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Research Report

Technical and Economic Assessment of Grain Drying Systems

For:
Keystone Agricultural Producers
Winnipeg, Manitoba

PAMI
Innovative Solutions for Agriculture and Beyond

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Research Report

Technical and Economic Assessment of Grain Drying Systems

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1. Introduction

Grain storage is often a critical and necessary component of crop production. Each bin of grain can be worth tens of thousands (if not hundreds of thousands) of dollars. It represents the producer's investment in management, seed, fertilizer, chemicals, machinery, labour, and marketing. As a result, careful management must continue after the crop is harvested and while it is stored. Good storage management decisions require a comprehensive understanding of the conditions that affect grain quality during storage. The purpose of this document is to shed light on factors that affect moisture movement in the bin and moisture removal from the grain.

2. Safe Storage Times and Target Moisture Contents for Common Crops

The main concern when storing grain is to avoid spoilage. Microorganisms responsible for spoilage thrive in hot and moist conditions, so both temperature and moisture content must be properly managed.

The charts outlining safe storage times for several crops are shown in **Figure 1**, and the moisture content at which different crops are considered "dry" is shown in **Table 1**. Note that the safe storage times depend on both moisture content and seed temperature.

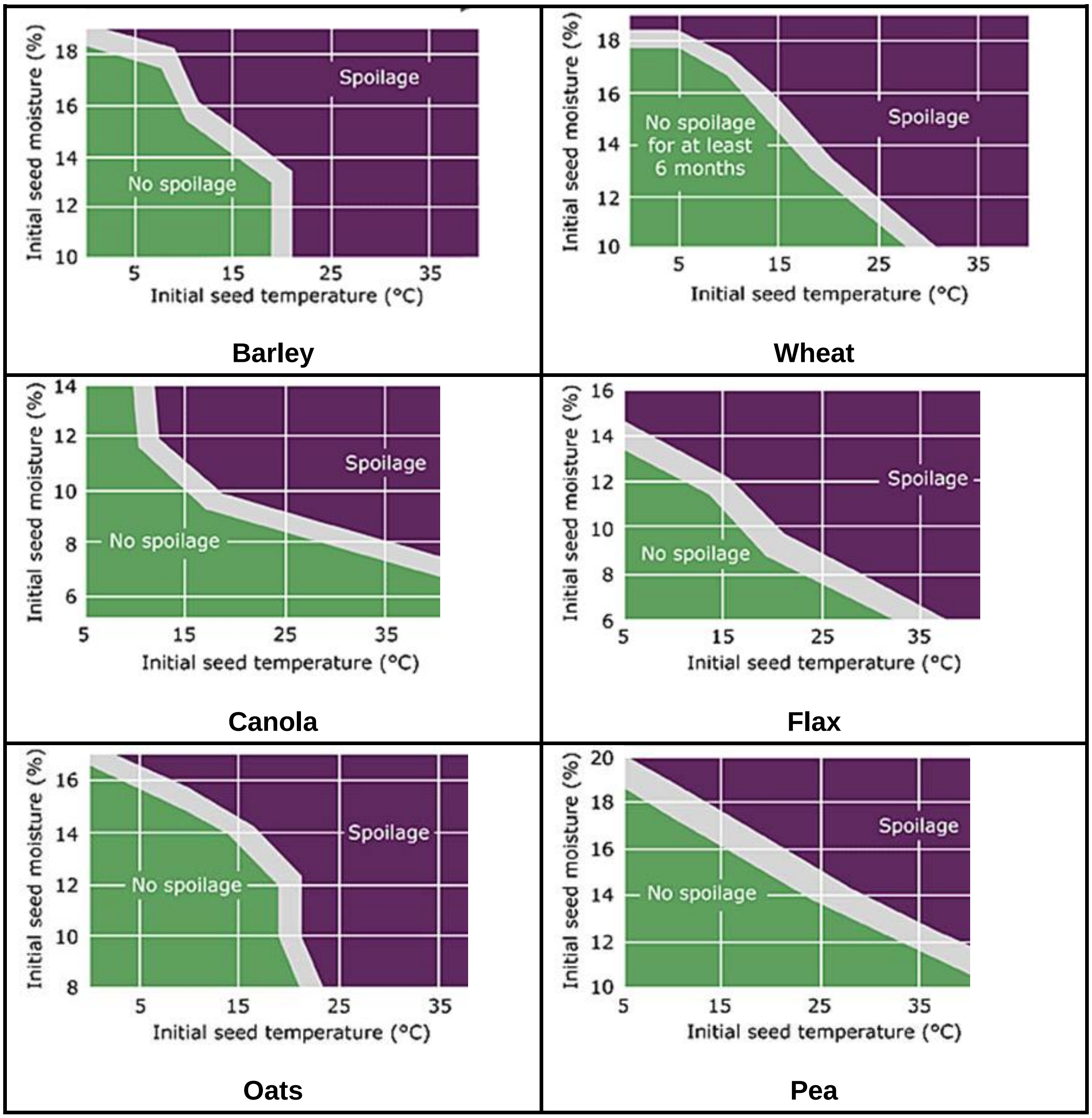

Figure 1. Safe storage times for several crop types (source: Canadian Grain Commission, 2013.

Table 1. Maximum moisture content (% wet basis) of straight grade seeds (source: Canadian Grain Commission Official Grain Grading Guide, 2013).

Cereals	Moisture (%)	Oilseeds	Moisture (%)	Pulses	Moisture (%)	Other Crops	Moisture (%)
Barley (feed)	14.8	Canola	10	Chick peas	14	Buckwheat	16
Barley (malt)	13.5	Flax	10	Fababeans	16	Corn/maize	15.5
Barley (hulless)	14	Mustard seed	9.5	Lentils (green)	14		
Oats	13.5	Safflower	9.5	Lentils (red)	13		
Rye	14	Soybean	14	Split peas	16		
Triticale	14	Sunflower	9.5				
Wheat	14.5						

Even grain that is dry when put in a bin is susceptible to spoilage if the grain temperature is too high. However, even if the grain moisture and temperature are initially in the safe zone, there may still be a danger of spoilage due to “hot spots” forming and moisture migration. Temperature and moisture variations may be caused by:

- Ineffective air distribution. Even if the bin has an aeration system, if the ducting or air distribution system is not properly designed, or is not working properly, there will not be uniform airflow in all parts of the bin, which can result in temperature variation.
- Natural convection currents can be induced by temperature variation within the bin. For example, the sun shining on the south side of a bin will warm up the air inside of that part of the bin. Warm air rises and is replaced by cooler air causing a convection current within the bin. Similarly, cold air around the bin cools the air near the bin walls while the grain in the center is warm and again a convection current is induced.

Regardless of the cause, convection currents resulting from temperature variations can result in moisture migration, which may produce pockets of higher moisture grain and/or condensation in the space at the top of the bin.

Blowing air through grain with a properly designed fan and ducting helps equalize temperature variations and thus minimize the chance of “hot spots” forming. Blowing cool air through grain also reduces the grain temperature. If the grain is dry, cooling the grain will ensure that it is at a safe-to-store condition. Ideally, cooling dry grain provides the best protection as cooling very wet grain will not always prevent spoilage.

Grain can be dried after harvest using either heated air systems or natural air systems. Heated air systems rely on hot air’s ability to hold a lot of moisture while the higher temperature difference between the grain and the air quickly draws moisture from the grain. These high temperature systems use air between 60°C and 80°C with high airflow rates in either a batch or continuous-flow process.

Natural air systems use ambient air to remove moisture from the grain. The effectiveness then depends upon the air's temperature, relative humidity (RH), and air flow rate as well as the grain's condition. The pros and cons of heated air and natural air drying (NAD) systems are listed in **Table 2**.

Table 2. Natural air drying versus heated air drying for grain.

	Pros	**Cons**
Heated air drying	• Does not depend on ambient conditions • Dries grain quickly and effectively	• Can result in seed damage due to high temperatures • Requires cooling cycle • High capital and energy costs • Can have higher labour requirement
NAD	• Energy savings • Smaller investment • Higher quality grain	• Slow • Requires management • Effectiveness is dependent on ambient conditions

Generally, heated air drying systems are well understood and thus more easily managed. Because the effectiveness of NAD systems depend on several interacting factors, managing the system is as easily understood. Therefore, the focus of this document is on explaining NAD systems and management options.

3. Understanding the Role of Airflow Rate

The terms aeration and natural air drying are often used interchangeably, but they are not the same as there is a fundamental difference between the two systems. Aeration is intended to cool and condition the grain to a uniform grain temperature, while NAD can also remove moisture from grain. The main physical difference between the two is the difference in airflow rates.

Aeration utilizes airflow rates from 0.1 to 0.2 cubic feet per minute per bushel (cfm/bu). If ambient air is cooler than the grain, the grain will cool. It takes approximately 200 hours (eight days) of continuous fan operation to equalize the grain temperature within a bin. This length of time depends on the temperature difference between the grain and air and the difference in air temperature between day and night. While it takes several days to equalize temperature of an entire bin of grain, it takes only a few hours of fan operation to affect the temperature of the grain near the air distribution duct system. There may be a small amount of moisture removal from or added to the grain during aeration; however, the main purpose of aeration is to reduce and equalize the temperature of the grain in the bin.

Natural air drying or near ambient drying requires minimum airflow rates of 0.75 cfm/bu to 1.5 cfm/bu, which is almost ten times higher than for aeration. If the air has “capacity-to-dry”, the grain will dry (**Section 4** describes “capacity-to-dry”). Because air’s ability to dry depends on air temperature, the air’s RH, grain type, grain temperature, and grain moisture content, it is not easy to accurately predict how long it may take for the NAD fans to reduce the grain’s moisture content. For example, it may take only a few days of continuous fan operation to get wheat’s moisture content from 17% to 15%, but it may take another week or more to reduce it to 14.4%. Estimated drying times are discussed in more detail in **Section 6.2.**

The target airflow rate of air through grain is often described using cubic feet per minute per bushel (cfm/bu). In some cases, the metric unit of litres per second per cubic meter (L/s per $m^{3)}$ is also used, which can lead to some confusion. For reference, both units of airflow for aeration and NAD are shown in **Table 3**. English units of cfm per bushel are used throughout this document (unless otherwise stated).

Table 3. Target airflow rates per unit of grain for aeration and NAD.

L/s per m^3	Purpose	cfm per bushel
1.3 to 2.7	Aeration	0.1 to 0.2
10 to 20	NAD	0.75 to 1.5

3.1 Understanding Static Pressure

The airflow rate generated by a specific fan depends on the static pressure the fan is working against. In other words, a specific fan will not produce the same airflow rate under all conditions. Static pressure is commonly measured and expressed in terms of inches of water column (English units) or Pascals (metric units). The operating static pressure or resistance to airflow depends mainly on three things:

- Grain type. The size of the grain kernels is proportional to the size of voids between the kernels. Since air passes through the grain voids, the resistance to airflow will be higher for smaller voids. Therefore, smaller kernels, like canola, result in higher static pressure than for larger kernels such as wheat.
- Depth of grain. The deeper the bed of grain over the ducts, the greater the resistance to airflow.
- Airflow rate. The faster the fan tries to push air through grain, the greater the resistance to airflow.

