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??
Vapour Pressure

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 $VP_{grain} > VP_{air}$
- This is not practical because:
  - Although $VP_{air}$ is easy to determine from temperature and relative humidity; it varies across the bin
  - $VP_{grain}$ cannot be measured directly, and it too varies across the bin.
  - We need another approach
The Black Box Approach

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

If $\text{H}_2\text{O} \text{ IN} > \text{H}_2\text{O} \text{ OUT}$ 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

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<tr>
<th>Temperature Deg F</th>
<th>lbs water @100%RH</th>
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<td>80</td>
<td>9.5</td>
</tr>
<tr>
<td>90</td>
<td>12.84</td>
</tr>
</tbody>
</table>

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

Psychrometric Chart
Water Holding Capacity

Relative Humidity

- Relative Humidity:
  - 100%
  - 75%
  - 50%
  - 25%

- Temperature (Deg C):
  - -10 to 30

- Water Holding Capacity (lbs water/6000 cf):
  - 0 to 14

Graph showing the relationship between temperature and water holding capacity at different relative humidity levels.
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

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<th>Temperature Deg F</th>
<th>lbs water in 6000 cf</th>
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<tr>
<td>60</td>
<td>2.74 lbs at 60° 100%</td>
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<tr>
<td>80</td>
<td>4.27 lbs at 80° F 45%</td>
</tr>
<tr>
<td>80</td>
<td>9.5 lbs at 80° F 100%</td>
</tr>
</tbody>
</table>

Saturation

4.97 x .55 = 2.74

9.5 x .45 = 4.27
The Black Box Approach

**H₂O IN**

- 2.74 lbs at 60°F 55%
- Per 6000 cu ft.

**H₂O OUT**

- 4.27 lbs at 80°F 45%
- Per 6000 cu ft.

If H₂O OUT > H₂O IN then FAN ON (drying)

4.27 lbs > 2.74 lbs → FAN On (1.53 lbs/6000)

Fan 3000 cfm or 6000 cu ft/2 min → 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

Temperature Probes
Panel with Instruments
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 leaving the bin

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 Excel

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<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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Pea Bin 10 2009

lbs water removed/hr

hours
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 = 15.2% by 9 AM
Air Wetness (how much water is in the air) kg/6000cf

Air is typically holding the most water just after noon 1:00 PM

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

A strategy would be to turn the fan on only when the air is dry or below this line
How Do Temperature Cycles Line Up with Drying Cycles?

Typical High 23.5°C
~ 3:00 PM

25.6°C 3:09 PM

Outside Air Temperature (°C)

