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Maintaining Corn Quality for Wet Milling

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"Corn producers have some control over corn quality through variety selection, timing and care used in harvesting, selection and operation of dryers and conveyors, and storage management."

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Desired Quality for Wet Milling

Desired corn characteristics for wet milling include uniform kernel size, high kernel integrity (no scratches, holes, cracks or breaks), high test weight, good starch quality, uniform moisture, soft endosperm, and no mold. The milling industry estimates that poor corn quality causes about a 5-10% reduction in milling capacity. Corn producers have some control over corn quality through variety selection, timing and care used in harvesting, selection and operation of dryers and conveyors, and storage management.

Obtaining quality corn for wet milling starts with selecting corn varieties that will reach maturity prior to frost. Frost-damaged corn has small kernels, a low test weight, poor starch quality, and is often susceptible to cracking and breaking.

Test weight is a bulk density measurement; it is the number of pounds of grain in a volume bushel (1.244 cubic feet). In addition to being affected by maturity, test weight is affected by corn variety, growing season, and corn moisture content. Test weight is also affected by drying temperature and drying rate. Generally, lower drying temperatures and slower drying rates result in higher test weights. Slower cooling rates also typically give higher test weights. Test weight usually increases during drying in a high temperature dryer by about 0.25 lb/bu per percentage point of moisture reduction.

Cracks in the kernel affect the steep time, cause non-uniform steeping, and cause more starch to be lost in steepwater during processing. Mechanical cracking and breakage occur during harvesting and rough handling. Stress cracks are caused by fast drying with high drying temperatures followed by fast cooling. Stress cracks and over drying increase kernel breakage during handling. Since some corn varieties are more susceptible to cracking and breaking, this characteristic needs to be considered in selecting the variety to plant.

Harvesting

Take care at harvest to limit the amount of kernel damage. The optimum moisture content for limiting mechanical damage during harvest is about 22%. Increased damage occurs both below and above this moisture content. Combine cylinder speed and cylinder-concave clearance are also important factors determining mechanical damage at harvest. Damage increases with increasing cylinder speed.

Follow the recommendations in the operators manual for combine settings and recommended harvesting procedures. Know why you must make an adjustment before doing it. Make only one adjustment at a time, checking the results before making another adjustment. Check for grain losses and damage frequently, particularly as harvest conditions change.

Holding Wet Corn

To avoid mold damage while holding wet corn, it is necessary to keep the corn cool. An aeration system delivering a uniform airflow of about 0.5 cfm/bu with cool outdoor temperatures is needed to carry away heat generated by corn and mold respiration. The approximate allowable storage time for corn is shown in Table 1. The allowable storage time is approximately doubled by reducing the corn temperature by 10°F.

Table 1. Approximate allowable storage time for shelled corn based on 0.5% maximum dry matter loss. (Transactions ASAE 333-337, 1972)

Grain Temp.	Corn Moisture (%)						
	18	20	22	24	26	28	30
(F)	Days						
30	648	321	190	127	94	74	61
40	288	142	84	56	41	32	27
50	128	63	37	25	18	14	12
60	56	28	17	11	8	7	5
70	31	16	9	6	5	4	3
80	17	9	5	4	3	2	2

Selecting and Managing Dryers

The kernel temperature should not exceed about 140°F during drying to prevent damage to milling quality. At temperatures exceeding about 140°F, milling efficiency is reduced because of starch gelatinization, protein denaturation, and proteolytic denaturation. Also, the germ of the kernel is damaged causing a loss of viability. Some wet millers use a germination test to assess corn quality.

The kernel temperature reached during drying depends on the initial moisture content, drying air temperature, the type of dryer and dryer management. In some dryers, the kernel temperature of part of the corn reaches the drying air temperature. Corn harvested at higher moisture contents will be in a dryer longer, so there is more potential for some of the kernels next to the inside of the drying column to become excessively hot in some types of dryers.

Dryers should be selected and operated to produce as uniform a final moisture as is possible. Uniform corn moisture facilitates management of the steeping process.

Column Dryers

A cross-flow dryer, shown in Figure 1, is the most common type of dryer used. It is referred to as a cross-flow dryer because the heated air moves across the grain column perpendicular to the flow of the grain. The grain moisture content and temperature varies across the column of a cross-flow batch dryer as shown in Figure 2. Grain near the inside of the column is at a lower moisture content and a higher temperature than grain near the outside of the column. Therefore, even though the average moisture content may be at 14%, the moisture content of grain near the inside of the column may be 6 to 10%, and grain near the outside of the column may be at 16 to 28% moisture. Also, even though the average temperature may be at 140°F, grain near the inside of the column may be at 200°F, and grain near the outside of the column may be at 80°F.

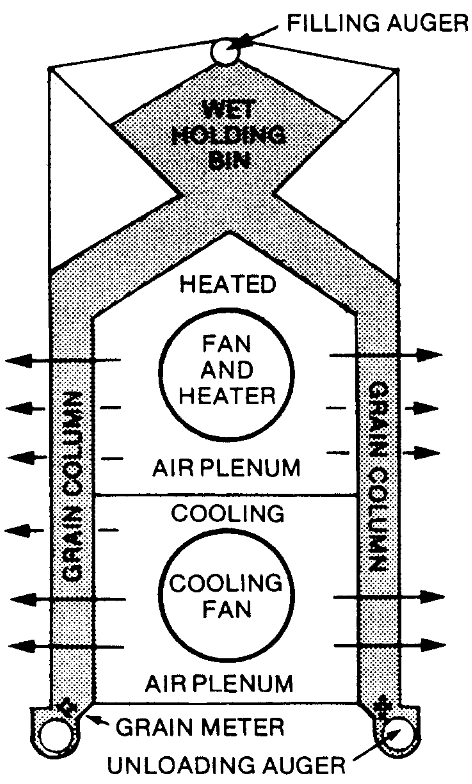


Figure 1. Cross-flow dryer with forced-air drying and cooling.

