Impact of Surface and Physical Property on Rayleigh Taylor Instability in Sealed Vessel

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Background

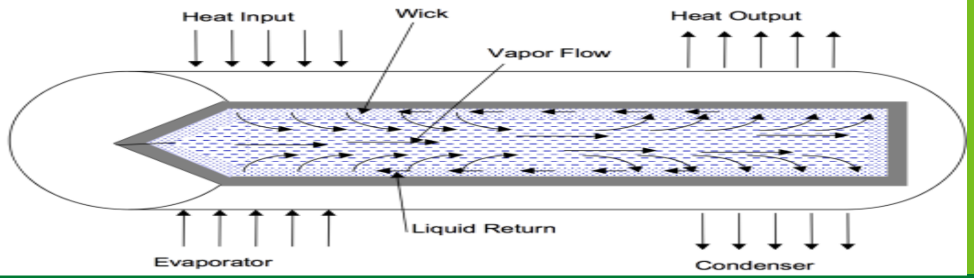
Principles

- Heat pipes are heat transfer devices
- Utilize thermal conduction and phase transition of a working fluid
- Two-phase (boiling and condensation) allow large heat transfer with minimal △T between heat source and sink

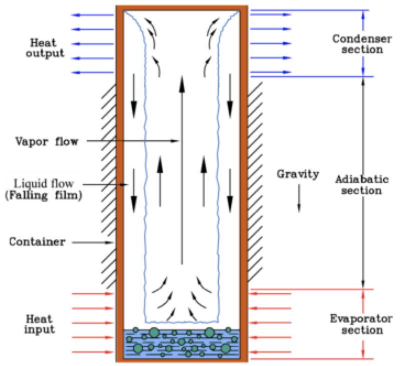
Benefits

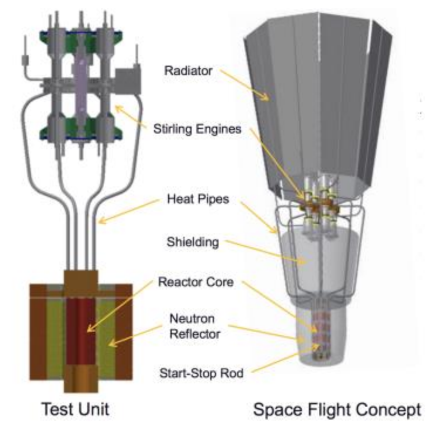
- Excellent heat transfer rates
- Completely passive, no power sources, no moving parts (other than fluid)
- Completely sealed system, no exchange of fluid or interfacing systems

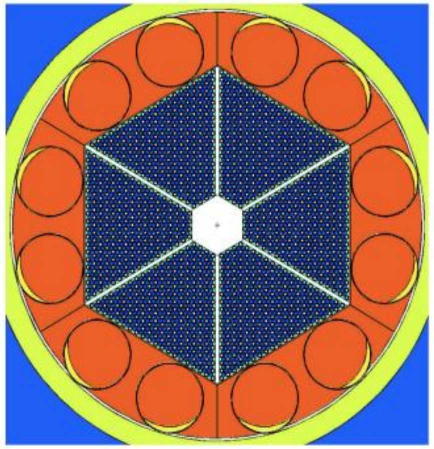
Capillary
(wicking)



Gravitational
(thermosyphon or Perkins tube)







Heat Transfer Rates

- Very high heat transfer rates are possible due to energy of phase transitions
  - Heat capacity of water:
    - ~4.22 kJ/kgK (100ºC)
  - Enthalpy of vaporization of water:
    - ~2250 kJ/kg (100ºC)

- Very high thermal conductivity
  - Thermal conductivity of solids
    - Aluminum (~200 W/mK)
    - Copper (~400 W/mK)
    - Diamond (~1,000 W/mK)
  - Effective thermal conductivity of heat pipes
    - 5,000 – 200,000 W/mK

