AERATION and COOLING of Stored Grain

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IAOM Pest Management Workshop
Professional Experience

GMPRC

20+ years: crop storage & handling research and teaching

1981: B.S. Mechanical Engineering (P.E.)

1980s: corn, tobacco, peanuts (Ky. & NC)

1990s: wheat, barley, & potatoes (Idaho)

2000s: wheat, corn (Kansas)
AERATION and COOLING of Stored Grain

- **Introduction... Grain Storage Basics**
  - Grain Moisture: affect on storage
- **Grain Temperature & Cooling**
- **Grain Aeration Systems**
Grain Storage

The Good News:

*Cool, dry, clean* grain stores very well: we expect no quality loss.

Aeration is the tool to keep grain cool:

Always below 60°F, below 50°F when weather allows.
Grain Storage

The Bad News (grain storage threats):

- Insects
- Fungi (molds)
- Sprouting
- Loss of Germination
- Handling Damage
- Rodents and Birds
- Other (Spoutlines, Moisture Migration, ...)

Grain Storage

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Stored Grain Factors

- Temperature
- Grain Moisture Content
- Initial Grain Quality
  - soundness
  - degree of contamination (fungi, insects, ...)
  - amount of foreign material
- Time in Storage
- Other (Oxygen Supply, pH, ...)

- Cool
- Dry
- Clean
Stored Grain Factors

- Temperature
- Grain Moisture Content
- Initial Grain Quality
  - soundness
  - degree of contamination (fungi, insects, ...)
  - amount of foreign material
- Time in Storage
- Other (Oxygen Supply, pH, ...)
Dealing with the Threats

The Top Two Threats

- Insects: control with temperature
- Fungi (molds): control with moisture
GRAIN MOISTURE
Dry vs. Wet Grain

For this lecture:
- Emphasis on dry grain (or over-dry).
  - Moisture problems usually very limited.
  - Insects usually the bigger issue (temperature).
    - Low moisture content may slow or stop some primary infesting insects.
Grain Moisture Equilibrium

Corn Moisture Isotherm (68°F)

Equilibrium Moisture Content, %

Relative Humidity, %
Grain Moisture & Mold Control

◆ Moisture Content
the key to mold control

<table>
<thead>
<tr>
<th>Corn at 68°F</th>
<th>M.C.</th>
<th>ERH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 %</td>
<td>79 %</td>
</tr>
<tr>
<td></td>
<td>15 %</td>
<td>73 %</td>
</tr>
<tr>
<td></td>
<td>14 %</td>
<td>66 %</td>
</tr>
</tbody>
</table>

Relative Humidity, %

60% 70% 80%

Storage Mold Growth

Min. 65% Max.
<table>
<thead>
<tr>
<th>Grain Stored</th>
<th>South</th>
<th>Central</th>
<th>North</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn/Milo</td>
<td>13</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Soybeans</td>
<td>12</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Wheat/Barley</td>
<td>11</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Sunflower</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>
Grain Moisture

Average Moisture Content –

Very little grain is at the “average” moisture content

Must deal with the **highest** moisture content in the bin
Grain Moisture

Moisture migration causes additional moisture variation

Aerate to eliminate temperature differences
Grain Moisture

Watch for “simple problems”

A leak is a leak...
Grain Moisture

Watch for “simple problems”

Spouting can channel leaking water...

Wet grain
Temperature & Insects

Temperature is the key to insect control

60°F

Storage Insect Growth

Max.

Min.

Temperature, °F

60 70 80 90
Temperature & Insects

- Optimum for population growth
- Helpful to slow population growth
- Generally stops population growth
- Leads to eventual death of storage insects
- Winter storage (stops moisture migration)
- Only way to achieve quick kill...
Insect Control in Stored Grain

Meet **SAM**: Sanitation, Aeration, Monitoring
Insect Control in Stored Grain

**Sanitation**
- eliminate sources of infestation

**Aeration**
- cool immediately to slow development

**Monitoring**
- temperature & insect numbers
Controlled Aeration

Using thermostatic controllers to automate the aeration cycles

Objective: keep grain within 10 – 15°F of average ambient temperature

Summer: Cool grain immediately below 75°F

Fall: Cool below 60°F as soon as weather permits

Late Fall: Cool to 40°F for winter storage
Controlled Aeration

- Simple aeration controllers are:
  - cheap (pay off ≤ one year)
  - easy to use (thermostat + hour meter)
  - effective and efficient
  - and should be on every grain bin.
Controlled Aeration