The temperature of corn in a dryer increases as the corn dries. At higher moisture contents, the kernel is kept cool by the cooling effect of moisture evaporation. In many dryers, grain temperature is used to determine when the grain is dry.

A cross-flow dryer used for drying corn for wet milling should be operated at moderate temperatures or include features to minimize variation across the column.

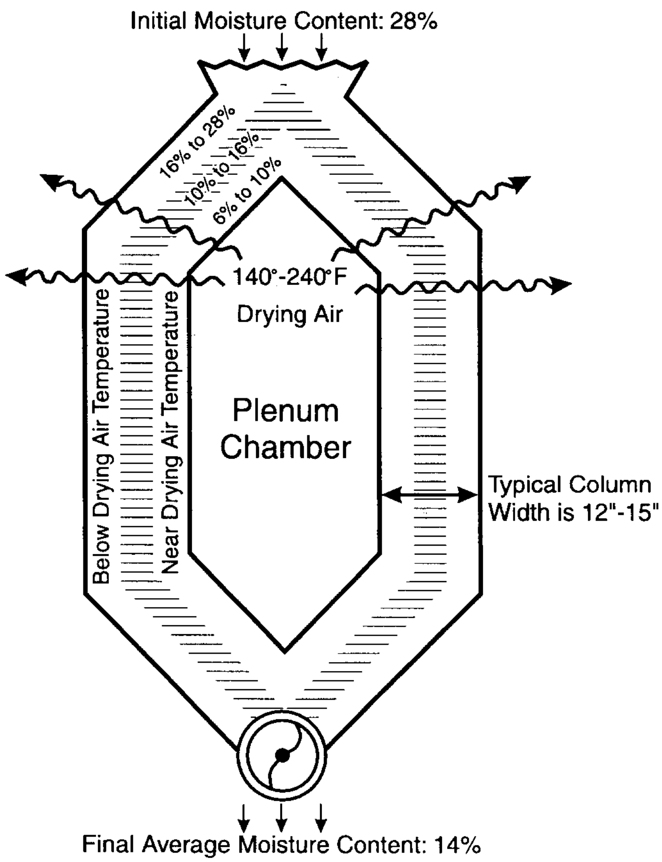


Figure 2. Example of different temperature and moisture zones in a cross-flow dryer.

A recirculating batch dryer is one way to mix the grain to create more uniform drying (Figure 3). Some continuous cross-flow dryers use a grain turner that moves corn from the inside of the column to the outside, and corn from the outside of the column to the inside (Figure 4). This minimizes the amount of time that the corn is adjacent to the inside of the column.

Another feature that can minimize variation across the drying column is having the drying columns tapered, so the grain on the plenum side of the column moves faster than grain near the outside of the column. In multi-stage, continuous-flow, cross-flow dryers, the top stage, which contains the wettest corn, can be operated at higher temperatures, and the bottom stages, which contain drier corn, can be operated at lower temperatures.

Some cross-flow dryers use tempering sections to limit the exposure to high drying-air temperatures. Tempering sections installed between the drying section and cooling section of a continuous-flow dryer reduce the potential for stress crack formation during cooling.

Although lower drying temperatures give better corn quality, they unfortunately decrease drying capacity and energy efficiency. The energy required to remove a pound of water from corn at various airflow rates and drying temperatures is shown in Figure 5. The airflow rate selected is a compromise between energy efficiency, dryer capacity, average grain temperature, and moisture variation across the column. Using a higher airflow rate results in a higher drying rate and less variation in temperature and moisture across the column, but it increases the energy requirement. Higher airflow rates also increase the average grain temperature, as shown in Figure 6. Some cross-flow dryers utilize air recirculation to increase energy efficiency (Figure 7).

In concurrent-flow dryers, airflow enters the wet grain and travels in the same direction as the grain. This results in a much lower grain temperature (see Figure 6). A two-stage concurrent-flow dryer with cooling is shown in Figure 8.

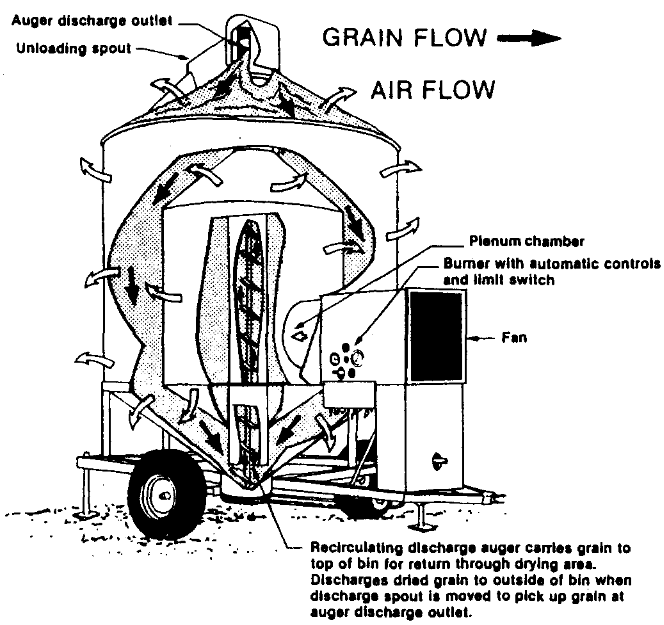


Figure 3. Recirculating batch dryer.

