New Insights into Natural Aeration Grain Drying

Agri-ARM Research Update
Saskatoon Inn
Friday Jan 11, 2013  1:45 - 2:30

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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??
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 VPgrain > VPair

• This is not practical because:
  – Although VPair is easy to determine from temperature and relative humidity; it varies across the bin
  – VPgrain can not be measured directly, and it too varies across the bin.
  – We need another approach
The Black Box Approach

If $H_2O \text{ OUT} > H_2O \text{ IN}$ then FAN ON (drying)

If $H_2O \text{ IN} > H_2O \text{ OUT}$ 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, ie 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

- 9.5 lbs at 80°F
- 5 lbs at 60°F
- 2.5 lbs at 40°F
- 1 lb at 20°F
- 12.84 lbs at 90°F
Water Holding Capacity

![Graph showing the relationship between temperature and water holding capacity with relative humidity]
H₂O IN/OUT Example

• We have a 2000 bu. Bin with an aeration fan with a flow of 3000 cfm. The air going into the fan and into the bin is 60° F @ 55% RH. The air leaving the bin is 80° F @ 45% RH. Are we drying? How much?

• From the previous psychrometric chart for 6000 cu ft, 80° @ 45% = 4.27 lbs H₂O ->air
  6000 cu ft, 60° @ 55% = 2.74 lbs

• Every 2 min remove 1.53 lbs ::(drying)
Amount of Water that 6000 cu ft of Air Can Hold

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<th>Temperature Deg F</th>
<th>lbs water in 6000 cf</th>
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<td>80° F 100%</td>
<td>9.5 lbs</td>
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<td>60° F 100%</td>
<td>4.97 lbs</td>
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<td>60° F</td>
<td>2.74 lbs</td>
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Saturation

9.5 x .45 = 4.27

4.97 x .55 = 2.74
The Black Box Approach

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 (1.53 lbs/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 5 years with 3 different grains
– peas, barley, and wheat
Sampling ports for Grain Moisture

Temperature Probes
Air Tubes for Recording CFM
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.

Amount of Air Out = Amount of Air In

Sensor measuring T and RH of the air entering the bin.

can calculate the number of lbs of water entering the bin per hour.
## Data Stored Hourly in Excell

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Pea Bin 10 2009

Pea Bin 10 2009
-100.0
-50.0
0.0
50.0
100.0
150.0
200.0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113

4 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 9:00 AM, -- turn the fan off at 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%

-1.8% so MC = 15.8% by 9 AM
Air is typically holding the most water just after noon, 1:00 PM.

There is a strong correlation between drying and dry air.

A strategy would be to turn the fan on only when the air is dry or below this line.

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?

Typical High 23.5 °C
~ 3:00 PM

Outside Air Temperature (°C)

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%

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.
Trial 3 Sept 14 2007 3:28 AM, it froze

- 2283 lbs H2O removed
- Reduces MC by 1.9%
- With 12.25°C temp drop
- So freezing air can dry

Freezing -2°C
Yet still removing water
Drying in Freezing Temperatures

Wheat Oct 17, 2010

143 kg of water removed
Reducing MC by 0.3%

9:23 AM

-2°C 7AM Oct 17 2010
Control Bin 10 Wheat 2012 first run

Started Aug 17 5:25 PM
17.86% MC
Grain Temp 32.2°C

Ran Fan for 115 / 420 hours

Temperature does go up slowly when fan is off, but only a fraction of a degree/day

Can heat a few degrees with little wetting

Ended Sept 4 9:20 AM
MC = 14.5%
Grain Temp 14 ºC

Remove 162 lbs with only 2.2º drop

7:25 AM
Drying Front – Bottom Dries First -- WHY??

