DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

CHAPTER 10

On-Farm Corn Drying and Storage

Sammy Sadaka and Lalit Verma

Increasing corn acres over the past several years has led to increasing interest in on-farm drying and storage. Corn quality is the highest at harvest, and producers should promptly dry newly harvested corn to safe moisture levels in order to maintain quality and marketability. Producers need to dry corn to 15.5% moisture content (MC) when corn is to be marketed immediately. Otherwise, corn needs to be dried to 12.0% MC if it is expected to be stored for several months. This chapter will briefly discuss the fundamentals of on-farm corn drying, drying methods, fans, storage, grain handling safety and corn drying costs.

Figure 10-1. Grain drying and storage bins.

Fundamentals of Corn Drying

Drying Process

Corn drying is the process of reducing grain moisture to reach safe moisture levels for long-term storage. Corn is dried in most cases by passing relatively large volumes of low-humidity air, either ambient or heated, through the grain. The quality of the drying air determines the final moisture content of the corn kernels. In addition, the speed of corn drying (known as the drying rate) depends on moisture content and temperature of kernels as well as on the temperature, relative humidity and velocity of the drying air. Corn is typically dried down to 15.5% or 12.0% depending on whether it is going to be marketed directly or stored for several months. Figure 10-1 shows an on-farm grain drying and storage site in Arkansas.

Role of Air in Drying Process

To dry corn, large quantities of dry air are pushed through the corn after it is deposited in the drying bin. Air quantity and quality are important factors that play the main role in determining the final moisture content of corn kernels. The term air quality refers typically to its equilibrium moisture content (EMC). The air EMC is determined by knowing its temperature and relative humidity. Table 10-1 shows the EMC of corn at different levels of air temperature and relative humidity. For example, if the air temperature and relative humidity are 60°F and 70%, respectively, corn will be dried to 15.7% moisture content, assuming that air is allowed to pass through the corn, under the same conditions, for a sufficient time.

It should be mentioned that 1 cubic foot of air at a certain temperature has the capability of holding a specific amount of moisture. Increasing

Table 10-1. Corn equilibrium moisture content.

Temperature (ºF)	Relative Humidity (%)						
	30	40	50	60	70	80	90
40	10.0	11.8	13.5	15.3	17.1	19.3	22.3
50	9.5	11.2	12.9	14.5	16.3	18.5	21.4
60	9.1	10.7	12.3	13.9	15.7	17.7	20.5
70	8.7	10.3	11.8	13.4	15.0	17.0	19.8
80	8.4	9.9	11.4	12.9	14.5	16.4	19.1
90	8.1	9.5	11.0	12.4	14.0	15.9	18.5
100	7.8	9.2	10.6	12.0	13.6	15.4	17.9

the air temperature increases its capacity to carry more moisture as shown in Figure 10-2. It is noticeable that air temperature at T2 (90°F) is greater than air temperature at T1 (70°F). As a result, the air humidity ratio at HR2 is greater than the air humidity ratio at RH1. Therefore, we can increase the drying potential or reduce the time it takes for corn to reach equilibrium with air (increasing drying rate) by passing larger volumes of air over corn or by increasing the air temperature, or both.

Corn Shrink Factor

Most buyers use the grain moisture content of 15.5% as the base moisture for corn. When any grains are delivered to the elevator above its base MC, buyers use a factor called "shrink factor" in order to adjust the quantity for the excess moisture. This is because grain buyers will not pay for excess water. Applying a shrink factor approximates the equivalent number of bushels that would be in the load if the grain were dried to the base MC. Conversely, some farmers often deliver grain to the grain terminal at moisture levels below the base MC. These factors clearly demonstrate how sensitive corn production economics are to the moisture content of the corn sold. Following is a good example that estimates the potential loss due to corn shrinkage. Assume that a truck is hauling 1,000 bushels, a normal truckload of wet corn. It is clear from Table 10-2 that marketing corn at any moisture level greater than 15.5% will decrease the total profit.