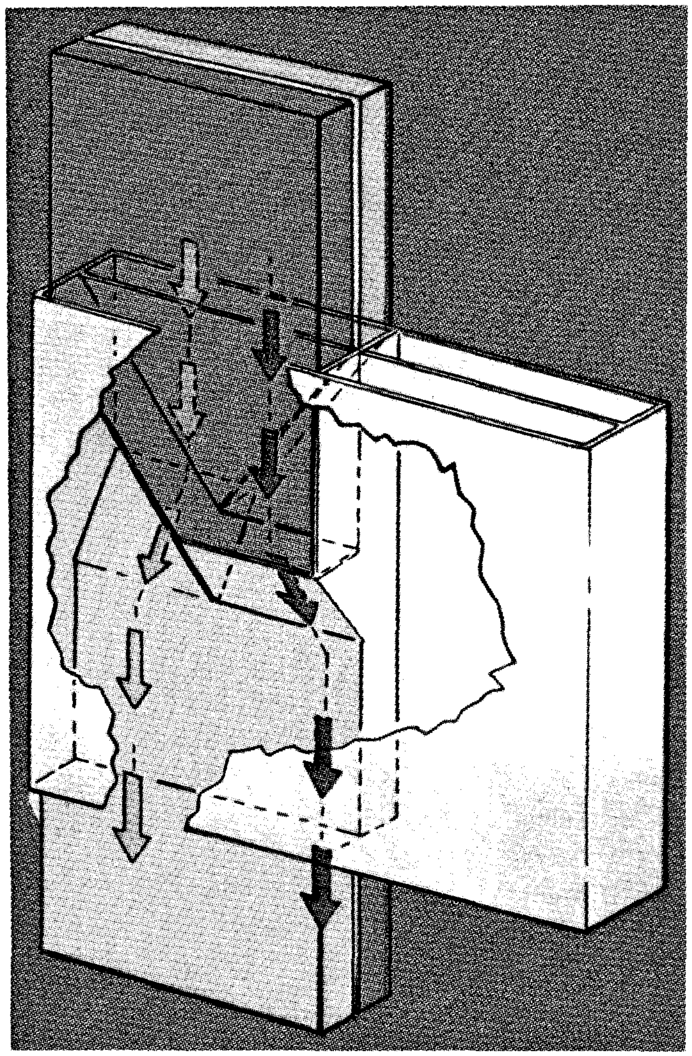


Figure 4. Grain turner used to mix grain in column-type dryers.

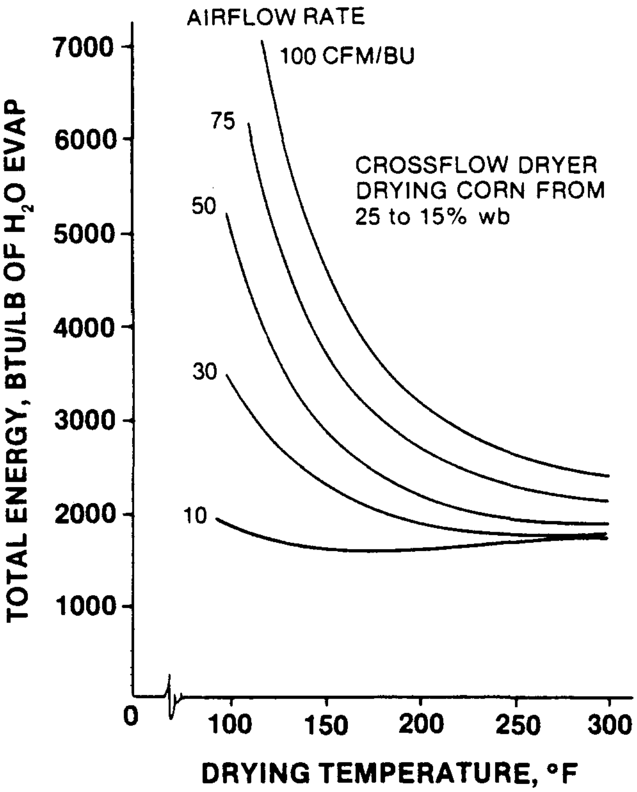


Figure 5. Energy requirements of a conventional crossflow dryer as a function of drying air temperature and airflow rate. (University of Nebraska)

cfu/bu = cubic feet of air per minute per bushel of corn

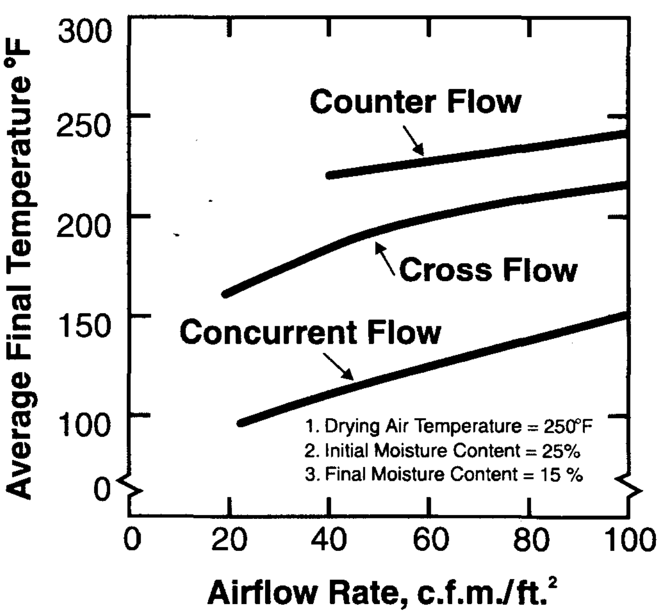


Figure 6. Final grain temperature in the three basic continuous-flow drying methods.