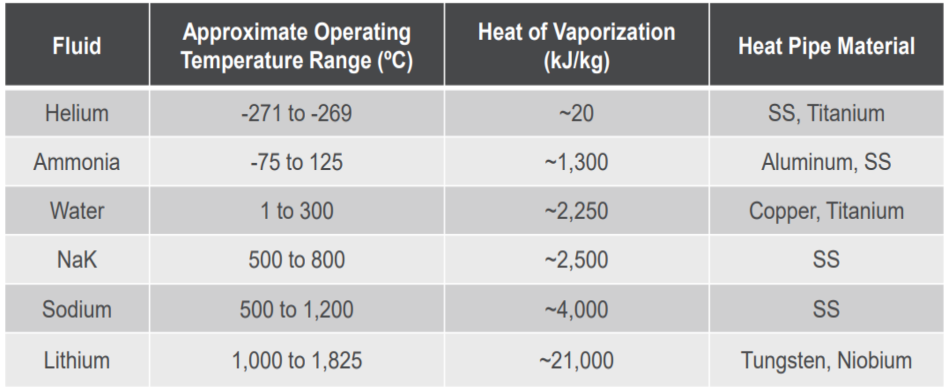
- Very high heat transfer rates
  - Heat transfer rates of 23,000 W/cm^2 have been achieved with lithium heat pipes
  - For comparison, the heat emitted from the sun is 6,000 W/cm^2

Courtesy: Argonne National Lab

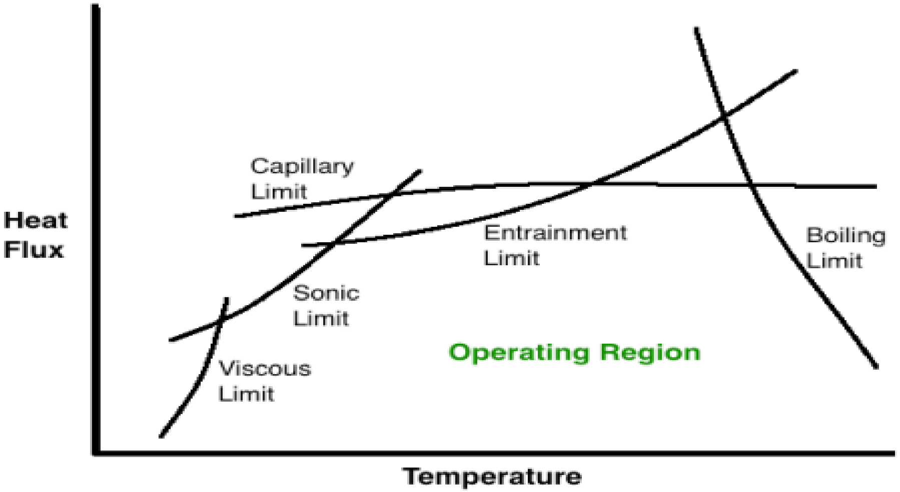
Background

- Limits
  - **Viscous**: Near triple point or melting point of fluid, high viscosity prevents circulation back to the evaporator
  - **Sonic**: At high power but low temperature, the vapor flow reaches sonic velocity, choking the flow
  - **Entrainment**: High vapor velocity strips the liquid from the walls (larger concern for thermosyphons with no wick)
  - **Capillary**: Capillary force is insufficient to overcome pressure drop
  - **Boiling**: Rapid boiling and surface bubbles in the evaporator prevent condensate from entering and re-wetting

In this photo taken in the early 1960s, physicist George Grover tests a heat pipe.

