10 Drying, Handling, and Storage of Raw Commodities

Carol Jones
Mark Casada
Otto Loewer

The goal of postharvest grain drying, handling, and storage operations is to preserve the harvest quality of the grain and to add value by removing impurities and identifying and segregating lots with special characteristics when appropriate. For agricultural products, quality loss may occur due to poor drying techniques, improper handling, or lack of proper storage environments resulting in deterioration from cracking, splitting, mold growth, insect damage, sprouting, loss of germination, or dry matter loss from respiration. Large grains such as corn — especially when dried at high temperatures — are particularly susceptible to physical damage during handling. Physical damage also makes grain more susceptible to invasion by storage fungi and insects.

Grain Quality Characteristics

All postharvest operations attempt to maintain the initial quality of the harvested grain. During storage, grain must be protected from deterioration or attack by molds, insects, rodents, and birds. Drying and handling operations must prevent physical or chemical deterioration. The physical protection provided by modern grain storage structures should eliminate serious bird and rodent damage. Molds and insects cannot be physically excluded from grain with current storage designs. They can be controlled through grain temperature and moisture management.

End-use quality

The definition of grain quality varies depending on the intended end-use of the grain. For hard wheat, the ultimate criteria may be loaf volume for baked bread; for soft wheat, the objective may be cookie spread. Soybeans are processed for protein and oil content. Corn has many uses and applications. For the ethanol industry, the amount of starch available for fermentation is a critical quality factor. Ethanol producers may have other quality concerns because they sell co-products such as dried distillers grains (DDGS) with minimal or no mycotoxin content; mycotoxins are more concentrated in the distillers grains than in the incoming corn (Bennett and Richard, 1996; Murthy et al., 2005).

Milling is an important processing step for many grain products, so milling characteristics are often important quality parameters for hard, soft, and durum wheat; corn; and rice. Specialized end-uses may focus on one grain quality parameter, for example, high oil content in corn and soybeans to provide energy and amino acids in livestock and poultry diets.

Grain grading

Originally, U.S. grain grading standards did not focus on product quality characteristics of interest in today's specialty grains markets. Early grain standards were developed to facilitate trade, describe physical properties and storability of the grain, and characterize product yield and grain quality. Initial grading standards addressed deterioration issues that adversely affect product quality. Over the years standards have changed as rapid measurement technologies have been developed that emphasize product quality characteristics.

Some standards relate to specific product quality issues. For example, insect damaged kernels (IDK), addressed in Federal Grain Inspection Service (FGIS) wheat standards, pertain to potential milling problems of insect fragments in the flour. FGIS added tests to address characteristics of interest to buyers such as protein content of wheat and oil and protein content of soybeans.

Sampling

Quality measurement, or grading, of a grain sample assumes that the sample is representative of the quality of the lot sampled. A representative sample is critical. Without it, the grade assigned is meaningless. The FGIS recommends continuous diverter-type samplers for the most representative samples. The agency requires the use of specific grain probes: a grain trier, which is a gravity fill probe, and a vacuum probe. The probe must be long enough to reach the bottom of the truck or other container. The sample must be collected using an approved probing pattern. Explicit probing patterns require up to nine probe locations on shallow flat-bottom trucks. More probe locations are required for grain on barges (USDA-GIPSA, 1995).

Nonofficial sampling in the grain industry often involves using two or more probes to obtain a useful sample quickly. There is not as much assurance that such a sample is representative. For nonofficial sampling, simulating a diverter-type sampler by crosscutting a stream of flowing grain is recommended (Hellevang et al., 1992; Maier, 1993). See USDA-GIPSA (1995) for complete recommendations on sampling.

Grain Quality Degradation

Preserving grain quality is a problem in many parts of the world (Gras et al, 2000). Quality never improves during storage. The best a manager can hope for is to preserve the initial quality as closely as possible. Grain and feed can be stored for long periods of time if storage conditions are managed correctly and the material is in good condition to begin with. When degradation occurs, swift intervention is needed to minimize product damage and loss of market value.

Influences

The main reasons for grain quality decline are under drying (storing grain with unsafe moisture and temperature levels), overdrying, grain respiration, insect and rodent damage, and mold or other bacterial contamination (Kazazis, 1980; Wilcke et al., 2000). Proper grain moisture and temperature management is essential for reducing damage to the stored crop. High humidity and temperature conditions promote insect infestation and mold development. Generally, the drier the grain in storage, the higher the storage temperature can be before mold begins to form. Each grain or seed variety has its own safe storage moisture and temperature, and equilibrium relative humidity (ERH) criteria.

Drying damage

Overdrying grain causes cracking, darkening, and seed damage. Although drying damage is often associated with corn, oilseeds such as soybeans, rape, and canola also can be damaged when overdried. Seeds shatter during handling when dried to less than 6% moisture. Drying can cause damage that is not visible. For example, overheated wheat may look normal, but contain denatured protein that affects performance in making flour. Reducing heat levels during drying will minimize or prevent drying stress damage.

Handling damage

Mechanical handling can damage grain and seeds, reducing quality and encouraging other unfavorable-conditions. These include insect population growth and moisture hot spots due to poor aeration through accumulated trash and fines generated by broken kernels. Damage can occur because of high velocity impact, kernel stress cracks during drying and cooling, and very dry or very cold grain. Proper selection and sizing of handling equipment such as augers and drag conveyors is essential in reducing kernel damage. Augers must be operated at the rated capacity and speed for the grain handled. Larger, slower augers can reduce handling damage. Bearing-supported augers make operating at rated capacity under variable incoming flow rates much easier to achieve. An accumulating bin over the intake hopper for the auger also can provide a more constant feed rate by keeping the intake full. Level control switches allow the auger to run periodically at or near full capacity, minimizing mechanical damage.

Bucket elevators cause less damage to grain as long as drop heights are less than 40 feet. Above this height, grain damage is much more likely to occur. Grain decelerators can be installed in downspouts to reduce the grain velocity and subsequent damage.

Properly installed and operated pneumatic conveyors reduce grain damage. Large drop heights, sharp spout turns and transitions, and misalignments are avoided that cause increased grain velocities, turbulence, and high velocity grain impact that result in damage, particularly to cracked or brittle seed.

Storage damage

Mold and insects are the primary causes of damage to stored grain. Grain in poor condition due to improper management is a prime target for mold growth and insect population increases. Damaged kernels, excessive fines, trash, and improper drying create conditions for spoilage. Pockets of fine material impede aeration distribution, allowing insects to multiply, which increases moisture and temperature. Mold forms under high moisture, high temperature conditions. Cleaning grain before storage, spreading grain to reduce fine concentrations, and properly managing aeration systems helps reduce pockets of high moisture grain and minimizes mold and insect activity.

Grain Management During Handling and Storage

The key to maintaining grain quality during storage is the proper moisture and temperature management. Becoming familiar with the interaction between these two conditions and how they control grain storage is essential to successful storage of grains and seeds. Improper management provides conditions for increased insect infestation and mold damage. Toxins caused by molds and kernel damage caused by insect infestation reduce the uses and value of the product being stored. In fact, the product may not be marketable if damage is extensive. Insects thrive and multiply at temperatures between 60° and 100°F. Molds also develop at these same temperatures. The higher the grain moisture, the more damage these temperatures will cause. If grain is kept cooler, the moisture content can be higher. If storage temperatures are expected to be high, as in summer harvested crops, grain must be at lower moisture content to store successfully. Fall harvested crops generally can be stored at higher moisture content because of low initial ambient storage temperatures that usually continue through the fall and winter months. The lower the moisture content, the longer grain can be stored successfully. Table 1 shows expected storage periods for grain held at various moisture contents.

Temperature management is affected by moisture migration during the storage period. Convection air currents caused by temperature differences between ambient conditions and the grain cause moisture migration as warm moist air meets cool grain. Differences in temperatures surrounding grain bins due to shading, temperature differences between day and night, and cold weather cause moisture problems within bins. Grain is a good heat insulator. The center of the grain mass (or bulk) stays warmer longer than grain near the bin walls. When the center of the grain is warmer, convection air currents move down through the wall area of the grain and push the concentrated warmer air up through the center of the grain. The warmed rising air absorbs moisture and deposits it on cool grain near the surface of the grain at the middle of the bin. Some diffusion of moisture also can occur between warm and cool grain.

