Drying High Moisture Corn – Challenges of the 2009 Harvest Season

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Objective of Drying

To reduce the harvest moisture content of grains and oilseeds to levels that are...

- safe for storage, and
- optimum for marketing
Safe Storage Moisture Content
in Equilibrium with Intergranular Air at 65% Relative Humidity (Chung'89)
Drying System Categories
Drying System Categories

• **Low Temperature**
  • Natural air or air heated by up to 5-15°F
  • In-bin (or in-storage)

• **Medium Temperature**
  • Kernel temps *below 110°F* for seed and food grains, and *below 140°F* for all others (incl. #2 yellow corn, waxy, HOC)
  • In-bin or column

• **High Temperature**
  • Kernel temps above 140°F
  • In-bin or column

• **Combination**
  • Med temp plus dryeration or in-bin cooling
  • Med-low temp 2-stage drying
Crossflow

Hot Drying Air

Moist Exhaust Air
Conventional Crossflow Dryer

- Filling Auger
- Wet Holding Bin
- Grain Column
- Fan and Heater
- Heated Air Plenum
- Cooling Air Plenum
- Fan
- Grain Meter
- Unloading Auger
Drying Requires

- Energy
- Forced air
- Time
The higher the drying air temperature...

... the faster and

... the more efficient

the drying process will be!
Crossflow Dryer Drying Corn from 25 to 15% WB

TOTAL ENERGY, BTU/LB of H₂O Evap x 10^3

Drying Air Temperature, F

AIRFLOW RATE

100 CFM/BU

75

50

30

10

0  100  150  200  250  300
Dilemma #1:

The *higher* the drying air temperature and the *faster* the drying process ...

... the *lower* the end use quality of the dried grains and oilseeds!
Relative Magnitude of Factors Causing Breakage Susceptibility

Variety
- Strong

Combine adjustment
- Proper settings
- Excessive cylinder speed
- Concave clearance too narrow
- Corn moisture greater than 25%

Drying method
- High-temperature drying
- Rapid cooling
- Low-temperature drying

Cumulative effects
- Minimum brittleness
- Maximum brittleness

*Note: The diagram illustrates the relative magnitude of factors causing breakage susceptibility, with strong, proper settings, high-temperature drying, and minimum brittleness having the least impact, while weak, improper settings, low-temperature drying, and maximum brittleness having the greatest impact.
Breakage Susceptibility

**Interior Damage:**
Stress failure of the endosperm resulting in stress-cracked and brittle kernels

**Causes:**
Excessive compressive or tensile stresses during or after drying, cooling or rehydration (conditioning)
Effect of Final Moisture on Breakage

Breakage

Moisture

0%  10%  20%  30%  40%

11%  13%  15%  18%
Effect of Drying Method on Stress Cracks

- Low temperature <5%
- Medium temperature & slow cooling 10-35%
- High temperature 50-100%
Wet Milling Quality – Effect on Extractable Starch

Dryer 1
Dryer 2

Drying Air Temperature (F)

Extractable Starch Reduction (pts)

200°F
Grain Kernel Temperature versus Drying Air Temperature
### Grain Type - End Use
- Maximum Kernel Temperature

<table>
<thead>
<tr>
<th>Grain Type</th>
<th>End Use</th>
<th>Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>CORN</td>
<td>Dry Milling &amp; Seed</td>
<td>100-110°F</td>
</tr>
<tr>
<td></td>
<td>Wet Milling</td>
<td>130-140°F</td>
</tr>
<tr>
<td></td>
<td>Feed Use</td>
<td>160-180°F</td>
</tr>
<tr>
<td>WHEAT</td>
<td>Seed (&gt; 24%)</td>
<td>110°F</td>
</tr>
<tr>
<td></td>
<td>Seed (&lt; 24%)</td>
<td>120°F</td>
</tr>
<tr>
<td></td>
<td>Flour</td>
<td>120-170°F</td>
</tr>
<tr>
<td>SOYBEANS</td>
<td>Seed</td>
<td>100°F</td>
</tr>
<tr>
<td></td>
<td>Oil Crushing</td>
<td>120°F</td>
</tr>
<tr>
<td>SUNFLOWER</td>
<td>Food</td>
<td>140-170°F</td>
</tr>
<tr>
<td></td>
<td>Oil Crushing</td>
<td>170-195°F</td>
</tr>
<tr>
<td>RICE</td>
<td>Milling (&gt;20%)</td>
<td>105°F</td>
</tr>
<tr>
<td></td>
<td>Milling (&lt;20%)</td>
<td>110°F</td>
</tr>
<tr>
<td>BARLEY</td>
<td>Malting</td>
<td>105-120°F</td>
</tr>
<tr>
<td></td>
<td>Feed</td>
<td>165-185°F</td>
</tr>
<tr>
<td>EDIBLE BEANS</td>
<td>Food Use</td>
<td>100°F</td>
</tr>
</tbody>
</table>
# Maximum Drying Rates