The interactions of grain type, grain depth, and airflow rate on static pressure are summarized in **Figure 2**.

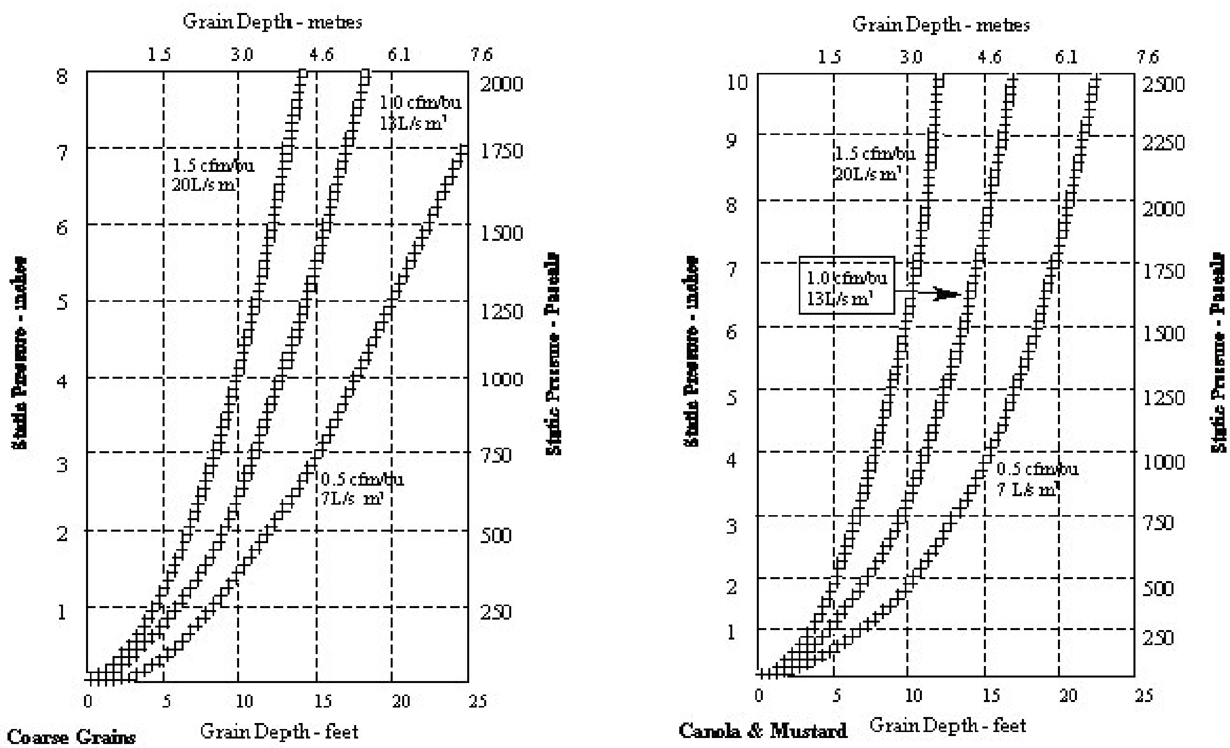

Figure 2. Effect of grain type (cereals, canola, flax, and pea), grain depth, and airflow rate on static pressure in a bin (source: Saskatchewan Ministry of Agriculture, 2008).

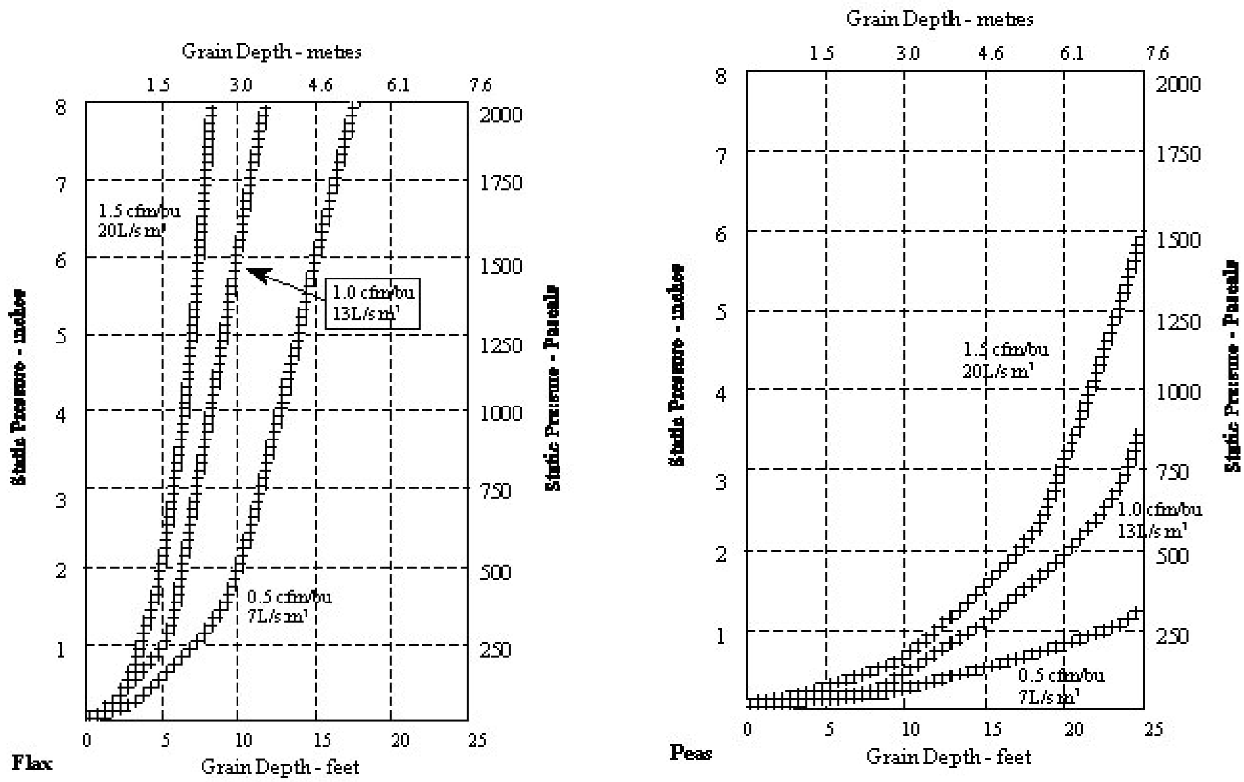

Figure 2 (continued). Effect of grain type (cereals, canola, flax, and pea), grain depth, and airflow rate on static pressure in a bin (source: Saskatchewan Ministry of Agriculture, 2008).

Several other factors may affect the static pressure across a fan:

- Type of ducting. The percentage of perforations and orientation of the ducting can also affect airflow resistance. The Prairie Agricultural Machinery Institute (PAMI) published several evaluation reports on the operating static pressure of several types of ducting systems such as cross duct, Y-duct, fully and partially perforated floors, rocket, etc. In recent years, new types of ducting have been developed (refer to **Section 5.1** for more information on ducting).
- Total area of exhaust vents. The space available for air to escape at the top of the bin will affect the pressure buildup in the headspace and thus increase the static pressure. A rule of thumb is to have 1 ft^2 of exhaust vent area for every 1,000 cfm of airflow.
- Bin fullness. Filling grain past the eaves or allowing the grain to pile in a cone will also increase the static pressure. Grain spreaders are recommended for evening out the grain pile at the top of the bin to reduce static pressure and improve airflow uniformity. Note, some research has reported conflicting results that claim using spreaders actually increased static pressure due to more uniform kernel orientation. However, it is generally recommended to use grain spreaders in large grain bins.
- Distribution of fines. Fine particles that collect in the same area of the bin will create a zone of higher density that in turn may increase the total static pressure. Again,

grain spreaders will help distribute finer particles more evenly and improve airflow uniformity.

3.2 Fan Types and Fan Curves

Fan types that can provide airflow include axial, in-line centrifugal, low-speed centrifugal, and high-speed centrifugal fans. Each fan type and size, based on horsepower (hp), operates most efficiently over a narrow range of static pressures. The higher the horsepower, the higher the static pressure it can work at.

3.2.1 Axial Fans

Axial fans, also known as propeller fans, are best suited for lower static pressures of less than 6 in. of water column (depending on horsepower). Axial fans are popular for aerating shallow depths of corn and soybeans. One drawback of axial fans is that they are noisy.

3.2.2 Low-Speed Centrifugal Fans

Both low-speed and high-speed centrifugal fans discharge air at 90° from the intake air's direction. Centrifugal fans are also known as squirrel cage impellers.

Low-speed centrifugal fans typically operate at 1,750 rpm. The low-speed centrifugal fan has a larger impeller and performs best in mid-range static pressures of 4 in. to 7 in. of water column (depending on horesepower). The low-speed centrifugal fan is the quietest operating fan.

3.2.3 High-Speed Centrifugal Fans

High-speed centrifugal fans typically operate at 3,500 rpm and can operate at higher static pressures of 7 in. to 10 in. of water column (depending on horsepower). High-speed centrifugal fans are physically smaller in diameter than low-speed fans; therefore, they do not deliver as much airflow at lower static pressures.

3.2.4 In-Line Centrifugal Fans

The airflow of in-line centrifugal fans does not turn the air 90°; therefore, they are sometimes referred to as an axial/centrifugal hybrid. In-line centrifugal fans typically operate at 3,450 rpm and perform the best at mid-range static pressure of 4 in. to 7 in. of water column (depending on horsepower). In-line centrifugal fans have a lower cost than other centrifugal fans, but axial fans are still the least expensive.

The airflow rate a specific fan can deliver is defined by the fan specifications or its "fan curve". Typical fan curves for a 5 hp axial, high-speed centrifugal, low-speed centrifugal, and in-line centrifugal fans are shown in **Figure 3**. For all fan types, as static pressure increases, the airflow rate decreases. Fan specification sheets, including fan curves, are available from the dealer or manufacturer.

