P09
Development of surface coatings on heat exchangers for reduced ice accretion

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Partners:
- SP (coordinator)
- Nibe AB
- Danfoss Värmepumpar AB
- Gränges AB
- Beneq Oy
Background

- Ice accretion on the surface of heat exchangers generally results in large energy losses due to decreased performance and required defrosting
Aim

The aim of the project is to prevent and/or delay the build-up of ice by developing functional coatings on heat exchanger surfaces.
Approach

Two main strategies

Superhydrophobic surfaces

$\theta > 150^\circ$

$\Rightarrow$ Water rolls off from the surface before freezing

Superhydrophilic surfaces

$\theta < 5^\circ$

$\Rightarrow$ Results in a thin ice-layer, which is expected to require less energy during defrosting
Superhydrophilic vs. Superhydrophobic
Hydrophilic surfaces

$\theta < 90^\circ$

Same chemistry, increasing surface roughness

Contact angle decreases

$\theta < 5^\circ$ Superhydrophilic surfaces
Hydrophobic surfaces

Smooth hydrophobic surface - maximum water contact angle $\sim 120^\circ$ (CF$_3$)

Rough hydrophobic surfaces

Wenzel state

Cassie-Baxter state

Liquid wets the surface texture

droplet rests on a solid-air composite surface

Characteristics for Wenzel and Cassie-Baxter states

Wenzel
High roll-off angle ("sticky surfaces")

Cassie-Baxter
Low roll-off angle ("non-stick")

Cassie-Baxter state is required for superhydrophobicity!
Work flow in the project

- Coating development
- Characterization at lab scale
- Upscaling & full-scale tests
Coating development

- Commercial superhydrophobic coating formulations
- Development of coating formulations in-house
- Coating techniques
Commercial superhydrophobic coatings

Ultra Ever Dry

NeverWet
Coating development in-house

Both superhydrophilic and superhydrophobic coatings requires a combination of chemistry and surface roughness

1. Top-down approaches
   - Surface roughness is created by removing material from the substrate

2. Bottom-up approaches
   - Surface roughness is created by adding material to the substrate
Top-down approaches

1. Creation of surface roughness e.g. by etching or anodization
2. Hydrophobization of the surface e.g. by self-assembly or plasma polymerization

Anodized Al
Bottom-up approaches

1. Adding a coating of e.g. nanoparticles

2. Hydrophobization of the surface e.g. by self-assembly or plasma polymerization (not necessary if the particles are hydrophobic)
Coating techniques

- Dipcoating
- Spraycoating
- A novel spray coating method, nFOG™
- Anodization
Work flow in the project

- Coating development
- Characterization at lab scale
- Upscaling & full-scale tests
Characterization

- Contact- and roll-off angle measurements (dry and wet conditions)
- Scanning electron microscopy (SEM)
- Condensation and frosting studies with light microscope
- Durability (sand test)
Contact angle measurements

• From pL to µL sized droplets
• Sample stage -20°C to 80°C
• Heating/cooling device for temperature control (-10°C-90°C) of dispensed droplets
• High-speed camera. Up to 2245 frames per second
• Tilting of the instrument possible
**Results – contact angles**

The water-repellancy at wet conditions is strongly dependent on the surface coverage!

The change in performance for some of the coatings can be referred to the transition from Cassie to Wenzel state.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Dry conditions (23°C and 50 RH)</th>
<th>Wet conditions (5°C and 50 RH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contact angle, (°)</td>
<td>Roll-off angle, (°)</td>
</tr>
<tr>
<td>Aluminum (ref.)</td>
<td>60–65</td>
<td>–</td>
</tr>
<tr>
<td>Coating 1.</td>
<td>&gt; 150</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Coating 2.</td>
<td>&gt; 150</td>
<td>&lt; 5</td>
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<tr>
<td>Coating 3.</td>
<td>&gt; 150</td>
<td>&lt; 5</td>
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<tr>
<td>Coating 4.</td>
<td>&lt; 5</td>
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</tbody>
</table>
Condensation measurements

Experimental conditions: Air temperature 23°C, surface temperature 5°C, RH 50%

Hydrophobic Si-wafer

Superhydrophobic surface
Frosting studies

"Bad" superhydrophobic surface (Coating 1)

Experimental details:
surface temperature lowered to -10°C at 50% RH and 23°C

All droplets are frozen after ~ 1-2 min
Frosting studies

"Good" superhydrophobic surface (Coating 2)

Experimental details:
surface temperature lowered to -10°C at 50% RH and 23°C

All droplets are frozen after ~ 9-10 min
Durability (sand test)

- Sand was dropped from 10 cm height with a flow rate of 40 g/min
- 1 abrasion cycle = 30 seconds
- Contact angle measurement after every abrasion cycle
Work flow in the project

Coating development

Characterization at lab scale

Upscaling & full-scale tests
Upscaling and Industrial scale tests

- Evaluation of a coated microchannel condensor (supplied by Gränges)
- Coating of Nibes HEX and evaluation of performance in their facilities (upcoming work)
Microchannel condensor

- Superhydrophilic and superhydrophobic coatings applied with nFOG™
- Water retention test after immersion in water for 10 s
  - Untreated and superhydrophilic: >110 % weight gain
  - Superhydrophobic: ~1.5 % weight gain
Microchannel condenser

From left to right:
Uncoated
Superhydrophilic
Superhydrophobic

Next step: evaluation of repellence against condensed water (vapor)
Heat exchanger from Nibe (45x25x25 cm)

- Will be coated at SP using nFOG™
- A full-scale performance test will be performed by Nibe in their climate chamber
Conclusions so far

- Both superhydrophobic and superhydrophilic coatings are achieved by a combination of the right chemistry and topography.
- A nanostructured superhydrophobic coating with good surface coverage seems promising against condensation and frost formation.
- The concepts need to be verified in full-scale tests.
Next steps

- Optimization of coating formulations
- New nFOG™ equipment designed for coating of 3D objects soon delivered to SP
- Coating of Nibe’s HEX and full-scale tests in climate chamber
Acknowledgements

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- Industrial partners
Thank you for your attention!