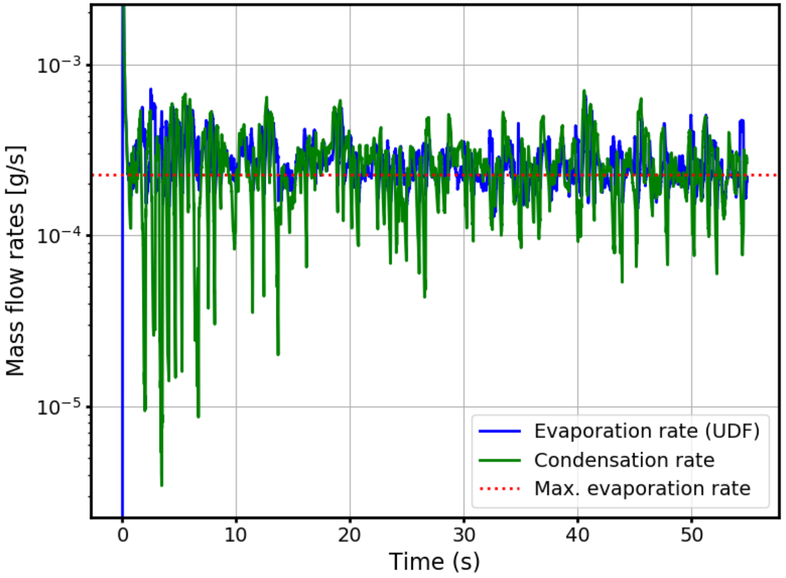
- Working fluid: Propylene
- 30W case
- All the vapour entering is condensed

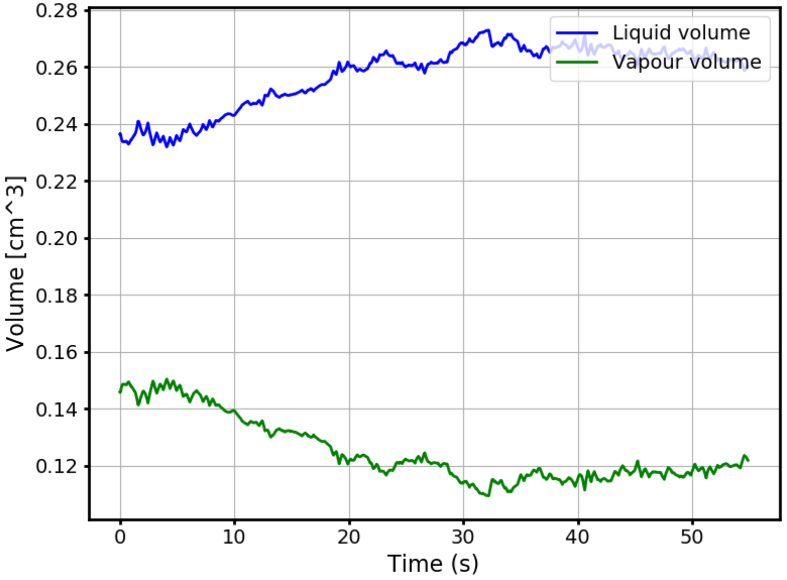


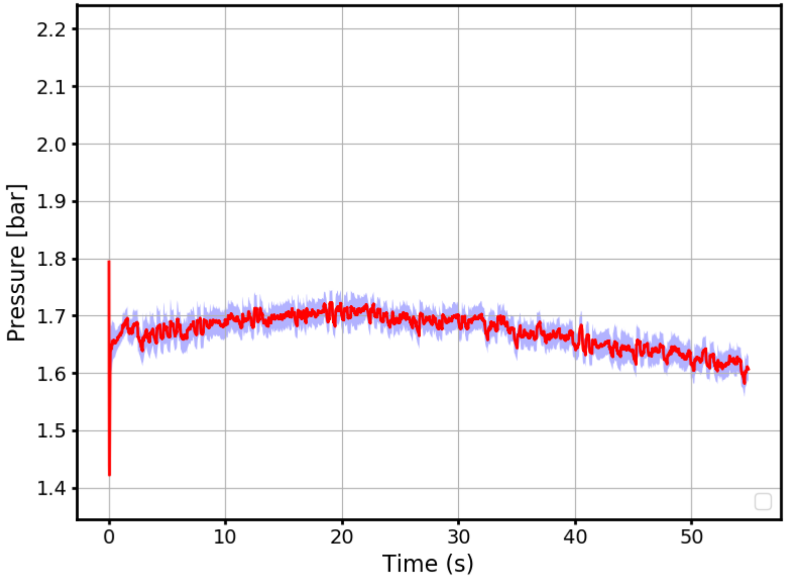
Full LHP Simulation Propylene 30 W

- Heat flux 13540 W/m^2
- Reaches steady operation in around 50 seconds.