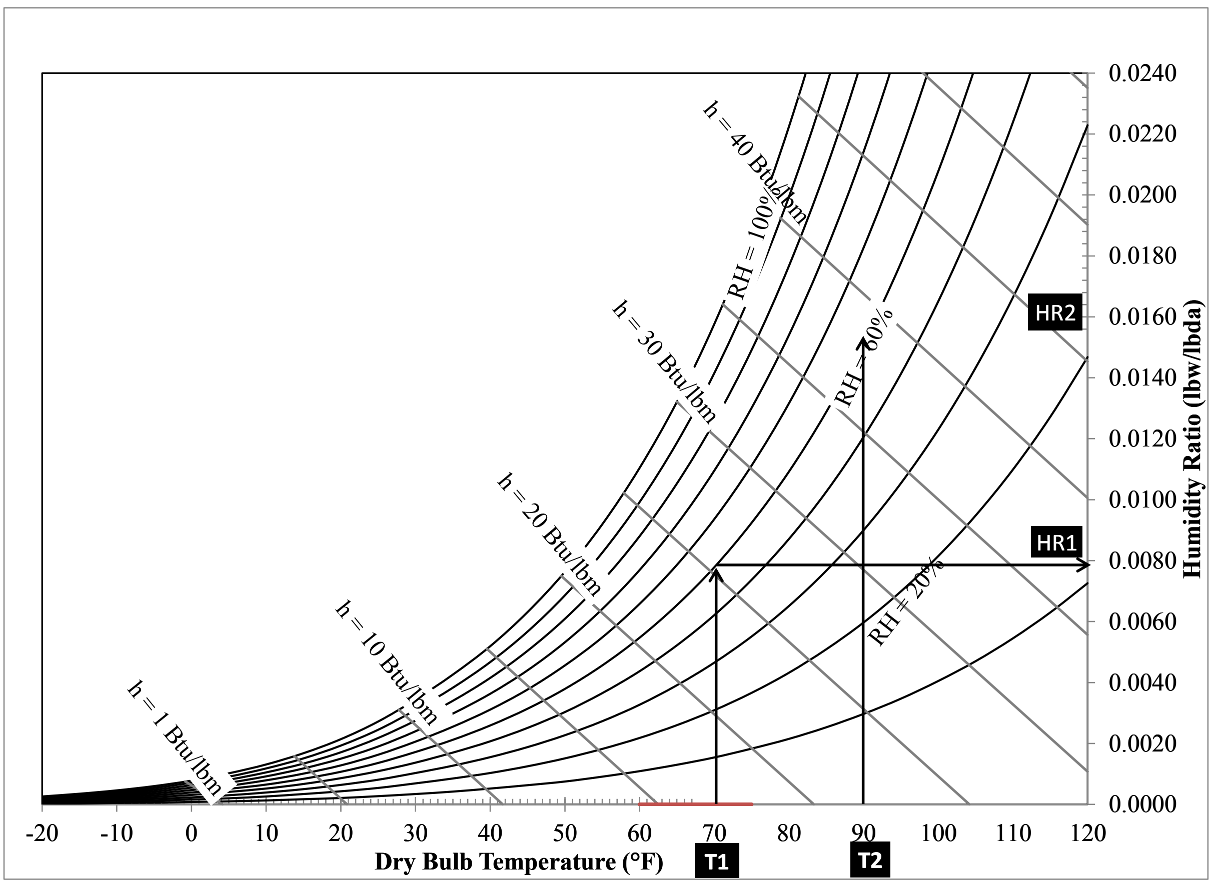

Figure 10-2. Psychrometric chart.

Table 10-2. Effects of shrinkage factor on total loss.

Initial Scale Weight, bu	Initial Moisture Content, %	100-Initial Moisture Content, %	Final Moisture Content, %	100-Final Moisture Content, %	Total Corn Weight, bu	Penalty Due to Shrinkage, bu
1,000	15.5	84.5	15.5	84.5	1000	0
1,000	16.0	84.0	15.5	84.5	994	6
1,000	17.0	83.0	15.5	84.5	982	18
1,000	20.0	80.0	15.5	84.5	947	53
1,000	23.5	76.5	15.5	84.5	905	95

On-Farm Drying Methods

Drying corn after harvest is an energy-intensive process. As a result, corn producers use various corn drying techniques based on grain moisture and grain facilities. There are various types of corn drying techniques which could be used to expedite the grain drying process efficiently. Among these techniques are natural air drying, low temperature drying, layer drying, batch in-bin drying, portable batch continuous-flow drying, combination drying and dryeration.