Between the convection currents and moisture diffusion, high moisture problems occur at the top, middle surface of the grain bulk. This is also the area where fine material collects under the fill point where aeration is least effective, providing an ideal place for molds and insects to multiply and infest the grain. Proper management in operating aeration fans can go a long way in reducing temperature differences within the bin and cooling the grain to desired low temperatures afforded by seasonal conditions. Knowledge of the interaction between ERH and equilibrium moisture content (EMC) — the ability of grain to accept and release moisture as determined by the temperature, moisture content, and relative humidity — will help managers know when to efficiently operate aeration systems. Comparing grain temperatures between the grain near outer walls and the center of the bin will also provide a basic guide on when to aerate. When outer grain is more than 10°F cooler than center grain, aeration should be considered. A 3- to 5-foot temperature probe is the essential aeration management tool.

Table 1. *Suggested grain storage moisture in the midwestern U.S., (%wet basis). Moisture values are for good quality grain that is aerated to control temperature. Reduce moisture content by about one percentage point for grain that has low quality at time of storage. (MWPS AED20).*

	Storage period (months)		
Crop	Up to 6 months	6 to 12 months	More than 12 months
Barley and oats	14	13	13
Buckwheat	16	13	13
Canola	10	8	8
Corn, sorghum	15	14	13
Edible beans	16	14	13
Flaxseed	9	7	7
Soybeans	13	12	11
Sunflowers (confectionery)	10	9	9
Sunflowers (oil type)	10	8	8
Wheat, including durum	14	13	13

Site selection of facilities

Many factors must be considered when selecting a site for a new grain handling facility or in the expansion of an existing facility. The purpose of the facility and place in the company's expected growth plans must be carefully evaluated. Here are things to consider when locating or expanding a facility:

- What are the space requirements for the immediate need as well as for future expansion plans?
- Is there adequate electric power available or is electric service economically feasible?
- Is there adequate drainage? (Flood plains are unacceptable sites.)
- Are access roads adequate both in size, number, and condition?
- What are the restrictions on fuel and pesticide storage, and chemical use within state regulation guidelines?
- Are there noise level limitations? Neighbors or possible future housing developments?
- Are there fugitive dust and fine material drift concerns beyond legal limits?
- Is the soil structure adequate for the increased weight of equipment and grain storage?
- Is there room for equipment and truck entrance and exit?
- Is groundwater near the surface?

With new bin design tending toward larger bins and silos, consulting with a reputable grain bin distributor and construction company is essential. Choose a company that has experience not only in the grain storage industry but experience in building these facilities in your geographic location. They will be familiar with weather issues, soil structures, water and drainage issues, and local code and standard requirements.

Bin layouts

The following equipment and buildings should be considered in planning the facility:

- Bins (steel bins, flat storage, or concrete silos) and room for future construction
- Handling and cleaning equipment
- Dryer
- Truck scales
- Feed processing equipment and storage buildings
- Fuel storage
- Chemical storage
- Electrical service and boxes
- Maintenance and management buildings

Adequate road access and roads within the facility large enough for trucking, combines, trailers, tractors, and loading/unloading equipment

Focus should be on the efficiency of equipment movement around the site and the safety of moving equipment and material throughout the facility. Some situations may call for several remote sites that are close to the production of the crop with a central collection point for processing or shipping. Other operations will require one central location that handles all of the operation's grain and feed processing. The road structure for each situation is critical. A seasonal storage facility may not need to be as extensive as a central handling location. Central storage facilities require careful planning of layout with respect to conveyors, overhead catwalks, downspouts for filling bins, distributor access, dust control equipment, and unloading access.

Safety and groundwater and drainage considerations are paramount when designing pits, tunnels, catwalks, driveways, placement of buildings requiring chemical application such as fumigants, and location of electrical control boxes. Management office buildings and equipment requiring computer support or network connectivity should be identified early so that cabling or remote wireless communication can be established, whether provided by satellite access, underground cabling, or telephone lines. Consulting engineers and university planning services have multiple examples of site and bin layouts available. The larger the facility and the more expansion anticipated, the more essential planning becomes. A bin layout that will not allow larger trucking access to accommodate an increase in operation size will be a big negative management factor in the future.

Storage

Grain can be stored in a variety of structures. The decision about which kind of structure to use is influenced by the type and volume of grain to be stored, the frequency of loading and unloading, the availability of facility space, and soil and climatic conditions. The goal of storage is to keep the grain in the best condition possible. Individual kernel or seed quality cannot be improved during storage but, cleaning grain can improve the overall quality of the stored and marketed product. Maintaining the least amount of damage and loss of quality depends on the storage facility and the management of the grain. Generally there are five categories of storage units: metal bins, concrete silos, flat storage buildings, hopper bottom bins, and temporary storage areas.

Metal bins

Round metal bins are the most common structure type for storing grain in farm storage facilities. They are relatively easy to build with aeration and loading/unloading equipment, and are relatively low cost compared to concrete structures and flat storage buildings. Metal bins come in a large range of diameters, heights and volumes. The life of these bins is considered to be 20 to 25 years. The frequency of loading and unloading the bins as well as the quality of maintenance and management has significant impact on the structure's integrity. Large metal bins are prone to collapse when unloaded or loaded on one side. Roof collapse is possible if proper maintenance and management of roof venting is not maintained during aeration. The larger the bin diameter, the greater the risk is for problems to occur. Sometimes several smaller bins are a better option than a single large bin. The sizes and number of bins available provide greater flexibility in the selection of bins for storage.

Concrete silos

Dry grain may be stored in upright concrete silos. These tall-roofed silos may be constructed of tile with external steel hoops (ensilage silos) as well as slip-formed reinforced concrete. Aeration can be installed using bottom duct work. The static pressures encountered with tall columns of grain are high. Therefore, it is essential that fan vendors be consulted to insure proper sizing of aeration equipment for deep silos.

An alternative to high static pressure vertical aeration is to use four-duct cross-flow aeration, which greatly reduces fan power, static pressure and "compression heating" of cooling air. Cross-flow aeration requires full silos or special control management of supply and exhaust vents. Four-duct cross-flow aeration uses two fans on opposite ducts. One fan operates at a time with three exhaust ducts (exhausting through the opposite nonoperating fan), then the operating fan is switched by a timer so each fan operates 50 percent of the time — an hour or two of air movement in each direction. This method eliminates the dead air zone in the center of the silo and provides full, uniform air distribution to all grain at all depths. (Navaro and Noyes, 2002)

Concrete silos should be unloaded from the bottom center. Offset loading and unloading can cause instability, cracking, and failure in the silo walls. Before loading silos, an inspection of the integrity of the silo walls should give managers a good idea of the safety and feasibility of using the silos, especially if the silo has been in place several years. Unloading from the bottom of these silos may cause bridging of the grain, especially if grain is out of condition or moist. Bridging can cause engulfment hazards for workers entering the bin and unloading failure before the bin is emptied. Upon inspection of the top surface of the grain, a shiny appearance should be present if some of the grain has been unloaded. If the surface is dull and dusty, workers should suspect a grain bridge has occurred and a gap or cavern exists under the top surface of the grain. Workers entering a concrete silo must use confined space entry procedures. They should use the buddy system for communication, operate the aeration system to provide fresh air, check the oxygen and dangerous gas levels in the silo headspace, wear safety harness tied off securely outside the silo, and have good lighting.

Flat storage

Flat storage structures are rectangular low-level buildings that generally contain only one kind of grain stored for a year or more. The advantage to flat storage is that the building can be used for other purposes such as machinery or supply storage. A major disadvantage is that it is more difficult to get even distribution of air for aeration as the grain pile is relatively shallow and peaked in the middle unless a mechanical spreader is available to level the top surface. This peak causes complications in distributing air evenly through the grain. Unless aeration ducts are built flush with the floor, ducting must be moved out of the way of unloading equipment as the structure is unloaded. Another method of unloading this storage is an unloading u-trough auger installed in the concrete floor.

The use of existing warehouse type storage buildings for flat storage poses structural problems. The walls of the building must be strong enough to withstand the excessive load from grain pressure on the walls. Reinforcement of the walls and flooring is essential to prevent deformation, cracking, or failure. Fabricated L-shaped bulkheads reinforced by diagonal steel rods from floor to wall sections of the bulkheads are used to keep grain pressure from walls. Check Midwest Plan Service (http://www.mwps.org/) for grain bulkhead plans.

Hopper bottom bins

The advantages of hopper bottom bins are ease of unloading and self-clean out. Gravity does the work as long as grain is dry and in good condition to flow from the 45-degree bin hopper. Hopper bins are used when grain must be moved frequently. Examples are overhead load-out bins and wet holding bins. Elevated hopper bins require extra support legs and are typically more expensive than flat bottom bins, but multiple uses and labor savings makes them affordable. Aeration involves perforated round or half-round ducts mounted down the slope of the cone bottom with a small vane-axial fan connected to the end or side of the duct through the hopper. Large hopper storage bins may use one large fan connected to three to four ducts inside the hopper by an exterior transition duct.

