Update on Natural Air Grain Drying

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IHARF Soil and Crop Management Seminar
White City Community Center
Wed Feb 4, 2015 1:45
Objective

• To build a fan controller that:
  – is **Efficient** – saves power, fan on only when necessary (if drying, fan on, if not drying, fan off)
  – Provides **Safe** Grain Storage – ie. No spoilage
    • **Cool** grain
    • **Dry** grain

Strategy

Only run the fan when ambient air conditions will result in the drying of the grain;

OR: only run the fan to make the grain as cold as possible??
SAFE STORAGE TIME (days) CEREAL GRAINS

\[
\log_{10} (\text{safe days}) = 6.2 - 0.3 \, \text{MC}\% - 0.07 \, ^\circ\text{C}
\]
Fraser & Muir

<table>
<thead>
<tr>
<th>Grain Temp °C</th>
<th>Grain Moisture Content</th>
<th>germination reduced by 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>14%</td>
<td>15%</td>
<td>16%</td>
</tr>
<tr>
<td>-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
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</tr>
</tbody>
</table>

14.5% @ 30°C = 38 safe days
14.5% @ 20°C = 128 safe days
14.5% @ 0°C = 1458 safe days

not safe

very dangerous

Safe storage > a year

80-120 40-60 40-60 40-60 20-30 20-30 20-30

5-8 3-5 3-5 3-5 3-5 3-5 3-5

< 5
Vapour Pressure

Air surrounding kernel

Water trying to get in
= Vapour Pressure Air
• temperature
• relative humidity

Grain kernel

Water trying to get out
= Vapour Pressure Grain
• % moisture content
• temperature
• type & condition of grain

When air vapour pressure is greater than grain vapour pressure, water enters the grain and WETTING occurs. When Vps are equal, → EMC

When grain vapour pressure is greater than the air vapour pressure, water evaporates from the grain into the air and we have DRYING
Controller – Vapour Pressure?

• Fan ON only if $VP_{grain} > VPair$
• This is not practical because:
  – Although $VPair$ is easy to determine from temperature and relative humidity; it varies across the bin
  – $VP_{grain}$ can not be measured directly, and it too varies across the bin.
  – We need another approach
The Black Box Approach

If $H_2O$ OUT $> H_2O$ IN then FAN ON (drying)

If $H_2O$ IN $> H_2O$ OUT then FAN OFF (wetting)
Lbs Water OUT – Lbs Water IN = Water Removed

If the Water Removed is positive, then this is the amount of water that must have come from the grain and therefore we are DRYING.

If the Water Removed is negative, i.e., there is more water that went in than came out; then the water must have gone into the grain: :: WETTING

For example: let’s say that in one hour we measured 80 lbs of water going into the bin and 90 lbs of water coming out. The net result is 10 lbs of water being removed from the bin. And it must have come from the grain, so we are drying.

But how do we measure the amount of water going in and out? How much water is the air carrying?
Maximum Amount of Water that 6000 cu ft of Air Can Hold

<table>
<thead>
<tr>
<th>Temperature Deg F</th>
<th>lbs water @100%RH</th>
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<tbody>
<tr>
<td>20° F</td>
<td>1 lbs</td>
</tr>
<tr>
<td>40° F</td>
<td>2.5 lbs</td>
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<tr>
<td>60° F</td>
<td>5 lbs</td>
</tr>
<tr>
<td>80° F</td>
<td>9.5 lbs</td>
</tr>
<tr>
<td>90° F</td>
<td>12.84 lbs</td>
</tr>
</tbody>
</table>

Psychrometric Chart

Table

Formula

Temperature Deg F
Water Holding Capacity

Relative Humidity

- 100%
- 75%
- 50%
- 25%

Temperature Deg C

lbs water/6000 cf
H₂O IN/OUT Example

• We have a 2000 bu. Bin with an aeration fan with a flow of 3000 cfm. The air:
  – entering the bin is 60°F @ 55% RH.
  – leaving the bin is 80°F @ 45% RH.

• Are we drying?

• How much?
Amount of Water that 6000 cu ft of Air Can Hold

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>Water at 100% RH</th>
<th>Water at 45% RH</th>
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<tr>
<td>80</td>
<td>9.5 lbs</td>
<td>4.27 lbs</td>
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<tr>
<td>60</td>
<td>4.97 lbs</td>
<td>2.74 lbs</td>
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</table>

Formula:

\[\text{Amount of Water} = \text{Temperature} \times 0.45\]
The Black Box Approach

Black Box = Grain Bin

$\text{H}_2\text{O IN}$

2.74 lbs at 60°F 55% Per 6000 cu ft.

$\text{H}_2\text{O OUT}$

4.27 lbs at 80°F 45% Per 6000 cu ft.