Using thermostatic controllers to automate the aeration cycles
Grain Storage Cycle

- Cool grain immediately below 75°F
- Cool to 60°F as soon as feasible (weather)
- Maintain the grain
  - monitor temperatures: aerate as needed
  - monitor insects: aerate/fumigate as required
- Cool to 40°F for winter storage
- Maintain the grain – seal fan opening
Grain Storage Cycle

- Cool grain immediately below 75°F
- Cool to 60°F as soon as feasible (weather)
- Maintain the grain
  - monitor temperatures: aerate as needed
  - monitor insects: aerate/fumigate as required
- Cool to 40°F for winter storage
- Maintain the grain – seal fan opening
Year-Round Grain Storage

Receive Grain All Year

- Insect infested grain mixed with clean grain
- Insects move through the system with grain
- Insect numbers often higher than on-farm
- Segregate by infestation level and treat
Year-Round Grain Storage

Storage Fundamentals

- Sanitation in and around grain bins
- Cooling grain (controlled aeration)
  - lower airflows (cfm/bu) important for cost
  - pressure systems add more heat with deep bins
- Monitoring grain
Grain Storage Safety

- Know & avoid equipment hazards
  - Practice lockout / tagout

- Always know the bin history
  - Beware: flowing grain (stay out!)
  - Beware: bridged grain (stay off of it)
  - Beware: steep piles (stay away from it)
  - Beware: dust/mold spores (wear mask)
  - Beware: CO₂ buildup (ventilate)

- Stop grain dust fires & explosions
  - Beware: grain dust & sparks (eliminate!)

Don’t be that Guy!
Grain Storage Safety

**Hazards:** Grain Dust is the Big One

- Grain dust is an airborne pollutant
  - Long-term effects under investigation
  - Nuisance in surrounding residential areas

- Grain dust is a fire and explosion hazard
  - Powerful and deadly explosions
  - Requires three ingredients
Grain Storage Safety

Stopping Grain Dust Fires/Explosions

- Grain dust suspended in air
  - Design and manage to eliminate dust

- Sparks initiate a flame (at 400°F)
  - Design and maintain to avoid sparks/hotspots

- Confined area permits high pressure/explosion
  - Design to eliminate confined areas
Grain Aeration Systems
Grain Aeration Systems

- Economics of Insect Treatments
  - Fumigation w/ turning
  - Fumigation
  - Turning
  - Aeration

lower cost
### Grain Aeration Systems

**Recommended Airflow Rates for Dry Grain** *(Foster & Tuite, 1982)*:

<table>
<thead>
<tr>
<th>Storage Type</th>
<th>Temperate Climate</th>
<th>Subtropic Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>0.05 → 0.10</td>
<td>0.10 → 0.20</td>
</tr>
<tr>
<td>Vertical</td>
<td>0.03 → 0.05</td>
<td>0.05 → 0.10</td>
</tr>
</tbody>
</table>

*Higher rates increase control, flexibility, and cost.

**Double these rates for controlled aeration**
Grain Aeration Systems

<table>
<thead>
<tr>
<th>Season</th>
<th>Airflow Rate (cfm/bu)</th>
<th>Cooling Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>0.05</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>36</td>
</tr>
<tr>
<td>Fall</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.05</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>48</td>
</tr>
<tr>
<td>Winter</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.05</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>60</td>
</tr>
<tr>
<td>Spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.05</td>
<td>270</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>54</td>
</tr>
</tbody>
</table>

High humidity increases cooling times (evaporative heat). Cooling times a little longer with controlled aeration.
# Grain Aeration Systems