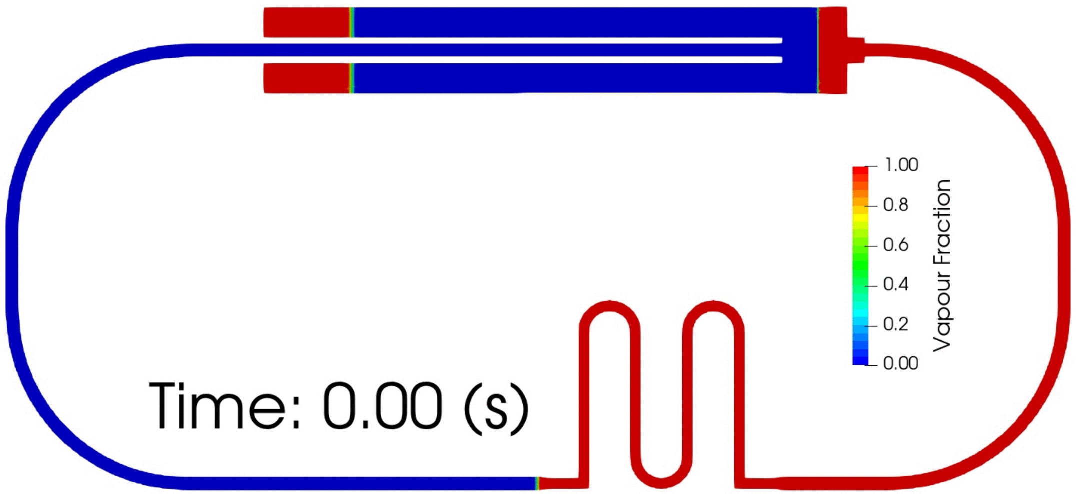


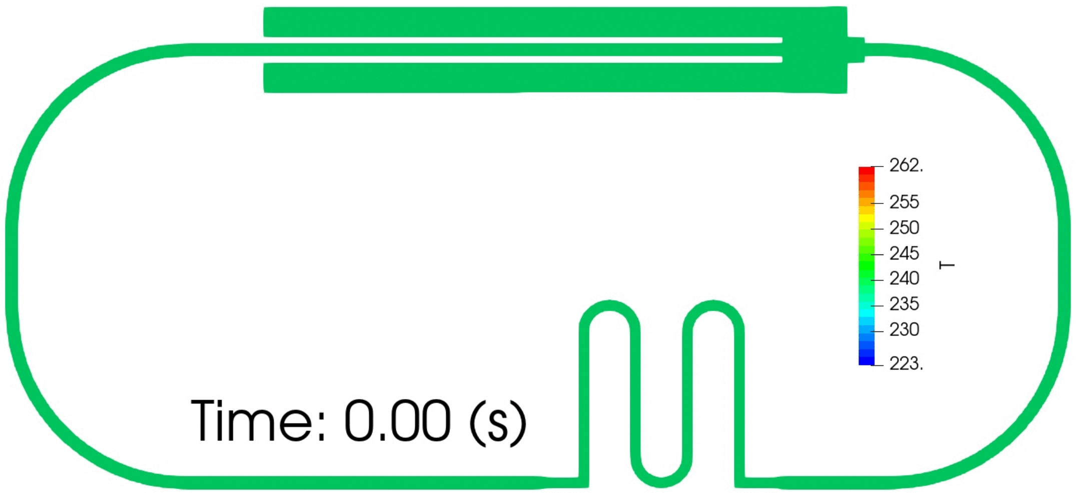




Full LHP Simulation Propylene 30 W

— Animation of gas volume fraction and temperature





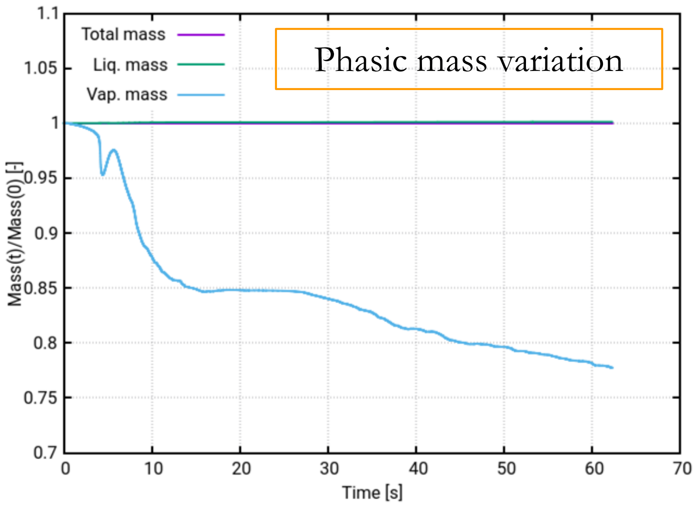
LHP simulation (water as a medium)