If $\text{H}_2\text{O OUT} > \text{H}_2\text{O IN}$ then FAN ON (drying)

4.27 lbs > 2.74 lbs $\rightarrow$ FAN On (1.53lbs/6000)

Fan 3000 cfm or 6000 cu ft/2 min $\rightarrow$ 46 lbs/hr drying
What we did

• Instrumented Two Bins and measured on an hourly basis:
  • Temp and Humidity – air in and out
  • Air Flow
  • Temp of Grain at three levels
• On a daily basis measured grain moisture at 4 levels

Have done this for 7 years with 3 different grains – peas, barley, and wheat: 23 runs
Sampling ports for Grain Moisture
RH and Temperature Probe On Inside Top of Bin Recording RH and T°.
Therefore we know the temp & RH of the air leaving the bin, and we can calculate the number of lbs of water leaving the bin per hour.

Sensor measuring T and RH of the air leaving the bin

Amount of Air Out = Amount of Air In

can calculate the number of lbs of water entering the bin per hour.

Sensor measuring T and RH of the air entering the bin
## Data Stored Hourly in Excel

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<th>Date / Time</th>
<th>10-LOW LEVEL TEMP</th>
<th>10-MID LEVEL TEMP</th>
<th>10-HI LEVEL TEMP</th>
<th>10-DISCH TEMP</th>
<th>10-DISCH HUMID</th>
<th>10-FAN CFM</th>
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<th>Outside RH</th>
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<td>77.75</td>
<td>3552</td>
<td>10.61</td>
<td>91.31</td>
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</table>
Pea Bin 10 2009

hours

lbs water removed/hr
Bin 9  Wheat 17% - 13.5%  Start 2:09 PM  Sept 9  continuous for 190 hrs (8 days)

Switch from drying to wetting at 9:30 AM, -- turn the fan off by 9 in the morning

If we turned the fan on only at night for 3 days, would take 20 + 12 + 12 = 44 hrs with MC to 14.2%
H₂O removed (gr) per cubic meter of air flowing through bin

Average Diurnal Drying Cycle of 19 trials

Best Drying ~ 2 AM

Drying to Wetting 9:30 AM

Most Wetting

Wetting to Drying 6:00 PM

Night               Morning             Noon    Afternoon         Evening
Air is typically holding the most water just after noon 1:00 PM.

Least Water at 6:30 AM.

There is a strong correlation between drying and dry air.

Air is typically wet during the day and therefore we get wetting of the grain.

Air is typically dry at night and therefore we typically dry the grain at night.
How Do Temperature Cycles Line Up with Drying Cycles?

Outside Air Temperature (°C)

Typical High 23.5° C
~ 3:00 PM

Grain Temperature

Drying when grain temp is decreasing

Cooling is Drying
Our data shows that cooling the grain by about 15° C will lower the Moisture Content by 1%

25.6° 3:09 PM

25.7° 3:09 PM

Heating the Grain Wets it
Our data shows that heating the grain by about 30° C will increase MC by 1%

So a good control strategy would be to only run the fan when the grain is cooling, i.e., Outside Temp < Grain Temp

Typical 11° 5:30
2014 trial – comparing continuous with new control

- Start: Aug 19 12:37 PM
- 2200 bu, barley
- Start Temp of Grain: 29.8° C
- Control Strategy: On Continuous
- 5 HP Flaman Fans – 3400 CFM – 7” H₂O
- End Sept 2 1:37 PM

<table>
<thead>
<tr>
<th>Bin #9</th>
<th>Bin #10</th>
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<tbody>
<tr>
<td>Start</td>
<td>Nine</td>
</tr>
<tr>
<td>2014 trial</td>
<td>–</td>
</tr>
<tr>
<td>2200 bu, barley</td>
<td>18.2%</td>
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<td>Start Temp of Grain:</td>
<td>29.8° C</td>
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<td>Control Strategy:</td>
<td>On Continuous</td>
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<tr>
<td>5 HP Flaman Fans – 3400 CFM – 7” H₂O</td>
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<tr>
<td>End Sept 2 1:37 PM</td>
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Continuous vs Controlled: 2200 bu of barley, 18% MC, 29.5°C
Started Tue Aug 19, 2014 12:37 – End Tue Sep 2 1:37
Continuous(9) vs Control (10)

- Continuous dried more: (9) 15.2% (10) 15.7%
- Continuous warmer grain: 18.2° 11° C
- Continuous more fan hours: 174 17 hrs
- @0.10/kwh 5HP $64.38 $6.29
- Bot -Top MC spread (9) 5%: 12.9 13.6 16.3 18 whereas control (10) had spread < 1%
- Control gets more into the safe zone, quicker
<table>
<thead>
<tr>
<th>Grain Temp °C</th>
<th>Grain Moisture Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>14%</td>
<td>80-120</td>
</tr>
<tr>
<td>15%</td>
<td>40-60</td>
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<td>16%</td>
<td>40-60</td>
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<td>17%</td>
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<td>23%</td>
<td>10-15</td>
</tr>
<tr>
<td>24%</td>
<td>10-15</td>
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</table>

- **< -5**: Safe storage > a year
- **10**: Safe storage
- **15**: Safe storage
- **20**: Safe storage
- **25**: Safe storage
- **30**: Safe storage

**NOT SAFE**

**VERY DANGEROUS**
What have we learned from the data!

• The *black-box* approach accurately measures the amount of drying/wetting. Verified with mass-balance.