Temporary storage

Temporary storage is used when crops exceed the available storage space in permanent bins. Different forms of temporary storage have become common for storing corn and milo. Temporary storage may consist of a pile of grain placed on the ground or on a plastic tarp and left uncovered for a short time period, or covered by tarps for a longer period until marketed or permanent storage space is available. Or it may consist of short bulkhead walls with aeration system ductwork set on the ground. The material is piled inside the bulkhead walls with a tarp covering the pile held in place by negative pressure of the aeration system.

Uneven aeration and pockets of wet grain and insect activity can cause areas of spoilage and fermentation in the pile and reduce grain quality due to mold and spoilage. The advantage of temporary storage is that the walls can be disassembled and stored when they are not needed, and the unsupported piles can be moved and the area cleaned for other uses when the storage area is not required. Generally this kind of storage is less expensive but provides a greater risk of losing product quality in storage and during unloading when the covering is removed.

Another method of temporary storage that is becoming popular is the use of long white UV-resistant plastic hermetic tubes. Grain is sealed inside the specially designed strong tubing, filled, and unloaded by machines specifically suited for such grain handling. Grain stored in grain tubes should be cleaned and be at a moisture content for medium to long term storage (Table 1). Hermetic grain tubes are relatively inexpensive, but are not reusable. Grain tubes are typically about 8 to 10 feet wide and 3 to 4 feet high when filled. They can be up to 200 feet long.

In hermetic storage, grain respiration gradually consumes the oxygen, which slows the respiration and eventually suspends biological activity. Insects in hermetic storage cause oxygen to be depleted faster, Insects die from lack of oxygen, and the entire storage remains in a carbon dioxide storage atmosphere. Grain tubes evolved from haylage tubes developed in New Zealand and Argentina. Grain managers using grain tubes should inspect the tubes for bird or animal damage every week or two, and monitor the internal gas content for carbon dioxide (CO2) versus oxygen (O2) levels until time to market the grain.

Sanitation, aeration, and monitoring

Insect infestation is a major contributor to spoilage in stored grain. Good housekeeping and integrated pest management (IPM) practices can help reduce infestations in bins. Removing old grain, fines, and dust when bins are empty reduces the residual habitat for insect populations before new grain is loaded into the bin. Remove vegetation and trash from around the outside of bins. Remove dust, grain, and fines by vacuuming or sweeping walls, floors, and under perforated floors if possible. Old moldy grain attracts and harbors insects. When new grain is placed on top of old grain, insect infestation is certain. These infestations will increase temperature, producing moist hot spots that lead to mold and grain spoilage. Cleaning of harvesting and handling equipment such as augers, conveyors, carts, wagons, and grain buggies is just as important as cleaning empty bins. Empty bin insecticides can be applied to empty storage bins and will help to reduce holdover populations of insects as well. Follow label instructions and federal/state regulations for application. Insecticides do not replace good storage housekeeping.

Along with sanitation and insecticide treatments, managing grain moisture and temperature can help minimize insect populations and keep stored grain from spoiling. When grain temperatures are below 70°F, insects cause less damage and reproduce more slowly than in 70° to 85°F grain. Below 60°F, most insect activity stops. Well-managed aeration using cool outside air can reduce grain temperatures. Operate aeration fans until the cooling front travels through the entire grain mass. The amount of fan operation time it takes to move a cooling front through the grain depends primarily on the airflow capacity of the aeration fans. Besides fans, the conditions of the grain, the amount of and distribution of fines in the grain, grain peaked versus level, which affects the airflow variation within the grain are critical factors.

Generally, for 60 lb/bu grain, the cycle time will be approximately 15 hours of fan operation/cfm/bu. At the minimum of 0.10 cfm/bu, it will take about 150 hours. At 0.2 cfm/bu (recommended as inexpensive insurance), cooling time is about 75 hours. Once the temperature front has progressed through the entire grain bulk, fans are turned off until the average fall or winter air temperature drops another 10° to 15° F. In the case of some oilseeds and summer harvest grains that tend to "sweat" or self-heat for a period of time after harvest, fans should be operated continually until this phase is complete, generally about a month. Then aeration should follow the method mentioned for lowering temperatures until the grain reaches 30° to 35° F for winter storage in the northern U.S. or 35° to 40°F for the central United States. Aeration fans should be covered to prevent insect entry until fan operation is required to cool the grain. Sealing fans is vital to keep cool air in the grain mass from moving out of the bin and pulling warm air down into the grain mass. The direction of fan airflow can be either upward or downward. Both directions have advantages and disadvantages, discussed in detail later.

Leveling equipment

Leveling the surface of the grain during loading is essential for providing the best air distribution during aeration. Peaks in the grain increase air flow resistance. Forced airflow tends to move around the peaked area instead of through it. More spoilage will occur because of higher temperatures, moister grain, and more insect activity in this center core area under the fill point, where fines and moist weed seeds concentrate. It is important to level the grain surface and spread fines, trash, and small seeds.

Electrically-powered grain distributors (auger types) in drying bins and dry grain storage bins, when properly adjusted, level the grain surface and spread fines evenly, distributing them uniformly throughout the bin. Grain spreaders reduce grain peaks to a rounded surface where the center may be 3 to 5 feet higher than grain at the sidewall. Without some form of distributor or rotary spreader, or a method called "coring" the grain, fines tend to accumulate in a cylindrical column down the center of the bin. In this dense core, grain fines and moist weed seeds fill the kernel spaces, which impedes air flow and harbors insect populations. Electric spreaders are commonly found in bins larger than 24 feet in diameter. In smaller bins, gravity-powered spreaders and grain cones help reduce concentrated fines by spreading fines across much of the surface. Gravity cone spreaders typically leave a donut shaped concentration of fines, which is preferable to peaked grain with a core of fines. If a spreader is not used, the core can be removed by operating the unloading auger until an inverted cone diameter of one-third to one-half the bin diameter is achieved at the top of the bin. This will lower the peak, loosen the center, and remove some of the fines from the center of the grain. Removing grain by coring at intervals while filling the bin (producing an inverted cone of about one-quarter bin diameter at each interval) helps prevent the center concentration of fines, provides some grain cleaning, and removes the peak, which greatly improves aeration uniformity and speeds cooling.

Unloading

Grain can be unloaded from a bin directly into transport vehicles or into another bin for mixing or comingling with other products. Depending on the kind of bin, layout of the facility, and type of grain being handled, load-out equipment can vary widely to include augers, belts, and hopper-bottom gravity fed cones. Unloading the bin evenly is important, so it does not collapse because of eccentric loading. The larger and taller the bin, the greater the risk for bin collapse during unloading.

Unloading grain is faster if grain can flow from the bin. A sweep auger is not required to move grain to the load-out gate if grain is in good condition and not clumped.

Conveyors

Grain conveyance systems vary widely in configuration, but they are all designed to move material from point A to point B. Selection of the type of conveyance system is should be aimed at reducing grain loss and damage during transfers. Common types of conveyors are augers, belt conveyors, flight (drag) conveyors, bucket elevators, and pneumatic conveyors.

Augers

Portable or permanently installed augers move grain horizontally and up inclines. Augers are relatively inexpensive and come in many sizes. Higher energy requirements are a disadvantage of larger capacity augers but they move material quickly. Compared to other conveyance systems, augers move less material per horsepower, but they are simple, easy to maintain, and adaptable to different materials and conditions. Auger power requirements are determined by the diameter, length, pitch of the flighting, speed (rpm), exposed flighting intake length, incline, and physical properties of the grain. Capacity is not affected by the length of the auger but by the diameter and operation speed of the auger. Augers range from from 4 to 16 inches in diameter). Higher grain moisture also decreases the amount of material the auger will convey and increases the power required. The handling capacity of an auger varies by grain type. Manufacturer literature contains information to assist in selection of the appropriate auger.

Belt conveyors

Belt conveyors have a higher capacity per horsepower than augers. Drawbacks are that they are limited to shallow angles of incline, expensive, require permanent installation, and require extra floor space. Their primary advantage is gentle conveying, causing minimal grain damage compared with other methods of handling grain. Belt conveyors are used primarily in large facilities and in facilities that handle seed grain, edible beans and soybean seed, or other products that cannot tolerate rough handling.