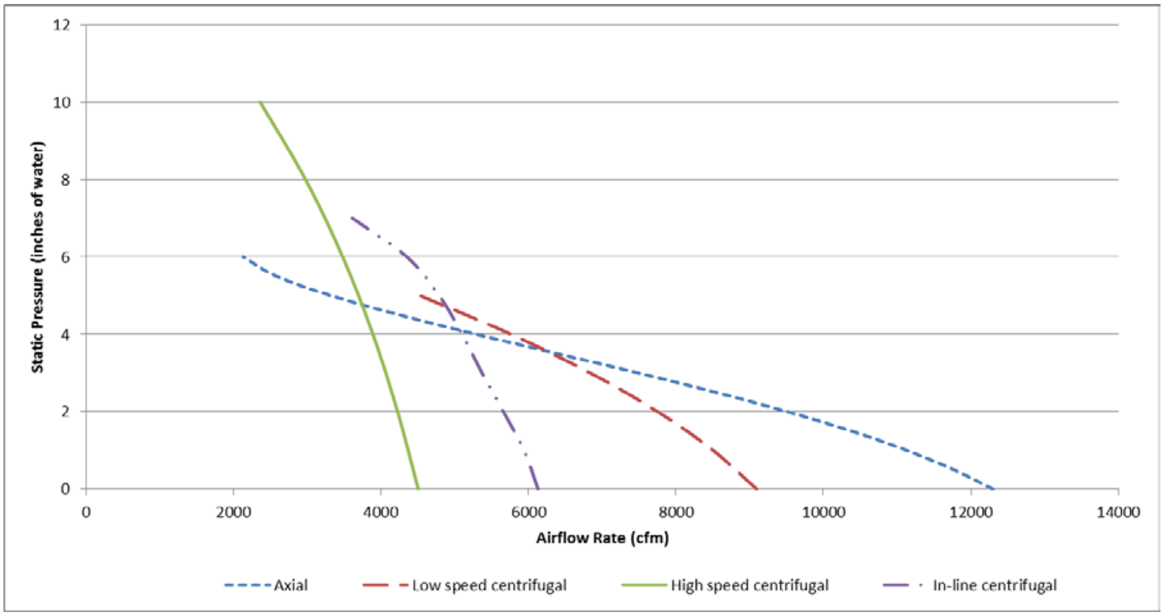

Figure 3. Typical fan curves for a 5 hp axial, low-speed centrifugal, high-speed centrifugal, and in-line centrifugal fans.

The only way to determine the operating static pressure is to measure it. Many systems come with a pressure gauge to help monitor static pressure. A simple manometer can also be made and installed in the transition duct. The open end of the manometer inside the airstream should be perpendicular to the airflow and be positioned where there is smooth airflow and not in a transition area.

A typical “rule of thumb” to help select the fan size you need is that 1 hp is needed for every 1,000 bushels. However, grain depth, not grain volume, affects static pressure and thus airflow rate. Therefore, all the factors such as grain type, grain depth, target airflow rate, and type of ducting should be considered when selecting a fan type and size.

NOTE: A system selected for aeration (cooling/conditioning) will never be able to achieve the airflow rate required for NAD.

4. Understanding Equilibrium Moisture Content

As mentioned in a previous section, the ability of air to draw moisture out of grain depends on the air's "capacity-to-dry". Air's capacity to dry depends on both its temperature and RH. Air's ability to hold moisture depends on its temperature; the warmer the air, the more water it can hold before it becomes saturated. The RH of air is a measure of how much water is in the air versus how much it can hold at a particular temperature. For example, air at an RH of 50% is "half full". Ultimately, air's capacity to dry depends on how much water it can hold before it becomes saturated. The water holding capacity and capacity to take up more water for one cubic meter of air at three temperatures and RH's are shown in **Table 4**.

Table 4. Water holding capacity and capacity to take up water for 1 m^3 of air.

Temperature (°C)	Water Holding Capacity (g)	Relative Humidity (%)	Actual Water in Air (g)	Capacity to Take Up Water (g)
30	30	50	15	15
20	20	65	13	7
10	8	75	6	2

As an example, nighttime air at 10°C and 75% RH is technically "drier" than daytime air at 30°C and 50% RH because it is holding less water (6 g vs. 15 g). However, nighttime air also has a limited capacity to take up more water (2 g vs. 15 g). Additionally, moisture movement between grain and air is very slow when the air temperature is cooler than 10°C. So nighttime air has a limited capacity to absorb moisture and moisture movement will be slow.

4.1 What is Equilibrium Moisture Content (EMC)?

Air's capacity-to-dry is dictated by the Equilibrium Moisture Content (EMC), which depends on air temperature, air RH and grain type. Essentially, the EMC concept is similar to the zeroth law of thermodynamics, which states that a warm object will transfer heat to a cooler object that it is touching until they are both the same temperature. The same is true for moisture movement; a wet object will transfer moisture to a drier object that it is touching until they are both the same moisture content.

This means that, for every temperature/RH combination, air has a specific moisture content or point where the moisture in the air and grain have reached a steady state or equilibrium. At this equilibrium point, the air will not take moisture or give moisture to the grain. The EMC of air for wheat is shown in **Figure 4**. Other methods of determining EMC may result in slight variations to those shown, but the method used in the following tables and figures was shown to be most suitable for wheat and barley and the ambient conditions prevalent in Western Canada (PAMI, 2011).

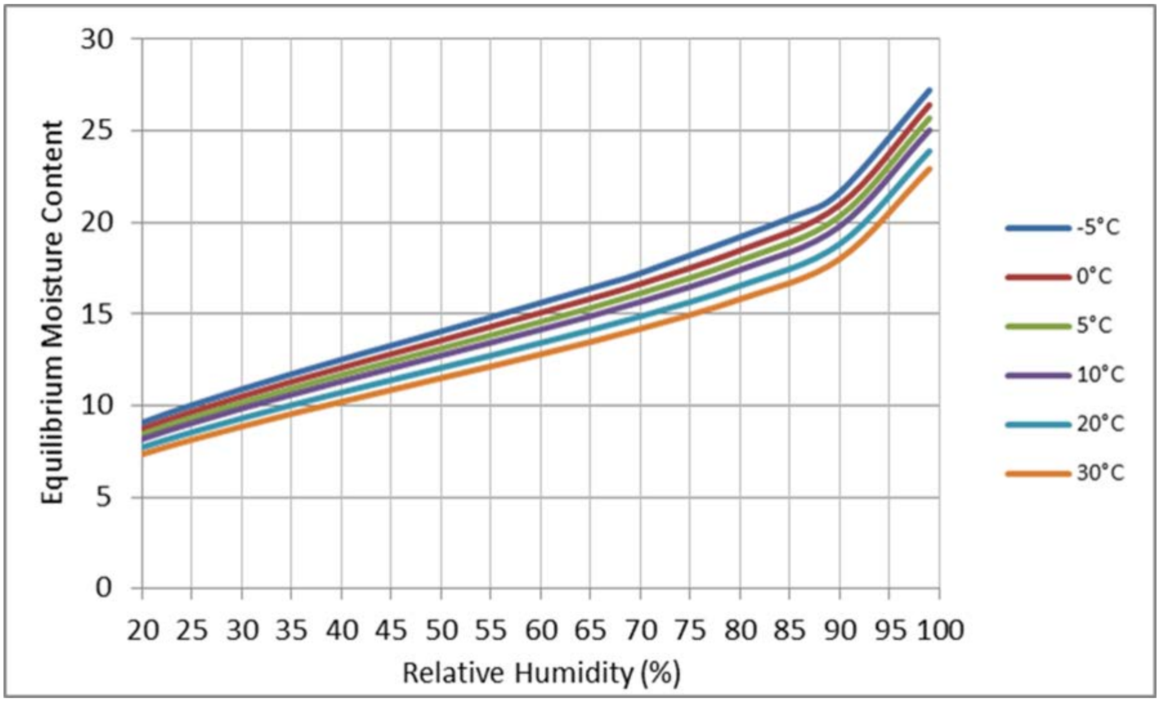

Figure 4. EMC of air for wheat.

Table 5. EMC of air for wheat.

Temp (°C)	Relative Humidity (%)										
	35	40	45	50	55	60	65	70	75	80	85
-2	11.5	12.2	13.0	13.7	14.5	15.3	16.0	16.9	17.7	18.7	19.8
2	11.1	11.9	12.6	13.4	14.1	14.9	15.6	16.4	17.3	18.2	19.3
5	10.9	11.7	12.4	13.1	13.8	14.6	15.3	16.1	17.0	17.9	19.0
8	10.7	11.5	12.2	12.9	13.6	14.3	15.1	15.8	16.7	17.6	18.7
10	10.6	11.3	12.0	12.7	13.4	14.2	14.9	15.7	16.5	17.4	18.5
13	10.4	11.1	11.8	12.5	13.2	13.9	14.6	15.4	16.2	17.1	18.2
15	10.3	11.0	11.7	12.4	13.1	13.8	14.5	15.2	16.1	17.0	18.0
18	10.1	10.8	11.5	12.2	12.9	13.6	14.3	15.0	15.8	16.7	17.7
22	9.9	10.6	11.3	11.9	12.6	13.3	14.0	14.7	15.5	16.4	17.4
26	9.7	10.4	11.1	11.7	12.4	13.0	13.7	14.4	15.2	16.1	17.1
28	9.6	10.3	11.0	11.6	12.3	12.9	13.6	14.3	15.1	15.9	16.9

The EMC information in **Table 5** suggests that air at 5°C and 50% RH, if passed through wheat for a period of time, will eventually equilibrate to 13.1%. It does not matter if the wheat started at 8% or 15%, if the air conditions stay at 5°C and 50% RH, the wheat moisture content will eventually equilibrate to 13.1%. This is because the moisture movement between air and grain works both ways. The air will both take and give moisture to the grain and reach equilibrium.

The EMC of air for wheat is also represented in the graph in **Figure 4,** which shows that as the RH increases, the EMC of air for wheat steadily increases for all air temperatures. At a RH of approximately 90%, there is a sharp increase in EMC.

Note that the EMC of air depends on air temperature, air RH, and grain type. The EMC of air for barley is shown in **Table 6** and **Figure 5**.

Table 6. EMC of air for barley.