• There is clearly a daily cycle of drying and wetting of grain.

• Wetting never occurs at night. Drying to wetting ~ 9:00 AM

• Drying occurs at night and occasionally during the day if dry.

• Cooling the grain – dries the grain (15ºC/%). The first night typically lowered the temp by 10º C. This lowered MC by 0.5% to 1.5%. Driest air and best drying conditions are typically at night; wettest air and wetting conditions typically occur during the day.

• Cold air, even freezing air, can dry grain

• Not a drying ‘front’ but a drying ‘gradient’— cause $\Rightarrow$ (compression)

• A simple, effective and safe control strategy would be to only have the fan ON when: Outside Air Temp + Offset $\leq$ Grain Temp

• Could use smaller fans ie less than one cfm/bu

• Following this control strategy will result in the least fan time and the SAFEST storage. (dry, cold grain) It’s best to work with Mother Nature!
First 24 Hours is Critical
Average of 33 Runs 2007 – 2014

- First 24 Hours: Start End Difference
- Grain Temp ⁰C 26.2 14.6 11.6
- Moist Cont % 17.65 16.77 0.88
- Safe Days 6 32 26
- Cooling/Drying 11.6/0.88 = 13.18 ⁰C/%MC

New Definition: Accumulated Deterioration = \( \sum \frac{1}{\text{safe days}} \times 100 \)

Example, if safe days is six, then after 3 days we will have an accumulated deterioration of: \( (1/6 + 1/6 + 1/6) \times 100 = 50\% \), after 6 days: \( (6 \times 1/6) \times 100 = 100\% \) accum. deterioration, 95% germination
09 10P

If fan turned off here, safe days constant @ 63.8 Accum Deterioration 4.66%
The Good, the Bad, and the Ugly: Guide for NAD

- **UGLY** – do nothing – get to it later. The first day is critical, get the temp down, even if the grain is dry – could even use a small 1 HP

- **BAD**: ON hot days, OFF at night. It does work, but Hot Wet grain – could end up badly. This is risky.

- **OK**: ON Continuous. This also works,
  - but not good to heat and wet the grain during
  - the day; and we are running the fan needlessly.

- **GOOD**: ON only at night. Yard Light rule: On at nite, you are bright; on during the day, you will pay. Turn off at 9 AM.

- **BETTER**: On only on cold nights. More efficient, less fan time and colder, safer grain storage.

- **BEST**: ON iff: Air Temp + Offset < Grain Temp

Strategy: Keep the grain as cold as possible and it will result in the least fan time & safest storage. Electronic control simple.
Best Control

- Turn the fan on immediately upon filling the bin with grain that is hot from the field, with more moist grain at the bottom.
- Leave fan on until 9 AM next day.
- Keep the grain as cold as possible by following this simple rule:
  - Fan ON if  Outside Temp + Offs< Grain Temp
  - OR: Drive the temp of the grain down as far as you can.
More to Learn

- Proper Offset: On if $T_{air} + Offset < T_{grain}$
- Mitigate MC content difference Top to Bottom
- Smaller Fans?
- Reversing Fans
- More sensors to get clarification “drying front”
- Larger bins $> 10,000$ bu
- More crops: oilseeds,
- Longer term studies: what happens in spring?
SPONSORS

• Western Grains Research Foundation (WGRF)
• Advancing Canada’s Agriculture and Agri-Food Saskatchewan (ACAAFS)
• Agriculture and Agri-Food Canada (AAFC)
• Indian Head Agricultural Research Foundation (IHARF)
• Great West Controls - Saskatoon
• 1200 hrs fan on -- $533 \times $0.10/kwhr
• Removed 5114 kg (11271 lbs) H₂O \(24.5\% \text{ to } 16.67\%\)
  removed 7.83\%
• First 48 hours removed 1609 kg H₂O \(\text{to } 22.3\%\)
  • MC lowered by 2.2\%
  • Grain temp lowered 48.5 to 14.1\º C \(15.6\º\text{C/\%}\)
• Final Grain Temp: 3º C
• 251 hrs fan on -- $93 @ $0.10/kwh  (21% of continuous)
• Removed 3690 kg (8132 lbs) H$_2$O  25.4% to 20%
  lowering the MC by 5.4%
• First 24 hours removed 987 kg H$_2$O  lowered MC 1.4%
  • Grain temp lowered 43.25 to 20.5° C   16°C/%
  • Fan Stopped at 9:30
• Warming: no fan  40 hr./deg > 0   88 hr./deg < 0
• Nov 22 -20.5 to -24.5 removing 80.5 kg H$_2$O  34° /%
• Final Grain Temp:  -24.5° C