Mass flow or bulk conveyors

Bulk flow conveyors consist of a housing or trough that contains flights that scrape or push the material along the conveyor path. The flights are usually made of low friction plastic or composition material. These conveyors are gaining in popularity for on-farm operations and used heavily in commercial elevators, particularly in handling seed. Although more expensive, bulk flow ‘drag’ conveyors are reliable and highly efficient, using relatively less horsepower to move grain than augers or belt conveyors .

Bucket elevators

Bucket elevators, or “legs”, have vertical conveyor belts equipped with cups for scooping and elevating grain and are common in bulk grain storage facilities . Generally elevator legs are at the center of the operation, with most of the grain handled through the leg. They consist of two metal vertical rectangular housings which enclose a belt that supports closely spaced buckets or "cups" bolted to the belt. This belt runs vertically between top and bottom wheels. Grain flows into the cups near the base of the leg and is lifted to the top of the leg where it is centrifugally discharged as the cups rotate over the head drive wheel. Elevator legs can handle almost all kinds of wet or dry grain, meals, processed materials, and feed. Legs can receive or deliver grain to most of the other conveyors in the facility. They require less relative power than most conveyors, are quiet, and have a long service life. Checking and lubricating bearings during routine maintenance will reduce the possibility of hot bearings causing grain fires or explosions. Other safety mechanisms should be in place such as power load indicators and leg backstop mechanisms.

Pneumatic conveyors

High capacity permanent or portable pneumatic conveyors are gaining popularity in commercial grain- handling facilities. Systems are equipped with positive or negative pressure conveyors. Some mobile units use both positive and negative pressure to vacuum grain and then discharge it into a truck or transfer it into another storage. Operators should watch for plugged airways in these conveyors. Generally these systems have a lower initial cost than a bucket elevator but require more power to operate. They often offer less capacity for the same amount of power as a bucket elevator. The advantage of a pneumatic conveyor system over a bucket elevator is flexibility in more easily reaching any bin location. Care must be taken to avoid grain impact damage. Sharp turns should be avoided. All 60- to 90-degree turns should use large radius elbows.

Portable pneumatic conveyors can be used as the central handling system on several storage sites located several miles apart where each site has pneumatic tubing permanently installed that can be quickly connected to the mobile conveyor as needed. Suction-pressure conveyors should have a vacuum and pressure gauge installed on the inlet and outlet of the rotary lobe blower. This allows the operator to fine-tune total pressure loads on the blower to keep it from overheating and warping the rotor lobes. Filters must be used to keep grain dust out of the blower. Dust quickly wears down lobes and housing, increasing lobe tip clearance, destroying blower performance through excess bypass air leakage.

Identity Preservation of Commodities

Identity preservation involves grain industry programs that begin at harvest by segregating grain with specific characteristics from other grain. After initial segregation, the IP program maintains the original purity of that grain through segregated handling until it reaches its intended use. Segregation of grain with desirable attributes increased substantially in the grain industry during the last twenty years. It is common to distinguish identity preservation programs from mere grain segregation, with identity preservation being a specific program that identifies a specific grain or seed trait and keeps it labeled and segregated until sold as a specialty grain. Although segregation is a key part of identity preservation grain handling, it does not include all the specific components, such as labeling the trait throughout the system and carrying the identity though until the grain is sold based on that special trait.

Before growth in identity preservation grain handling, traditional grain handling operations were usually *commodity gain* handling operations. Commodity grain is the standard grain flowing through the system that is not known to have special characteristics that command a higher price. For example, "number two yellow corn" is a standard for commodity corn. Much of the corn grown in the U.S. meets the criteria for U.S. Grade No. 2 corn. Even today there is much more grain handled as a commodity than as a specialty crop with its specific identity preserved until sale.

The commodity grain marketing system developed because of the economies of scale inherent in the large bulk handling systems developed and perfected during the 1950 and 60s. The motivation for IP grain handing is also economic. Grain dealers found that in some markets a premium (higher price) can be obtained for grain with a specific quality attribute that differentiates it from the usual commodity grain quality. That desirable quality attribute gives it more value to the buyer who is then willing to pay a higher price for the IP grain, compared to the commodity grain.

When processors are willing to pay a sufficiently higher price so that handlers recoup the additional expense of segregated handling plus enough additional profit to feel the identity preservation program is worthwhile in their operation, then identity preservation is economically viable. Identity preservation efforts may also be influenced by the desire to avoid commingling that would be viewed as "contamination." Avoiding the commingling of genetically modified (GM) crop varieties into grain that is intended to be GM-free is a recent high-profile example. Often these scenarios are perceived negatively because the economic incentive is a severe price penalty for excessive commingled grain of undesired characteristics. This is in contrast to positive scenarios where the focus is on the economic gain expected for grain with a special attribute.

Some of the earliest identity preservation programs were *passive* programs. In passive programs either the processor or a grain handler obtains grain with specific characteristics even though the grain came into the grain handling system without being identified in advance and segregated from other grain from the outset. The method of finding the special grain may have been fairly secretive in the early days of these practices. (See Christensen and Meronuck (1986) for a discussion of some of those quiet identity preservation buying practices that were known to them at that time.) Some buyers worked a little more openly, looking for grain with special characteristics and finding processors willing to pay extra for it, and passing on a bit of the extra profit to their source.

Grain commingling is usually an unintentional introduction of other grain during normal handling operations that directly reduces the level of purity maintained in grain moving through the system. For example, if white corn enters a facility that is 99% pure (contains 1% yellow corn), but another 1% of yellow corn gets commingled during handling in that facility, the color purity is reduced to about 98%. Whether intentional or unintentional, unwanted material introduced by commingling propagates through the grain handling system until it is removed or consumed (Herrman, 2002).

The starting point for an IP program is early in the process — if the program addresses the genetic purity of the crop the effort starts with proper field selection, seed selection, and evaluating pollen drift so that a high genetic purity level is available at harvest. The field should be selected to avoid volunteer plants with the wrong genetics, the seed must be the correct high purity variety, and pollen drift must be accounted for by segregating harvested grain from borders of the field subject to pollination from crops with the wrong genetics. Nielsen and Maier (2001) discuss these issues in more detail.

Once harvesting and handling of the crop commences, there is potential for commingling as grain passes through each piece of equipment. All equipment should be thoroughly cleaned of residual grain after the previous year's harvest is complete. This greatly reduces the possibility of insect-infested grain or grain of the wrong genetics being commingled with the new grain at harvest. Commingling data from grain harvesting equipment indicated that up to 185 lb (84 kg) of residual grain remained in some combines where it could commingle with new grain at harvest (Hanna et al., 2009). That amount is sufficient to cause 1% commingling, or "contamination," of 9 tons (8 T) of grain that was 100% pure originally. Thorough cleanout could theoretically reduce commingling in equipment to zero, but in practice some grain remains after cleaning, perhaps on the order of 1 to 2% of the original residual grain after thorough cleaning. Other items such as grain carts, trucks, trailers, augers, dump pits, legs, dryers, and holding bins have the potential to add additional commingled grain —including insect-infested grain — to the new grain if not thoroughly cleaned (Nielsen and Maier, 2001).

Some studies (Hurburgh, 1994; Wheeler, 1998; Herrman et al., 1999; Maltsbarger and Kalaitzandonakes, 2000; Hurburgh, 2003) have estimated the opportunities, revenues, benefits, and costs associated with segregation and identity preservation. Other studies (King, 1995; Bullock et al., 2000; Herrman et al., 2001; Krueger et al., 2000; Herrman et al., 2002) have investigated the impact of design configuration on the flexibility of elevator facilities in handling specialty crops and on their ability to maintain product identity. Nielsen and Maier (2001) identified key areas in an elevator that provide challenges for identity preservation: receiving pits, storage bins, legs, and other conveyors.

Commingling and residual grain levels have been measured for a receiving pit and elevator boot, grain cleaner, weighing scale, and grain scalper for a research elevator (Ingles et al., 2003). They found that the highest mean cumulative commingling of 0.24% occurred in the grain cleaner, followed by 0.22% in the inline weighing scale, 0.18% in the receiving pit and elevator boot, and 0.01% in the grain scalper. They also found that the largest amount of residual grain in any equipment was 120 kg in the elevator boot. Ingles et al. (2006) evaluated commingling during grain receiving operations in three different receiving pits at a country elevator. They found commingling levels varied significantly among the pits and produced a maximum of 1.3% commingling when receiving 10 t loads. To reduce commingling in handling equipment, grain elevators need to either clean the equipment thoroughly between loads of different grains or designate dedicated equipment for handing each type of specialty grain being handled. The second approach, using designated equipment, can be extended to dedicating an entire facility to a specific grain — an approach sometimes used for food corn.

