Validation of a Cross-Flow Dryer Model

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Cross-flow drying - Introduction

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Cross-flow drying research goals
1. Determine non-uniformity of drying across the column thickness and its impact on milling yields of rice
2. Optimize drying process variables, e.g. drying air temperature, airflow rate, grain flow rate, etc.
3. Evaluate feasibility of a single-pass drying process

Current objective:
Validate a mathematical model predicting rice MC and air temperature across the column during drying, using
a) a lab-scale dryer and
b) a commercial dryer

Mathematical Modeling: Possibilities
Distribution of grain and air properties throughout a drying column

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Distribution of grain and air properties throughout a drying column

(a) MC (% w/w)  
(b) Temperature (°C)  
(c) Material state

Discretization of 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
\[ (\rho_c c_p + \rho_w c_p W) \frac{dT}{dt} = -h_A(T_1 - T_2) \]

Heat balance for grain
\[ \rho_s c_s \frac{dT}{dt} = h_A(T_1 - T_2) + \frac{h_{op} \rho_s \Delta T}{\Delta x} \]

Mass (Moisture) balance for drying air
\[ \frac{dM}{dt} = \rho_c c_p \frac{dW}{dt} - \rho_w c_p W \frac{dW}{dt} \]

Mass (Moisture) balance for grain
\[ \frac{dM}{dt} = \text{Thin layer drying equation} \]

Require numerical solutions: MATLAB / JavaScript

Lab-scale rice dryer

Outside view of the dryer  
Inside view of the dryer

Lab-scale rice dryer

Controlled Environment Chamber
Fan
Connection to external datalogger
Air duct
Woven pouch (for MC measurement)
Lab drying experiments

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial rice MC (% w.b.)</td>
<td>17.6 (0.1)</td>
</tr>
<tr>
<td>Initial rice temperature (°F)</td>
<td>79 ± 2</td>
</tr>
<tr>
<td>Plenum air temperature (°F)</td>
<td>140</td>
</tr>
<tr>
<td>Plenum air RH (%)</td>
<td>10</td>
</tr>
<tr>
<td>Drying duration (min)</td>
<td>15, 30, 45, 60, 90</td>
</tr>
<tr>
<td>No. of replicate drying runs</td>
<td>2</td>
</tr>
<tr>
<td>Total number of drying runs</td>
<td>5 x 2 = 10</td>
</tr>
</tbody>
</table>

Model validation: MC of rice

Model validation: Air temperature
Model validation: Air temperature

Distance from heated-air plenum (in) vs. Air temperature (ºF)

- Model - 15 min
- Experiment - 15 min
- Model - 30 min
- Experiment - 30 min
- Model - 45 min
- Experiment - 45 min
- Model - 60 min
- Experiment - 60 min
- Model - 90 min
- Experiment - 90 min

Model validation: Air temperature

Drying duration (min) vs. Air temperature (ºF)

- Model - 3 in
- Experiment - 3 in
- Model - 9 in
- Experiment - 9 in
- Model - 15 in
- Experiment - 15 in

Model validation: RMSEs

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

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

<table>
<thead>
<tr>
<th>Drying duration</th>
<th>Rice MC (% w.b.)</th>
<th>Air temperature (ºF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 min</td>
<td>0.3</td>
<td>4.0</td>
</tr>
<tr>
<td>30 min</td>
<td>0.3</td>
<td>4.0</td>
</tr>
<tr>
<td>45 min</td>
<td>0.2</td>
<td>3.8</td>
</tr>
<tr>
<td>60 min</td>
<td>0.1</td>
<td>3.4</td>
</tr>
<tr>
<td>90 min</td>
<td>0.1</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Commercial-scale validation

Special thanks to Greg Baltz and Running Lake Farms, Pocahontas, Arkansas.
Commercial-scale validation

Need more tests at commercial facilities (Volunteers requested)

Grain inverters (or turnflows)

Grain inverters switch the position of rice kernels, and thus improve uniformity of drying.

Grain inversions: Experiments

Drying conditions for these experiments:
- Initial MC: 17% (w.b.)
- Duration: 60 min

Grain inverters (or turnflows)

Grain inverters switch the position of rice kernels, and thus improve uniformity of drying.
May 22, 2018

Grain inversions: Experiments

MC removed during drying

Drying conditions for these experiments:
Initial MC: 17% (w.b.)
Duration: 60 min

Grain inversions: model validation

Drying duration: 60 min
Initial rice MC: 17%
Plenum air temperature: 140°F
Grain initial temperature: 75°F
1. The model accurately predicts rice drying even when the grain flow is altered by inverters.
2. Need to validate at commercial scale.