Mathematical Modeling of a Cross-Flow Rice Dryer

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Cross-flow drying of rough rice

Cross-flow drying research

Current goals:
1. Determine non-uniformity of drying across the column thickness and its impact on milling yield of rice
2. Optimize drying process variables
3. Evaluate feasibility of a single-pass drying process

Two approaches

1. Performing experiments at industrial-scale dryer:
   - Large sample size
   - Large variation in sample
   - High cost
2. Develop a mathematical model to simulate cross-flow drying:
   - Need smaller-scale lab experiments
   - Enables what-if analysis
   - Provides deeper understanding of drying and fissuring phenomena

Mathematical Modeling: Expectations

Distribution of grain and air properties throughout the drying column
Mathematical description of drying

Grain properties:
\[ M = M(x, t) \]
\[ T = T(x, t) \]

Air properties:
\[ T = T(x, t) \]
\[ W = W(x, t) \]

Heat balance for drying air
\[ (G_e + G_w)T_{in} + \frac{\partial T}{\partial x} = -h_A(T_s - T) \]

Heat balance for grain
\[ \rho v \frac{\partial T}{\partial x} = h_A(T_s - T) + h_w T_{in} \]

Mass (Moisture) balance for drying air
\[ \frac{\partial (\rho v W)}{\partial x} = \frac{\partial}{\partial x} \left( \rho v \frac{\partial W}{\partial x} \right) - h_w \frac{\partial T}{\partial x} \]

Mass (Moisture) balance for grain
\[ \frac{\partial M}{\partial x} = \text{Thin layer drying equation} \]

Require numerical solutions: MATLAB / JavaScript

Discretization of the drying column

Model validation

Model validation with the lab dryer

Stationary-bed lab drying setup

Model validation: MC of rice

<table>
<thead>
<tr>
<th>Drying Runs</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying duration, min</td>
<td>30</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>Initial rice MC, % (w.b)</td>
<td>20.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial rice T, °F</td>
<td>71</td>
<td>67</td>
<td>73</td>
</tr>
<tr>
<td>Plenum air T, °F</td>
<td>134</td>
<td>135</td>
<td>137</td>
</tr>
<tr>
<td>Plenum air RH, %</td>
<td>13</td>
<td>13</td>
<td>11</td>
</tr>
</tbody>
</table>

Properties of air drying after 30 min of drying.

Model validation: T/RH of drying air

Properties of air drying after 30 min of drying.
Model validation: RMSEs

Root mean square error (RMSE) measures the goodness of model fit to the experiments.

\[ RMSE = \sqrt{\frac{e_1^2 + e_2^2 + e_3^2 + \ldots + e_n^2}{n}} \]

Root mean square error (RMSE) between the predicted and experimental grain/air properties at the end of three drying runs.

<table>
<thead>
<tr>
<th>Drying duration</th>
<th>30 min (Run-1)</th>
<th>60 min (Run-2)</th>
<th>90 min (Run-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice MC (percentage points)</td>
<td>0.9</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Air Temperature (°C)</td>
<td>3.2</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Air RH (percentage points)</td>
<td>9.7</td>
<td>7.9</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Material States of Rice

Rice starch material states:
- Glassy
- Rubbery

Material state of rice starch depends upon its temperature and moisture content and affect head rice yields.

Model Predictions: Material States

Model Applications: Impact of initial MC on Material States of Rice

Conclusions

- Mathematical model can describe MC, temperature, and material state within a rice dryer column.
- The model can be used to optimize dryer performance, develop a better drying operation, and design an improved dryer.

More information: