Evaporation of liquid nitrogen in a microchannel

Progress on the measurement of boiling delay for liquid nitrogen in a capillary channel

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Dry-shipper

A dry-shipper is a solution to transport for frozen biomedical samples at a temperature below -150 °C. This temperature is maintained with liquid nitrogen that is absorbed in a porous lining inside the container. The performance of a dry-shipper, for example the preparation time or the cleanability, is dependent on the interplay between the liquid and the porous material properties. Due to the large temperature difference between the room temperature porous material and liquid nitrogen, there is heavy evaporation during absorption, which is not very well understood. **The model problem of liquid nitrogen absorbing into a transparent, temperature controlled, and well defined microchannel is studied to investigate the physics on the pore scale.**

A microchannel as a model problem for porous media

As a model problem the effect of evaporation on the imbibition of liquids into a micro-channel is experimentally investigated to give insight in the micro-scale physics.

Porous media

$$\overbrace{\frac{2\sigma\cos(\theta)}{R_{\text{pore}}}}^{\text{Laplace}} = \overbrace{\frac{\mu\phi L}{K}U}^{\text{Viscosity (Darcy's law)}} + \text{evaporation term}$$

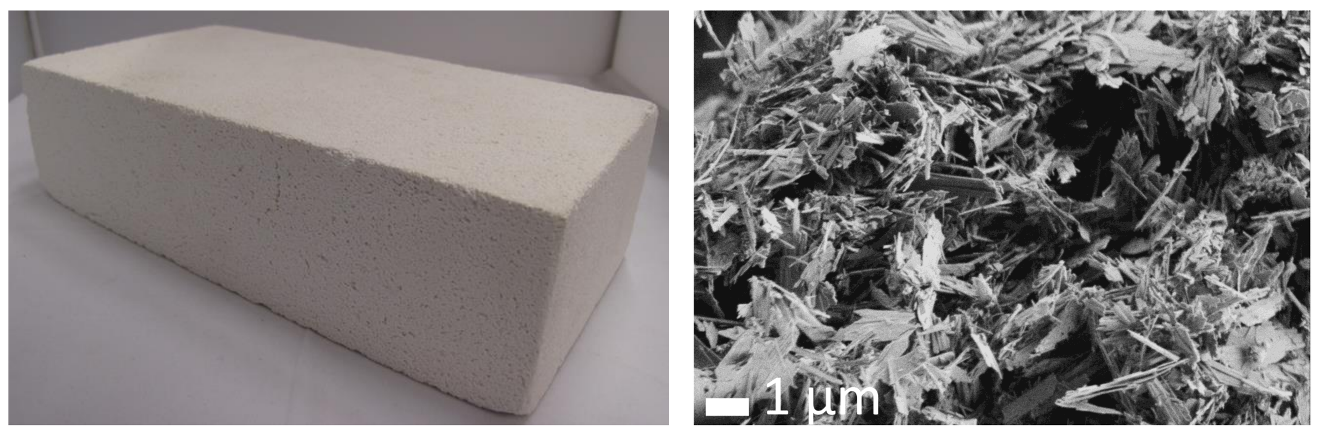
Microchannel

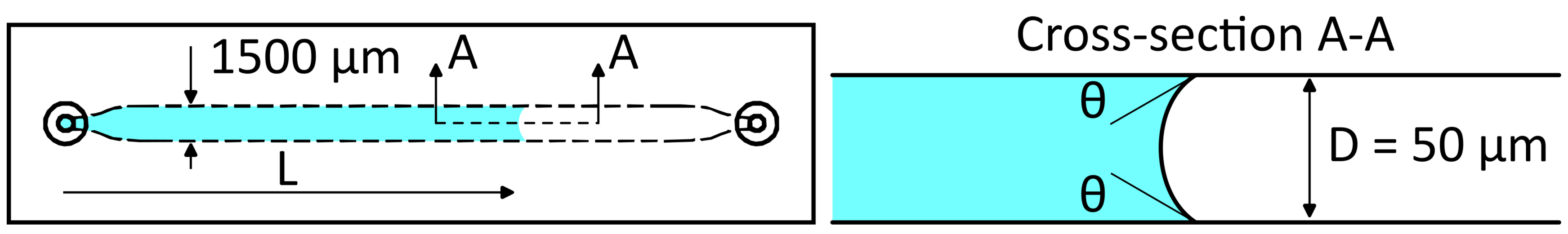
Theorical Lucas-Washburn type model for evaporation[2]

$$\overbrace{\frac{2\sigma\cos(\theta)}{D}}^{\text{Laplace}} = \overbrace{\frac{12\mu L}{D^2}U}^{\text{Liquid viscosity}} + \overbrace{\frac{j^2}{\rho_v}}^{\text{Vapor recoil}} + \overbrace{\frac{12\mu L}{D^2}U}^{\text{Vapor viscosity}}$$

Analogous physics

A photo and a SEM image of the porous calciumsilicate material that also lines the inside of the dry-shipper.

