EXPERIMENTAL ANALYSIS AND MODELING OF MANGOES DRYING KINETICS

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**Introduction**

**Fruits drying** is a widely used process in the food industry

- **Advantages:**
  - Increases the product shelf life
  - Reduces the mass of the products
  - Reduces the volume of the products

- **Disadvantages:**
  - Fruits are highly sensitive to heat changes
  - High energy consumption

**Mangoes** are chosen as product of interest

- One of the most exported dried fruit
- Large part of the production is usually wasted due to lack of market opportunities
THREE OBJECTIVES

Carry out several **drying trials** and analyze their **drying rates**

Develop an **original mathematical model**

Discuss the **influence** of the different **physico-chemical parameters** of the mathematical model
THE EXPERIMENTAL DRYER

- Fixed bed
- Sample holders
- $T_{in}, Y_{in}$
- Heating coil
- Rotameter
- $T_s$
- Temperature regulation, $T_b$
- $T_{out}, Y_{out}$

Blower

Heat exchanger
**DATA PROCESSING**

**Experimental drying rate**

\[
J_{\text{exp}}(t) = \frac{Q(Y_{\text{out}}(t) - Y_{\text{in}}(t))}{M_s}
\]

**Initial moisture content**

\[
X_0 = \frac{M_{f,\text{stove}}}{M_{0,\text{stove}}} \frac{M_{0,\text{stove}}}{M_{f,\text{stove}}}
\]

**Dry mass of mango slices**

\[
M_s = \frac{M_{\text{ma}}}{1 + X_0}
\]
Influencing parameters discussed:

- Superficial velocity of the air, $u$
- Thickness of the mango slices, $\Delta_0$
- Temperature in contact with the mango slices, $T$

Experimental conditions used during the drying trials:

<table>
<thead>
<tr>
<th>Drying trials</th>
<th>$u$ (m/s)</th>
<th>$T_{\text{ref}}$ ($^\circ$C)</th>
<th>$\Delta_0$ ($10^{-3}$ m)</th>
<th>$M_{\text{ma}}$ (kg mangoes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\sim 0.15$</td>
<td>60</td>
<td>4</td>
<td>0.196</td>
</tr>
<tr>
<td>2</td>
<td>$\sim 0.15$</td>
<td>50</td>
<td>4</td>
<td>0.284</td>
</tr>
<tr>
<td>3</td>
<td>$\sim 0.4$</td>
<td>60</td>
<td>4</td>
<td>0.272</td>
</tr>
<tr>
<td>4</td>
<td>$\sim 0.4$</td>
<td>60</td>
<td>7</td>
<td>0.225</td>
</tr>
<tr>
<td>5</td>
<td>$\sim 0.4$</td>
<td>60</td>
<td>4</td>
<td>0.278</td>
</tr>
</tbody>
</table>
EXPERIMENTAL DRYING RATES

High sensitivity to $T$, $A_0$, and $X_0$

No significant influence of $Q$

<table>
<thead>
<tr>
<th>Condition</th>
<th>Drying Rate (kg water/kg dry mass hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: 60°C, 4mm, 0.15m/s</td>
<td>3.5</td>
</tr>
<tr>
<td>2: 50°C, 4mm, 0.15m/s</td>
<td>3.0</td>
</tr>
<tr>
<td>3: 50°C, 4mm, 0.4m/s</td>
<td>2.5</td>
</tr>
<tr>
<td>4: 60°C, 4mm, 0.4m/s</td>
<td>2.0</td>
</tr>
<tr>
<td>5: 50°C, 7mm, 0.4m/s</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Theoretical drying rate (I)

\[ J_{th}(t) = a M_w k(X(t)) \left( \frac{p_{sat}(T(t))}{R_g T(t)} \frac{Y(t)}{M_w} \right) \]

Mangoes specific surface area

\[ a = \frac{2(1+ X_0)}{0 \text{ ma}} \]

Mass transfer coefficient

\[ k(X) = k_{max} \left( 1 - \left( \frac{X_0}{X} \right) \right) \]

Theoretical drying rate (II)

\[ J_{th}(t) = \frac{dX(t)}{dt} \]
**Adjusted Parameters**

Measured and fitted values of the key parameters of the proposed model, $\beta$ and $k_{\text{max}}$

<table>
<thead>
<tr>
<th>Drying trials</th>
<th>$X_0$ (kg water kg dry mass$^{-1}$)</th>
<th>$J_{\text{max}}$ (kg water kg dry mass$^{-1}$ h$^{-1}$)</th>
<th>$k_{\text{max}}$ (m s$^{-1}$)</th>
<th>$\beta$ (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.93</td>
<td>2.70</td>
<td>2.54 10$^{-3}$</td>
<td>0.87</td>
</tr>
<tr>
<td>2</td>
<td>6.06</td>
<td>2.14</td>
<td>1.43 10$^{-3}$</td>
<td>0.74</td>
</tr>
<tr>
<td>3</td>
<td>4.32</td>
<td>2.06</td>
<td>2.12 10$^{-3}$</td>
<td>1.15</td>
</tr>
<tr>
<td>4</td>
<td>6.42</td>
<td>3.32</td>
<td>1.65 10$^{-3}$</td>
<td>0.93</td>
</tr>
<tr>
<td>5</td>
<td>8.37</td>
<td>3.42</td>
<td>2.13 10$^{-3}$</td>
<td>0.77</td>
</tr>
</tbody>
</table>

**Average values**

- $k_{\text{max}}$: $10^{-3} \pm 5 \times 10^{-4}$
- $\beta$: $0.9 \pm 0.2$

95% confidence interval
DIRECT VALIDATION (I)
DIRECT VALIDATION (II)
CROSS VALIDATION
CONCLUSIONS

• The drying rate of mango slices **depends significantly on the air drying temperature** but not on the air superficial velocity of the air circulating through the dryer
  • There is a maximum temperature for drying: to avoid mango slices deterioration (e.g. change of color and taste)
• Original mathematical model **based on physical changes** occurring during the drying process
  • Excellent correlation between the experimental and theoretical drying rates
  • Model can be used for the design and optimization of mango dryers for a **large range of operating conditions**