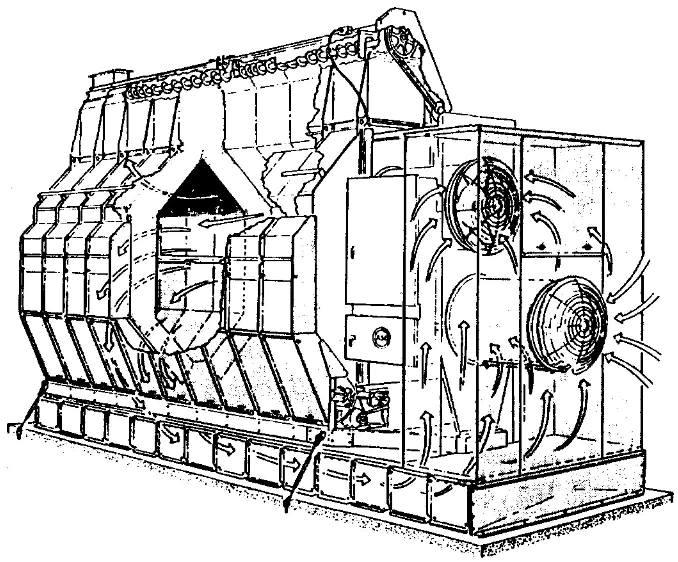


Figure 7. Exhaust air recirculation to improve energy efficiency.

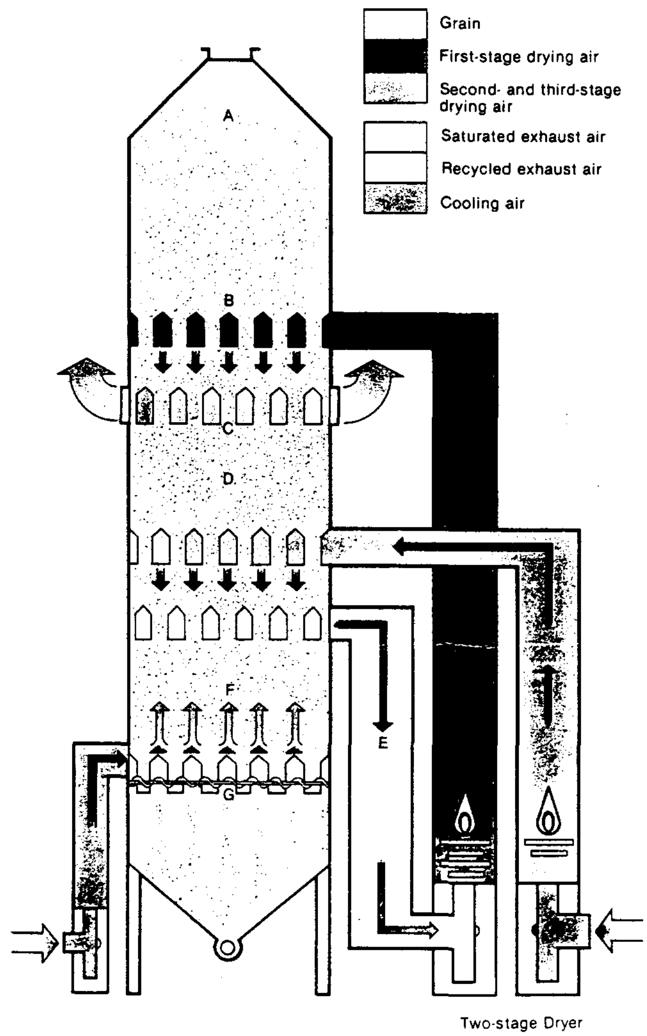


Figure 8. Two-stage concurrent-flow grain dryer.

In the mixed-flow or rack type dryer, the grain flows over alternating rows of air supply ducts and air exhaust ducts (Figure 9). This action provides mixing of the grain and alternate exposure to hot drying air and air which has been cooled by previous contact with the grain. This promotes moisture uniformity and limits grain temperature.

Bin Dryers

High-temperature batch-in-bin drying involves using a bin as a batch dryer. A 3 to 4 feet deep layer of corn is placed in the bin and the fan and heater are started. Typical drying air temperatures are 120 to 160°F with airflow rates of 8 to 15 cubic feet of air per minute per bushel of grain (cfm/bu.) Drying begins at the floor and progresses upward. Grain at the floor of the bin becomes excessively dry while the top layer of the batch remains fairly wet. As the grain is moved from the bin, the grain is mixed so the average moisture content going into storage is acceptable. There are variations, however, in grain temperature and moisture content in the dried corn.

