# Novel Grain Storage Systems

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## Introduction

- **Grain chilling** is a non-chemical preservation alternative to drying.
- Can be done with a heat pump system that could control the temperature and moisture content in stored grains.

Figure 1. On farm grain storage bin

- Chilling **advantages**:
  - Long-term storage of grains without quality deterioration
  - Lower energy requirement than drying
  - Potential for close control of moisture content
  - Increases farmer flexibility for marketing

## Objectives

- Develop heat & mass transfer model for grain-aeration
- Develop a simplified heat pump model
- Integrate heat pump model + grain-aeration model
- Design a model-based controller to optimize the process over time, with changing weather
- Economic analysis of potential on-farm savings
- Improved understanding of grain quality effects

## Equilibrium Moisture Content

- The equilibrium moisture content (EMC): the moisture content of grain after it has been exposed to a particular environment for an infinitely long period of time.

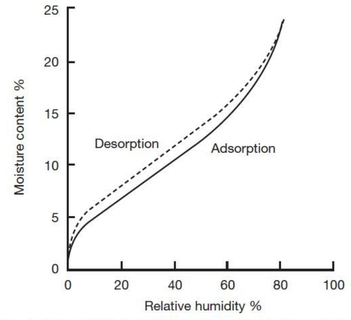


Figure 2. Sorption and desorption isotherms of wheat

## Heat Pump Systems

- Major components:
  - Evaporator + fan
  - Compressor
  - Condenser + fan
  - Expansion Valve
- Fans and compressor can be run at varying speed.

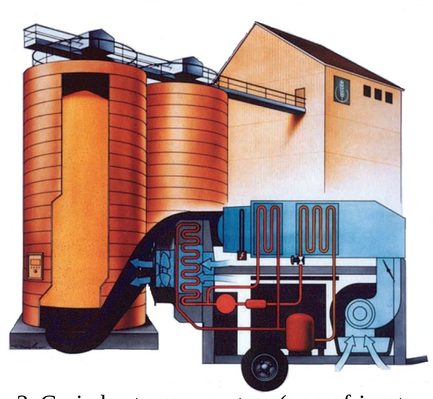

Figure 3. Grain heat pump system (www.frigortec.com)

## Deep-bed Drying Models

- The models for deep-bed drying are classified as:
  - Graphical and logarithmic models
  - Heat and mass balance models
  - Partial differential equation models
- Partial differential equation (PDE) model:
  - Provides a better description of the process.
  - Cannot be solved analytically.
  - Solution process is a numerical integration.
  - Deep-bed modeled as a series of thin layers.
  - Four PDEs must be solved:
    - Mass balance equation
    - Drying rate equation
    - Heat balance equation
    - Heat transfer rate equation
- PDE model was selected and programmed.

## Allowable Storage Time

- Allowable storage time is the storage period before quality loss is expected to affect grain quality.

Table 1. Example: Storage periods (days) for corn

| Grain temperature (°F) | Corn moisture (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **18** | **20** | **22** | **24** | **26** | **28** | **30** |
| **35** | 432 | 214 | 126 | 85 | 62 | 49 | 40 |
| **40** | 288 | 142 | 84 | 56 | 41 | 32 | 27 |
| **45** | 192 | 95 | 56 | 37 | 27 | 21 | 18 |
| **50** | 128 | 63 | 37 | 25 | 18 | 14 | 12 |
| **55** | 85 | 42 | 25 | 16 | 12 | 9 | 8 |
| **60** | 56 | 28 | 17 | 11 | 8 | 7 | 5 |
| **65** | 42 | 21 | 13 | 8 | 6 | 5 | 4 |
| **70** | 31 | 16 | 9 | 6 | 5 | 4 | 3 |

## Model Validation

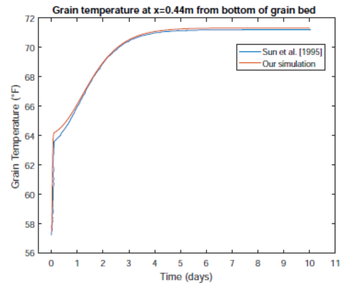


Figure 4. Grain temperature over time

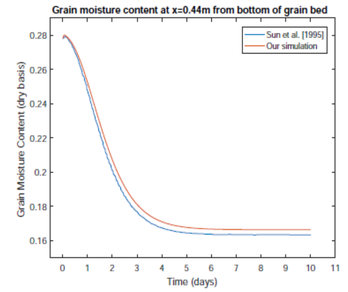


Figure 5. Grain moisture content over time

## Conclusions

- So far, a mathematical model of the grain drying process has been developed.
- The model accurately predicts temperature and moisture content of the grain over time.
- The simplified model can be used in an optimal controller for the storage management systems.
- When complete, this work will demonstrate the potential for advanced control of grain chilling, drying, and moisture management systems, as a cost-effective and energy-saving grain farming technology.