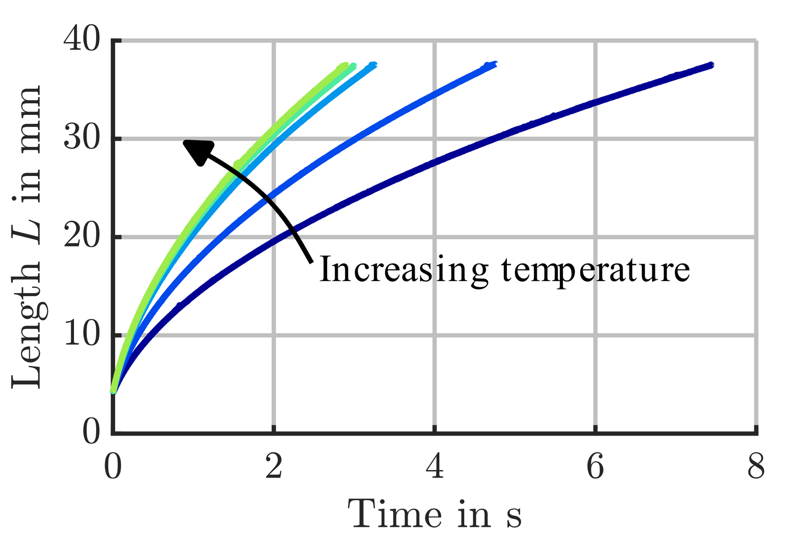




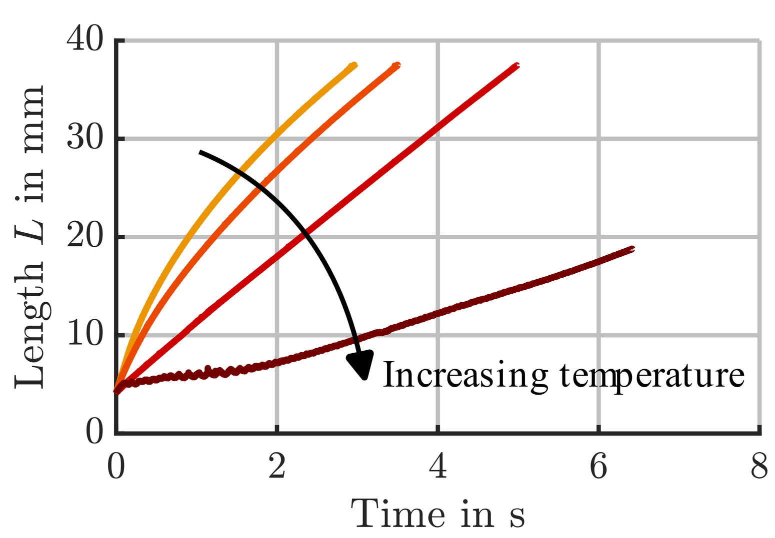
Boiling delay at room temperature

The length of the liquid column L measured as a function of time.

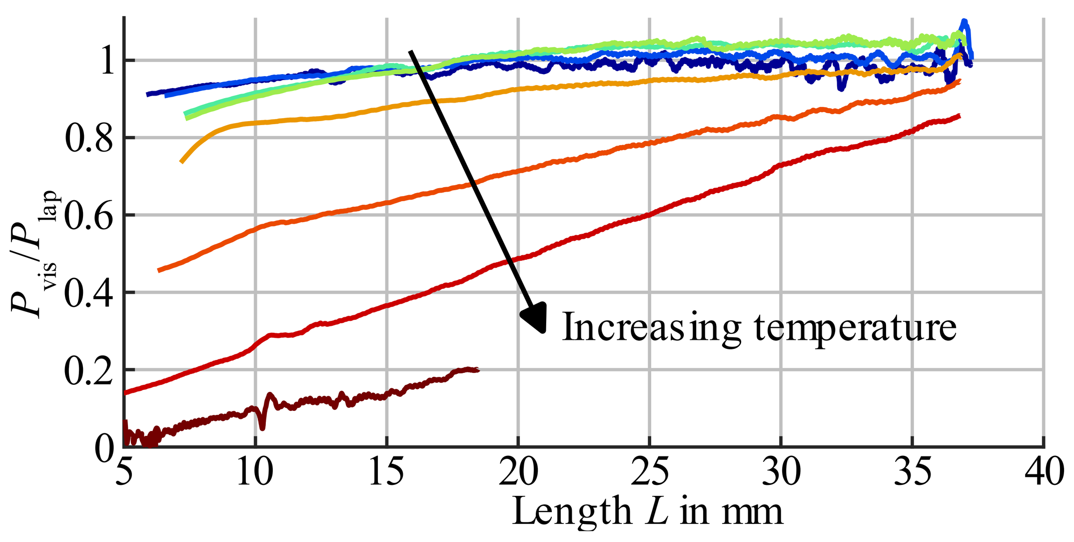
Below saturation temperature
Increased velocity with temperature due to viscosity and surface tension