Temp	Relative Humidity (%)										
(ºC)	35	40	45	50	55	60	65	70	75	80	85
-2	8.9	9.6	10.3	11.0	11.7	12.4	13.1	13.9	14.8	15.8	16.9
2	8.8	9.5	10.2	10.9	11.6	12.3	13.0	13.8	14.7	15.6	16.7
5	8.7	9.4	10.1	10.8	11.5	12.2	12.9	13.7	14.6	15.5	16.6
8	8.7	9.4	10.0	10.7	11.4	12.1	12.9	13.6	14.5	15.4	16.5
10	8.6	9.3	10.0	10.7	11.4	12.1	12.8	13.6	14.4	15.4	16.5
13	8.6	9.3	9.9	10.6	11.3	12.0	12.7	13.5	14.3	15.3	16.4
15	8.5	9.2	9.9	10.6	11.2	11.9	12.7	13.5	14.3	15.2	16.3
18	8.5	9.2	9.8	10.5	11.2	11.9	12.6	13.4	14.2	15.1	16.2
22	8.4	9.1	9.7	10.4	11.1	11.8	12.5	13.3	14.1	15.0	16.1
26	8.3	9.0	9.7	10.3	11.0	11.7	12.4	13.2	14.0	14.9	16.0
28	8.3	9.0	9.6	10.3	11.0	11.6	12.4	13.1	13.9	14.8	15.9

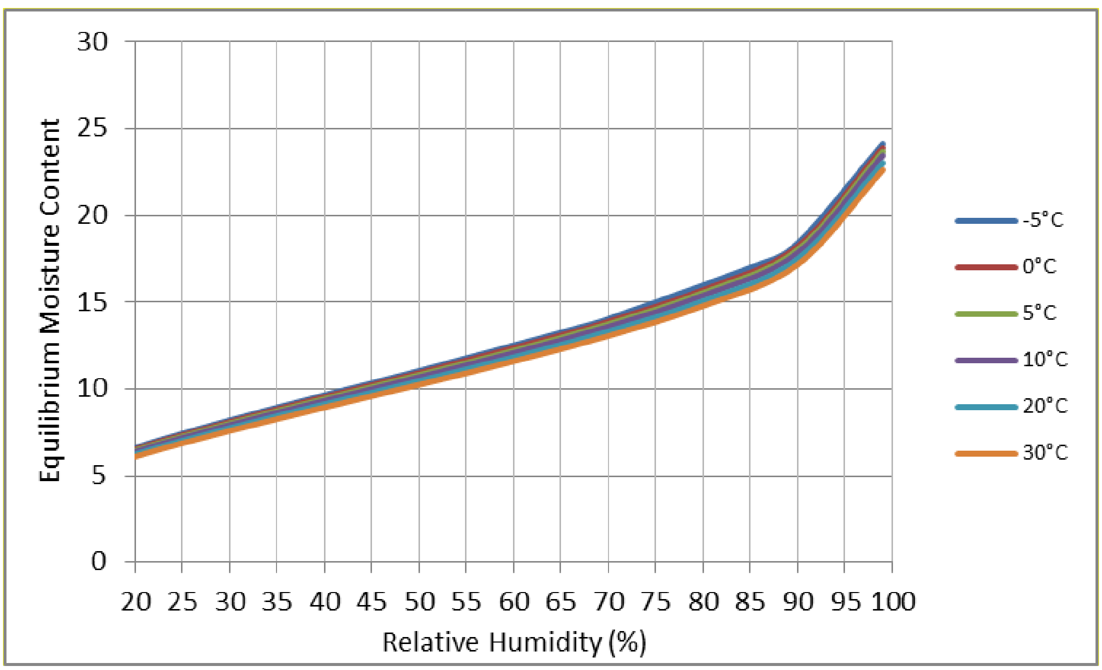

Figure 5. EMC of air for barley.

Note that the same air conditions of 5°C and 50% RH that resulted in a moisture content of 13.1% for wheat will result in a moisture content of 10.8% for barley. This is because the physical structure of the kernel and its composition (protein, oil, and carbohydrate content) affects the EMC for each grain. Also note that the air temperature does not affect the EMC of air for barley as much as it did for wheat as indicated by the lines on the graph in **Figure 6** for barley being much closer together than the lines on the graph in **Figure 5** for wheat.

The EMC of air for canola is shown in **Table 7** and **Figure 6**.

Table 7. EMC of air for canola.

Temp	Relative Humidity (%)										
(°C)	35	40	45	50	55	60	65	70	75	80	85
-2	6.7	7.5	8.2	8.9	9.7	10.5	11.3	12.2	13.2	14.3	15.7
2	6.4	7.0	7.7	8.4	9.1	9.9	10.7	11.6	12.5	13.6	14.9
5	6.1	6.8	7.4	8.1	8.8	9.5	10.3	11.1	12.0	13.1	14.3
8	5.9	6.5	7.1	7.8	8.5	9.2	9.9	10.7	11.6	12.6	13.8
10	5.7	6.3	7.0	7.6	8.3	8.9	9.7	10.5	11.3	12.3	13.5
13	5.5	6.1	6.7	7.3	8.0	8.6	9.4	10.1	11.0	11.9	13.1
15	5.4	6.0	6.6	7.2	7.8	8.5	9.2	9.9	10.7	11.7	12.8
18	5.2	5.8	6.4	7.0	7.6	8.2	8.9	9.6	10.4	11.3	12.4
22	5.0	5.6	6.1	6.7	7.3	7.9	8.5	9.3	10.0	10.9	12.0
26	4.8	5.4	5.9	6.5	7.0	7.6	8.2	8.9	9.7	10.5	11.6
28	4.8	5.3	5.8	6.3	6.9	7.5	8.1	8.8	9.5	10.4	11.4

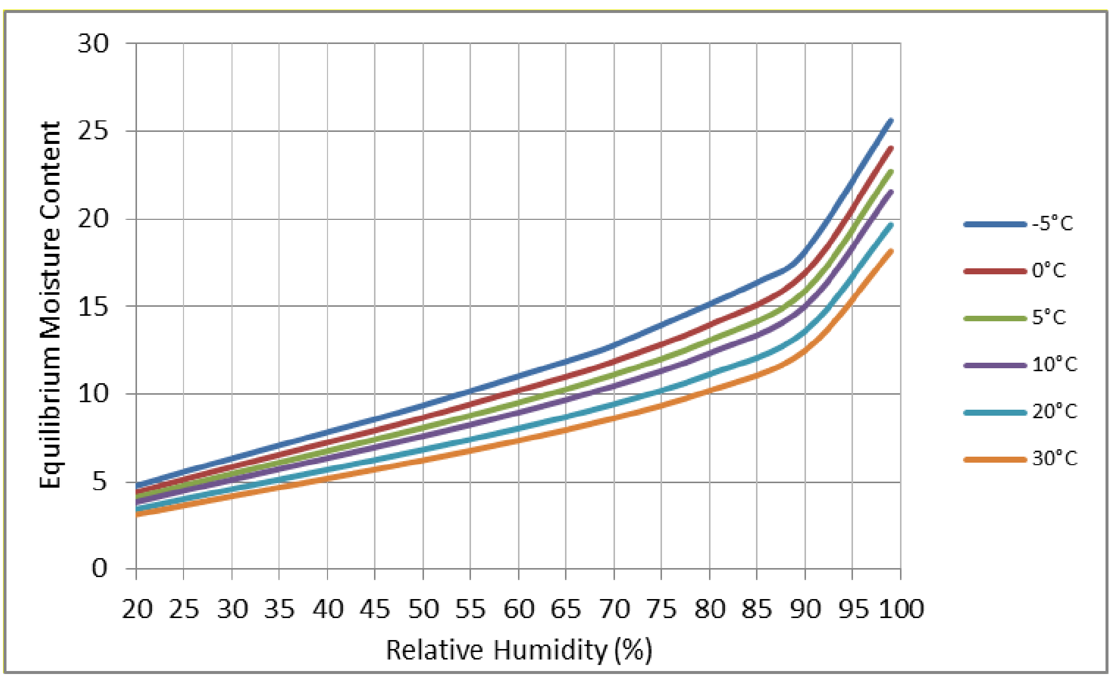

Figure 6. EMC of air for canola.

Note that air at 5°C and 50% RH now results in a moisture content of 8.1% for canola. Also note that air temperature has a greater impact on the EMC of air for canola than it did for barley or wheat, as the lines on the graph in **Figure 7** are spread farther apart.

The EMC charts for soybeans and corn can be found in **Section 9.1.2** and **Section 9.1.3**, respectively.

4.2 Factors Affecting Air's Ability to Dry Grain

As previously mentioned, the air's temperature, RH, and the grain type, affect the air's ability to dry grain. However, the grain temperature and starting moisture content also affect the air's ability to dry grain, which increases the complexity of predicting how specific air conditions will affect grain moisture content.

Remember that air at 5°C and 50% RH will result in moisture content of 8.1% for canola, provided the air stays at 5°C and 50% RH for long enough to reach equilibrium. However, ambient air rarely stays at a constant temperature and RH for longer than an hour or two. Complicating the issue further, the temperature of the air will also be affected by the temperature of the grain as it flows through the grain. So if the ambient air is at 5°C and 50% RH, but the grain temperature near the plenum is 20°C, the incoming air will warm and that will increase its ability to hold moisture, which changes its EMC.

To summarize, the factors that affect air's ability to dry grain include

- air temperature,
- RH of the air,
- grain type,
- temperature of the grain,
- moisture content of the grain, and
- airflow rate.

All these factors can be combined to predict how the air will affect the grain moisture content. This information can be used to strategically turn the fans on and off to improve drying efficiency (refer to **Section 8** for information on fan control strategies).

5. Aeration Systems

Aeration systems use basic components including a fan and air distribution duct system. In general, the goal is to cool warm grain and achieve relatively uniform grain temperature throughout the bin. Although this may seem somewhat limited in capability, it is none the less an important factor in reducing the risk of storing dry grain.

5.1 Available Equipment

The goal of grain aeration is to cool the grain and minimize temperature variation within the bin. The target airflow rate for aeration is 0.1 cfm/bu to 0.2 cfm/bu. Therefore, a system that works for a 2,000 bu bin will be different than a system for a 10,000 bu or 30,000 bu bin. Always consult the manufacturer for correct equipment sizing.

All aeration systems require three main components: the fan to provide airflow, the air distribution system (or ducting) to direct the air from the fan into the grain, and vents to allow the air to leave the top of the bin.

Flat-bottom bins with fully perforated floors are still the standard for best airflow and uniform distribution in the bin. However, a variety of alternatives such as half rounds, inverted troughs in triangles, crosses or Ys, and rockets are available. These alternative types of ducting may also provide aeration in temporary storage such as quonsets or grain piles.

A large variety of options exist for hopper bins. There are full-round screens, inverted Vs, rockets and screens, or ducts on the slope of the hoppers. There are also systems that move air horizontally rather than vertically in the bin or grain tube systems that promote the natural air currents without the use of fans.

Fans are categorized as axial, high-speed centrifugal, low-speed centrifugal, and in-line centrifugal (refer to **Section 3.2** for a more detailed explanation of fan types).

Systems to monitor temperatures or moistures in the bins and even control of fans are available (refer to **Section 8.4** for a discussion on monitoring equipment).

A listing of manufacturers and dealers in Manitoba and western Canada can be found in the Prairie Farmers Catalog “The Book” www.thebook.bz.

5.2 How Long Does it Take to Equalize Temperature In-Bin?

Grain cools much faster than it dries. The length of time required to move a cooling front all the way through the bin depends on the airflow rate. Intuitively, the length of time required for temperature to equilibrate should also depend on the temperature difference between the air and the grain; however, research has shown this differential has very little impact on cooling times. A simple rule of thumb to calculate cooling time is shown in the following formula:

$$Cooling\ time\ (hrs) = \frac{15}{airflow\ rate\ (\frac{cfm}{bu})}$$

For example, a bin with an aeration fan delivering 0.1 cfm/bu will require 150 hours or 6.25 days of continuous fan operation to bring the grain temperature down to the air temperature. The same bin with a NAD fan operating at 1 cfm/bu will require only 15 hours of continuous fan operation to cool the grain.

5.3 Considerations for Larger Bins

Large bins have deeper depths of grain that increase the static pressure across the fan. Therefore, larger bins require more powerful fans to provide required airflow rate for aeration. Fully perforated floors are recommended for all flat-bottom bins, particularly bins with a capacity greater than 10,000 bushels. Large hopper bins of 5,000 bushels to 8,000 bushels may require specialized ducting to provide a uniform airflow distribution for high-static pressures.