When an elevator has decided to use an identity preservation program where more than one type of grain is received, the inbound grain must be channeled to the appropriate location when it reaches the elevator. In some cases the desired quality characteristic, such as high protein content, is tested for and any grain meeting the specification is routed to a different receiving pit and then storage bin. This is the same approach that might be used for checking for insect-infested grain or wet grain and routing for treatment or for drying so it does not get commingled with clean or dry grain.

Safety

Accident and entrapment conditions

There are three different ways in which people become trapped in grain. All are generally associated with moving grain during unloading the bins and are especially dangerous when the grain is out of condition. The three ways are grain bridge collapse, avalanche of a vertical grain wall, and flowing grain to an unload conveyor, which creates a funnel effect that pulls a worker under the grain surface . Flowing grain acts much like quicksand; a victim can become entrapped and engulfed in just 2 to 3 seconds. Suffocation occurs when the weight of the grain around a victim's chest precludes him from breathing. If someone is trapped in grain above the knees, it is doubtful that the worker or others can pull him out of the grain. Rescue procedures and equipment should be readily available to secure victims from further engulfment until trained rescue personnel arrive.

Lock out/tag out procedures

Lock out/tag out procedures are established to control hazardous energy. OSHA Standard 29 CFR1910.147 gives the minimum requirements for these procedures. The purpose of the procedure is to reduce the likelihood that equipment will be energized while personnel are working inside the bin or the area where equipment is installed. Each qualified maintenance person must have a unique key, hasp/lock and tag that can be placed on equipment which will prevent the equipment from being energized as long as the lock is in place. If a lock is not available or the equipment cannot be locked, a tag may be used to notify users that the equipment cannot be energized until the tag has been removed by the person placing it on the equipment.

Any time a worker must enter a grain bin, lock out/tag out procedures should be employed. This secures the equipment (e.g., unload conveyors) that could cause grain to move and subsequently present a hazard for entrapment and engulfment. Managers must become familiar with the OSHA regulations and use the examples to set forth their facility's safety program.

During grain bin accident rescue operations, lock out/tag out must be a part of the procedures for securing the facility before entry into the bin by rescuers. An extra step for security would be to place an employee by the locked out/tagged out equipment to monitor the area making sure no one violates the set procedures for safety.

Coffer dams

Coffer dams are placed around a victim who is trapped in grain to keep the grain from continuing to engulf the victim. Once the coffer dam is in place, grain between the victim and the coffer dam can be removed using a vacuum or scoop until the victim is able to free himself or be safely lifted or pulled from the grain. Coffer dams are available commercially or can be constructed of readily available plywood or sheets of metal. The idea is to place a boundary between the victim and the grain to relieve the pressure of the grain entrapping the victim.

Emergency preparedness and training

All grain handling facilities have the responsibility of keeping their employees informed of safety regulations and prevention measures. Every employee should have an awareness level of knowledge about the hazards of handling grain and the causes of grain entrapment or engulfment. Along with elevator personnel, local fire departments and first responder units should have knowledge of the grain facilities within their jurisdiction. They should also be provided with the basic skills of stabilizing a victim until specially trained crisis teams can arrive at the scene of an accident to affect the recovery or rescue. This level of training would include methods of handling coffer dams, safe bin entry procedures, air quality monitoring, and victim stabilization.

Awareness level training should include information about what causes grain to go out of condition, the different ways a grain bin accident can occur, lock out/tag out procedures, safety procedures for entering a grain bin when it is necessary, bin entry permit requirements, and procedures for initial response in the case of a co-worker or individual accident. Advanced training should include high angle rescue techniques, stokes basket techniques, bin emergency unloading methods in addition to all of the information from the lower-level training.

Condition awareness

Many of the conditions requiring grain bin workers to enter bins and risk a dangerous situation are caused by grain going out of condition. Workers may enter the bin because grain has become stuck to walls, formed clumps that clogged unloading equipment, or formed a crust on the surface causing a bridge with a cavity under the surface to occur when grain was unloaded from the bottom of the bin. Each of these situations can entrap a worker who becomes covered by an avalanche from the wall of grain or falls through the crusted surface into the cavity below. Augers can cause limb amputation and even death if workers become entangled in the equipment while attempting to remedy unloading/recovery stoppages. The message here is that if the grain is kept in good condition, there are few reasons to chance entering the dangerous environment inside the bin.

It is important that rescue teams understand how grain can go out of condition so that they know what working conditions they will encounter when entering the bin during a rescue. Knowledge of potential air quality issues, possibility of fumigant presence, and the presence of molds and grain dust that may cause allergic reactions is important. Knowing that grain acts like a combination of a solid and a flowing liquid product at times is essential so workers are aware of the possible dangers. Monitoring grain temperature and conditions regularly gives workers and rescue units a hint of the conditions to expect when entering the bin. Temperature hot spots and moldy clumps of grain cause many accidents. These conditions can be monitored and remedied many times without entering the bin if managers are aware of their presence.

Drying

Those involved with the management, operation, and design of drying systems need to understand the principles of drying and how a particular situation may dictate the desired final moisture content for storage of grain and selection of a drying method. The following presents a broad overview of these principles and considerations.

Purpose of drying systems

Drying is usually the most economical choice for successful storage of grain and seed products, especially in the long-term. Economic considerations that influence the decision about the type of drying and storage system to purchase include the following:

- Opportunity for earlier harvest, which reduces the potential for weather- and pest-related field losses while maintaining the quality and quantity of harvested grain and seeds.
- Reducing the net price penalty (dockage) from the sale of high-moisture grain and seeds.
- Increasing options regarding when, where, and for what purpose the grain may be sold or used for feed.

- Greater total farm efficiency from better utilization of labor, equipment and other resources associated with shortening harvest and possible double cropping or fall planting.
- Risk associated with processing and maintenance of grain between harvest and time of sale.

Moisture content

Grain is comprised of moisture and dry matter. The "wet basis" moisture content of grain is defined as the percentage of total weight of the sample that is water; that is:

$M_{wb} = W_w \times 100/W_t$ where M_{wb} is the percent moisture content on a wet basis and W_t is the total sample weight comprised of water (W_w) and dry matter (W_{dm}).

The "dry basis" moisture content of grain is the ratio (expressed as a percentage) of the water in the grain to the dry matter; that is:

$M_{db} = W_w \times (100)/W_{dm}$, where M_{db} is the percentage moisture content on a dry basis.

Wet basis readings are used in the grain industry (and in this chapter). Dry basis readings are used primarily in scientific research and professional journals. Conversion from one basis to another may be made using the following equations:

$M_{db} = [M_{wb}/(100 - M_{wb})] \times 100$ and $M_{wb} = [M_{db}/(100 + M_{db})] \times 100$

Bushel

In producing, marketing and utilizing grain, the quantity involved is usually stated in terms of bushels. However, the term "bushel" can have different meanings depending on the situation in which it is applied. By definition, the bushel is a volume measure containing 1.25 cubic feet. For trading purposes it is usually designated for each type of grain as a unit weight for a certain moisture content as specified by USDA Grain Standards (often called a "dry bushel"). Sometimes a bushel may refer only to a weight without regard to moisture content (called a "wet bushel").

Shrinkage

Shrinkage refers to the loss of grain weight and volume associated with drying (and to a lesser extent handling in the form of dust, foreign material (f.m.) shrunken and broken kernels (s.b.) and trash). Shrinkage is an important economic consideration when buying and selling grain.

Dockage

Dockage refers to the reduction in price associated with failure to meet the standards in place at the time of the sale. Excess moisture is usually the largest component of dockage — in effect, the penalty associated with the difference between buying/selling wet bushels and dry bushels.

Airflow

In drying grain, airflow is usually expressed in terms of cubic feet of air per minute per bushel (cfm/bu). It is important to recognize in grain drying systems that cfm/bu decreases non-linearly with increases in the height of the grain column through which the drying air passes.

Air-water vapor properties and mixtures

Grain drying depends on air -water vapor mixtures and properties as well as grain moisture content. The following properties are all interrelated mathematically so that any two of these can be used to compute the remaining ones (dry bulb temperature, wet bulb temperature, dew point temperature, humidity ratio, vapor pressure, relative humidity, enthalpy, humid volume and specific volume). All are important when analyzing the drying process scientifically (which is beyond the scope of this chapter). Furthermore, changes in the air-water vapor state during the drying process can be visualized graphically and computed for design purposes using a psychrometric chart.