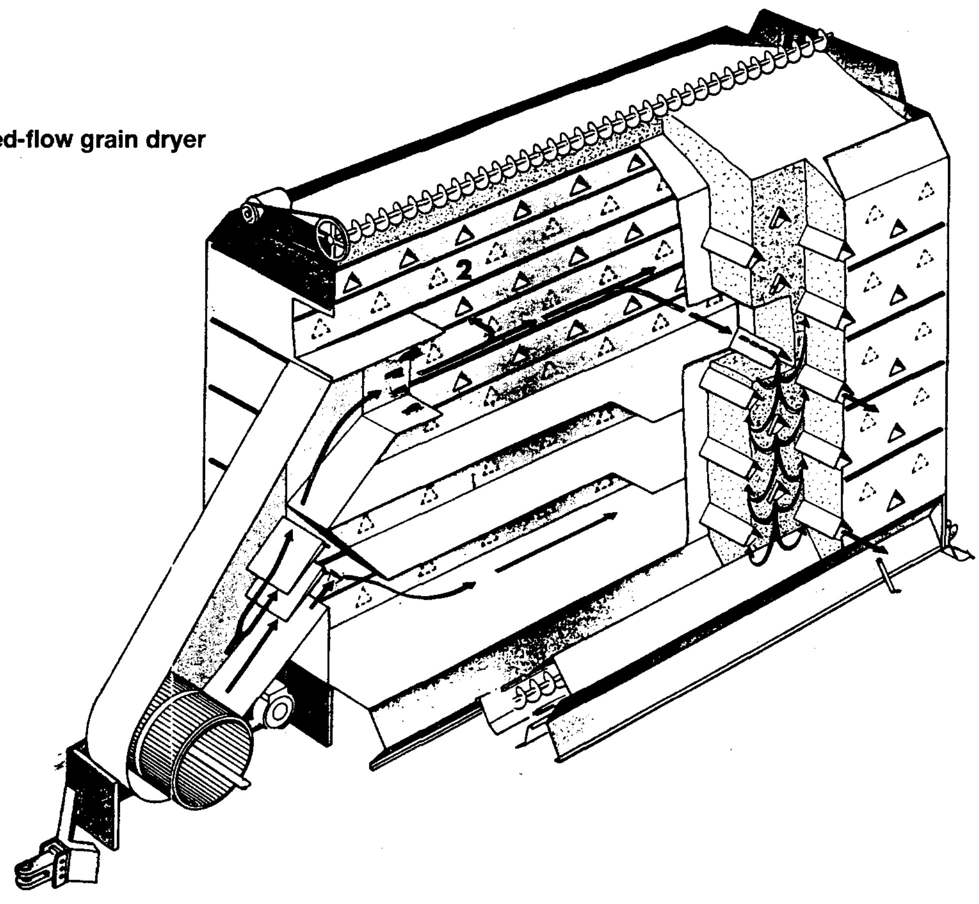
A stirring device can be added to batch-in-bin dryers to provide a more uniform moisture content and corn temperature. Stirring will also increase the airflow, which increases the drying speed. Stirring allows depths of up to 6 to 8 feet for corn. Grain stirrers tend to sift fine materials to the bin floor, so it is important to clean the bin floor between batches.

A recirculating bin dryer incorporates a tapered sweep auger which removes grain from the bottom of the bin and places it on the top of the corn in the bin (Figure 10). This creates more uniform drying.

A continuous-flow bin dryer also incorporates a sweep auger which removes the corn on the bottom of the bin when it is dry. Cooling occurs in a separate bin. Counterflow drying occurs in these dryers (Figure 10). The airflow moves from the driest grain on the bottom to the wettest grain on the top. Because all kernels approach the drying air temperature in this type of dryer, the drying temperature needs to be reduced to prevent damaging the grain.

Be aware that increasing the grain depth reduces the airflow rate (cfm) and therefore the drying rate of in-bin dryers.

Figure 9. Mixed-flow grain dryer



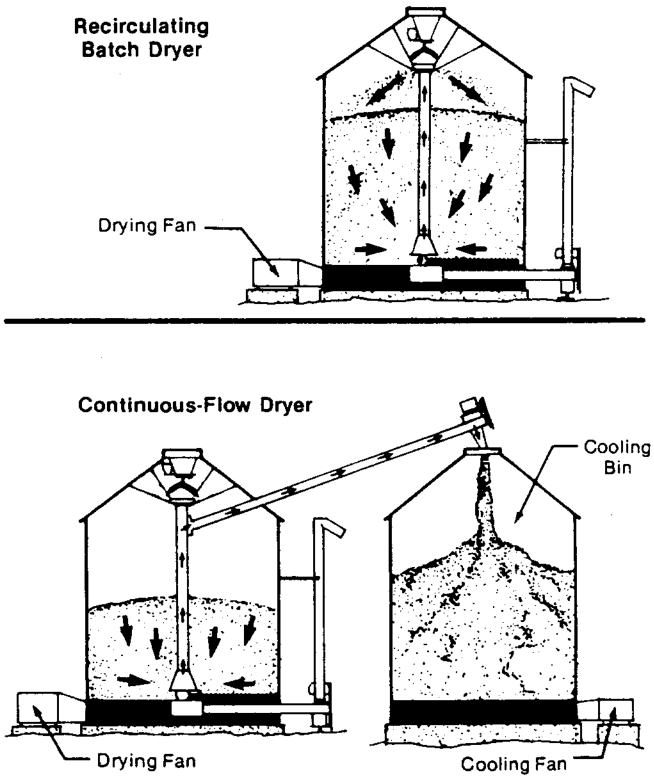


Figure 10. Grain recirculators convert a bin dryer to a high speed recirculating batch or continuous flow dryer.

Cooling Corn from High-Temperature Dryers

Dryeration involves tempering, then cooling the grain slowly in a bin rather than in the dryer to achieve a large reduction in breakage susceptibility. Other advantages of dryeration include about 2 percentage points of moisture removal, a 20 to 40% energy savings, and a 50 to 75% increase in dryer capacity. The dryer capacity increases because the corn is only dried to about 17.5% moisture and cooling time is eliminated. The amount of moisture removal is related to the amount of cooling that occurs. About 0.25 percentage point of moisture is removed for each 10°F of cooling. For example, about 2 percentage points of moisture removal would be expected when cooling corn from 130 to 50°F; [(130 - 50) / 10 x 0.25 =2.0].