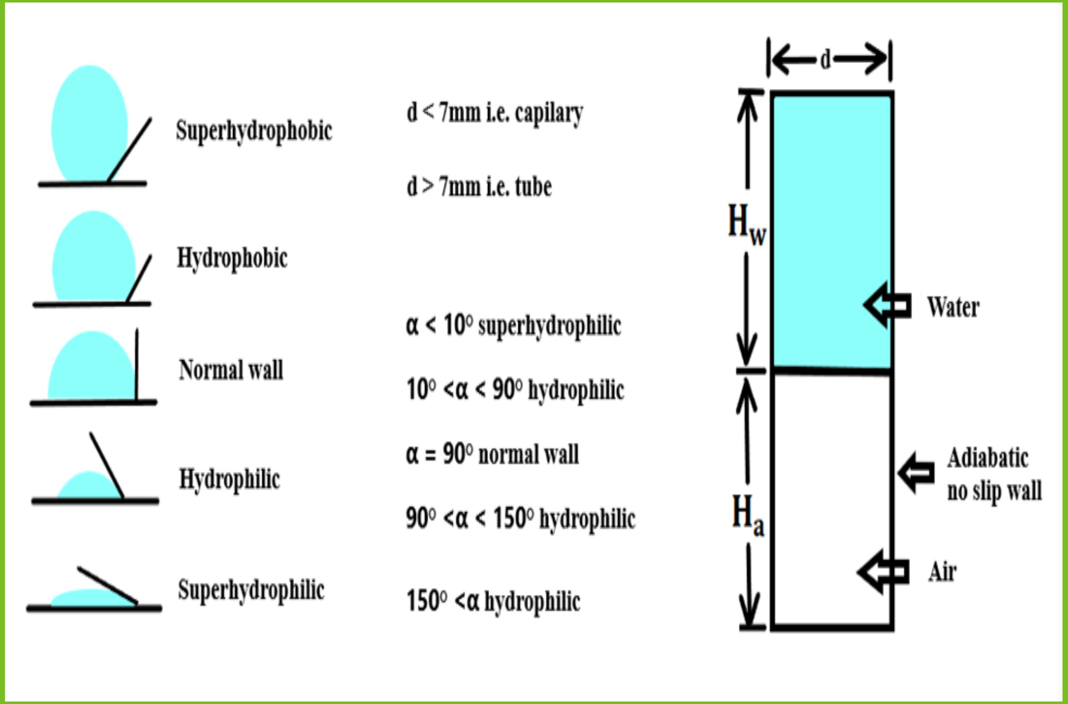


Fluid	Approximate Operating Temperature Range (°C)	Heat of Vaporization (kJ/kg)	Heat Pipe Material
Helium	-271 to -269	~20	SS, Titanium
Ammonia	-75 to 125	~1,300	Aluminum, SS
Water	1 to 300	~2,250	Copper, Titanium
NaK	500 to 800	~2,500	SS
Sodium	500 to 1,200	~4,000	SS
Lithium	1,000 to 1,825	~21,000	Tungsten, Niobium



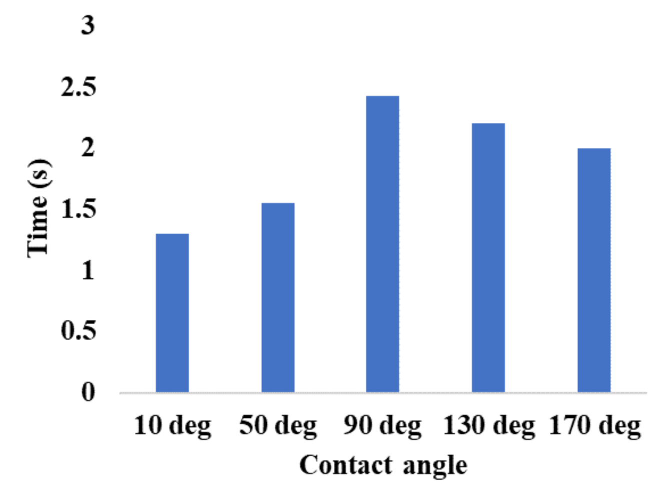
Objective

- To check the effect of coatings on Rayleigh Taylor instability for heat pipes
- To check the drop-down performance of condensed liquids from monoliths to large diameter channels
- To check how gravitational heat pipes perform in different planets for space application
- To check different working fluids performance from light (water) to high viscous fluid (silicone oil)



Mesh size	Dropping time
2.5 mm, 172102 cells	2.61 s
1.5 mm, 481707 cells	2.4 s
1 mm, 1028033 cells	2.42 s

Role of Contact Angle



- Drop down time is lower for super hydrophilic coatings
- Different flow nature for super hydrophilic coatings than normal and super hydrophobic walls
- Normal wall takes the longest time