For purposes of this chapter, it is especially important to consider the following air – water vapor properties.

- **Vapor pressure –** Vapor pressure is the pressure exerted by the water vapor in a given sample of air. If the air is saturated with water vapor (that is, it contains all the water vapor it can hold under the existing conditions), the pressure is referred to as the *saturated vapor pressure*. Both the dry air and the water vapor components of any air-vapor mixture produce partial pressures related to the mixture temperature and the relative concentration of the components. Total vapor pressure is equal to the sum of the component partial pressures and, in an unpressurized environment, is equal to the prevailing atmospheric pressure.

- **Relative humidity –** Relative humidity is defined for a given dry bulb temperature as the ratio of the vapor pressure of the water vapor contained in an air-vapor mixture to the vapor pressure of an air-vapor mixture that is completely saturated (air having a relative humidity of 100%).
- **Enthalpy (heat content) –** Enthalpy is the amount of heat energy contained in an air-vapor mixture per unit weight of dry air. It is usually expressed in terms of btu/lb dry air and includes both sensible and latent heat components. Sensible heat is that heat associated with a dry bulb temperature increase of an air mixture. Latent heat, as used in air-vapor mixtures, is the heat required to change the state of water (liquid to vapor or vapor to liquid) without changing its temperature.

Grain equilibrium moisture content

Drying and storage relationships for various grains are directly related to their equilibrium moisture properties. Because grain is hygroscopic, it will exchange moisture with the surrounding air until the vapor pressure of the moisture in the grain and that of the air reach a state of equilibrium. If grain comes to equilibrium with air moving through it at constant environmental conditions, the grain moisture content is referred to as the equilibrium moisture content (EMC) corresponding to the existing air conditions. But if the grain is surrounded by a limited amount of air (such as in interstitial spaces of a grain mass in storage bins), the air will reach moisture equilibrium with the grain without any significant change in the grain moisture content. The relative humidity of the air in this situation is referred to as the equilibrium relative humidity (ERH) corresponding to the existing grain moisture content at the prevailing temperature. All equilibrium moisture properties are a function of temperature; that is, the properties change with changes in temperature. Furthermore, equilibrium moisture properties are specific for each type of grain.

Equilibrium moisture properties are important in analyzing drying and storage systems and in developing storage and drying recommendations. Especially noteworthy is that most storage fungi cannot grow and reproduce in grain that is in equilibrium with air at a relative humidity (ERH) less than 65%. Many molds are limited at 70% ERH. Furthermore, the activity of storage insects greatly decreases at relative humidity below 50% (most insects cannot maintain body moisture eating very dry grain), although this is not commonly used as a control tool for stored grain insects.

Grain drying fundamentals

In most grain drying systems, ambient air is heated and passed through grain so that a relatively high vapor pressure gradient is produced between the moisture in the grain and the moisture in the drying air. This differential causes moisture to move from the grain to the air that is flowing past the kernel where it is then exhausted from the grain mass to the outside atmosphere. In the most simplistic drying situation, the grain and the air that surrounds it are in equilibrium before the introduction of heated air, and the properties and rate of flow of the heated air entering the grain mass remain constant during the drying period. In such a situation, the heated air transfers its heat to the grain and creates a new equilibrium moisture content based on the new differential vapor pressure. The drying air begins absorbing moisture from the first kernels that the air contacts. This process continues until the drying air, falling in temperature and increasing in relative humidity, can no longer add additional moisture because it is in equilibrium with the remaining grain mass. Simultaneously, the transfer of moisture from the grain to the drying air becomes increasingly more difficult as the grain dries, so much so that stress cracks can occur if the grain is dried too quickly or is overdried.

Effectively, the above process produces a drying front and a drying zone. All grain behind the trailing edge of the drying zone would be in a new, stable equilibrium moisture condition with the heated air. The grain ahead of the drying zone would remain essentially in its initial equilibrium moisture condition. The grain in the drying zone would range from its highest moisture content at the start (leading edge) of the drying zone to being driest at the end (trailing edge) of the drying zone.

The simplistic drying situation described above seldom happens for very long. In practice, the grain being dried varies during the harvest period (gradually losing moisture in the field during harvest) in temperature and moisture content and may contain differing levels of fines and trash that influence the distribution of airflow. Heat is lost or gained in the grain mass because of changes in ambient air conditions surrounding the mass. Properties of the ambient and heated air also change during the drying process as daily weather changes occur. Given all of this, there are some generalizations that should be considered when evaluating the drying process:

- If there is sufficient variation in the temperature and relative humidity of the drying air relative to the grain mass, some zones in the grain mass may experience heating, cooling, drying or rewetting relative to other zones.

- Safe storage conditions are reached when all the grain has been dried to a safe equilibrium moisture content (65 to 70% ERH or lower), either by passing the drying front completely through the gain mass or by thoroughly mixing the grain so that the overdried and under-dried grain can equilibrate to a safe storage moisture condition in an acceptable amount of time.

- Drying is most efficient when the drying air has come into full temperature and moisture equilibrium with the grain as it passes through the grain mass.

Efficiency, design considerations and management

Measuring efficiency in grain harvesting, handling, drying and storage systems has many dimensions. It's important to recognize that the goal is to optimize the entire system rather than any particular component such as drying. With this in mind, the following considerations with regard to design and management are important:

- Drying capacity increases with increases in drying air temperature and airflow as does the potential for over drying and associated grain quality reductions.

- Drying efficiency alone is usually measured by dividing the sum of energy required to heat the drying air and to force this air through the grain by the theoretical amount of energy required to evaporate that same amount of water (sometimes only the numerator is used as the basis for comparison).

- Overdrying and inefficient use of airflow reduces drying efficiency.

- Efficient design of grain harvesting, handling, drying and storage systems begins with determining a daily harvest rate that properly balances the composite set of equipment needed to both harvest and safely secure the entire crop.

- After determining the daily harvest rate, the next design key is to determine the allowable drying time for successful storability, which depends on a combination of grain temperature and moisture content.

- The final choice for a type of drying system is based on a combination of daily harvest rate and allowable drying time linked with individual values and resources concerning such things as cost, marketing, risk, flexibility, convenience, and future expansion.

Basic grain drying systems and techniques

While there is no guarantee that past trends will continue, the average daily harvesting rate has increased for many years in magnitude and importance as a design factor. This has generally shifted the selection of grain drying systems away from comparatively lower temperature in-bin drying systems to higher temperature external drying systems. Contributing to this trend has been the advancements in sensor and control technology that has enhanced energy efficiency in the higher temperature dryers.

The assumption in the discussion that follows is that each of the drying systems, including those using bins, is adequately designed and equipped with drying/cooling fans, perforated floors, grain spreaders, venting systems and handling equipment for efficient loading and unloading. Inadequate venting can be especially problematic for in-bin drying, or cooling when moisture removed from the grain is restricted from efficiently exhausting from the bin, resulting in condensations on the roof or bin walls causing rewetting of parts of the grain mass.

Note also that the choice of drying system and technique is based on individual situations; no single type of drying system will work well for everyone. Accordingly, the following options are offered that reflect possible needs of producers and commercial grain managers extending from relatively low to relatively high daily harvest receiving rates.

Natural or ambient air drying

Natural air drying is a process where unheated air is forced through the grain mass until the grain reaches equilibrium moisture condition with average ambient air conditions. Drying with natural or ambient air can be accomplished only if the air temperature and relative humidity conditions allow a net moisture transfer from the grain to the air, which may be problematic. The potential for natural air drying is enhanced because the energy inefficiency from operating the drying fan results in a temperature rise in the drying air of 2° to 3°F. Other than heat from the fan operation (fan motor heat and mechanical "heat of compression"), energy for evaporating the moisture from the grain comes from the energy contained in the ambient air. Natural air drying is a basic form of solar drying.

Natural air drying is usually the most energy efficient method for drying grain. It is also the slowest, and usually becomes slower over the harvesting period because air temperature generally decreases as does airflow rate per bushel as the bin is filled. Because of slow drying, natural air drying also has the greatest potential for grain spoilage because drying capacity often lags harvest capacity, and weather losses or harvested wet grain may mold while waiting to be dried. Consequently, natural air drying requires the highest level of management if spoilage and/or aflatoxin problems are to be prevented.

Low temperature drying

Low temperature heated air drying of grain is the process by which relatively low amounts of energy are added to the drying air, raising its temperature approximately 10° to 15°F above ambient conditions. Usually, electricity is the thermal energy source; hence the term "electric drying" is sometimes used instead of "low temperature" drying. LP gas and solar energy may also be used as thermal energy sources.

