Neutron radiography/tomography for visualising and quantifying the novel fruit pulp concentration process

”Solar Assisted Pervaporation”

Randi Phinney¹, Thijs Defraeye², Peter Vontobel³, Petr Dejmek¹, Ingegerd Sjöholm¹ and Marilyn Rayner¹

¹ Department of Food Technology, Engineering and Nutrition, Lund University, Lund, Sweden

² Multiscale Studies in Building Physics, Empa, Überlandstrasse 129, 8600 Dübendorf, Switzerland

³ Paul Scherrer Institut (PSI), 5234 Villigen, Switzerland
Key message

Neutron imaging is a promising technique for quantifying Solar Assisted Pervaporation (SAP)
Outline

• What is Solar Assisted Pervaporation (SAP)?
• Aim
• Methods Explored
• Preliminary Results
• Main Findings and Limitations
• Future Work
Solar Assisted Pervaporation (SAP)

- “Breathable” fabric pouch
- Permeable to water vapour but not liquid water
- Homogeneous hydrophilic
Solar Assisted Pervaporation (SAP)

- “Breathable” fabric pouch
- Permeable to water vapour but not liquid water
- Homogeneous hydrophilic

Driving force for mass transport: \( a_w - \frac{RH}{100} \)
Where can SAP be used?

Mozambique

Almost anywhere...
Aim of the study

Test various neutron radiography/tomography setups to see which are compatible with SAP

Can we use neutron imaging to quantify internal mass transport and drying uniformity during SAP?
Collaborating partners

Empa
Materials Science and Technology

Lund University

PAUL SCHERRER INSTITUT

PSI
Paul Scherrer Institute

- Villigen, Switzerland

- Neutron source:
  - **SINQ (Swiss Spallation Neutron Source)**
    - Continuous source
    - Flux: $10^{14}$ n/cm$^2$/s

- Beamline:
  - **NEUTRA**
    - Thermal neutron radiography station
NEUTRA: NEUtron Transmission Radiography

Neutron energy: 25 meV thermal Maxwellian spectrum
Neutron flux at sample position: >5 \times 10^6 \text{ neutrons cm}^{-2} \text{ sec}^{-1} \text{ mA}^{-1} (p\text{-current})
Maximum field of view: 30 cm x 30 m

Image source: https://www.psi.ch/sinq/neutra:description
NEUTRA: NEUtron Transmission Radiography (PSI)

Image source: https://www.psi.ch/sinq/neutra:description
Methods Explored
### Summary of Experimental Setups

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Bag orientation</th>
<th>Bag type</th>
<th>Irradiance (W/m²)</th>
<th>Materials tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>horizontal</td>
<td>mini</td>
<td>80</td>
<td>solid apple (w and w/o bag), purée and juice</td>
</tr>
<tr>
<td>2</td>
<td>vertical</td>
<td>mini</td>
<td>210</td>
<td>solid apple (w and w/o bag), purée and juice</td>
</tr>
<tr>
<td>3</td>
<td>vertical</td>
<td>big</td>
<td>210</td>
<td>apple purée</td>
</tr>
<tr>
<td>4</td>
<td>vertical</td>
<td>column</td>
<td>210</td>
<td>apple purée and juice</td>
</tr>
<tr>
<td>5</td>
<td>vertical</td>
<td>column + D₂O</td>
<td>210</td>
<td>apple purée</td>
</tr>
</tbody>
</table>

Apple: Organic Golden Delicious (94021) from Italy, purchased in Sweden
The Challenge
Spatiotemporal Tomography
“Mini” Bags (Horizontal)

**Purpose**: create a 3D reconstruction of the dehydration process for horizontal ”mini” bags 10 mm x 10 mm [L x W]
Radiography
”Mini” Bags (Vertical)

**Purpose:** visualise and quantify drying patterns in ”mini” vertical bags with:

- Apple purée [1]
- Apple juice [2]
- Solid apple (in bag) [3]
- Solid apple (no bag) [4]
Radiography
”Big” Bag (Vertical)

**Purpose**: visualise and quantify drying patterns in a ”big” vertical bag with apple purée
Radiography
”Column” Bags (Vertical)

**Purpose:** visualise and quantify drying patterns in vertical column bags to compare apple purée vs. apple juice
Radiography
”Column” Bags (Vertical) with D₂O Injection

**Purpose**: to see if D₂O can be used to quantify mass transport inside the bags
Preliminary Results
Vertical Radiography: Effect of viscosity on drying uniformity
Vertical Radiography: Effect of viscosity on drying uniformity
Vertical Radiography:
Effect of viscosity on drying uniformity
Vertical Radiography: Effect of viscosity on drying uniformity

Local moist spots and uneven drying: food safety risk
D$_2$O Injection: diffusion-driven process
D$_2$O Injection: to quantify mass transport
Limitations of the setup

• 10 mm sample depth
  – Forced to use “mini” horizontal bags

• Vertical setup: 15 x 15 cm Field of View
  – Smaller than real ”SAP” bag

• Hard to distinguish water from carbohydrates
Conclusions and Next Steps

• D$_2$O injection seems promising for visualising and quantifying mass transport inside the bag
  – Next step: calculate diffusion rates

• Local moist spots and drying heterogeneity can be identified
  – Next step: calculate local drying rates

Data from other experimental setups to be analysed
Future Work

Use a vertical setup with

1) purées of differing viscosity and
2) $\text{D}_2\text{O}$ injections to:

– validate a multiphysics model of the process
– quantify internal mass transport
– understand food safety risks with non-uniform drying
Acknowledgements

• Swedish Research Council (PhD Project Funding)
• Thijs Defraeye, Empa, Switzerland
• Peter Vontobel, PSI, Switzerland
• Petr Dejmek, Ingegerd Sjöholm and Marilyn Rayner (supervisors at the Department of Food Technology, Engineering and Nutrition)
Questions?