With dryeration (Figure 11), the corn is moved directly to a cooling bin, is allowed to temper without airflow for 4 to 6 hours, and then is cooled over a 12 to 24-hour period. An airflow rate of 0.5 to 1.0 cfm/bu is normally needed to cool the corn within 24 hours. Condensation forms along the bin wall, which rewets some corn during the tempering period. The corn must be moved from the cooling bin to prevent this wet grain from spoiling. The wet corn is mixed with dry corn as it is moved into storage.

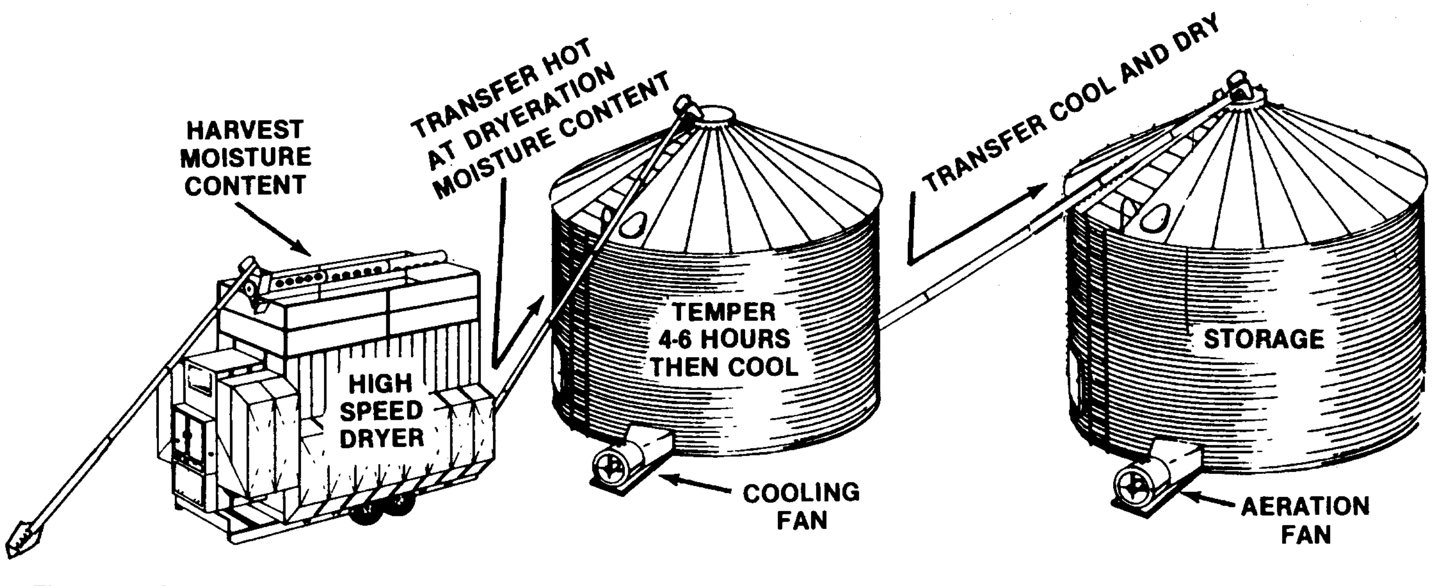


Figure 11. Schematic of dryeration system. Grain is dried in a high speed dryer to within 1-2% of safe storage moisture content. The hot grain is moved to the dryeration bin where it sits without airflow for 4 to 6 hours. After cooling, the grain is moved to storage.

In-storage cooling is different than dryeration. The grain is moved directly to the storage bin without cooling in the dryer, but unlike dryeration, the grain is cooled without delay. Size the fan to provide an airflow rate of 12 cfm per bushel per hour of dryer capacity or fill rate. For example, if hot corn is being added to the bin at the rate of 500 bushels per hour, size the fan to provide 6,000 cfm of airflow. The air should flow upward through the corn, so additional hot corn can be added to the top to be cooled without reheating the corn below.

Advantages of in-storage cooling over cooling in the dryer include increased dryer capacity of 20 to 40% in a batch dryer, and in a continuous flow dryer if the cooling chamber is used as a drying chamber. There is, however, some potential for condensation along the bin wall and on the underside of the bin roof, which can lead to grain spoilage. The potential for condensation increases as the cooling rate decreases, or if cooling is not started immediately. There is not as much moisture removal or as large a reduction in cracking potential with in-storage cooling as with dryeration, but you do not need to move the corn after cooling.

Combination Drying

Combination drying combines some high-temperature drying and some low-temperature or natural-air drying. Advantages of combination drying include increased high-temperature dryer capacity, improved corn quality, and improved energy efficiency. Also, higher moisture contents can be dried than are allowable with natural-air and low-temperature drying alone. With combination drying, corn may be harvested at moisture contents in excess of 20%, dried in the high temperature dryer to about 20%, then, without any cooling, moved to a bin equipped for natural-air or low-temperature drying to finish drying.

Natural-Air and Low-Temperature Drying

Natural-air and low-temperature (NA/LT) crop drying (Figure 12) maintain the high quality of the corn, do not require constant supervision, are energy efficient, and do not limit harvest capacity. A drying fan is required for each bin, and the initial moisture content that can be dried in a full bin is limited to about 21%. An airflow rate of 1.25 cfm/bu will dry 21% moisture content corn to about 15% in about 36 days under average Upper Midwest October conditions.