6. Natural Air Drying Systems

Natural air drying systems serve two purposes: first it can perform the same function as an aeration system, but much more quickly. However, it is its ability to affect the grain moisture content in the bin that makes it an important in-bin grain storage management tool.

6.1 Available Equipment

The equipment required for NAD is very similar to the equipment required for aeration except the fan sizes for NAD are much larger. The air distribution systems (ducting) suitable for aeration are generally acceptable for NAD. The key difference is airflow rate, which is mainly dependent on fan size.

Other types of distribution systems are on the market for NAD. For example, JTL Industries Ltd., based in Neilburg, Saskatchewan, has developed innovative ways to distribute air into hopper bins without the need for awkward ducting. One system introduces air into the hopper through the hopper legs and another involves an enclosed hopper.

GATCO Manufacturing Inc., based in Swift Current, Saskatchewan, developed the concept of using grain air tubes in the center of the bin. These hollow tubes are claimed to help promote natural convection drying within the bin without using a fan. GATCO is also working on developing systems with fans to perhaps increase the drying capacity of the system. The theory is that the hollow tube helps reduce the resistance to airflow so that smaller fans can be used. According to GATCO representatives, a one or two horsepower fan is all that is required to provide airflow for a 7,000 bushel bin.

It should be noted that these new systems have not been tested by an independent, unbiased party. Therefore, there is no scientific data to confirm the operating efficiency and efficacy.

6.2 How Long Does it Take to Dry Grain Using Natural Air?

As discussed in **Section 4**, air's capacity-to-dry grain depends on many factors including air temperature, air RH, grain temperature, grain type, airflow rate, and grain moisture content. As a result, it is difficult to predict how long it will take to remove moisture from grain. Cooling fronts move through grain much faster than drying fronts. Even with NAD's higher airflow rate, it takes longer to equalize moisture in a bin than it does for aeration fans to equalize the temperature.

The length of time required to reach equilibrium depends on the difference between the moisture content of the grain and the EMC of the air for that grain. For example, if wheat initially has a moisture content of 17% and the EMC of the air for wheat is 11%, it will take only a few hours to dry the bottom layers by 2%. If wheat starts at 17% and the EMC of the air for wheat is 15%, it will take at least 12 hours to dry the bottom layers by 2% during which the EMC of the air is likely to change.

Generally during harvest, it takes 7 days to 14 days of continuous fan operation at 1 cfm/bu to dry wheat to an average of 14.4% moisture content, but that depends upon ambient conditions. This illustrates the critical need to monitor grain moisture content and/or temperature during drying (refer to **Section 9** for more information on monitoring and control equipment).

6.3 Considerations for Larger Bins

Similar to aeration of large grain bins, the high-static pressure must be managed for efficient NAD. For NAD, airflow uniformity is critical as non-uniform airflow will result in pockets of high moisture that may further disrupt airflow distribution and result in problem zones. Fully perforated floors are recommended for all flat-bottom bins and specialized ducting may be required for large 5,000 bushel to 8,000 bushel hopper bins. For very large bins, multiple fans may be required to achieve the required airflow rate for NAD. Use of multiple fans requires a specialized plenum to ensure that the fans are not working against each other and increasing the static pressure.

7. Natural Air Drying and Supplemental Heat

Later in the fall as air temperatures drop, NAD systems lose their effectiveness for drying grain. If the grain is not dry, this can be a problem for producers. Adding heat to a NAD is often considered as a way to accelerate or prolong the drying process.

7.1 Benefits of Supplemental Heat

The drying rate of an NAD system can be slowed or completely stopped during adverse weather conditions. Cool air can only hold a small amount of moisture and moisture movement from grain to air is very slow at temperatures less than 10°C. Heating the inlet air increases the air's ability to hold moisture. Assuming the actual amount of water in the air does not change due to heating, the RH of the heated air will be lower than the RH of the ambient air. This increases the drying rate.

The rule of thumb relating temperature increase to RH decrease is that a temperature increase of 10°C reduces the RH of the air by one-half. For example, air at 0°C and 70% RH heated to 10°C results in an RH of 35%; heating an additional 10°C to 20°C will reduce the RH to 17%.

Using supplemental heat with NAD widens the "good drying weather" window and allows for drying even when nighttime temperatures are near 0°C. However, the disadvantages of using supplemental heat are increased capital and operating costs and it increases the possibility of overdrying the grain, especially at the bottom of the bin.

7.2 Using and Sizing Supplemental Heating Systems

Based on research conducted in Saskatchewan, the following best practices will help minimize drying costs when incorporating supplemental heat with NAD:

- Only use supplemental heat if an airflow rate of at least one cfm/bu (13 L/s/m^3) can be guaranteed.
- Limit air temperature increase to 10°C.
- Use supplemental heat when ambient air temperature is between -5°C and 15°C. The maximum air temperature after the heater should be between 5°C and 25°C.
- Run fans with a heater until the bin is "average" dry, mix the grain, then cool (with aeration).
- Natural gas should only be used if installation cost is low. The estimated saving over propane is 4:1.

The size of the heater required for supplemental heating depends on the desired temperature change between the ambient and heated air and the airflow rate. The following formulas can be used to estimate the size of a supplemental heater or to determine the approximate temperature rise that can be expected from a particular heater.

For metric units:

$$Watts = temperature\ change\ (°C) x\ airflow\ rate\ \left(\frac{L}{s}\right) x\ 1.02$$

For English units:

$$\frac{BTU}{h} = temperature\ change\ (°F) x\ airflow\ rate\ (cfm) x\ .08$$

For example, to raise the temperature by 10°F in a 5,000 bushel bin with an airflow rate of 1 cfm/bu, you will need a heater with a capacity of approximately 40,000 BTU/h.

$$\frac{BTU}{h} = 10\ x\ 5{,}000\ x\ 0.8 = 40{,}000\ BTU/h$$

Or, if you have a 20 kW heater and an airflow rate of 2,000 L/s (approximately 4,200 cfm), you will be able to increase the temperature of the incoming air by approximately 9.8°C.

$$20{,}000\ Watts = temperature\ change\ (℃)\ x\ 2{,}000\ x\ 1.02$$
$$Temperature\ change = 9.8℃$$

The above calculations were made using normal atmospheric conditions of 20°C (68°F) and 101.325 KPA (14.7 psi).

7.3 Efficiency and Cost of Supplemental Heating Systems

Heaters for supplemental heating can be fired by natural gas, propane, or heated using electricity, depending on availability and cost. DryAir systems that use conductive or “hot water” heating are also gaining popularity. It may be possible to retrofit an existing hot water heating system to provide supplemental heat for natural air drying, but there is limited information on guidelines for their installation or for their safety and efficiency.

Natural gas and propane heaters are often called “direct-fired” systems because their flame is used to directly heat the air. Combustion of fuels such as natural gas and propane produce water. Therefore, there has been some debate and concern that direct-fired heating systems are not suitable for NAD as they will add water to the air and subsequently to the grain. In fact, the amount of water added to the air by direct combustion is minimal. The effect of supplemental heating on the RH of air using natural gas, propane, and conductive heating (DryAir) is shown in **Table 8**.

Table 8. The effect of heating method on RH and EMC of air for wheat.

		Relative Humidity of Air (%)			EMC of Air for Wheat (%)		
Incoming Air	**Final Temperature**	**"Dry" Heated Air**	**Natural Gas Heated Air**	**Propane Heated Air**	**"Dry" Heated Air**	**Natural Gas Heated Air**	**Propane Heated Air**
0°C /70%	5°C	48.9	49.0	49.0	13.0	13.0	13.0
0°C/70%	10°C	34.6	34.8	34.7	10.5	10.6	10.5
5°C/70%	10°C	49.6	49.7	49.6	12.7	12.7	12.7
5°C/70%	15°C	35.5	35.7	35.6	10.4	10.4	10.4
10°C/70%	15°C	50.2	50.2	50.2	12.4	12.4	12.4
10°C/70%	20°C	36.3	36.5	36.4	10.2	10.2	10.2

Propane heating systems are most common as natural gas-fired systems require proximity to a natural gas line.

The cost of adding heat (energy cost only) also varies depending on the fuel (natural gas, propane, or electricity). These fuel costs are summarized in **Table 9** and are based on energy costs provided by Manitoba Hydro (as of November 1, 2013).

Table 9. Summary of energy costs for supplemental heating using electricity, natural gas and propane.

		Fuel Cost ($/hr)		
Incoming Air	**Final Temperature**	**Electricity**	**Natural Gas**	**Propane**
0°C /70%	5°C	0.54	0.19	0.66
0°C/70%	10°C	1.09	0.37	1.32
5°C/70%	10°C	0.62	0.21	0.75
5°C/70%	15°C	1.24	0.43	1.51
10°C/70%	15°C	0.73	0.25	0.89
10°C/70%	20°C	1.46	0.50	1.78

This same fuel cost information is summarized in **Figure 7**, **Figure 8**, and **Figure 9** for natural gas, propane, and electricity. **Figure 10** shows all three sources of energy on one chart and assumes the ambient temperature is 5°C.

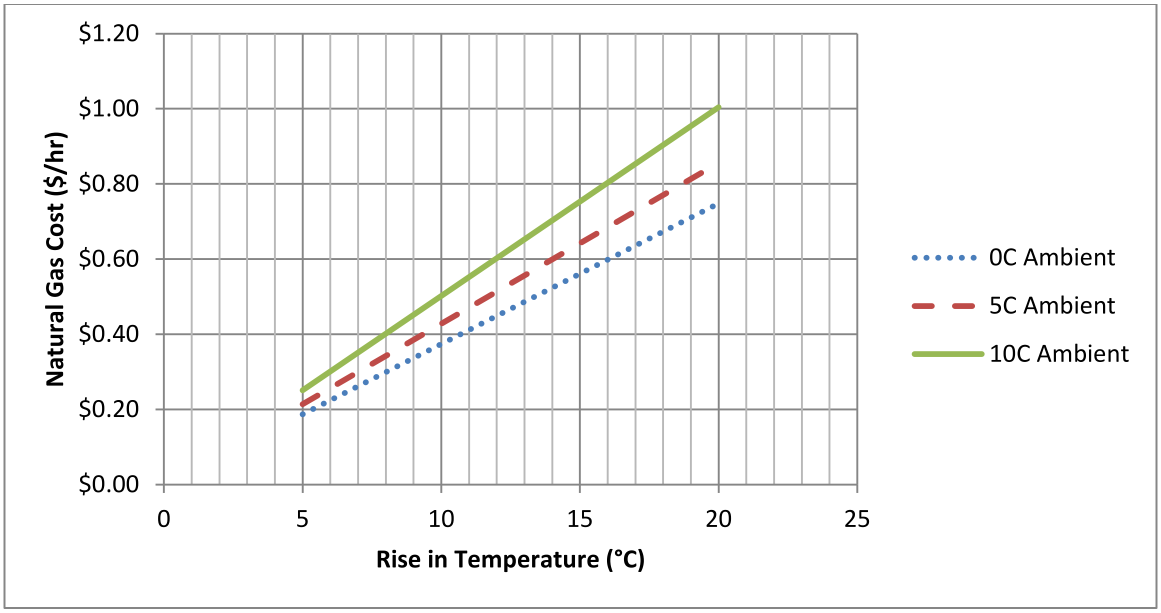

Figure 7. Natural gas cost ($/hr) for supplemental heating for three ambient temperatures.

