Influence of wetting and dewetting phenomena on evaporative heat transfer

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(I) Nucleate pool boiling

(II) Droplet impingement onto a superheated wall
Commonality: Dynamic wetting / dewetting front with conjugated heat transfer

moving 3-phase contact line region with phase change and conjugated wall-fluid heat transfer
Commonality: Dynamic wetting / dewetting front with h.t.

(I) Nucleate pool boiling

(II) Droplet impingement onto a superheated wall

(III) Evaporation in a capillary slot
Outline

- Overall research approach
  - Experimental setups
  - Numerical model and simulation

- Results
  - Pool boiling
  - Droplet impingement
  - Contact line evaporation in a capillary slot

- Summary and open questions t.b. addressed
We combine experimental & numerical studies

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Simulation</th>
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<tbody>
<tr>
<td>− generic studies on multiple scales</td>
<td>− model development on multiple scales</td>
</tr>
<tr>
<td>− high temporal and spatial resolution</td>
<td>− even higher resolutions</td>
</tr>
<tr>
<td>− parameter variation (fluid, pressure,</td>
<td>− individual parameter variations</td>
</tr>
<tr>
<td>temperature, wall material, …)</td>
<td>(fluid properties, wetting angle, …)</td>
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Experiment:
- Image of droplet shape
- Image of heat flux

Simulation:
- Image of droplet shape
- Image of heat flux

q [W/m²]
Experimental concept for boiling

High speed-black/white camera

Resolution:
14µm / pixel
1000Hz

Boiling test cell
(pressure controlled pure vapor atmosphere)

Light source

Heater wall
(details see next slide)

Fluid

High speed IR camera

Resolution:
30µm / pixel
1000Hz
IR-transparent heater design

- pure chromium heating layer, approx. 400 nm
- CrN emissivity layer, approx. 400 nm
- CaF$_2$ IR-transparent substrate
- copper carrier plate
- laser beam milled cavity (only for boiling experiment)
Experimental setups for boiling

Ground setup \((g = g_{\text{Earth}})\):
- Boiling cell
- Window
- Microscopic lens
- High-Speed camera
- High-Speed IR camera

Parabolic flight setup \((0 < g/g_{\text{Earth}} < 2)\):

Images of experimental setups and equipment.
Experimental concept for drop impingement

High speed-black/white camera
Resolution: 14µm / pixel 1000Hz

Drop impingement test cell
(pressure controlled pure vapor atmosphere)

Droplet generator
Light source
IR transparent heater

High speed IR camera
Resolution: 30µm / pixel 1000Hz
Experimental concept for contact line evaporation in a capillary slot

I-v displacement unit

2-phase system with capillary slot

DC Hybrid Linear Schrittmotor

stainless steel belows

condenser

FOV b&w camera

Thermostat

power

IR camera

IR transparent heater
Numerical method – multiscale approach

VOF model based on OpenFOAM

including own developments:
- phase change model
- 3D interface reconstruction
- adaptive grid refinement

Subgrid contact line model
Overall research approach
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  - Numerical model and simulation

Results
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Summary and open questions t.b. addressed
Temperature & heat flux profile

FC-72 ($\text{C}_6\text{F}_{14}$)

Gravity $\sim$0.2g

$\dot{q}_{\text{el}}$: 7.8 kW/m²

$T_{\text{fluid}}$: 42.1 °C

$T_{\text{sat}}$: 42.4 °C
Modeling and numerical simulation

→ local transient cooling near moving contact line during bubble growth and detachment
Transient conduction in the wall

→ Influence of conjugated transient h.t. higher at lower gravity
Thermal boundary layer near contact line

Phase I
(growing bubble, receding c.l.)

Phase II
(detaching bubble, advancing c.l.)
Overall research approach
- Experimental setups
- Numerical model and simulation

Results
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Summary and open questions t.b. addressed
Experimental results: temperature & heat flux profile

\[ Re = 2040 \quad We = 65 \quad T_{w} - T_{sat} = 17.3 \text{ K} \]
3 Phases of droplet dynamics and heat transfer

I. Spreading (inertia dominates) → advancing c.l.
II. Contracting (surface tension dominates) → receding c.l.
III. Sessile Drop
Validation – hydrodynamics

I. Spreading $\rightarrow$ II. Contracting $\rightarrow$ III. Sessile Drop
Heat transfer – influence internal flow

Phase I (spreading, advancing c.l.)

- single phase convection in boundary layer is dominant

Phase II (contracting, receding c.l.)

- hot liquid flows towards interface, evaporation becomes dominant
Heat transfer paths

Phase I
(spreading, advancing c.l.)

Phase II
(contracting, receding c.l.)

(a) spreading phase (I)
(b) receding phase (II)
Overall research approach
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Summary and open questions t.b. addressed
Heat flux distribution at a receding contact line

fluid: FC-72

\[ p_{\text{crit}} = 18.3 \text{ bar} \]
\[ T_{\text{crit}} = 449 \text{ K} \]
2 different regimes for receding contact line

- Contact line evaporation regime
  - Moderate receding velocity (< 10 mm/s)

- Microlayer evaporation regime
  - High receding velocity (> 35 mm/s)

→ There seems to be a threshold velocity for the regime transition

Influencing factors: velocity, fluid, surface roughness, pressure, heat flux, …?
Heat flux at receding vs. advancing contact line

\[ p_R = 0.05, \Delta T_W = 3.5 \, \text{K} \]

Higher local heat flux for advancing contact line
Heat flux at receding contact line

\[ p_R = 0.05, \Delta T_W = 2.2 \text{ K} \]

\[ q = \frac{\rho c}{\nu} \]  

\( \rightarrow \) no influence of contact line velocity for receding contact line

for moderate velocities below threshold value for microlayer formation
Heat flux at advancing contact line

\[ p_R = 0.05, \Delta T_W = 2.3 \text{ K} \]

\[ q \approx Wm^{-2} \]

\[ \xi / \text{mm} \]

- local heat flux increases with contact line velocity for advancing contact line
Summary and open questions

- **Advancing & receding contact line** situation (= wetting & dewetting) differs quite a lot due to different liquid flow direction
  - advancing c.l.: flow from cold bulk towards hot boundary layer, convection dominated regime
  - receding c.l.: flow from hot boundary layer towards bulk and I-v interface, evaporation dominated regime

→ **We should try to derive dimensionless, predictive models for c.l. heat transfer**

- **2 receding contact line regimes** were observed depending on velocity
  - contact line regime
  - microlayer regime

→ **We should try to derive dimensionless threshold velocity values for the regime transition**
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esa

- MAP Manbo Project, RUBI Project
Thank you for your attention!!

Questions?

for publications see: http://www.ttd.tu-darmstadt.de/