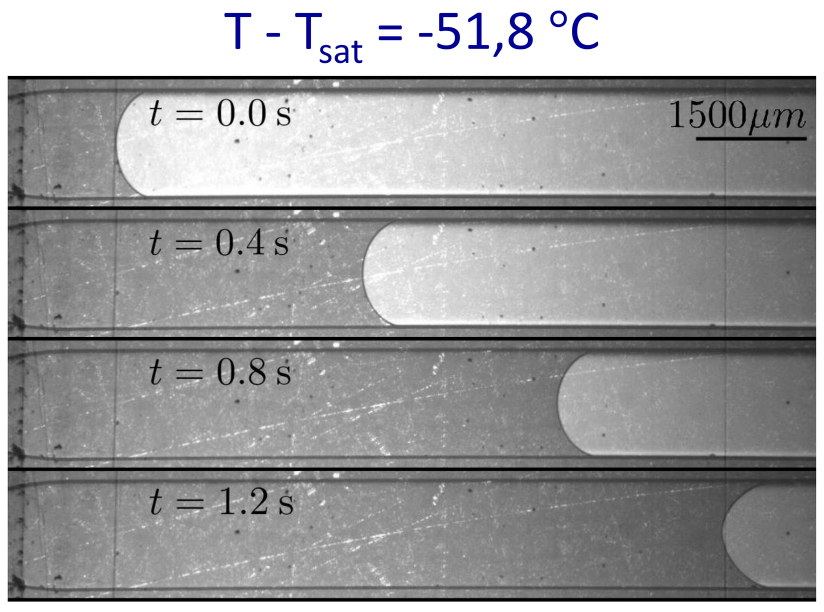
Above saturation temperature
Reduced velocity with temperature due to evaporation



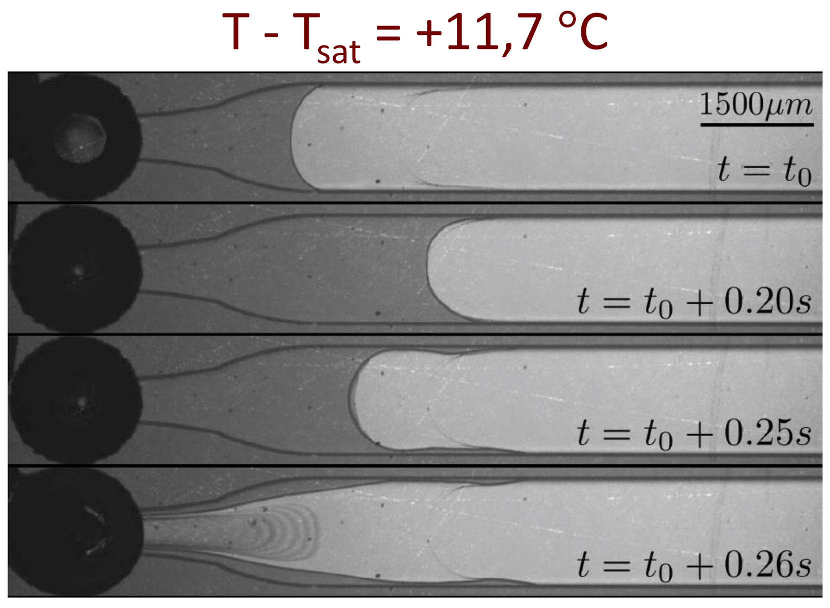
Lucas-Washburn without evaporation: Viscous term/Laplace term = 1



$T - T_{sat}$ = -51,8 °C



$T - T_{sat}$ = +11,7 °C



At elevated superheat, the liquid oscillates into and out off the channel.

Adapting to cryogenic liquids

The material, thermodynamic and transport properties at cryogenic temperature vary strongly compared to room temperature, therefore a subsequent study with cryogenics liquids will be performed.