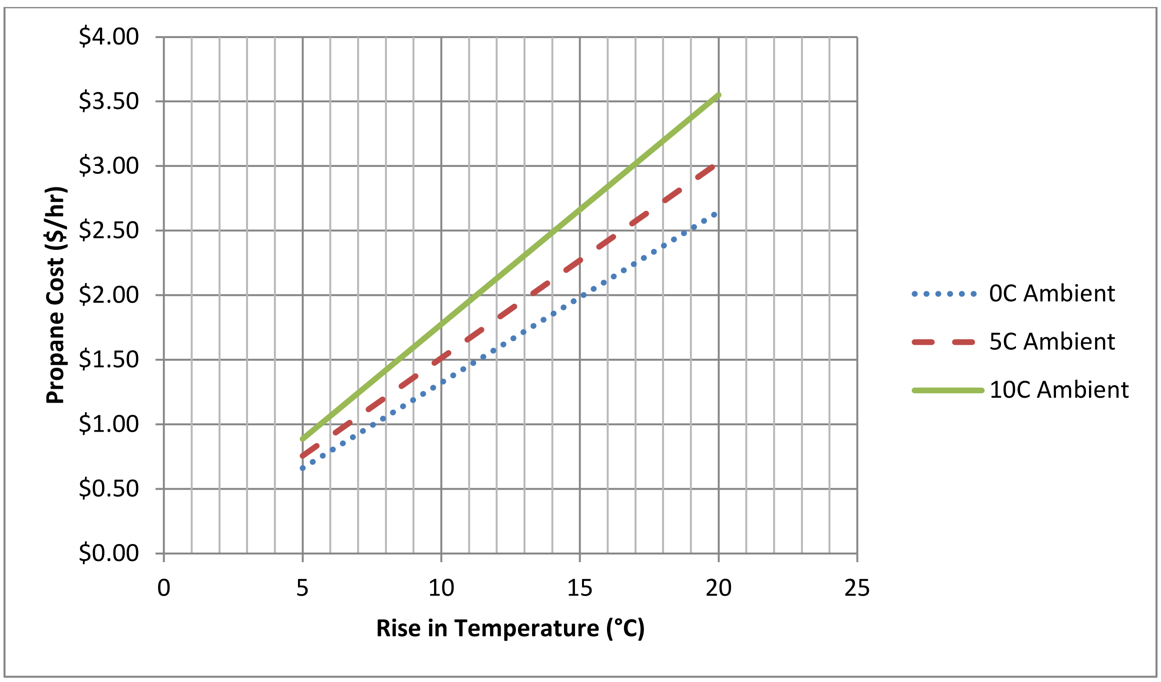

Figure 8. Propane cost ($/hr) for supplemental heating for three ambient temperatures.

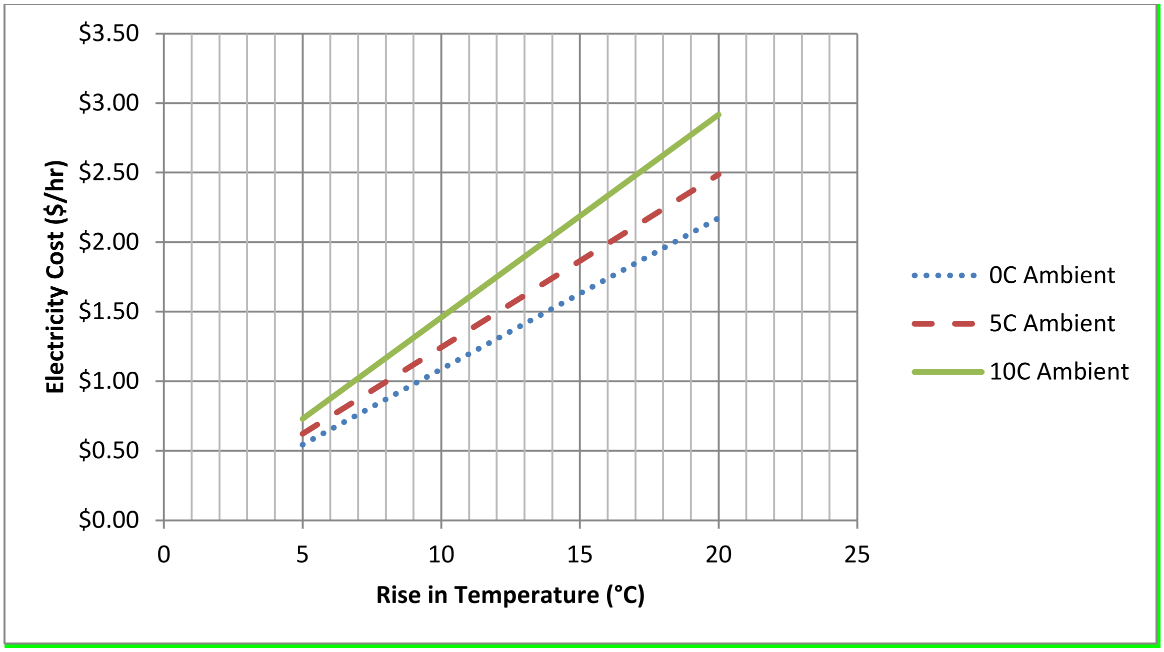

Figure 9. Electricity cost ($/hr) for supplemental heating for three ambient temperatures.

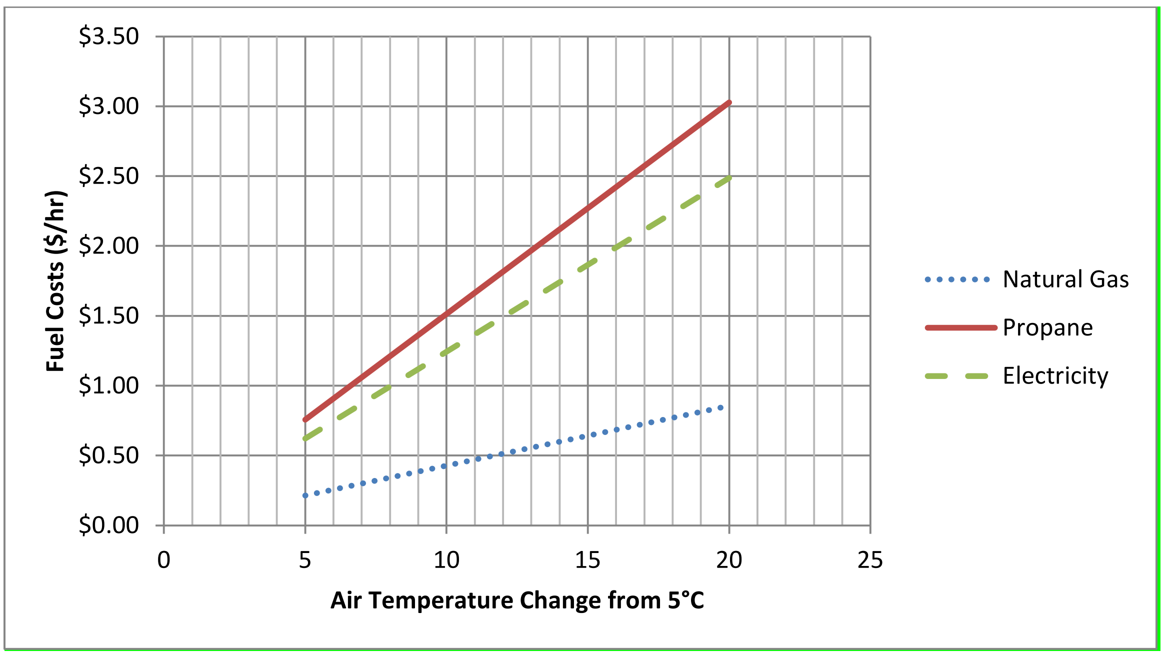

Figure 10. Comparison of energy costs ($/hr) for supplemental heating (assuming ambient temperature is 5°C).

7.4 Equipment Requirements and Safety Considerations for Supplemental Heat

No bin modifications should be required to add supplemental heat to an existing NAD system. When adding supplemental heat, ensure the NAD system is sized to provide a minimum airflow rate of 0.75 cfm/bu. Burners are designed to be placed in front of the fan or between the fan and bin. Contact the manufacturer for proper location of specific burners.

Regulations and safety must also be considered when adding a supplemental heating system. All supplemental heaters purchased through a dealer or manufacturer should carry a Canadian Standards Association (CSA) sticker. Presently in Manitoba, farmers need to contact the Office of the Fire Commissioner and Inspection and Technical Services when installing a heater. A Manitoba provincial inspector and a CSA inspector need to be on site for the installation. The CSA inspector has to affix the blue CSA Special Field Service Inspection sticker on the heater.

CSA withdrew CSA 3.8-99 (R2011) Gas-Fired Equipment for Drying Farm Crops. Manufacturers could build heaters to this standard until October 1, 2013. A new standard, part of the CSA B149 series, has been drafted but is not final. It will be called Test Standards for Crop Drying heaters. The new standard will have a new CSA North American decal.

Equipment should continually be inspected for leaks, deterioration, and damage. Prior to starting a burner, the fuel flow should be turned off and the fan operated to purge the bin of any gases before lighting the burner.

Adding a home-made torch in front of the fan is not recommended and must never be used because if the flame goes out, there is no safety shutdown to prevent unburnt fuel from entering the bin and creating a very dangerous situation as well as contaminating the grain.

7.5 Considerations for Larger Bins

Similar to aeration and NAD, the main concern with using supplemental heat in large bins is achieving the required airflow rate with a high static pressure. Non-uniform airflow will negatively affect the performance of a supplemental heating system because parts of the bin may dry down quickly and leave moist pockets that may restrict airflow.

The use of supplemental heating on large bins 10,000 bushels and up has not been properly evaluated. One concern with using supplemental heat on large bins is that insufficient airflow rates (less than 0.5 cfm/bu) may pose heating or stress cracking risks in the grain. Consult dealers or manufacturers that specialize in large grain bins for more information on using supplemental heat in large bins.

8. Fan Control Strategies

The general recommendation for both NAD and aeration fans is to turn the fans on as soon as the grain has covered the ducts and let the fans run continuously until the cooling or drying front has moved all the way through the grain. The temperature and EMC of air fluctuates significantly during the day, meaning the air's capacity-to-dry or wet the grain changes throughout the day. It may be beneficial to strategically turn the fan on and off during the day to take best advantage of the air conditions.