NA/LT drying works very well during October but is not efficient with typical mid to late November weather conditions. It will take about 70 days to natural air dry 21% moisture content corn to 18% under November conditions with an airflow rate of 1.25 cfm/bu. The corn only dries to 18% moisture content, because that is the equilibrium moisture content (EMC) of corn for November conditions. Heating the November air by 5°F reduces the EMC to 14.6% moisture and reduces the drying time to 52 days. However, since November has only 30 days, 43% of the corn still is not dried after running the fan and heater the entire month of November. Adding more heat will overdry the corn without substantially increasing the drying speed. A stirring device in the bin is required if more than a 5°F temperature rise is used.

The drying fan will warm the air 3 to 5°F depending on fan type and operating conditions. This needs to be considered in designing a system.

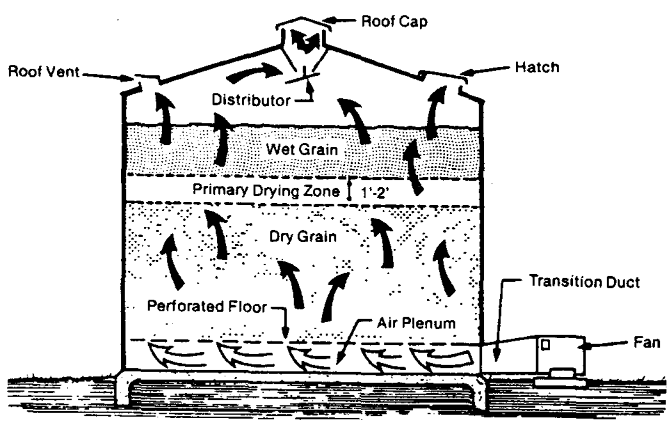


Figure 12. A typical bin dryer utilizing natural air/low temperature drying.

The following equation can be used to size a heater:

Btu/hr = cfm x 1.1 x Temperature Increase (F)

For example, to heat 10,000 cfm of airflow by 5°F requires a 55,000 Btu/hr heater.

To convert to kilowatts (kW) for an electric heater, divide the Btu/hr by 3,413. A 16 kW electric heater is equivalent to the 55,000 Btu/hr.

Corn can be held over winter and dried in the spring. Based on average April conditions, 21% moisture corn can be dried to about 15.3% in 41 days using an airflow rate of 1.25 cfm/bu. Based on average May conditions, the corn can be dried to about 13.5% moisture in 35 days using the same airflow rate. This is a good option instead of drying during late November, if the corn does not need to be delivered before spring. Cool the corn to about 25°F for winter storage.

Higher airflow rates and larger amounts of heat increase the cost of drying (Table 2). With an electrical cost of $0.06/kWh, the cost per bushel to dry 23% moisture corn with a 3°F temperature rise is $0.11/bu with an airflow rate of 1 cfm/bu, $0.16/bu with an airflow rate of 2 cfm/bu, and $0.22/bu with an airflow rate of 3 cfm/bu. Drying speed is related to the airflow rate. Since doubling the airflow rate requires increasing the fan horsepower by about five times, the cost of drying increases with higher airflow rates. Costs vary depending on climatic and operating conditions, so these values should be considered estimates.

Table 2. Estimated energy required to dry corn.

Temperature Increase (F)	Final Moisture	Airflow Rate (cfm/bu) 1	2	3
(F)	(%)	-------- kWh/bu	--------	
3	14.9	1.8	2.7	3.7
10	11.9	2.5	4.5	6.0
20	10.0	5.0	7.5	10.4
30	8.0	5.3	7.9	11.1

Initial corn moisture content = 23%

Outside air conditions = 45 F, 80% relative humidity

Resistance to airflow, static pressure, and fan horsepower requirements may become excessive at higher airflow rates. For example, for a 21-foot diameter bin filled 18 feet deep with corn, at 1 cfm/bu the static pressure is about 3.2 inches and the fan horsepower needed is about 5 hp. At 2 cfm/bu, the static pressure is about 8.7 inches and the fan horsepower needed is about 27 hp. At 3 cfm/bu, the static pressure is about 16 inches and the fan horsepower needed is about 76 hp.

Corn wetter than 21% can be dried by filling the bin only part full, which results in a higher airflow rate. This can be done by adding batches of 4 to 6 feet, with progressively drier corn added when the corn in the bin is dry (Figure 13).

A fully perforated drying floor is recommended for in-bin drying. The corn should be cleaned before it is placed in the bin to eliminate fines and "bees wings" which reduce airflow. The top surface needs to be leveled, so uniform airflow and drying is achieved. If the corn is peaked, air will tend to flow near the edges and corn in the peak will dry much slower. A grain spreader helps level the grain surface.

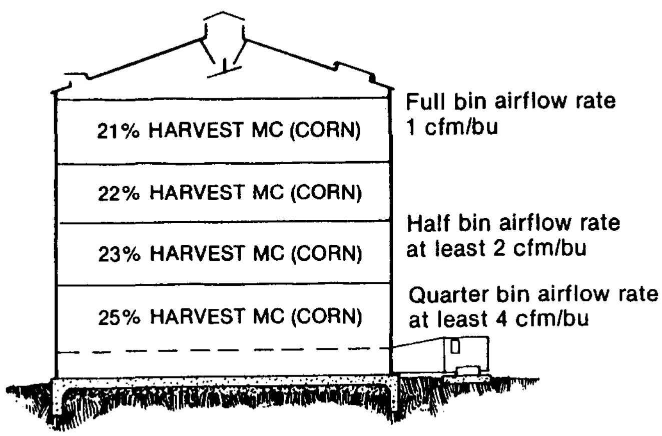


Figure 13. Example of layer drying. The higher airflow rates on a per bushel basis early in the filling permit a higher initial moisture content to be loaded.