The low temperature drying method is assumed to always have potential for drying grain within the accepted moisture contents associated with long-term storage. This is contrasted with natural air drying where outside air conditions may not allow adequate drying for extended periods of time.

Low temperature drying is a relatively high risk drying system requiring substantial management ability. Generally, it is preferable to natural air drying because drying can occur in most types of weather. When used successfully, low temperature drying results in high quality grain. Its susceptibility to failure during high temperature – high relative humidity conditions during harvest limits its application to warm to hot, low humidity or cooler geographic regions.

Layer drying

In-storage layer drying is a process whereby the grain is dried in layers in the storage structure with the entire grain depth ultimately being dried in place. The process begins when the initial grain layer is placed in the drying bin. The drying air establishes the drying front that moves through the grain. Additional layers of wet grain are added periodically so that a depth of wet grain always precedes the drying front. As the drying bin fills, each successive layer is thinner. The quantity of grain that can be placed in any one layer is limited to that which can be dried before excessive mold growth or aflatoxin develops in the top of the layer. This drying technique is used most successfully in grain systems where relatively slow harvest rates are acceptable and harvest volumes are low to moderate.

Layer drying offers the advantage of low heat input, making it one of the most energy-efficient drying methods in terms of the amount of heat required to remove moisture from the grain. The drying air temperature should be limited to no more than a 20°F rise above ambient conditions in order to prevent excessive overdrying. A criticism of layer drying is that the bottom 15 to 25% of the grain is always overdried. A control mechanism for limiting the drying capacity of the air, and hence the final equilibrium moisture content of the grain, is to place a humidistat in the plenum chamber. The control level for the humidistat normally ranges from 50 to 60% relative humidity (Rh) depending on the type of grain, with 55% being a typical setting.

Layer drying necessitates superior management skills. The system leaves little margin for error because of its relatively low reserve drying capacity.

Batch-in-bin drying

Batch-in-bin drying refers to the process where the grain is dried in a drying bin each day in a batch, usually 2.5 to 4 feet deep, then cooled and moved to a storage bin in time for the next day's harvest. When storage bins are full, the drying bin may be filled and the grain dried in layers. No wet grain storage is needed with this technique because the batch size constitutes one day's harvest. The basic principle behind the operation of a batch-in-bin dryer is to force high volumes of air through a relatively shallow grain depth in order to obtain rapid drying, allowing the producer to accommodate larger harvest rates than with other in-bin drying methods. A batch-in-bin system allows drying flexibility in that the drying depth may be varied based on day-to-day operating conditions. As a result, the producer is able to adjust the harvesting schedule if necessary.

Batch-in-bin drying air temperature typically ranges from 120° to 160°F, with 140°F being a recommended average drying temperature for shelled corn. When designing batch-in-bin systems, it is desirable that the fan/bin combination dry the daily 8 to 10 hour harvest in about 16 hours. After drying is completed, the cooling process will usually require another 2 hours. Handling will also require 2 additional hours for a total of 20 hours of activity each drying day. The remaining 4 hours provide catch-up time in case of breakdowns, harvesting delays, etc.

With a good fill leveling system, drying can begin after ½ to ⅔ of the day's harvest is binned. Two drying bins allow the operator to alternate filling, so that unloading the bin into storage bins is less critical. Two bins provide more flexibility and drying capacity to handle wetter grain during the early part of the harvest. Batch-in-bin drying is often unacceptable from a labor and management perspective because the system requires attention on a 20- to 24-hour basis and the grain must be handled twice before going into storage. Management skill is not as critical as with other in-bin drying methods because the operator has many learning experiences per harvest season and can make daily adjustments in system operations.

Operators must recognize that deep batch-in-bin drying results in drier bottom grain mixing with wetter surface grain for an "average" storage moisture. In 15% average moisture dried corn, bottom grain may be 11 to 12% while upper grain may be 17 to 19%, depending on the initial moisture of the corn. Thus, good mixing of the entire batch during transfer is essential, as mixed kernels will equilibriate to within 1 to 2% from the average moisture in storage.

Automatic batch/continuous flow

Automatic batch and continuous flow are two popular high-speed grain drying techniques. Both dryer types are similar in appearance and operation. Both also require wet grain storage ahead of the dryer, and some facilities may require a surge bin for temporarily holding dry grain that exits the dryer. The basic principle in both dryer types is to force high quantities of air (50 to 125 cfm/bu) through 12- to 24- inch grain columns to obtain high drying rates. The automatic batch units usually self-load, dry, cool and unload a fixed amount of grain into storage per batch, whereas continuous flow units meter cool-dry grain from the drying chamber continuously. Automatic batch dryers are classified as stationary bed dryers. Continuous flow dryers may be categorized into three types:

1. **Cross-flow –** Drying air is blown across the grain column similar to automatic batch driers.
2. **Counter-flow –** Drying air and the grain move in opposite directions, and
3. **Concurrent-flow –** Drying air and grain move in the same direction.

The main advantage of an automatic batch or continuous flow drying unit is its greater drying capacity compared to bin drying. Most are completely automated, thus reducing labor for loading and unloading. They are available in many different sizes to accommodate a wide range of drying needs. They are somewhat portable which allows for relatively easy replacement associated with either wear-out or expansion of capacity. The main disadvantage of these drying units is relatively low energy efficiency. But advances in electronic control systems and the addition of heat- recapture systems have improved the energy efficiency of these dryers by 35 to 50% compared to non-energy saving models.

In-bin continuous flow

In-bin continuous flow drying most often utilizes the grain bin as a combination wet-holding and drying bin. Wet grain from the harvest is loaded directly into the drying bin. As the grain becomes dry, it is removed from the bottom of the drying zone by either gravity (for systems with drying platforms near the roof) or by a tapered sweep auger (for floor supported systems); thus, to some extent, this system is a "counter-flow" dryer in that grain and air are moving in different directions.

In-bin continuous flow systems have several advantages over other in-bin drying systems. The use of higher drying temperatures increases the drying capacity without overdrying the bottom grain layers because the dried grain is continually removed at the desired final moisture content. The drying capacities of in-bin continuous flow units are similar to that of automatic batch - continuous flow dryers but usually have greater drying efficiency.

Combination drying systems

Combination drying is an approach to drying where both high-temperature processes and in-bin drying (natural air, low-temperature or layer) procedures are used in combination. The high-temperature method is used to dry relatively wet grain to a sufficiently low moisture content so that in-bin drying can be used to successfully complete the drying process before spoilage would occur.

The advantages of combination drying relate primarily to risk, drying fuel energy savings, facility expansion cost, and enhancement of grain quality as compared to using only high temperature drying. Combination drying offers a low risk method of utilizing in-bin drying. Drying efficiency is less than most in-bin drying methods but greater than high-temperature processes. Combination drying requires a relatively high level of capital investment and management if purchased as a unit because two complete drying systems are included. It may represent a relatively inexpensive way of adding drying capacity to an existing system. Keep in mind that in combination drying, both the high temperature and bin driers are sized smaller than if each was designed to do all the drying.

Supplemental aids to drying

A supplemental aid to drying is some secondary combination of equipment and management that enhances the drying process. Examples are the following:

Stirring devices

Stirring devices are used to enhance in-bin drying performance. These devices are machines suspended from the top of the bin at the roof eave level with one or more small vertical augers extending through the grain mass to within 1 to 2 inches of the drying floor. The augers move continually through the grain mass lifting grain kernels from the bottom of the bin toward the surface, mixing them with kernels in the upper layers in order to constitute a continuous mixing effect in the grain mass.

Stirring devices may be used to enhance most in-bin drying systems. Continuous lifting and mixing reduces the moisture gradient in the drying bin and practically alleviates overdrying of the bottom grain. Stirring loosens the grain density by about 10% (operators can only fill 85 to 90% of the grain depth below the eave), which significantly reduces the resistance to air flow in the bin, which in turn provides a proportional increase in the fan airflow and drying rate.

Dryeration

"Dryeration" is the process by which high temperature grain (mostly used in corn drying), taken directly from a dryer, is systematically tempered (no aeration), and then cooled in order to extract additional moisture from the grain without using any additional fossil fuel for direct heating of the drying air to dry grain to final moisture. Under proper management and representative conditions, approximately 2 points of moisture content may be removed through *dryeration*.