8.1 Potential Benefits of Strategic Fan Control (vs. Continuous Operation)

Because the air's capacity to dry grain fluctuates from day to night and hour to hour, there will be hours during the day when the air conditions do not achieve anything positive. In fact, certain conditions can actually do the opposite such as drying when you are trying to wet or wetting when you are trying to dry. Typically, running NAD fans continuously can result in "two steps forward and one or two steps back" every day. Producers can help eliminate the steps backward by strategically turning the fans on and off. To do this, the in-grain moisture content during drying and ideally a moisture content profile as well as information on the ambient air conditions must be known.

It must be noted that strategic aeration and NAD fan operation should be done with care and with the understanding that when there is no airflow, tough grain is at risk of spoilage. In addition, it has been suggested that starting and stopping airflow can form crusting that may inhibit air movement or that leaving fans off for an extended period when the drying front has not moved entirely throughout the grain can cause zones of high moisture. Anecdotal evidence from producers using fan control strategies indicates that crusting and airflow restrictions are not a concern. However, with most fan control strategies, the fan is not off for more than 12 hours and these systems are not recommended for very tough grain. More research is required to determine the risk of crusting and airflow restriction for a variety of scenarios and grain conditions.

Continuous fan operation is the recommended practice for safe storage of grains in a variety of ambient conditions. But, strategic fan operation may offer several benefits that should be considered.

If fans run only when the conditions will result in the target outcome (e.g. drying), then there will be energy savings because the fan will not run needlessly. Strategic fan operation can also help rewet overdry grain at the bottom of the bin once the grain at the top is dry. Minimizing overdried grain will result in added revenue (refer to **Section 10.2**). Establishing and maintaining a uniform moisture content profile with fans can help reduce labour associated with grain turning, which might also have a positive economic impact.

8.2 Control Strategies for Aeration

The goal of aeration is to simply cool the grain and equalize the temperature within the bin. Aeration system strategies exist and are based simply on differential temperature. In other words, when the ambient air is more than five degrees cooler than the grain, the fan starts. Other control systems are simply based on time of day; the fan turns on at night and off again the next morning in order to take advantage of the coolest air temperature.

Because the cooling front moves through grain much more quickly than the drying front (even at lower airflow rates), there is very little moisture removal or addition with aeration. Running aeration fans through extended high-humidity periods will not add significant water to the grain, but the constant airflow will have a beneficial temperature conditioning effect on the grain. Therefore, the recommended practice is to run aeration fans continuously.

8.3 Control Strategies for Natural Air Drying

One recent suggestion was based on the air at night being technically “drier” than air during the day (not lower in RH, but drier), and consequently it may be beneficial to run fans at night only for drying. However, this recommendation or theory works until the grain has cooled, assuming the grain was put into storage warm. Therefore, this recommendation was met with skepticism. Nighttime drying will cool the grain and only allow a final MC of the nighttime air’s EMC.

The EMC of the air is generally lowest during daytime hours, so the air has the greatest capacity to dry grain during the day. Although cool, nighttime air can effectively dry grain, it will only do so for a short time while the grain is warm. The role of grain temperature on the air’s capacity to dry is a key factor that can lead to confusion concerning daytime and nighttime drying.

The EMC of air depends on the air’s temperature and RH. The RH is an indication of how much water is actually in the air. Assuming a daytime air temperature of 20°C and a RH of 60%, then the air can hold 20 g of water but is actually holding only 12 g of water. This daytime air has an EMC of 13.5% for wheat. If the grain temperature near the plenum is also approximately 20°C, then the water-holding capacity and amount of water it is holding will remain unchanged as it moves through the grain. Therefore, the EMC of the air will remain relatively unchanged as it passes through the grain, and if the grain moisture content is higher than 13.5%, the grain will start to dry.

However, if daytime air is passed through cool grain (10°C), the air will cool and its capacity to hold moisture will drop to 8 g, but the daytime air was already holding 12 g of water. Since the air has more water than it can hold, the air will tend to transfer moisture to the grain, causing wetting. Note that this only happens when the grain is cool and the air is warm.

On the other hand, assume that nighttime air has a temperature of 10°C and an RH of 70%. This air can hold 8 g of water but is actually holding 5.6 g of water. Its EMC for wheat is 15.7%. If nighttime air passes through warm grain and warms to 20°C, its capacity to hold water will increase to 20 g. Since it is still holding only 5.6 g of water, it now has a greater capacity to take on moisture. In fact, the EMC of this "warmed nighttime air" is now 9%, which will dry the wheat. However, this only happens when the grain is warm and the air is cool.

When nighttime air passes through cool grain (10°C for example), its water-holding capacity will not change and its EMC will not change (15.7%). Unless the wheat is very tough, it is unlikely to dry.

The recommendation to run fans only at night is effective for cooling and for short-term drying. Nighttime air will only result in drying if the grain is warm. Since grain cools after 8 hours to 12 hours of fan operation, the grain will likely be cool after a single night so will only dry in the first night.

When is the best time to run NAD fans? During the day or during the night? Should the fans run continuously? Unfortunately, there is no strategy that will work for every single situation. The best strategy is dependent on conditions that include grain type, grain moisture content, grain temperature, air temperature, air RH, etc. In addition, the "best" strategy is dependent on the storage goal (refer to **Table 10)**.

Table 10. Summary of suggested NAD fan strategies based on storage goal.

Goal	Suggested NAD fan strategy
Safe storage for all grain types in a variety of ambient conditions	Run fans continuously
Minimal fan hours	Run fans at night only OR during the day only (depending on ambient air temperature and grain conditions)
Cool grain	Run fans at night only (with NAD fans) or continuously (with aeration fans)
An even moisture content profile (no overdrying)	Run fans during day only until average moisture content is within 1% to 2% of dry, then run fans at night until grain is cool (tough grain will dry and overdry grain will rewet)

8.4 Available Tools for Grain Storage Monitoring

There are several online worksheets and calculator tools to help producers determine duct size, fan size, and required vents for aeration and NAD. Many dealers also take advantage of sizing calculators provided by the equipment manufacturers to ensure the system is sized correctly for the bin and target airflow rate.

Several new tools have been developed to help producers make storage management decisions. One online tool called BINCast (WIN: Weather Innovations Consulting) provides a five-day forecast of the air temperature, RH, and EMC for a selected grain. Producers can use this information to decide if it will be beneficial to turn on NAD fans. BINCast currently has weather information for southern Manitoba only. BINCast is available at www.weatherwest.ca/bincast.cfm

8.4.1 Monitoring Temperature

There are many options for in-bin monitoring equipment. OPI Systems (Calgary, Alberta) has a wide range of temperature cable systems. OPI cables can be purchased from many large bin dealers.

IntraGrain Technologies (Regina, Saskatchewan) offers a remote monitoring system where bin temperatures are measured, and the user is sent an e-mail or text if any hot spots form. The monitoring system is solar powered so it can be installed in bins where no power is available. IntraGrain is also working on a technology to monitor fan status and possibly provide fan control. MiFarm Ag Management (Calgary, Alberta) also offers remote sensing technology including fan and heater status, etc.

8.4.2 Monitoring Moisture Content

OPI Systems (Calgary, Alberta) also offers moisture content sensing cables in addition to temperature cables. Again, OPI cables can be purchased from several dealers.

The existing monitoring technologies rely on in-grain sensors to collect information. There are several drawbacks to in-bin sensors. In-bin sensors are technically only monitoring the temperature or moisture surrounding them. Realistically, with in-bin sensors, only a small percentage of the grain is actually monitored. In addition, if the sensor cables are not designed or installed correctly, they can cause issues during unloading (roof collapse, etc.)

Research is underway in southern Manitoba to develop a 3-D moisture map of the bin using microwave technology. This will allow monitoring of the entire bin without a need for in-grain sensors.

8.4.3 Controller Systems

Automatic fan control systems are available. OPI offers a wide array of control systems for large bins 30,000 bushels and up. OPI systems can automatically control fan and heater cycle, ventilation ducts, etc.; however, they are not cost-effective for smaller bins 10,000 bushels and under.

Some systems from the United States (AgriDry, Intelliair) are cost-effective for smaller bins and offer fan control systems, but they are not widely marketed or available in Canada. In addition, the control algorithm has not been tested in the Canadian climate for Canadian crops. Aeration Australia has developed a control system that does not require in-grain sensors and is cost-effective for all bin sizes, but it has not been tested in the Canadian climate.

Research at Perdue University in the United States has shown that a control system could determine when it was most beneficial to add supplemental heat to natural air. The system was able to add the minimum amount of heat to the incoming air in order to reduce the air EMC in the plenum to the desired level. This strategy successfully minimized the overdrying of the grain bottom layers while drying the wet upper layers of corn, compared to a continuous strategy that overdried the bottom layers by up to 2.2%.

9. Other Challenges

Good grain storage management is a delicate balancing act and poses many challenges. Some of those challenges are discussed in this section.

9.1 Dealing with “Tricky” Grains

Storage, aeration, and NAD of some grains must be handled with care due to their composition, size, or time of harvest.

9.1.1 Canola

Canola storage poses several challenges:

- Canola has a higher oil content compared to other crops and is sensitive to spoilage so its target moisture content is lower (10%) and safe storage time is shorter than other grains (three months).
- Canola “respires” or “sweats” for up to six weeks after harvest. This metabolic activity can generate heat and moisture, so even dry, cool canola can be susceptible to heating or pockets of higher moisture forming during storage. Canola should always be aerated for two to six weeks after harvest.
- The small seed size of canola results in high-static pressures during aeration and NAD. A system sized for NAD of another grain (e.g. wheat) may not be sufficient for NAD of canola. In flat-bottom bins, fully perforated floors are recommended for aeration and NAD of canola.

9.1.2 Soybeans

Similar to canola, soybean storage poses several challenges:

- The RH of the drying air must be kept above 40% to prevent seed coats from splitting.
- The high oil content of soybeans makes them more susceptible to spoilage so its target moisture content (14%) is lower than for corn.
- Since soybeans are normally harvested late September or early October, supplemental heating is usually required for soybean NAD. As with other grains, the temperature rise should be limited to 10°C maximum.

The EMC of air for soybeans is shown in **Table 11** and the general safe storage time chart for beans is shown in **Figure 11**.

Table 11. EMC of air for soybeans.

	Relative Humidity (%)				
Temp (°C)	**50**	**60**	**70**	**80**	**90**
0	10.0	11.8	13.7	16.2	19.8
5	9.8	11.5	13.5	16.0	19.6
10	9.5	11.2	13.2	15.7	19.4
15	9.2	11.0	13.0	15.4	19.1
20	8.9	10.7	12.7	15.2	18.9
25	8.6	10.4	12.5	15.0	18.7

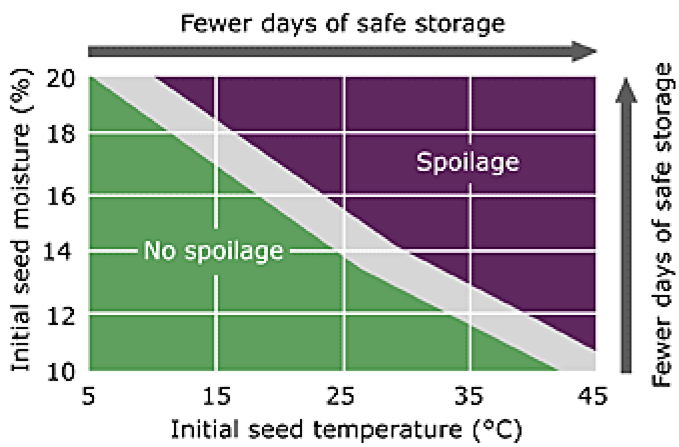

Figure 11. General safe storage time guidelines for beans (Source: Canadian Grain Commission).

