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

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

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

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

**Lbs water @100%RH**

- **9.5 lbs at 80° F**
- **5 lbs at 60° F**
- **2.5 lbs at 40° F**
- **1 lbs at 20° F**

**Saturation**

12.84 lbs at 90° F
Water Holding Capacity

Relative Humidity

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

Temperature (Deg C)

Lbs water/6000 cf

Temperature Deg C

Relative Humidity

- 100%
- 75%
- 50%
- 25%
H$_2$O 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?
**Psychrometric Chart**

**Amount of Water that 6000 cu ft of Air Can Hold**

**lbs water @100% RH**

- **9.5 lbs at 80° F 100%**
- **4.97 lbs at 60° 100%**
- **4.27 lbs at 80° F 45%**
- **2.74 lbs at 60°**

**Table**

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<tr>
<th>Temperature Deg F</th>
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**Formula**

- 9.5 x 0.45 = 4.27
- 4.97 x 0.55 = 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 7 years with 3 different grains:
  • peas, barley, and wheat: 23 runs
Sampling ports for Grain Moisture

Temperature Probes
Panel with Instruments
Air Tubes for Recording CFM
RH and Temperature Probe
On Inside Top of Bin Recording
RH and °.
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

Sensor measuring T and RH of the air entering the bin

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

Sensor measuring T and RH of the air leaving the bin

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.
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Pea Bin 2009

The graph shows the hourly water removal rate in pounds (lbs) for Pea Bin 2009. The x-axis represents the hours, and the y-axis represents the pounds of water removed per hour. The data points indicate fluctuations in water removal over time.
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%

-1.8% so MC = 15.2% by 9 AM
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

Wetting to Drying 6:00 PM

Most Wetting
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

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

25.6°C 3:09 PM
25.7°C 3:09 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
Ie Outside Temp < Grain Temp

Typical 11°C 5:30
2.6°C 5:09 AM

Typical High 23.5°C
~ 3:00 PM
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<th>Finish</th>
<th>Overall Hrs</th>
<th>Hrs. Fan On</th>
<th>% 1st loss</th>
<th>Low Temp ⁰C</th>
<th>Mid Grain Temp ⁰C</th>
<th>High Grain Temp ⁰C</th>
<th>MC% start</th>
<th>CFM</th>
<th>Transition Dry-Wet</th>
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<th>kg wet</th>
<th>kg dry</th>
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Run ruined because of faulty discharge relative humidity sensor --

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| 12 09 | SJ | S2 9:58 | S12 6:58 | 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 day 10da %MC °C °C °C %MC CFM kg kg kg Drying Rate Mass Balance for every 3 kg out, we put 1 in
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→( 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 of barley (mc)  24.5%  25.4%
- Start Temp of Grain:  43.5\(^\circ\) C  43.25\(^\circ\) C
- Control Strategy: On Continuous  ON if: Air Temp < Grain Temp
- 5 HP Flaman Fans – 3400 CFM – 7” H\(_2\)O

Bin #9 Bin #10
• 1200 hrs fan on -- $533 @ $0.10/kw hr
• Removed 5114 kg (11271 lbs) H$_2$O 24.5% to 16.67% removed 7.83%
• First 48 hours removed 1609 kg H$_2$O to 22.3%
  • MC lowered by 2.2%
  • Grain temp lowered 48.5 to 14.1$^\circ$ C 15.6$^\circ$C/%
• Final Grain Temp: 3$^\circ$ 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
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 night, 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 if:  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.
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