Specific heat capacity (J kg^{-1} K^{-1})	
Glass 355.6 K	843
Glass 77.4 K	207

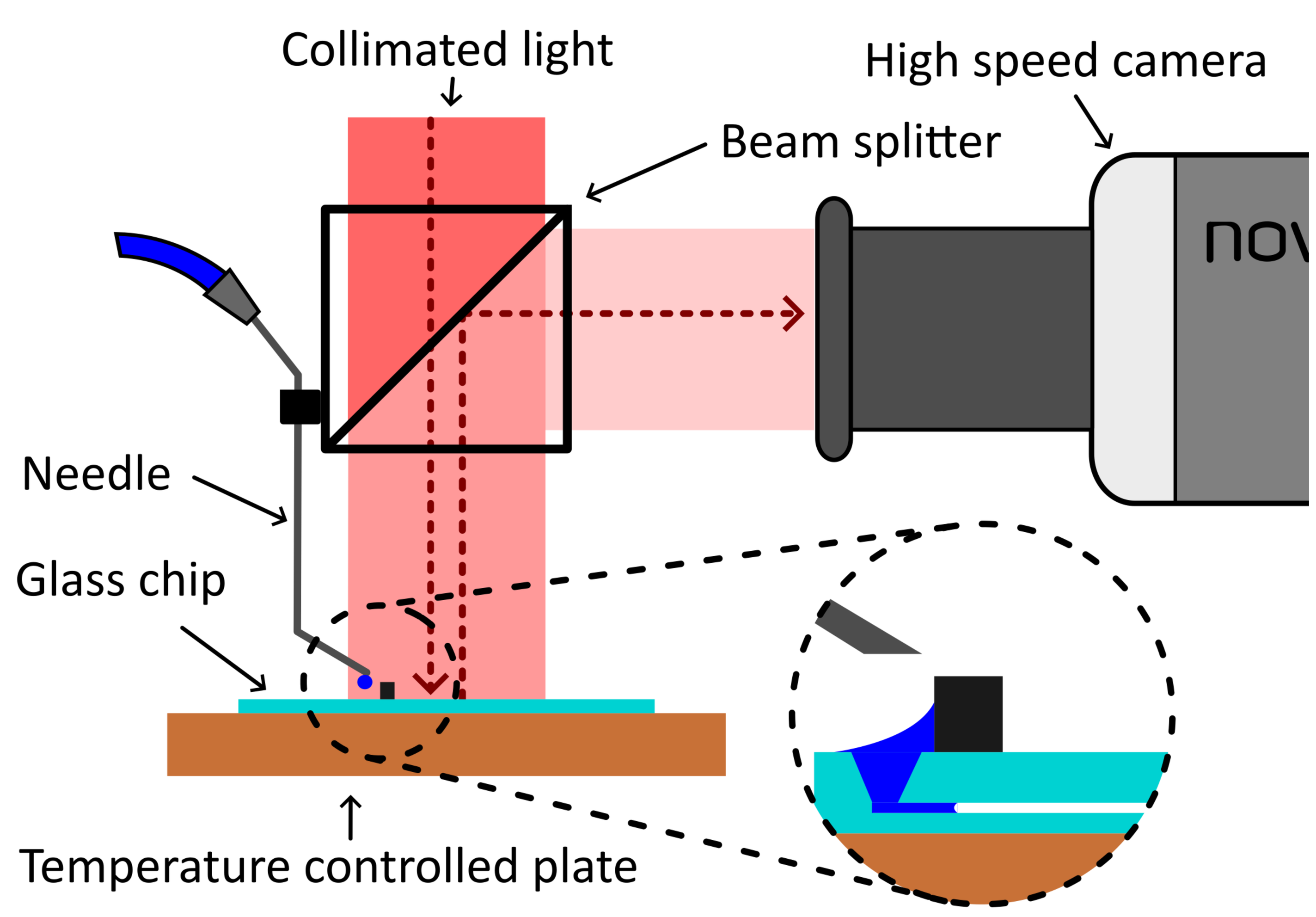
Latent heat of evaporation (kJ kg^{-1})	
Water 373.2 K	2256
Isopropanol 355.6 K	663.1
Nitrogen 77.4 K	199.2

Adaptation of the test rig to cryogenic temperatures

- Vapor free droplet generator[3]
- Temperature controlled surface 70 - 85 K
- Helium environment
- Optical access through thermal insulation

Experimental procedure

- Deposit droplet on the entrance to the channel
- Record absorption process using a high-speed camera



1. Applied Thermal Sciences, University of Twente, The Netherlands
2. Ramon, G., & Oron, A. (2008). Capillary rise of a meniscus with phase change. *Journal of Colloid and Interface Science*, 327(1), 145–151.
3. Schremb, M., Kalter, M., & Vanapalli, S. (2023). Development of a lab-device for evaporation-free supply of pure liquid nitrogen for droplet- and jet-generation. *Scientific Reports*, *13*(1), 1–13.

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