Storage Management

Corn needs to be dried to a safe storage moisture and then cooled by aeration during storage to prevent mold growth and limit insect activity. Molds consume corn dry matter, produce odors, and sometimes produce toxins. Corn should be dried to 15.5% for short-term storage over winter, to about 14% for one-year storage, and to 13.5% for long-term storage.

Grain stores best if kept cool and dry. Optimum temperatures for insects and mold are between 70 and 90°F. At grain temperatures below 40°F, insect and mold activity is limited. Corn should be cooled, using aeration, to about 25°F for winter storage to minimize moisture migration and to enhance storability.

Stored grain should be checked at least monthly. Check the corn temperature and moisture content at several locations and record the information.

Cover fans and air ducts when not in use to prevent rodents and moisture from entering and to prevent excessive warming in the spring.

Measuring Moisture Content

A representative sample must be used to determine the moisture content of a load of grain. Also, the moisture content should be uniform in the kernel. Most meters are affected by the moisture content of the outside surface of the kernel, so if the outside is drier than the inside of the kernel, such as when corn comes directly from a dryer, the meter will give an erroneously low reading. A temperature adjustment must be used if the sample is not at the standard temperature, which is usually about 75°F. A moisture meter should be checked against a reference, such as where the grain is marketed or other meters, periodically to assure that accurate readings are being provided.

It is difficult to accurately measure the moisture content of hot grain. It is best to cool the samples slowly in a sealed moisture-proof container before checking the moisture content. By comparing the difference between the moisture content of a cooled sample and a sample immediately out of the dryer, an adjustment factor can be developed and used as an estimate for managing the dryer. It is only an estimate, since the adjustment factor will vary depending on initial moisture content, drying rate, and other factors. Remember to add or subtract the temperature correction factor for your moisture meter, if your meter doesn't have automatic temperature compensation.

Conveying and Handling

Select conveyors that are gentle on the grain and operate them in manner to reduce damage. Augers are not a primary source of grain damage if operated properly. Reducing auger speed and operating the auger at full capacity greatly reduces the risk of kernel damage. Damage can occur when grain is pinched between the auger flighting and casing, so select and maintain the clearance either greater or less than the corn kernel thickness.

Drop height should be minimized during grain transfer. Consider installing grain decelerators for heights exceeding about 40 feet.

Connections between pipe sections need to be smooth in a pneumatic system, and corners in piping should be made with a large radius turn to minimize kernel damage. Grain damage is related to conveying velocity. Research indicates that air velocity should not exceed about 5,000 feet per minute to minimize grain damage. Maintain the manufacturer's recommended air-to-grain volume ratio to minimize kernel damage. Also, use a grain decelerator at the discharge.

Corn breakage susceptibility during handling increases as moisture contents decrease below about 14%. Breakage susceptibility is also higher for colder grain. Handling corn with kernel temperatures below about 0°F will increase the breakage potential.

Grain Sampling

Accurate grain sampling is important because information from the sample is used to establish the quality characteristics and the value of the grain. Grain stream sampling done properly at the farm will permit knowing the characteristics of the corn in storage. Tests have shown that the following requirements must be met if an endgate sample of grain is to be representative:

1. Sampling device must collect grain from the entire grain stream without overflowing.
2. Samples must not be taken from the first or the last portions of a load.
3. The entire grain stream must be cut (sampled) with a side-to-side sweep of the sampler, cutting the full thickness of the stream – front to back.
4. Take at least two samples from the load at random intervals.

Summary

To produce corn having the quality needed for profitable wet milling:

- Select corn varieties that have low breakage susceptibility and are mature with low moisture contents before frost.
- Harvest at corn moisture contents and with combine settings that result in minimum corn kernel damage.
- Select and manage dryers to keep kernel temperature below 140°F and achieve uniform corn moisture.
- Dry corn to 15.5% moisture for winter storage, 14% for storage through summer, and to 13.5% for long-term storage.
- Cool corn to about 25°F for winter storage.

Other Drying and Storage Information Available

**Available from Distribution Center,
North Dakota State University (701) 231-7882.**

AE701	Grain Drying
AE791	Crop Storage Management
AE808	Crop Dryeration and In-Storage Cooling
AE850	Pneumatic Grain Conveyors
AE905	Grain Moisture Content Effects and Management
AE923	Calculating Grain Drying Cost
AE945	Equivalent Weights of Grain and Oilseeds
AE1044	Grain Stream Sampling and Sampler Construction
EB-35	Natural Air and Low Temperature Crop Drying
EB-45	Insect Pest Management for Farm Stored Grain
MWPS-13	Grain Drying, Handling and Storage Handbook
NCH-14	Energy Conservation and Alternative Energy Sources for Corn Drying

**Available from University of Minnesota
Distribution Center, (612) 625-8173.**

MN BU-6577-E	Natural-Air Corn Drying in the Upper Midwest
MN AG-FO-1324	Dryeration and In-Storage Cooling for Corn Drying
MN AG-FO-1327	Management of Stored Grain with Aeration
MN AG-FO-5716	Selecting Fans and Determining Airflow for Crop Drying, Cooling, and Storage

**Available from Biosystems and
Agricultural Engineering Department,
University of Minnesota, (612) 625-9733**

FANS	A Fan Selection Computer Program

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