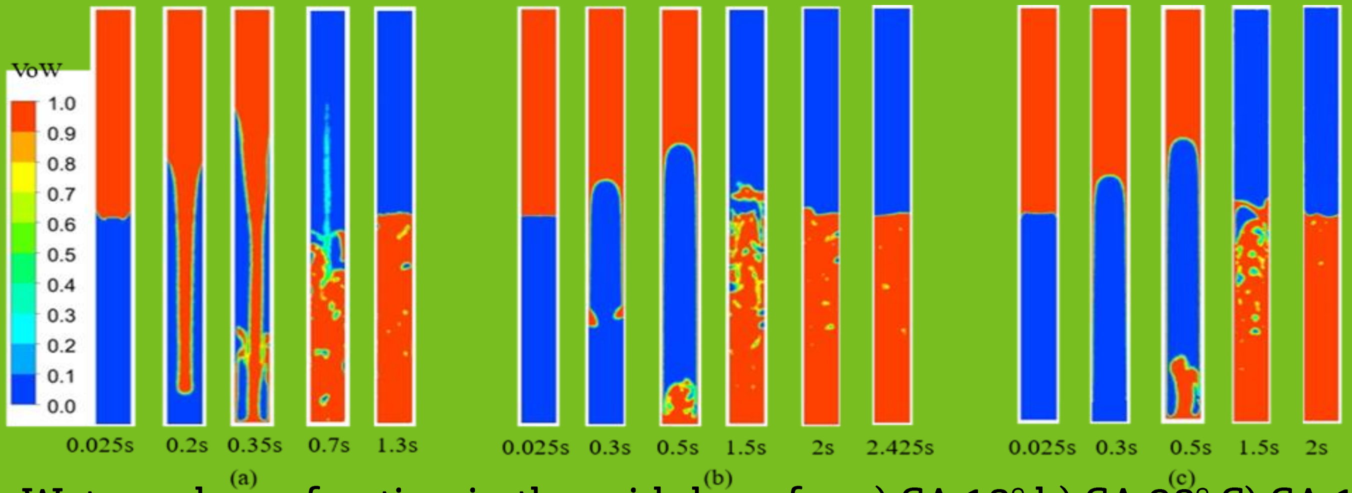


Figure: Water volume fraction in the midplane for a) CA 10° b) CA 90° C) CA 170°

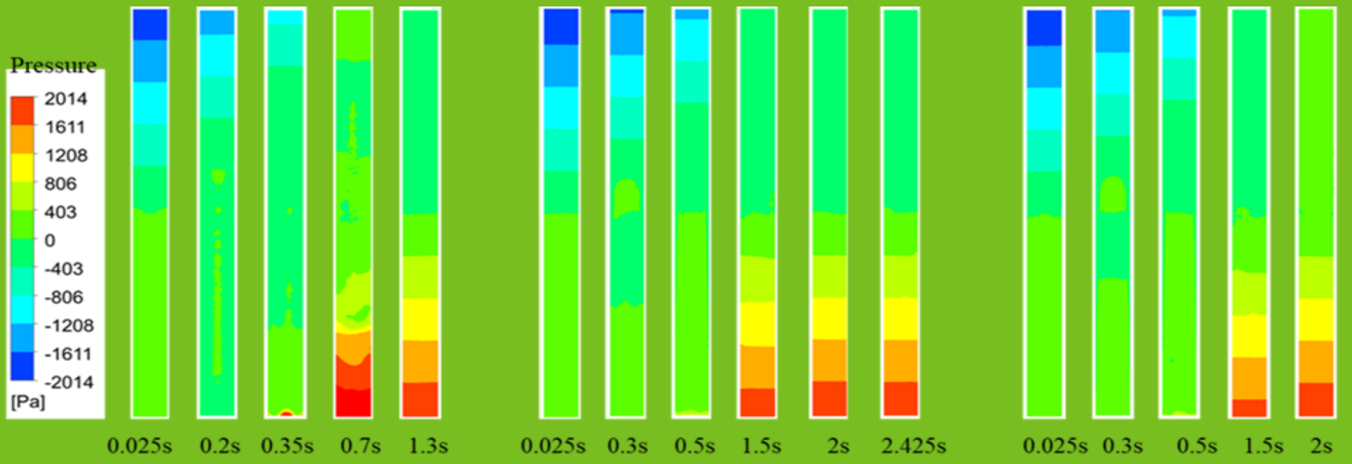
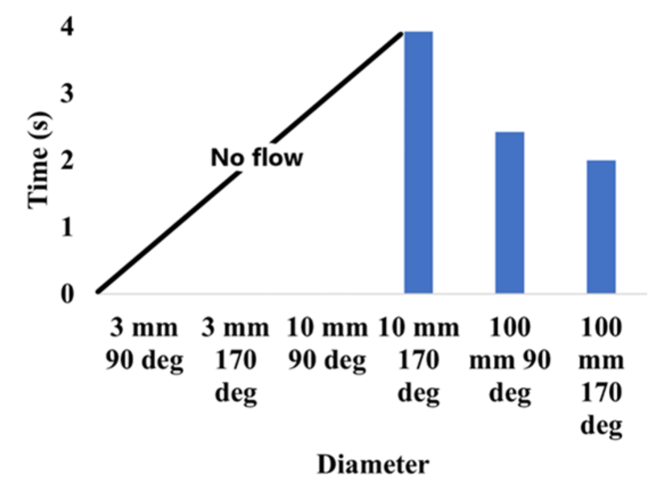