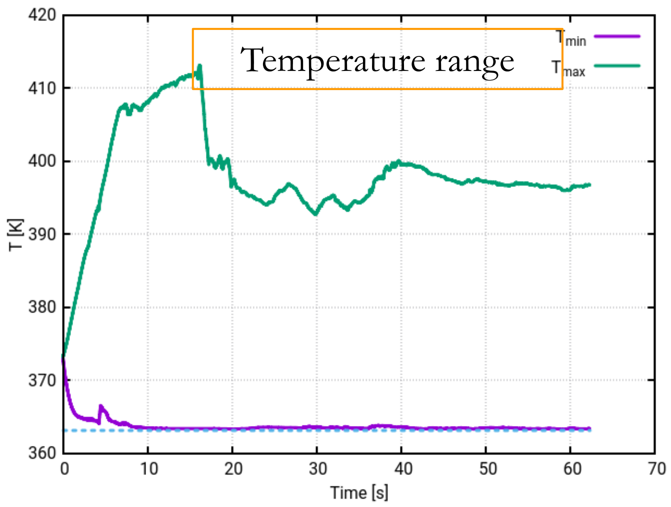
— Model
- Compressible 2-phase flow with phase change
- Evaporator not modelled → Left wall direct heat flux imposed
- Condenser coil not modelled → Right wall is set with subcooling
- Dispersed phase-change model with specified bubble/drop radius
- Peng-Robinson EoS for 2 phases
- Antoine Eq. for saturation curve

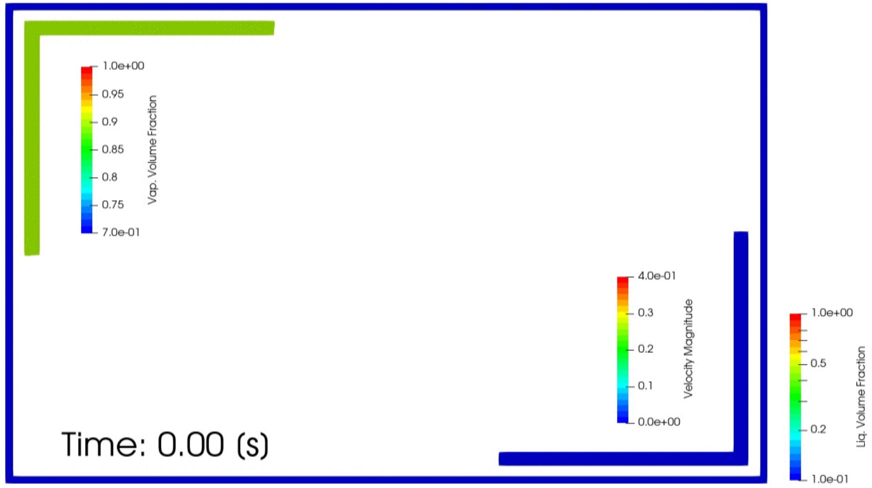
— Conditions
- 2D domain with mass filling of ~3 g
- Initialized as 10% liquid with initial pressure of 1 atm and temperature of 100°C
- Length: 610 mm
- Height: 410 mm
- Pipecross-section: 6mm x 2.4mm
- Left heat input: 1 W
- 10°C subcooling at Condenser wall

LHP simulation

- Temperature range has equilibrated
- Pressure and average quality are still evolving
- Clockwise flow has been established by introducing momentum sources to mimic the capillary suction of the wick in the evaporator section.
- Vapour condenses on the right pipe segment and flows towards the evaporator segment.







LHP simulation (Ethane as a medium)

— Model

- Compressible 2-phase flow with phase change
- Evaporator not modelled → Left wall direct heat flux imposed
- Condenser coil not modelled → Right wall is set with subcooling
- Dispersed phase-change model with specified bubble/drop radius
- Peng-Robinson EoS for 2 phases
- Antoine Eq. for saturation curve.