Natural Air Drying

Natural air drying is a technique used to dry corn by passing unheated (natural) air through the corn mass until its moisture content reaches EMC. Drying corn with natural air can be accomplished only if the air temperature and relative humidity conditions allow a net moisture transfer from the corn to the air. A natural air drying system (Figure 10-3) consists of a perforated-floor bin equipped with a drying fan, a grain spreader, a sweep auger and an unloading auger. Stirring devices may also be added to the system. Successful corn drying with natural air is usually the most energy-efficient method of drying. However, it is also the slowest drying method and has the greatest potential for corn spoilage or mycotoxin development. Natural air drying is extremely sensitive to weather conditions and requires the highest level of management.

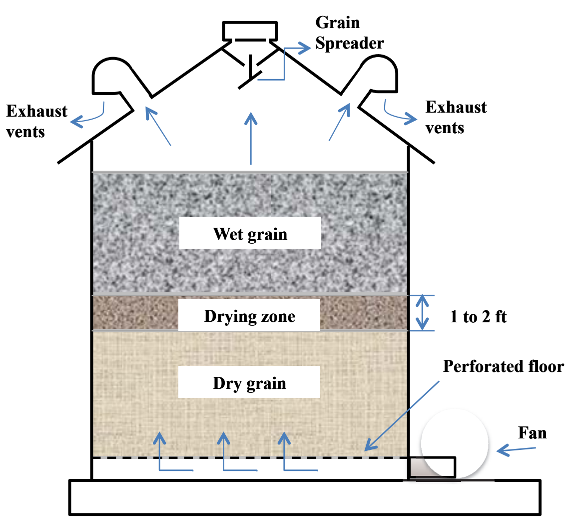

Figure 10-3. Natural air drying bin.

Low Temperature Drying

In low temperature drying of corn, the drying air is heated to raise its temperature by only 10°F above ambient conditions. Similar to natural air drying, low temperature drying also requires a perforated-floor bin, a grain spreader, under-floor unloading auger and a sweep auger. A stirring device may also be added. The low temperature drying technique has a higher potential, when compared to natural air drying, to dry corn to the accepted long-term storage moisture contents. Corn could be dried using the low temperature drying technique then stored in the same bin, thus minimizing handling and labor costs. Generally, the comparative total cost for drying decreases as less energy is used to heat the drying air even though more energy is required to operate the drying fans. Successful low temperature drying is relatively economical in terms of energy cost when compared to higher temperature techniques.

Layer Drying

This process involves drying the newly harvested corn in layers. It is typically accomplished by placing an initial corn layer in the drying bin. The drying air starts the drying front that moves through the corn. Then, additional layers of wet grain are added periodically so that the depth of wet grain always precedes the drying front. Layer drying requires a bin, a perforated drying floor, a fan, a heating unit with a transition, a grain spreader, a sweep auger, a stirring device and an unloading auger. Layer drying offers the advantage of low heat input, making it one of the most energy-efficient drying techniques in terms of heat required for drying. In addition, corn stays in the storage bin after drying, thus minimizing the handling and labor costs. Conversely, the drying rate of the system is relatively slow which necessitates greater system management. The slowness of the system may also affect the harvesting rate and eliminate the possibility of multiple uses of the same bin during the drying season.

Batch In-Bin Drying

In this process, corn is added to the drying bin in daily batches, usually between 2.5 and 4 feet deep, then dried and cooled. The dried corn batch is then moved to storage bins as a new batch of wet corn is added to the drying bin. The main idea of the batch in-bin dryer is to pass relatively large quantities of air through a shallow corn depth to achieve drying rapidly. This allows corn producers to accommodate larger harvest rates than with other in-bin drying methods. No storage of wet corn is necessary in batch in-bin drying since the batch size is adjusted to accommodate the day's harvest. The batch in-bin drying technique requires a perforated floor, a fan, a heating unit, a grain spreader, a sweep auger and an under-bin unloading auger. In this process, it should be noted that the diameter of the drying bin must be large enough so that the recommended maximum grain depth of 4 feet is not exceeded. Batch in-bin drying is popular due to its flexibility when selecting the drying system equipment. In addition, the management of the batch in-bin system is less intensive than that required for other in-bin drying systems.