Figure: Pressure contour in the midplane for a) CA 10° b) CA 90° C) CA 170°

Role of Diameter



- No flow in capillaries
- Strong affinity between wall and water in super hydrophilic coatings
- Curved interface formation in capillary for super hydrophobic coatings. However, viscosity is still dominant.
- Flow happens when gravity force is dominant over viscosity and interface breaks up to initiate the flow

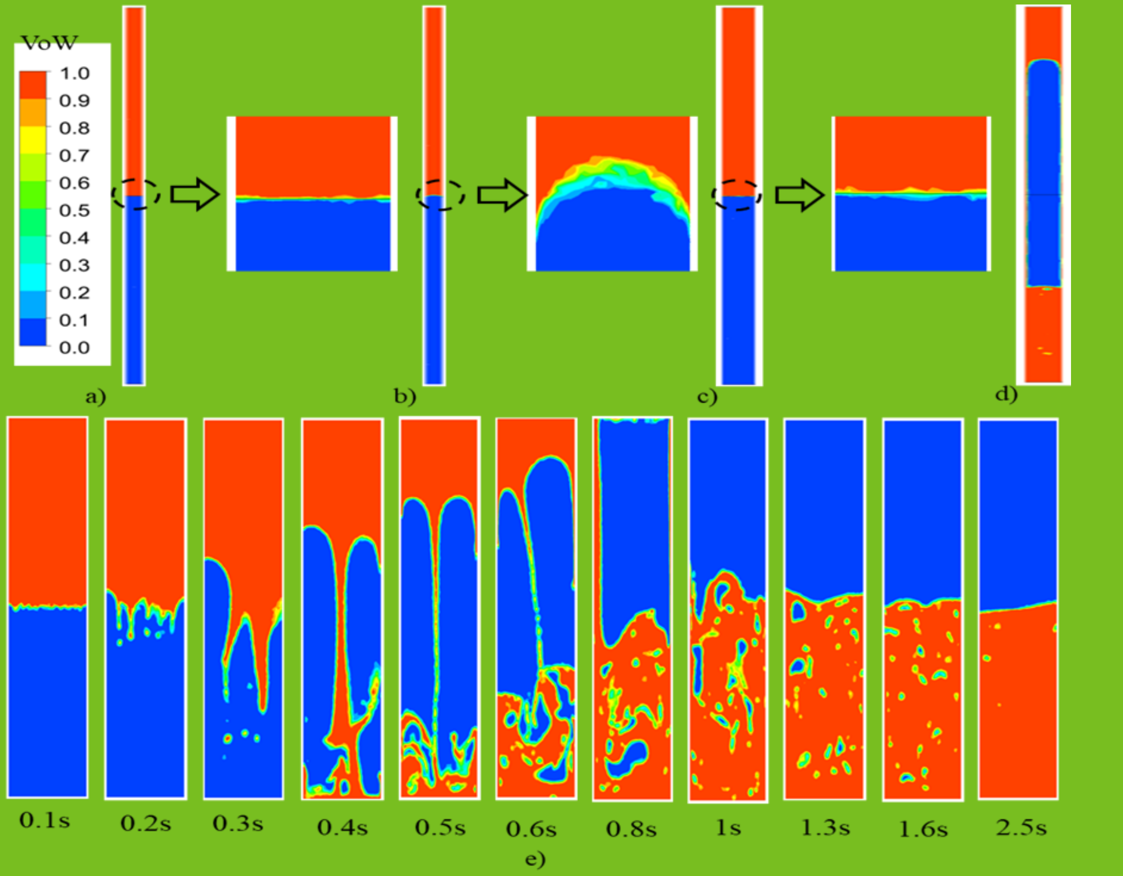


Figure: Water volume fraction for different diameter channels a) d= 3mm, α= 90° b) d= 3mm, α= 170° c) d= 10mm, α= 90° d) d=10mm, α= 170° e) d=100mm, α= 90°