— Conditions

- Square channel (2.8 mm) with mass filling of ~ 8 g
  - Initialized as 80% liquid with initial pressure of 0.43 bar and temperature of 170 K
- Length: 600 mm
- Height: 400 mm
- 10°C subcooling at Condenser wall
- Left heat input: 2 W
- Heat flux can be increased to 20 W in steps

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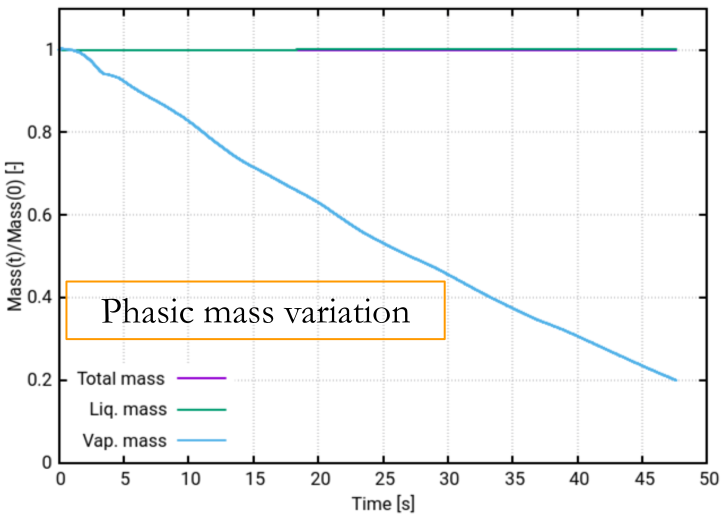
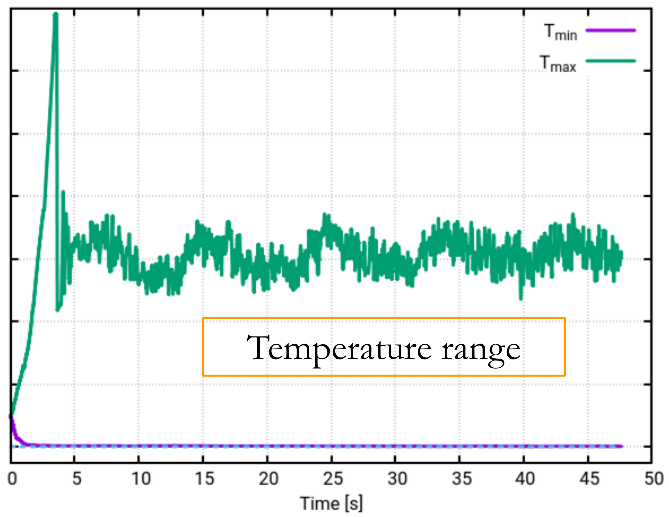
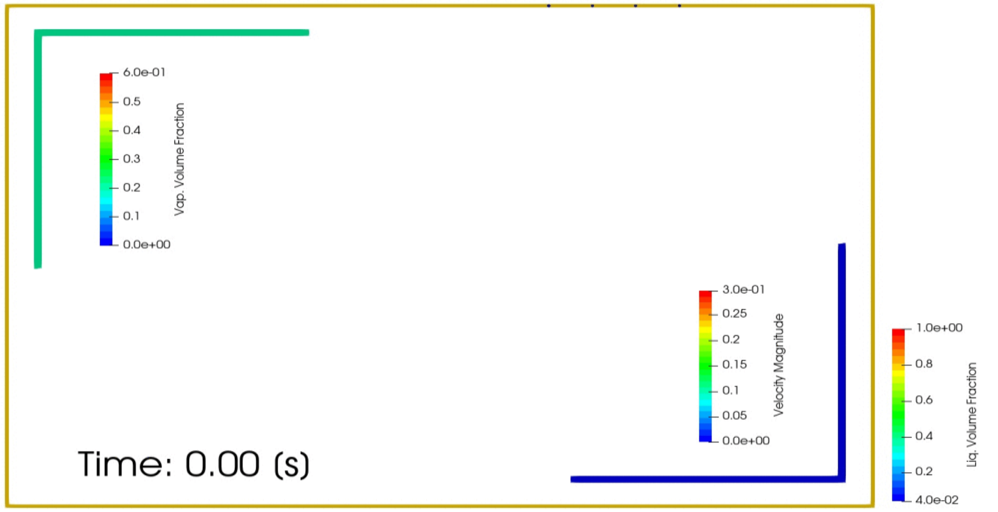
LHP simulation

- Temperature range has equilibrated
- Pressure and average quality are still evolving
- In the demonstration cases, evaporation and condensation is achieved using wall boundary conditions.
- Modeling of the Evaporator and condenser is required and can be achieved using UDFs.







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