Bottom Dries First and Lowest

Top layers dry last

Low level lags

Moisture Content of Grain % dw
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 < Grain Temp
  • OR: Drive the temp of the grain down as far as you can.
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 (15⁰C/%). The first night typically lowered the temp by 10⁰ C. This lowered MC by 0.5% to 1.0%. 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 → (compression)
- A simple, effective and safe control strategy would be to only have the fan ON when Outside Air Temp <= 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!
Removed over 2% MC by 7:00 AM
10wheat2100 start Sep13 14:25 16.25% 25.5°C
stop Sep21 9:01 13.6% 11.2°C

Over 1% removed by 9:01
Top ~16%   Bottom ~ 14%
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
16 start Aug23 10:05 17.5% 29°C
barley3500 stop Sep3 7:30 12.56% 15°C
18 start Sep4 2:29 17.55% 30.2° C
barley3500 5Hp stop Sep21 8:29 13.95% 10.5° C
19 start Sep 4 2:29 18.9% 30°C
barley3500 5Hp stop Sept 21 8:29 13% 11°C
Bin 10 2011

lbs water vs. hours

0 1 16 31 46 61 76 91 106 121 136 151 166 181 196 211 226 241 256 271 286 301 316 331 346 361 376
Start 2:30 to 9:30 AM remove 532 lbs

Add 152 lbs

During next day 19°
Start 5PM 25°C Wheat 15.6%
First Night 500 lbs removed grain cooled 23° to 16°

9AM  6PM
27° 76 lbs

➢10 lb/hr would remove 4332 lb
➢In 134 hours about 60% time
Start 1:30PM to 9AM removed 1370 lbs
Wheat chilled from 20° to 4°
Outside temp goes to -3°
Bot
Mid
Top
EMC

Moisture Content (MC) measurements
bin 10  wheat  first run  2012

Fan on or on 1hr before

EMC sensors between Mid and Bottom ports

Bottom Layer Dries First

Measured With Labtronics

Bottom Layer Dries First

Measured from RH and Temp
What’s going on here??

• First day, warm air hits the warm grain and plenty of drying takes place.

• First night, cool dry air hits the warm grain. The air is warmed by the grain, lowering its RH – so it can hold more water, and so it does by drying the grain.

• The next day, the warm moist air hits the cool grain, cooling the air. Moisture is released into the grain.
By observation it was noted that the temp difference of the discharge air minus the ambient air temp is a close match to the drying.

If the discharge temp (temp of grain) > ambient then FAN ON

If the temperature of the grain is greater than the outside air temp, then we are in a drying condition and the fan should be turned on. If the grain temp is < outside air temp, then turn the fan off. The controller only needs to monitor these temps.
Bin 10 2012 second run showing drying conditions

Grain TempH - Out Air

H2O
Controller Strategy

• A controller based on the black box approach of “water-out minus water-in” can and did work, but it has a couple of drawbacks:
  – Awkward in knowing when to start the fan
  – Humidity sensors are not reliable.

• I think a better controller is based on temp:
  Temp difference:  **If** \( T_{Grain} > T_{Air} \) **then** Drying
  – **Simpler**: very few components, -> Low cost & Reliable
  – **Safer**: Keeps grain **as cold as possible** and maximizes the energy gathering, (solar collector) effect of the bin.
Other Observations

• The controlled bin had a less distinct drying front. (MC content, top to bottom –closer)
• Provided that we can cool the grain to a safe temp. the first day; there might be an advantage in using a smaller fan to conserve the energy in the grain??
• Change our way of thinking: we must cool the grain before it spoils, rather than dry the grain before it spoils.
It Works!

• Chad Skinner has tried this with side by side trials and found the on-night/off-day was as effective as the continuous-fan-on.

• Lentils 18% to 14% in 5 days (3hp 2000 & 3300)

• Wheat 17% to 13% in 7 days (7.5hp 5000bu)

• Canola

Conclusion: Only need to run the fan a fraction of the time and your grain will be **cooler** and **safer**
Conclusions

• Best drying conditions are when the air is cold and the grain is hot.

• It's not a race to dry the grain before it spoils, it is a race to cool the grain before it spoils.

• For the best grain storage, keep the grain as cold as possible. < spoilage, < OTA, < mold

• Only need to run the fan half the time (night), 50% saving in electricity.

• Best strategy is to run the fan only if we are drying the grain.

• Adding supplemental heat is not required, and can increase the risk of spoilage.