Role of Gravity

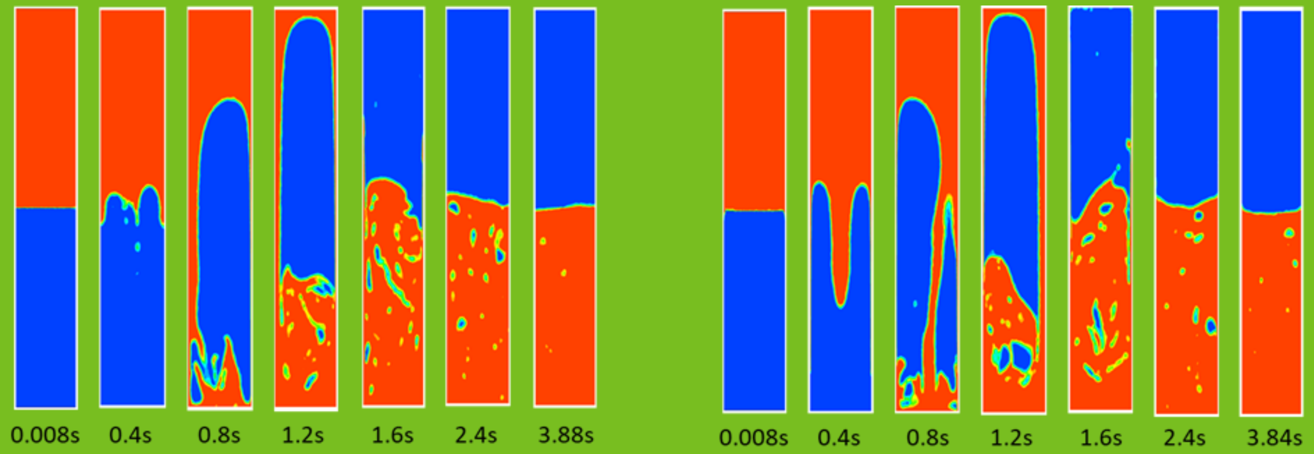


Figure: Water volume fraction for a) g= 9.81 ms^2 b) 3.84 m/s^2

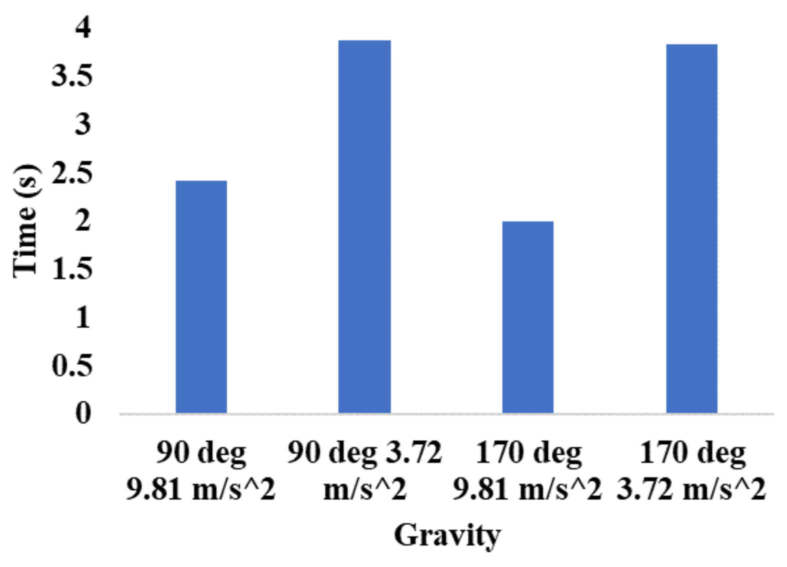


Figure: Gravity vs time

- ❖ Coating showed impact on drop down time
- ❖ Gravity doesn’t show any impact on dropdown time