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

Cooling is Drying

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

2.6°C 5:09 AM
Typical 11°C 5:30

Grain Temperature

Drying when grain temp is decreasing

Heating the Grain Wets it

Our data shows that heating the grain by about 30°C will increase MC by 1%
| Field | Start | Finish | Overall Hrs | Hrs. Fan On | % 1st loss | Low Temp | Mid Grain Temp | High Grain Temp | MC% start | CFM | Transition Dry-Wet | Kg net loss | Kg wet | Kg dry | Mid °C dec / MC% | Top °C dec / MC% | MC% loss measured | MC loss calculated | % ambient °C | Air amb °C | Ave Temp | End of Run |
|-------|-------|--------|-------------|-------------|-------------|-----------|---------------|----------------|------------|------|-------------------|------------|--------|--------|----------------|---------------|-----------------|-----------------|-------------|-----------|----------|----------|----------|
| 07 1  | Fir WA29 16:28 S7 23:28 | 225 210 | 0.5 | 20.1 19.1 17.5 | 15.6 | 3318 | 8:45 | 1445 | 574 | 2018 | 12.0 | 7.6 | 3 | 3.1 | 16.6 | 18.3 |
| 07 2  | WS13 13:28 S25 23:28 | 300 250 | 1.3 | 14.0 13.4 11.9 | 16.3 | 3168 | 9:15 | 1690 | 487 | 2177 | 10.9 | 9.4 | 3.8 | 3.6 | 14.3 | 11.9 |
| 07 3  | WS27 12:28 O12 12:28 | 362 345 | 0.7 | 10.8 10.5 9.5 | 3129 | 9:15 | 1357 | 394 | 1751 | 9.8 | 10.1 | 3.2 | 2.9 | 10.8 | 8.25 |
| 08 10B| Bc A29 17:18 S10 18:18 | 291 283 | 1.1 | 14.3 13.7 13.1 | 17.2 | 3632 | 7:45 | 1514 | 322 | 1837 | 10.6 | 8.5 | 3.57 | 3.3 | 18.0 | 12.4 |
| 08 09P| Pc A20 10:28 A22 14:21 | 54 52 | 2.9 | 21.9 21.9 22.7 | 14.5 | 8703 | 1421 | 0 | 1421 | 3.7 | 6.3 | 3.95 | 3.1 | 15.0 | 21.1 |
| 08 09W| WS12 15:28 S24 13:28 | 288 286 | 2.4 | 16.1 15.6 14.7 | 14.6 | 4997 | 9:55 | 2729 | 1092 | 3821 | 7.8 | 7.0 | 3.33 | 3.5 | 12.0 | 14.2 |
| 08 10W | W O8 10:18 O10 7:18 | 215 212 | 0.9 | 13.6 13.2 12.0 | 17.2 | 3499 | 8:48 | 1087 | 207 | 1295 | 12.8 | 8.6 | 3.3 | 2.3 | 7.9 | 11.8 |
| 09 0B | Bc S6 10:36 S12 15:36 | 151 149 | 2.2 | 19.1 18.7 17.0 | 15.4 | 5183 | 8:15 | 1153 | 397 | 1550 | 12.0 | 8.5 | 1.73 | 2.5 | 20.0 | 17 |
| 09 0B | Bc S6 10:36 S25 13:36 | 461 458 | 1.7 | 20.3 19.8 18.8 | 17.0 | 3113 | 8:03 | 1813 | 845 | 2658 | 14.3 | 11.0 | 4.45 | 3.9 | 20.4 | 18.3 |
| 09 10P | Pc A29 13:36 S3 8:36 | 117 113 | 1.2 | 19.1 18.7 18.1 | 15.6 | 4888 | 7:24 | 327 | 845 | 1218 | 16.8 | 7.9 | 1.4 | 0.8 | 18.8 | 9.3 |
| 09 09W | WS14 12:36 S25 13:36 | 267 265 | 1.7 | 20.9 19.5 18.2 | 17.3 | 4772 | 8:45 | 2094 | 1117 | 3211 | 7.4 | 6.0 | 4.4 | 4.5 | 20.3 | 9.1 |
| 10 10 | WS23 14:23 O24 14:2 | 746 650 | 0.5 | 13.9 12.6 10.8 | 20.5 | 3004 | 10:30 | 3107 | 1471 | 4578 | 15.0 | 11.6 | 6.8 | 6.7 | 9.5 | 12 |
| 10 09 | WS26 12:23 O24 14:2 | 676 572 | 1.1 | 14.2 13.0 12.1 | 18.5 | 3270 | 9:29 | 2717 | 1652 | 4369 | 13.9 | 11.6 | 6.18 | 5.9 | 9.4 | 11.9 |
| 11 10 | Ul S2 9:51 S12 6:51 | 239 173 | Run ruined because of faulty discharge relative humidity sensor -- |
| 11 10 | Ul S2 9:58 | 239 231 | 2 | 20.0 16.5 15.9 | 18.4 | 2953 | 9:13 | 1585 | 571 | 2156 | 11.7 | 9.4 | 3.83 | 3.4 | 19.0 | 18.8 |
| 12 09 | WA17 19:29 A27 7:29 | 230 162 | 1.4 | 20.6 19.0 18.4 | 16.9 | 4077 | 6:30 | 733 | 554 | 2120 | 13.1 | 13.5 | 2.98 | 2.1 | 19.1 | 18.9 |
| 12 09 | WS13 14:09 S21 9:09 | 189 188 | 1.7 | 14.2 12.9 12.2 | 17.1 | 3867 | 9:09 | 1540 | 421 | 1960 | 7.4 | 6.6 | 4.55 | 3.3 | 13.3 | 13.1 |
| 12 10 | WA17 19:29 A27 6:29 | 229 62 | 1.1 | 16.6 14.6 16.2 | 17.9 | 3042 | 639 | 98 | 737 | 18.7 | 18.0 | 2.36 | 1.8 | 13.0 | 11.9 |
| 12 10 | WS13 14:01 S21 9:01 | 189 187 | 1.1 | 14.3 13.0 11.4 | 16.3 | 2830 | 12:00 | 892 | 268 | 1160 | 12.0 | 14.6 | 2.7 | 1.9 | 11.0 | 13.1 |
| 12 16 | Bc A23 10:05 S3 7:05 | 263 262 | 17.5 | 2054 11:30 | 1538 | 204 | 1742 | 4.93 | 1.9 | 15.0 | 20 |
| 12 17 | Bc A23 10:05 S6 7:05 | 335 98 | 18.3 | 3053 | 9:05 | 1092 | 342 | 1472 | 4.75 | 1.3 | 10.0 | 19.9 |
| 12 18 | Bc S4 1:29 | 417 190 | 17.6 | 3113 | 2268 | 7 | 2274 | 3.6 | 2.8 | 10.0 | 13.2 |
| 12 19 | Bc S4 14:29 | 402 327 | 18.9 | 2959 | 9:15 | 4026 | 227 | 4433 | 5.98 | 5.2 | 9.0 | 13.2 |

Average: 299 249 1.4 16.9 15.9 15.0 17.1 1681 552 2271 11.6 9.8 4.19 3.2 13.6 15.3

for every 3 kg out, we put 1 in

Drying Rate Mass Balance

%MC  °C  °C  °C  %MC  CFM  kg  kg  kg

12 day 10da
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 1.5%. 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 → (compression)
- A simple, effective and safe control strategy would be to only have the fan ON when Outside Air Temp <= Grain Temp + Offset.
- 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!
2013 trial – comparing continuous with new control

- Start: Aug 29 10:00 AM  
  - Nine  
  - Ten
- 2000 bu, barley  
  - 24.5%  
  - 25.4%
- Start Temp of Grain:  
  - 43.5°C  
  - 43.25°C
- Control Strategy:  
  - On Continuous  
  - ON iff: Air Temp < Grain Temp
- 5 HP Flaman Fans – 3400 CFM – 7” H₂O
• 1200 hrs fan on -- $533 @ $0.10/kwhr
• Removed 5114 kg (11271 lbs) H₂O  24.5% to 16.67% removed 7.83%
• First 48 hours removed 1609 kg H₂O  to 22.3%
  • MC lowered by 2.2%
  • Grain temp lowered 48.5 to 14.1º C  15.6ºC/%
• Final Grain Temp: 3º C
• 251 hrs fan on -- $93 @ $0.10/kwh  (21% of continuous)
• Removed 3690 kg (8132 lbs) H₂O  25.4% to 20%
  lowering the MC by 5.4%
• First 24 hours removed 987 kg H₂O  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 H₂O  34° /%
• Final Grain Temp:  -24.5° C
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.
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