Portable Batch and Continuous-Flow Drying

Portable batch (Figure 10-4) and continuous-flow drying are considered fast drying techniques. They share similarities in configuration and operation. The basic idea in both processes is to pass large volumes of air, i.e., 50-125 CFM/bu, through relatively thin corn columns (12 to 24 inches) to attain high drying rates. The portable batch units

Figure 10-4. Continuous-flow grain dryer.

typically dry, cool then unload a fixed amount of corn into storage at set intervals. Drying temperatures range from 160°F to 200°F and heater capacities are from 2 to 5 MMBtu/h. The main advantage of these units is their large drying capacity that enables corn producers to dry large volumes of harvested grain rapidly. Most portable drying units are fully automated, thus reducing labor requirements for loading and unloading. Their movability allows for easy replacement or capacity expansion. The main disadvantage of these drying units, however, is their relatively low efficiency in terms of energy consumption. Heat recapture devices may improve the energy efficiency of these dryers. Drying cost may be relatively higher than other drying systems.

Combination Drying

In this configuration, high-temperature drying and in-bin drying processes are integrated making a combination system. The high-temperature drying method is an initial drying step used to reduce the moisture content of wet corn so that in-bin drying can be used to finish the drying process. Combination drying needs an auger or bucket elevator, a wet holding bin, a high temperature dryer, a drying bin, a drying fan, a heater, a perforated floor, unloading and sweep augers and a grain spreader. Combination drying allows corn producers to begin harvesting whenever the grains mature instead of waiting for sufficient field drying. Furthermore, this process is more energy efficient than high-temperature drying systems alone. On the other hand, combination drying requires a relatively high capital investment and management if purchased as a unit because it incorporates two complete drying systems.

Dryeration

This process combines drying and aeration and is known for maintaining the quality of corn kernels during drying. In this process, wet corn is taken directly from the dryer, at a high temperature, to a tempering bin. Then, grain is allowed to steep in their vapors, for about 4 hours, before air-cooling (aeration) is initiated. This approach facilitates moisture removal without the use of additional energy. Heat is removed from grain through two processes, sensible heat transfer and latent heat transfer. Sensible heat transfer between the kernel and the surrounding air depends on the temperature differences. Latent heat transfer, on the other hand, occurs when the excess heat stored in the grain evaporates the kernel moisture. The gradual grain cooling in this process minimizes the prospects of thermal stresses or cracks. Therefore, dryeration is an economical drying method that maintains grain quality at a high drying rate with higher energy efficiency.

Grain Drying Fans

Grain bin fans are responsible for circulating air through the grain for holding, drying and cooling processes. Fans also determine the rate of air circulation. Air is the most essential element to successful grain operations since it controls grain moisture and temperature, reduces biological and insect activity and prevents moisture migration. Therefore, it is desirable during grain drying to move as much air through the grain as possible. Technically, doubling the airflow reduces the drying time by about 50%. However, all fans are susceptible to a drop in the capacity of air that can be circulated as the static pressure increases. Therefore, careful selection of grain fans is a necessity to ensure fast and efficient drying.

Types of Grain Drying Fans

There are two basic types of fans, i.e., the axial flow fan and the centrifugal fan. The axial flow fan (Figure 10-5) closely resembles a ceiling fan. On the other hand, centrifugal fans (Figure 10-6) are encased in a round housing that rotates and forces air to move in a direction perpendicular to that of air entry.

Axial fans supply more cfm per unit horsepower at low grain depths (static pressures below 4.0 to 4.5 inches of water) when compared to centrifugal fans. That is why axial fans are preferable in shallow-depth bin drying systems such as batch in-bin and continuous in-bin systems. Axial fans are also suitable for deep bin drying (up to 20-foot depth) when a flow of 1 cfm/bushel or less is required. They are generally lower in initial cost but operate at a higher noise level than centrifugal fans. These fans are generally not acceptable for use with bins that will also handle rice because of the high static pressures expected – typically, air is more difficult to move up through a column of rice. Axial flow fans are less costly than a centrifugal fan. However, when a high static pressure is involved, centrifugal fans are usually selected.