<table>
<thead>
<tr>
<th>Grain Type</th>
<th>% Moisture Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn, Sorghum, Sunflower</td>
<td>Less than 5% / hours</td>
</tr>
<tr>
<td>Wheat</td>
<td>Less than 4% / hours</td>
</tr>
<tr>
<td>Soybeans</td>
<td>Less than 3% / hours</td>
</tr>
<tr>
<td>Rice</td>
<td>Less than 2% / hours</td>
</tr>
</tbody>
</table>
Effect of Excessive Drying Air Temperature
Dilemma #2: Temperature and Moisture Distribution in Dryers
Crossflow

Temperature

MEAN
IN
AIR TEMP
OUT

Hot Drying Air

Moist Exhaust Air
Crossflow

Grain Moisture

Temperature

Hot Drying Air

Moist Exhaust Air
## Drying Corn from 25% to 19% at 230° F

<table>
<thead>
<tr>
<th>Distance from Air Inlet</th>
<th>Grain Temperature</th>
<th>Moisture Content</th>
<th>Breakage Susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>°F</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>0.5</td>
<td>215</td>
<td>10</td>
<td>48</td>
</tr>
<tr>
<td>3.0</td>
<td>172</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>5.5</td>
<td>124</td>
<td>24</td>
<td>10</td>
</tr>
</tbody>
</table>
Modified Crossflow Dryer

- Filling Auger
- Warm Air Out
- Heated Air Plenum
- Heating Chamber
- Control Box
- Cooling Air In
- Grain Meter
- Unloading Auger
## Effect of Exhaust Air Recirculation

<table>
<thead>
<tr>
<th></th>
<th>Air Temp. (°F)</th>
<th>Moisture Gradient</th>
<th>Specific Energy (Btu/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No recirculation</td>
<td>154</td>
<td>5.0</td>
<td>3,000</td>
</tr>
<tr>
<td>Recirculation/</td>
<td>149</td>
<td>1.3</td>
<td>2,100</td>
</tr>
<tr>
<td>Suction Cooling</td>
<td>-74%</td>
<td>-30%</td>
<td></td>
</tr>
</tbody>
</table>
Grain Column Turning
Differential Grain Speed Dryer
Dilemma #3:
Initial Kernel-to-Kernel Moisture Variability
Average moisture content (MC), moisture content range, percentage point differential, and standard deviation (SD) in maize kernels collected at the inlet and outlet of commercial crossflow (CF), concurrent-flow (CCF), and mixed-flow (MF) dryers. (Source: Montross et al. 1994)

<table>
<thead>
<tr>
<th>Dryer Type</th>
<th>Average MC (%)</th>
<th>MC Range (%)</th>
<th>Point Differential</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>In</td>
<td>Out</td>
<td>In</td>
<td>Out</td>
<td>In</td>
</tr>
<tr>
<td>CF</td>
<td>20.8</td>
<td>15.0</td>
<td>10.0 – 33.1</td>
<td>8.5 – 31.5</td>
</tr>
<tr>
<td>CCF</td>
<td>21.7</td>
<td>14.7</td>
<td>14.5 – 37.5</td>
<td>7.0 – 34.0</td>
</tr>
<tr>
<td>MF</td>
<td>22.4</td>
<td>14.8</td>
<td>8.5 – 38.5</td>
<td>8.0 – 35.5</td>
</tr>
</tbody>
</table>
Segregating Initial Moistures

Silo 1 = 22-25%

Silo 2 = 19-22%

Silo 3 = 16-19%
Tempering (steeping)
Medium Temperature Drying and Slow Cooling
Slow Cooling Methods:

- In-bin cooling
- Dryeration
- Combination high-low
- Continuous slow cooling
High Capacity Drying followed by Dryeration

- 6-12 hours tempering of hot grain
- 0.5-1.5 cfm/bu cooling airflow
- 12-24 hours cooling time
- 2-3 points moisture loss during cooling
- Transfer cooled & dried grain to final storage
  - batch or continuous
Effect of Tempering on Single Kernel MC and Stress Cracks

Single Kernel Moisture Test 1

2.45  2.39  1.96  1.40  1.09  1.30  1.17  1.26  1.04  0.87

MC s.d.