**Fan horsepower per 1000 bu of wheat:**

<table>
<thead>
<tr>
<th>Depth, ft</th>
<th>Airflow rate (cfm/bu)</th>
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<th>Airflow rate (cfm/bu)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05</td>
<td>0.10</td>
<td>0.25</td>
</tr>
<tr>
<td>100</td>
<td>0.20 hp</td>
<td>0.79 hp</td>
<td>6.1 hp</td>
</tr>
<tr>
<td>50</td>
<td>0.057</td>
<td>0.19</td>
<td>1.3</td>
</tr>
<tr>
<td>20</td>
<td>0.020</td>
<td>0.050</td>
<td>0.20</td>
</tr>
</tbody>
</table>
Pressure vs. Suction Aeration

Suction (downflow)  Pressure (upflow)
Grain Aeration Systems

Airflow Options:

- Pressure (push) System
- Suction (pull) System
- Push-Pull System
- Crossflow Aeration System

Tall Silos
Pressure System Advantages

- Required if warm grain placed on top of cool grain
- Last grain to cool is at top: easily monitored
- Natural convection aids aeration in deep bins
- Fan energy compensates for too cool or moist air
- More uniform airflow in flat storages (long ducts)
- No solar heat pulled in from top to over dry grain
- Won’t cause roof collapse if vents freeze
Suction System Advantages

- Excess moisture is easily detected at top
- Allows you to smell the exhaust at ground level
- Condensation ≈ below the grain; limited in duct
- High inlet brings in less dirt and debris
- Eliminates potential to suck in winter snow
- Can aerate spots in flat storages using plastic
Aeration Duct Selection

- **Arrangements:**
  - “X” System
  - “Y” System
  - Parallel “I”
Aeration Duct Selection

- Best “duct” arrangement:
  - Close to full drying floor effectiveness
  - Less expensive than drying floor

Pad System

\[ d_{wall} = \frac{1}{2} \text{grain depth} \]
Aeration Duct Selection

Aeration Fan Selection

...
Grain Storage Summary

- **Moisture Content** to Control Molds
  ERH < 65 % for long term storage
  Use the highest moisture in the bin

- **Temperature** to Control Insects
  $T \leq 40^\circ F$ in winter (always < 60°F)
  Watch the highest temperature in the bin

- **Safety** Practices to Control Hazards
Grain Storage Summary

Remember **SAM**:  

**S**anitation  
  – eliminate sources of infestation  

**A**eration  
  – cool immediately to slow development  

**M**onitoring  
  – temperature & insect numbers
Grain Storage on the Web
http://www.gmprc.ksu.edu/

- http://pasture.ecn.purdue.edu/~grainlab/
- http://www.oznet.ksu.edu/wheatpage/
- http://www.bae.umn.edu/extens/postharvest/
- http://bru.gmprc.ksu.edu/proj/sga/
Aeration Duct Selection

- **Three criteria:**
  - **Duct spacing** not “excessive”
    - less than ½ grain depth to duct anywhere on floor
  - **Air velocity** < 2500 fpm for pressure system
    < 1500 fpm for suction
  - **Perforated surface area** = 1 ft² per 25 cfm
Aeration Duct Selection

- Miscellaneous:
  - Use well-designed fan-to-duct transition
  - Perforated ducts: minimum 10% open
  - Roof vents: 1 ft²/hp (pressure)
  - In-floor ducts don’t interfere with unloading
  - Effective area = 75% for round ducts on floor
Aeration Fan Selection

1. Select lowest airflow (cfm/bu) for cooling rate

2. Airflow: \( \text{cfm/ft}^2 = (0.8) \times (\text{depth}) \times (\text{cfm/bu}) \)

3. Pressure drop: \( \Delta P = (\text{inH}_2\text{O/ft}) \times (\text{depth}) + 0.4 \)

4. Total airflow: \( \text{cfm} = (\text{cfm/bu}) \times (\text{total bushels}) \)
   or: \( \text{cfm} = (\text{cfm/ ft}^2) \times (\text{floor area}) \)

5. Select fan to deliver flow & pressure (fan data)
Grain Aeration Systems

Double the Recommended Airflows for Controlled Aeration Systems

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Grain Aeration Systems

- Closed-Loop Fumigation (CLF)
  - More effective than probing
  - More efficient than probing
    - time
    - fumigant
  - Safer than probing
    - reduces exposure to fumigant
    - reduces dust
    - eliminates enclosed space entry