Figure 10-5. Axial flow fan.

Figure 10-6. Centrifugal fan.

Centrifugal fans supply more cfm per horsepower at static pressures above 4.0 to 4.5 inches of water than axial fans (Figure 10-7). These are especially advantageous in deep grain levels (12 to 20 feet) when high volumes of air circulation are required. In addition, centrifugal fans are selected when low operation noise is a factor. Larger diameter centrifugal fans typically move more air per horsepower.

Fan Performance

Fan performance is normally illustrated as a graph (performance curve) showing the correlations between airflow rate (cubic feet per minute, cfm), static pressure (inches of water) and horsepower. Each fan type has unique performance characteristics similar to the curves presented in the graph below (Figure 10-7). The static pressure of a drying bin is a measurement of the resistance to flow air through the grain. In a properly designed system, grain is the main restrictor to air-low within the bins. The selected fan must operate at the static pressure needed to overcome the airflow resistance in the bin. From the graph below it is clear that using a centrifugal fan is recommend in most cases particularly with medium to high static pressure. This is because, as the depth of the grain increases, the value of static pressure required to move the air through the grain increases. In addition, centrifugal fans generate less noise as compared with axial fans if both move the same amount of air. It should be mentioned that the curves shown here are presented as examples and should not be used in system planning.

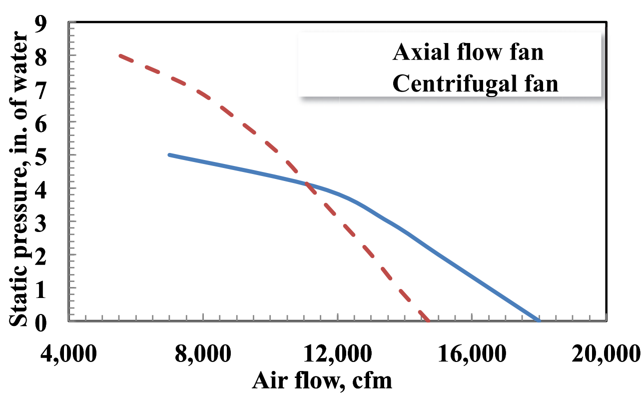

Figure 10-7. Axial and centrifugal fan curves.

Selection of Drying Fans

Airflow rates for drying vary from 0.5 cfm/bu to more than 50 cfm/bu for commercial or batch dryers. Airflow rates for on-farm drying vary from 0.5 to 6 cfm/bu depending on the initial moisture content of the grain and on the amount of heat added to the drying air. Several rules of thumb have been developed for sizing fans in drying systems: (1) doubling the grain depth at the same airflow rate (cfm/bu) requires 10 times the horsepower, and (2) doubling the airflow rate (cfm/bu) on the same depth of grain requires 5 times the horsepower. These rules can be seen clearly in Figure 10-8. Available power can be quickly overwhelmed as the grain depth and/or air requirements (CFM) increase.

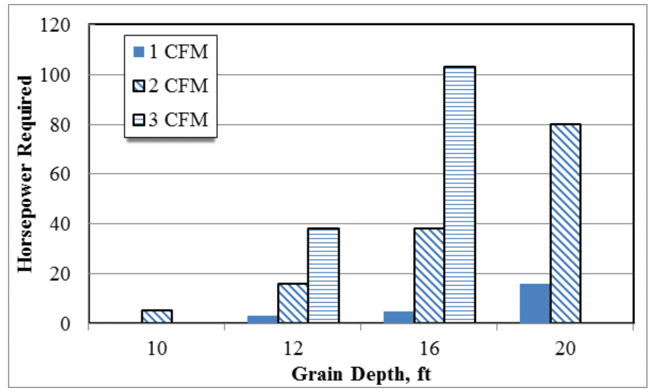

Figure 10-8. Fan power requirements versus depth.

Fundamentals of On-Farm Storage

Corn should be stored immediately after the drying process is complete. The storage space must be appropriate to avoid spoilage. Corn spoilage is the result of microorganism activities using grain nutrients for growth and reproductive processes. During their growth, microorganisms produce heat that can increase the temperature of stored corn, which in turn can lead to heat damage and reduces corn quality. These conditions can also cause fires and dust explosions in storage structures. The factors that affect corn quality during the storage period include moisture content, temperature, aeration, storage and time.