SC s.d.

10/29/2003

Hour 0
Hour 1
Hour 2
Hour 3
Hour 4
Crack Test
Continuous-Flow Dryeration System
Dilemma #4: Hybrid Effects on Drying Capacity
Drying Times for Four Corn Hybrids – Conditions: 22.5% → 15% mc at 180°F (82°C)

Drying time difference of 2x
Soybeans were dried at 140°F (60°C) from 22 to 13% moisture
Managing Energy Costs

• **Energy efficiency**
  - Hot corn transfer (dryeration, in bin cooling)
  - Vacuum/suction cooling
  - Exhaust air recirculation

• **Avoid drying on extremely cold days**
  - Natural gas use penalties may apply

• **Alternative fuels**
  - Biofuels (biodiesel)
Drying Frost-Damaged Corn

Milk Stage
• low yield, difficult to pick & shell, chaffy
• green chop or ensile whole plants

Dough Stage

Dent Stage
Drying Frost-Damaged Corn – Dough Stage

Low yields & TW (50 lb/bu and less)

High kernel MCs
- Soft dough 60-62% MC; field dry to 35% MC before harvest

High cob MCs

<table>
<thead>
<tr>
<th>Kernel (%)</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cob (%)</td>
<td>9</td>
<td>18</td>
<td>33</td>
<td>45</td>
<td>52</td>
<td>56</td>
<td>59</td>
</tr>
</tbody>
</table>

- “Drier Damage” of doughy kernels at high drying air temperatures
  - Wrinkled, blistered, darkened, brown
  - max grain kernel temp below 120-140°F

- Dry to 14% MC for short-term winter storage
  - Longer storage increases risk for self-heating
Drying Frost-Damaged Corn – Dent Stage

Below normal TW
- >50 lb/bu similar feeding value
- <50 lb/bu may contain:
  - hard to digest free sugars
  - less oil
  - incompletely developed protein

MC at frozen stage
- early dent: 50-55% MC
- late dent: 40% MC

Harvest at 30-35% MC
- If black-layered before frost, corn is physiologically mature

Dry but keep max grain kernel temp below 120-140°F
Dry to safe storage moisture content
Average rate of grain moisture loss for three corn hybrids planted in late April to early May in Indiana

Source: Nielsen 2002
Summary

Dilemma 1:
- High temperatures and rapid drying results in poor grain quality
  - breakage susceptibility, stress cracks, processing quality, end use quality

Solution:
- Do not exceed maximum grain temperatures
- Do not exceed maximum drying rates
- Use medium and low temperature drying systems
Summary

Dilemma 2:
- High temperature, high capacity crossflow drying systems cause temperature and moisture content gradients

Solution:
- Use modified crossflow dryers with ...
  - suction cooling
  - column inverters
  - variable column speeds
- Use mixed flow (rack) or concurrent-flow dryers
Summary

Dilemma 3:

- High temperature, high capacity drying systems cannot improve the initial kernel-to-kernel moisture content variability

Solution:

- Segregate grain based on initial moisture
- Use multiple drying and tempering stages
- Use continuous-flow dryeration process
Summary

Dilemma 4:
- Capacity of high temperature, high capacity drying systems can be significantly affected by hybrid drying rate differences

Solution:
- Choose dryer based on 70-80% of rated drying capacity
- Utilize moisture-based automatic drying control systems
- Use stochastic dryer control
Summary

• When drying poor quality, frost-damaged corn, ...
  – don’t exceed maximum grain kernel temperatures of 120-140 F on doughy kernels to avoid/minimize “dryer damaged” kernels
  – don’t plan to store low quality corn past the cold winter period
  – dry and store at 14% to avoid storage problems
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