Dryeration operates as follows: (1) Hot grain is transferred from the dryer into a specially sized hopper holding tank immediately after being dried at high temperatures and thus contains excess (stored) heat; and (2) The hot grain then tempers for several (4 to 10) hours after which the stored heat is slowly removed using relatively high aeration airflow rates (preferably 0.5 to 0.75 cfm/bu) and latent heat rather than sensible heat transfer mechanisms. Because high temper drying stops before the final 2 to 2.5

points are removed, and the hot grain tempers before being cooled slowly for 8 to 12 hours, high grain quality is maintained and drying energy efficiency is increased while the external drier capacity is increased by 75 to 100%. The primary disadvantage of dryeration is that the logistics of this process are somewhat more difficult to manage than with a conventional high temperature drying system, and additional equipment costs may be incurred to install dryeration bins and fans. Doubling the capacity of an existing dryer often makes dryeration economically attractive for the farm and commercial grain industries when compared to adding another new dryer of the same size with wet holding tank plus the necessary electric power and other handling equipment. Moreover, dryeration may result in a premium final grain quality.

Theoretically, dryeration has the potential of 3.5 % moisture removal in high temperature corn drying. The development of insulated continuous-flow dryeration tempering/cooling bins minimizes management issues while further improving the efficiency to 2.5 to 2.75% removal during the temper/cool process.

In-bin cooling

In-bin cooling is an alternative to conventional dryeration. In this process the grain is cooled and stored in one bin so that extra handling is not required, and logistical management is not needed with regard to scheduling. As with conventional dryeration, air is blown upward through the grain, with the hotter grain being added on top of existing grain. The fan begins operation after the floor has been sufficiently covered with warm or hot grain. Fans are operated continuously until the grain reaches the average daily temperature.

Typically, this process is used with a system that had been employed previously for in-bin drying (natural air, low temperature or layer drying) so that little additional investment is needed. It offers another advantage in that any of these in-bin techniques may be used to further dry the grain, thus becoming a combination drying method.

Disadvantages of in-bin cooling, as compared to using an intermediate bin for *dryeration*, relate primarily to a lack of tempering time, which results in reduced moisture removal, lower quality, and possible condensation under the roof and/or along the bin walls. It is also important that sufficient roof venting be in place to prevent moisture from condensing in the bin and rewetting the grain mass.

References

Bennett, G. A., J. L. Richard, J. L. 1996. Influence of processing on Fusarium mycotoxins in contaminated grains. Food Technol. 50: 235-238.

Bullock, D. S., M. Desquilbet, and E. I. Nitsi. 2000. The economics of non-GMO segregation and identity preservation. Urbana, Ill.: Department of Agricultural and Consumer Economics, University of Illinois.

Christensen, C.M. and R.A. Meronuck. 1986. Quality Maintenance in Stored Grains and Seeds. University of Minnesota Press: Minneapolis.

Greenlees, W. J., and S. C. Shouse. 2000. Estimating grain contamination from a combine. ASAE Paper No. MC00-103. St. Joseph, Mich.: ASABE.

Hanna, H. M., D. H. Jarboe, and G. R. Quick. 2006. Grain residuals and time requirements for combine cleaning. ASABE Paper No. 066082. St. Joseph, Mich.: ASABE.

Hellevang, K. J., L. F. Backer, G. G. Maher. 1992. Grain Stream Sampling and Sampler Construction. AE-1044. Fargo: NDSU Extension Service, North Dakota State University. Available at: http://www.ag.ndsu.edu/pubs/plantsci/smgrains/ae1044w.htm. Accessed on: 26 August 2011.

Herrman, T. 2002. White paper on traceability in the U.S. grain and plant protein feed ingredient industries. Prepared for the Ad Hoc Intergovernmental Task Force on Animal Feeding at the request of the American Feed Industry Association. Available at: http://www.oznet.ksu.edu/grsiext/TraitSp.htm. Accessed on 29 August 2011.

Herrman, T. J., M. Boland, and A. Heishman. 1999. Economic feasibility of wheat segregation at country elevators. In Proc. 2nd Annu. Natl. Wheat Industry Res. Forum, 13-16. Washington, D.C.: National Association of Wheat Growers.

Herrman, T. J., S. Baker, and F. J. Fairchild. 2001. Characterization of receiving systems and operating performance of Kansas grain elevators during wheat harvest. Applied Engineering in Agriculture 17(1): 77-82.

Herrman, T. J., M. A. Boland, K. Agrawal, and S. R. Baker. 2002. Use of simulation model to evaluate wheat segregation strategies for country elevators. Applied Engineering in Agriculture 18(1): 105-112.

Hurburgh, C. R., Jr. 1994. Identification and segregation of high-value soybeans at a country elevator. J. Am. Oil Chem. Soc. 71(10): 1073-1078.

Hurburgh, C. R., Jr. 2003. Certification and source verification in the grain-handling industry. Paper presented at the symposium on "Product Differentiation and Market Segmentation in Grain and Oilseeds: Implications for Industry in Transition." Washington, D.C.: Economic Research Service, U.S. Dept. of Agriculture and Farm Foundation.

Ingles, M. E., M. E. Casada, and R .G. Maghirang. 2003. Handling effects on commingling and residual grain in an elevator. Transactions of the ASAE 46(6): 1625-1631.

Ingles, M. E. A., M. E. Casada, R. G. Maghirang, T. J. Herrman, and J. P. Harner, III. 2006. Effects of grain-receiving system on commingling in a country elevator. Applied Engineering in Agriculture 22(5): 713-721.

Kazazis, I. 1980. Change of quality attributes in stored cereal grains and storability tests. Geotechnical Sci., 4: 12-20

King, H. 1995. Re-engineering yesterday's country elevator to meet today's needs. Paper presented at the 66th Annual International Technical Conference and Exposition of the Grain Elevator and Processing Society. March. Seattle, Wash.

Krueger, A., F. Dooley, R. Berruto, and D. Maier. 2000. Risk-management strategies for grain elevators handling identity-preserved grains. Paper presented at the International Food and Agribusiness Management Association (IAMA) World Food and Agribusiness Congress. June. Chicago, Ill. Available at: www.ifama.org. Accessed on 1 December 2008.

Maier, D. E. 1993. Proper use of moisture meters. Grain Quality Fact Sheet #14. Purdue University: West Lafayette, Ind.

Maltsbarger, R., and N. Kalaitzandonakes. 2000. Direct and hidden costs in identity-preserved supply chains. AgBioForum 3(4): 236-242. Available at: http://www.agbioforum.org. Accessed on 16 August 2011.

Murthy, G. S., D. E. Townsend, G. L. Meerdink, G. L. Bargren, M. E. Tumbleson, and V. J. Singh. 2005. Effect of aflatoxin B1 on the dry-grind ethanol process. Cereal Chem. 82: 302-304.

NASDA. 2001. National Association of State Departments of Agriculture. The Animal Health Safeguarding Review: Results and Recommendations. Washington, DC: NASDA.

Navarro, S. and R. Noyes, Editors. 2002. *The mechanics and physics of modern grain aeration management*, Chap. 8, Supplemental Aeration Systems, CRC Press, p. 413-428.

Nielsen, R. L., and D. E. Maier. 2001. GMO issues facing Indiana farmers in 2001. Grain Quality Task Force Fact Sheet #46. 4 April. West Lafayette, Ind.: Purdue University. Available at: http://www.extension.purdue.edu/extmedia/GQ/GQ-46.pdf. Accessed on 19 August 2011.

Nganje, W., W. W. Wilson, and J. Nolan. 2004. Agro-terrorism and the grain handling systems in Canada and the United States. Current Agriculture, Food & Resource Issues 5: 148-159. Available at: cafri.usask.ca/j_pdfs/nganje5-1.pdf. Accessed 16 August 2011.

USDA-GIPSA. 1995. Grain Inspection Handbook, Book I. Washington, D.C.: USDA Grain Inspection, Packers, and Stockyards Administration, Federal Grain Inspection Service.

Wilcke, W. F., P. Gupta, R. A. Meronuck, and R. V. Morey. 2000. Effect of changing temperature on deterioration of shelled corn. Transactions of the ASABE 43(5): 1195-1201.

Zellen, B. S. 2004. Preventing Armageddon II: confronting the specter of agriterror. Strategic Insights 3(12), 7 p. Available at: http://www.nps.edu/Academics/centers/ccc/publications/OnlineJournal/2004/dec/zellenDec04.pdf. Accessed on 16 August 2011.

K·STATE
Research and Extension

Publications from Kansas State University are available at: ***www.ksre.ksu.edu***

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

K-State Research and Extension is an equal opportunity provider and employer. Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, as amended. Kansas State University, County Extension Councils, Extension Districts, and United States Department of Agriculture Cooperating, Gary Pierzynski, Interim Director.

S156 – 10 March 2012