Moisture Content

Corn moisture content is the most important factor affecting the growth of microorganisms. High moisture content in combination with warm temperatures can provide optimum environment for microorganisms to grow and reproduce. Reducing the moisture content to safe levels as quickly as possible can minimize spoilage and the development of mycotoxins. As mentioned earlier, over long time storage corn will equilibrate with the surrounding air. For example, if a relatively wet sample of shelled corn with a moisture content of 25% is placed in an environment being maintained at 80°F and 60% relative humidity, it will dry to about 12.9% moisture content (Table 10-1). Likewise, if a dry sample is placed in this environment, it will absorb moisture until it reaches the 12.9% EMC. Moisture often accumulates in the top layers of stored corn even though initially corn is stored at safe moisture content in weather-tight bins. The accumulation is a result of moisture migration caused by temperature differences within the grain mass.

Temperature

Storage fungi, i.e., thermophiles and mesophiles, grow rapidly at temperatures between 85°F and 90°F, and 60°F and 90°F, respectively. Below these temperatures, fungi growth rates decrease and reach a minimum at 35°F to 40°F. This explains why cooling stored grain to about 40°F by aeration is recommended whenever possible. Cooling below 40°F, however, is not necessary because storage fungi activity is already at a minimum. Corn producers in the northern states could store their grain safely at slightly higher moisture contents than producers in southern states. Cooling to below 32°F may freeze the grain. If the grain is frozen, the fan(s) must run longer to warm the grain, and condensation may occur.

Aeration

Aeration is an important factor that controls the quality of stored grain since appropriate aeration contributes to the prevention of grain spoilage. Corn must be aerated to minimize the risk of storage losses. Potential problems exist when damaged and/or high-moisture grain is stored, the aeration system is inadequate or the grain bin is incorrectly filled or unloaded. Rewetting and over-drying occur to some extent in all aeration systems, but they usually offset each other. This issue could be minimized by operating the fans only when needed to maintain proper grain temperature.

Storage Time and Initial Quality

The length of storage influences the amount of spoilage in grain. In general, the longer the grain is stored, the lower the moisture content should be to ensure safe storage. Corn contamination by microorganisms is another important factor affecting its quality. Corn producers in general are concerned with aflatoxin in corn. It is a key problem for corn producers and handlers in relatively wet years. Several *Aspergillus* fungi, i.e., *Aspergillus flavus* and *Aspergillus parasiticus*, can produce aflatoxin under certain conditions. Research indicates that if conditions are suitable for aflatoxin production, it is extremely difficult to prevent infection from *Aspergillus* spp. and subsequent aflatoxin production. Thus, a best practice management is to minimize the pre-harvest infection and minimize post-harvest fungal growth with careful handling and storage practices.

Corn Storage Tips

- Cool grain as soon as possible in the fall. Target temperatures should be initially around 60°F.
- Continue to aerate and uniformly cool grain to between 30°F to 40°F if possible. This will help avoid internal moisture migration and insect activity.
- Monitor grain and aerate monthly to maintain uniform temperature and moisture levels throughout. Aerate more often if moisture or temperatures increase.
- Keep the grain cool as long as possible into the early spring.
- Do not aerate in early summer unless problems develop.
- Cover fans and openings when not in use to help avoid air, moisture and potential insect movement.
- Monitor carefully and fumigate if needed.
- Inspect corn surface at least every week throughout the storage period.

Grain Handling Safety

- Always think safety first around grain bins.
- Wear appropriate masks when working in dusty conditions – particularly these resulting from moldy or spoiled grain. Exposure and inhalation of mold can cause severe allergic reactions.
- Never enter a bin when grain is being unloaded.
- Beware of crusted grain.
- It is best to work in pairs – one inside with a safety harness and one outside for assistance if needed.
- Grain suffocation accidents happen all too often – think before you act or enter a bin.