9.1.3 Corn

Corn is typically harvested late in the year and comes off of the field at a high moisture content (20% to 25%); therefore, NAD is not recommended for corn. If NAD is used for corn, the grain depth should be shallow to allow for higher airflow rate and powered exhaust vents should be used to help remove the moist air from the headspace during drying. The target moisture content for corn storage is 15%. The EMC of air for corn is shown in **Table 12** and safe storage times are shown in Table 13. Note that all information included in these tables should be used as a guideline only.

Table 12. EMC of air for corn.

	Relative Humidity (%)				
Temp (°C)	**50**	**60**	**70**	**80**	**90**
0	13.7	15.1	16.6	18.4	21.3
5	13.1	14.4	15.9	17.8	20.7
10	12.5	13.8	15.4	17.3	20.2
15	11.9	13.3	14.9	16.8	19.8
20	11.5	12.8	14.4	16.4	19.4
5	11.0	12.4	14.0	16.0	19.0

Table 13. Safe storage time for corn (guideline only; Source: Midwest Plan Service, Ames, IA, 1980).

	Corn Moisture Content (%)							
Corn Temp (°C)	**15**	**18**	**20**	**22**	**24**	**26**	**28**	**30**
	Days of Safe Storage Time							
20	125	31	16	9	6	5	4	3
15	225	56	28	17	11	8	7	5
10	384	128	63	37	25	18	14	12
5	864	288	142	84	56	41	32	27
2	1140	432	214	126	85	62	49	40

9.2 Storing Tough Grain Over the Winter

Once the fall weather no longer permits NAD with or without supplemental heat, the grain can be “frozen” for winter storage. The microorganisms that cause spoilage require both heat and moisture so spoilage can be prevented by keeping the grain very cold. To freeze the grain, run the fan (NAD or aeration) until the grain is below -5°C.

To finish drying in the spring, remember that when warm air hits cool grain, the tendency is to wet the grain (refer to **Section 8.3**). This rewetting can be minimized by slowly warming the grain in the spring. Restart the fans at night or on cool days to slowly warm the grain to approximately 0°C and then gradually increase the grain temperature in five degree intervals. Once the grain temperature is approximately 15°C, operate the fans as normal. The alternative is to sell the grain frozen or to use a heated air dryer to remove the excess moisture in the spring. Storing frozen grain for an entire year is not recommended as radiative heating and natural convection inside the bin will cause temperature and moisture variations.

Caution should be taken whenever tough grain is stored over winter. Grain that is frozen tough and has not matured may suffer a germination loss. For previously matured but rewetted grain that is frozen, germination loss is unknown. Be aware that any time you operate a fan, foreign objects in the air can be pulled into the fan and lodge on the inside of the distribution air screen. This is a major problem during spring fan operation during the “poplar fuzz” season. If the screens plug on the inside, they have to be cleaned once the grain is removed from the bin or airflow cannot pass through the screens. To prevent this problem, a simple inlet screen can be manufactured and attached to the fan inlet.

9.3 Grain Bag Storage

Storage of grain in bags is gaining popularity in western Canada. Grain bags provide flexible and unlimited grain storage and help reduce the transportation requirements during the busy harvest season. Grain bag storage requires specialized equipment for loading and unloading the bags, and the bags themselves must be disposed of after a single use.

However, storage in bags must be temporary (less than eight months) to minimize the chance of spoilage. It is not possible to aerate grain stored in bags; therefore, grain should be dry or nearly dry before bagging. Bags must be monitored and tears or rips should be promptly fixed to prevent moisture from entering the bags. Bags should be positioned on clear ground that is gently sloping to facilitate draining. They should also be positioned to allow access in winter.

If grain spoilage is minimized in the bags, grain bags are a low-cost storage option (refer to **Section 10.3** for a cost per bushel analysis of grain bag storage).

10. Economic Assessment

Obviously, there is a cost associated with all storage, aeration, monitoring, and management equipment. Producers are encouraged to consider these costs as “insurance” or a risk mitigation measure against grain spoilage. The costs to purchase, install, and operate an aeration fan are small compared to the cost of a bin of spoiled grain.

10.1 Lost Revenue Due to Spoiled Grain

Actual losses of revenue due to spoiled grain are not monitored; therefore, this value is difficult to verify. It has been estimated that $750,000,000 is lost annually in Canada due to grain bin spoilage, assuming a 5% in-bin spoilage loss.

A single 5,000 bushel bin of spoiled grain can represent a loss of $10,000 to $50,000, depending on the grain and the market for heated or spoiled grain. This loss is significant and producers are keen to prevent spoilage loss. This may mean selling grain as quickly as possible and not taking advantage of marketing opportunities. The alternative is to store the grain longer. Longer storage requires monitoring and management.

10.2 Lost Revenue Due to Overdried Grain

To minimize the chance of spoilage, grain should be cooled and dried as soon as possible after binning. Generally, the lower the moisture content, the longer it can be stored safely. However, selling over-dried grain also represents a significant loss of revenue. This is because, in Canada, producers are paid on a wet tonne basis. Drying grain beyond the allowable moisture content means a lower tonnage.

For 1,000 bushels of canola, overdrying by 2% (8% instead of 10%) results in a loss of 0.512 tonnes of water. If canola is worth $600 per tonne, that water is worth $600 per tonne as well; therefore, overdrying by 2% results in a loss of over $300 per 1,000 bushels. Over drying wheat by 2% (12% instead of 14%) results in a loss of approximately $200 per 1,000 bushels. These losses will fluctuate with the market value of the crop.

It is economically beneficial to prevent overdrying grain or to rewet grain that is harvested too dry. This can be achieved by careful management of the NAD system or by using a fan control strategy that will result in an even moisture content profile in the bin.

10.3 Estimated Cost ($/bu)

The estimated cost of grain storage for bins and grain bags is presented in **Table 14**. The information in **Table 14** was provided by the Saskatchewan Ministry of Agriculture.

Table 14. Summary of grain storage costs for hopper bins, large flat-bottom bins, and grain bags.

	Steel Bins		**Grain Bags**
	Hopper with aeration	**Flat bottom with aeration**	
Volume to store	120,000 bu	120,000 bu	120,000 bu
Bin/bag size	5,390 bu	12,500 bu	12,500 bu
Number of bins/bags	22.3	9.6	9.6
Cost of bin or bag	$19,300.00	$27,500.00	$790.00
Added equipment cost	$29,500.00	$29,500.00	$105,000.00
Years of life	25	25	10
Salvage value	**10%***	10%	10%
Spoilage rate	0%	0%	**2%***
Total annual cost per bushel	$0.59	$0.38	$0.37

To conduct this analysis, the total volume to store was assumed to be 120,000 bushels. This requires 22.3 hopper bins, 9.6 flat-bottom bins, and 9.6 bags. The cost of the bin includes the cost of the fan and air distribution system. Supplemental heating systems and energy costs to run the fans are not included. For both bin sizes, the total cost of fans and air distribution system was less than 10% of the total cost of the bin. The added equipment cost for the bins includes augers and added equipment cost for the bags includes the bagger and extractor.

For this analysis, the salvage value of all equipment was assumed to be 10%. Many producers agree that the salvage value of hopper bins is higher than other equipment, which will help reduce the total annual cost per bushel. The spoilage rate was assumed to be 0% for bin storage and 2% for bag storage. If bags are not well monitored or managed, the spoilage rate can be much higher.

Using the assumptions outlined above, the total annual cost for large bin and bag storage are the lowest at approximately $0.38 per bushel. The annual cost for hopper bin storage is $0.59 per bushel. If the salvage value of the hopper bin is increased to 30% and the spoilage rate of grain stored in bags is increased to 5%, the total annual cost per bushel becomes $0.58, $0.38, and $0.52 for hoppers, flat-bottom bins, and grain bags, respectively. This illustrates that the spoilage rate in grain bags must be minimized to keep bag storage costs low.

An aeration or NAD system will cost roughly $2,000 for a hopper bin and $3,000 to $5,000 for a larger bin, which works out to be approximately five cents per bushel per year. Adding a heater for supplemental heat will cost an additional $1,500 for a hopper bin up to 5,000 bushels and up to $3,300 for larger bins up to 10,000 bushels, which works out to be an additional four cents per bushel per year (refer to **Section 7.3** for energy costs for supplemental heating).

While the up-front costs for aeration or NAD systems may seem prohibitively high, the lost revenue from a single bin of spoiled grain will be much higher. Aeration and NAD systems also offer producers some peace of mind during a busy harvest season.

11. Summary

Farming continues to evolve, which has in many cases increased the importance of managing grain storage to prevent spoilage and optimize grain quality. Managing grain storage requires an understanding of the factors that affect grain in-bin storage and the role that equipment plays.

Aeration and NAD are considered to be basics for grain conditioning. Aeration is low airflow through grain that is only capable of moderating temperature and temperature uniformity. This is especially useful when dry grain is harvested at higher temperatures and cooling is required for safe storage and when temperature uniformity is needed to prevent “hot spots”.

Natural air drying uses a much higher airflow and, in addition to temperature moderation and uniformity, is capable of affecting grain moisture content. To understand the behaviour and control of NAD systems, it is important to understand the interaction of air temperature, air RH, air flow, air distribution, grain characteristics, static pressure, fan characteristics, and equilibrium moisture.

Effectively utilizing control strategies for NAD requires recognition of the opportunities and limitations of each strategy. Some strategies focus on stabilizing grain condition, while for others the goal may be drying the grain or even increasing grain moisture. These strategies are being gradually automated but are generally cost prohibitive for smaller bins and still require refinement. Because the moisture movement between air and grain depends on numerous factors, there is not a single strategy (e.g. run your fans between 10 am and 3 pm) that will be effective for every situation.

In addition, new concepts for safe grain storage are being developed, but there is no scientific data available to support performance claims. As well, the movement to much larger bins means the information developed for smaller bins years ago needs to be evaluated for today’s large bins.

Grain storage is a critical and necessary component of grain farming and grain spoilage is a complex process that depends on numerous factors. Producers tend to invest a lot of time and technology in growing and harvesting the grain but are reluctant to invest in the management of grain once it’s in the bin. Each bin of grain often represents tens of thousands of dollars of investment so it is critical to manage the grain to minimize spoilage. This may mean investment in time and technology and requires knowledge of the factors that affect grain spoilage.

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