Role of Viscosity

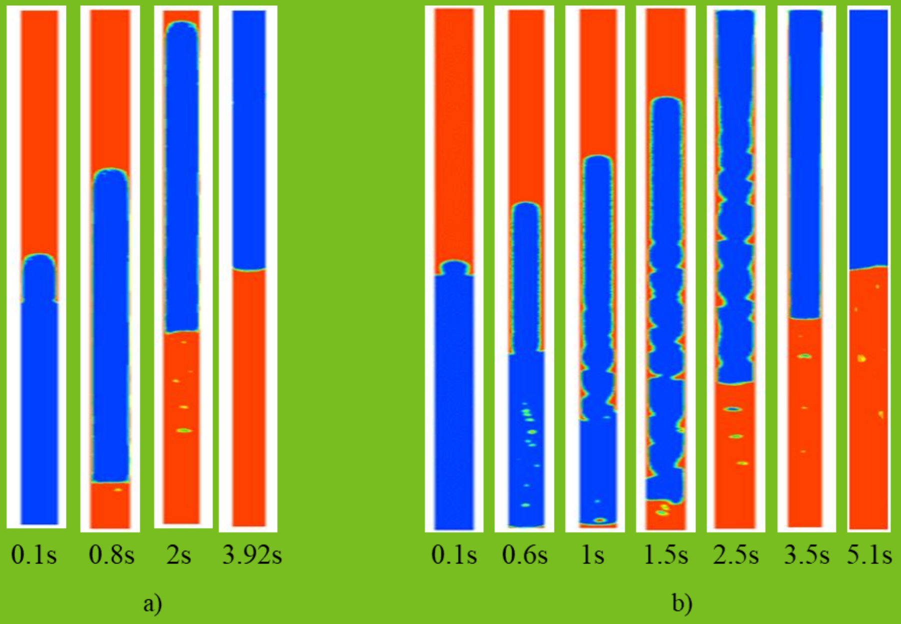


Figure: Water volume fraction for a) water flow b) silicone oil flow

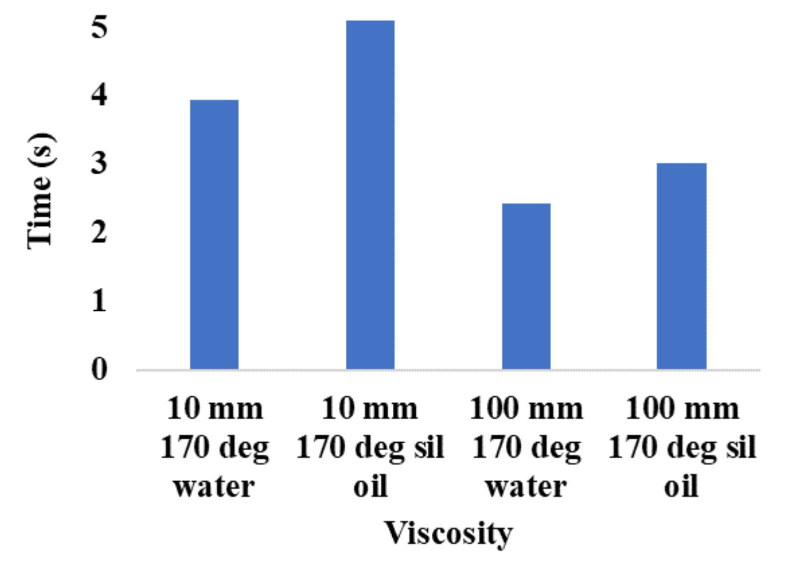


Figure: Viscosity vs time

- ❖ Water dropdown time is lower for than silicone oil
- ❖ Instability formation in silicone oil flow
- ❖ Instability might have negative effect in heat pipe performance such as choking

Conclusions

- Five different wall coatings (super hydrophilic, hydrophilic, normal, hydrophobic and superhydrophobic) are computationally tested for capillaries to large diameter channels for assessment of Rayleigh Taylor instability
- Super hydrophilic coating showed the lowest dropdown time
- Normal and superhydrophobic walls showed similar flow nature
- Super hydrophilic materials showed good performance for large channels but blocks the flow in capillaries due to high affinity for water
- Hydrophobic and superhydrophobic materials showed consistent performance for different diameters
- High viscosity fluids has the chance to block the flow
- Flow in low gravity faces higher interface breakup but no change in dropdown time

Thank you

Any questions?