Corn Drying Cost

As discussed earlier, in order to dry corn, producers need to determine the total pounds of water they will remove from 1 bushel. The number of BTUs needed to extract 1 pound of water will vary from 1,100 to 1,400 depending on how easily moisture is given up by the kernel. As the kernel begins to dry, more energy is needed to extract the last bit of moisture out. A good estimate is to use an average of 1,200 BTU/pound of water to calculate the energy needed to dry 1 pound of moisture. It is quite important to maintain the drying cost in the minimum level in order to maximize the profits (returns on investment). Table 10-4 summarizes the BTU/unit of fuel as well as the burning efficiency.

Table 10-4. Heating values of fuel as well as their corresponding efficiencies.

Fuel	BTU	Unit	Burning Efficiency
LP gas	92000	gallon	80%
Natural gas	1000	ft^3	80%
Electricity	3413	kWh	100%

The following equation can be used to calculate the corn drying per bushel.

$$\text{Fuel cost (\$/bu)} = [(\text{BTU/lb}_{water}) \times (\text{lb}_{water\ removed}/\text{bu}) \times \text{fuel cost (\$/unit of fuel)} \times 100] / [(\text{BTU/unit of fuel}) \times \text{burning efficiency \%})]$$

Example 1

Assume you have a 20 HP fan with electricity cost at $0.10 kW-hr, no demand charges are applied; determine the cost per hour of operation for this fan:

$$\text{Fan motor cost (\$/h)} = 20\ \text{HP} \times 0.7475\ (\text{kW/HP}) \times 0.10\ (\$/(\text{kW.h})) = \$1.50$$

Example 2

Determine the drying cost per bushel of 20% moisture corn down to 13% moisture using LP at a cost of $2.40/gallon.

There are 2.98 pounds of water per bushel above the value for 15.5% corn to be removed. The fuel cost could be determined using the following equation:

$$\text{Fuel cost (\$/bu)} = [1200\ (\text{BTU/lb})_{water} \times 2.98\ (\text{lb}_{water\ removed}/\text{bu}) \times 2.40\ (\$/\text{unit of fuel}) \times 100] / [92{,}000\ (\text{BTU/unit of fuel}) \times 80\%] = \$0.117$$

References

Bern, C., and J. McGill. 2012. Managing grain after harvest. Iowa State University.

Bern, C., C. Hurburgh and T. Brumm. 2011. Managing grain after harvest. Agricultural and Biosystems Engineering Department, Iowa State University.

Bridges, T., O. Loewer and C. Whitelayer. Drying of stored grain. Available online at: http://www.bae.uky.edu/publications/AENs/AEN-56.pdf. Accessed November, 2014.

Farm Fans. Grain bin drying and aeration systems. Farm Fans, Inc. http://www.fficorp.com/english/aeration/contents.html. Accessed November, 2014.

Hansen, R., H. Keener and R. Gustafson. 1990. Natural air grain drying. The Ohio State University. Bulletin 805.

Hellevang, K. 2011. Corn drying and storage tips for 2011. Available online at: http://www.ag.ndsu.edu/graindrying/documents/Corn_Drying_and_Storage_Tips_for_2011.pdf. Accessed November, 2014.

Hellevang, K. 2013. Grain drying. Available online at: http://www.ag.ndsu.edu/pubs/plantsci/smgrains/ae701.pdf. Accessed November, 2014.

Hellevang, K. J. 1994. Grain drying. North Dakota State University Cooperative Extension Service. November 1994. AE-701.

Loewer, O., T. Bridges and R. Bucklin. 1994. On-farm drying and storage systems. ASABE.

Sadaka, S. 2013. Selection, performance and maintenance of grain bin fans. Available online at: http://www.uaex.edu/publications/pdf/FSA-1075.pdf.

Sadaka, S., and J. Hardke. 2014. Fundamentals of on-farm rice drying and storage. Available online at: http://www.uaex.edu/publications/pdf/mp192/chapter-16.pdf.

Strobel, B., and R. Stowel. 1999. Using a psychrometric chart to describe air properties. Available online at: http://ohioline.osu.edu/aex-fact/0120.html. Accessed November, 2014.

Sukup Report. Managing stored grain. Available online at: http://www.sukup.com/content/safety/L1109_ManagingStoredGrain.pdf. Accessed November, 2014.

VanDevender, K. 2010. Grain drying concepts and options. Available online at: http://www.uaex.edu/publications/pdf/FSA-1072.pdf.