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Optimizing Grain Dryer Operations

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Highly variable harvest moisture, late and uneven crop maturity and poor weather conditions can expose many weaknesses in terms of grain dryer operations. Management and equipment shortcomings can create significant bottlenecks and frustration among farmers and elevator managers alike. Whether you own and operate your own drying system or deliver to someone else's dryer, long drying times frustrate everybody. The following is a summary of operational tips to help farmers and elevator managers optimize the performance of their grain dryers.

In-bin Dryers

Before loading a drying bin, cleaning of the grain should be considered. High concentration of fine material in the center of the bin can produce non-homogeneous airflow (up to 30% difference in airflow between center and side wall locations have been documented). Uneven airflow produces uneven movement of the drying front through the grain bulk. In addition, fine material tends to be wetter than grain. Thus, the combination of lower airflow and higher moisture content in the center results in significantly slower drying and greater potential for spoilage in the center compared to grain close to the sidewall. Although fines are more difficult to remove from wet than from dry corn, wet corn should be screen-cleaned if it is to remain in the same bin for storage. A spreader is generally the only feasible way to come close to a level fill, which is critical in assuring even air distribution for drying. Although undesirable, some hand leveling may be needed at times to compensate for uneven spreading. Utilizing a spreader to distribute fines when filling a bin with dry corn can be less effective than combining a grain cleaner and the drawing of a core. Drawing out dry corn multiple times while filling a bin is even more effective than drawing a core once after filling is complete.

Low Temperature Systems - The biggest mistake while operating a natural air/low temperature (NA/LT) drying system (i.e., bin dryers operating with natural air, or air heated up to 10°F) is filling it too quickly. Drying time is directly related to the airflow rate, which is a function of grain depth and fan power. The optimum combination of airflow and fan power typically results in a grain depth of 14-16 ft. However, grain depths of 18-21 ft are most typical for NA/LT drying systems. Although more expensive initially, buying diameter is preferable over buying depth, and results in lower operating costs and better system performance.

Table 1. Schedule for layer drying of corn given warm high humidity ambient conditions with humidity control to obtain a desired final moisture content of 16%.

Grain: corn; initial moisture: 24%; bin diameter: 24.0 ft; bin eave: 16 ft; fan: ID XL430-7 (10 HP); drying air relative humidity: 55.0%; drying air temperature: 68°F

Layer No.	Layer Depth (ft)	Total Depth (ft)	Bu/Layer	Bu Total	Drying Days/Layer	Drying Days Total	CFM/undried Bu
1	4.0	4.0	1,448	1.448	3.8	3.8	11.2
2	3.0	7.0	1,086	2,533	3.7	7.5	11.6
3	2.5	9.5	905	3,438	3.6	11.1	12.1
4	2.0	11.5	720	4,162	3.3	14.5	13.9
5	2.0	13.5	720	4,886	3.5	18.0	12.7
6	2.0	15.5	724	5,610	3.7	21.6	11.8
7	0.5	16.0	181	5,791	1.9	23.5	46.3

From: O.J. Loewer, T.C. Bridges, and R.A. Bucklin. 1994. On Farm Drying and Storage Systems.

If the bin is completely filled with corn above 20% in a single batch, by the time the drying front reaches the top layer, the grain could be spoiled and mycotoxins could develop. If moisture contents are above 20%, a drying bin should not be filled in a single batch but rather in layers. The wetter the grain, the shallower the layers should be (see Table 1). Better yet, if several bin dryers are available, layers of grain should be spread into all of them. Distributing the drying load over more than one bin maximizes the drying capacity. Also, early in the season, the moisture content is highest. Thus, the wettest grain can be dried closest to the bottom of each bin where the drying potential of the air is highest.

The drying front must be monitored closely. Often layers of higher and lower moisture content grain are added on top of each other. As the drying front moves up through the grain, moisture is added to some layers and removed from others. Monitoring the top layer of the grain mass has to occur over several days. A reading of 18% moisture on one day may increase to a reading of 20% the next day as the drying front pushes through the different moisture layers. When the moisture readings remain consistently below 16-17% for several days, drying is nearing completion.

Finally, low temperature drying cannot always be completed by December. As a matter of fact, after the middle of December the drying potential of the air is too low in most parts of the Midwest. Thus, after the top layer has dropped below 18% moisture and the grain temperature below 30-35°F, the drying fan can be turned off. Fan operation should subsequently occur about once a week for 4 to 6 hours on dry, cool days until the weather turns warmer again in March. Drying to 15% can then be completed by running the fan continuously in the spring. To assure that the top layer is below 18% moisture by mid-December, supplemental heat may be needed in a poor drying year. However, a Purdue study has clearly shown that most operators use too much heat too often, and thus lose significant amounts of water due to overdrying while paying larger than necessary energy bills (see Grain Quality Facts Sheets #5, #20 and #30 for more information on optimum NA/LT drying under Indiana weather conditions).

Addressing this problem is the focus of a current research project at Purdue University. A new in-bin low temperature burner control strategy that varies the burner heat as a function of air and grain conditions has been developed that avoids overdrying of the grain bottom layers by rejecting the driest air hours. During the wettest air hours when heat is needed, the variable burner control strategy adds the exact amount of heat to the ambient air producing a uniform drying effect and minimizing energy consumption and costs. This

Table 2. Average, minimum, and maximum values for 28 years of computer-simulated data for Variable Heat (VH), Continuous Natural Air (CNA), and Continuous Heat (CH) in-bin drying strategies given Indianapolis weather conditions.

Airflow: 1 cfm/bu; grain: corn; initial moisture content: 22%; initial drying date: October 1; final drying date (End Date), final average moisture content (Average MC), final minimum moisture content (MC minimum), final moisture content range (MC range), and final total cost (Total Cost in terms of cents/bu) due to fuel (80 cents/gal LP) and electric (7 cents/kWh) energy used, shrink loss due overdrying below the 15% target moisture content ($2.50 corn/bu), and dry matter loss.

Strategy	End Date	Average MC (%)	Minimum MC (%)	MC Range (%)	Total Cost (cents/bu)
VH	**11/24**	**14.7**	**14.5**	**1.5**	**11.9**
Max	12/3	14.9	14.9	3.2	13.1
Min	11/17	14.0	12.8	1.1	10.1
CNA	**1/14**	**14.4**	**13.1**	**2.9**	**17.2**
Max	5/10	15.1	14.4	4.7	32.5
Min	10/27	12.7	11.3	1.2	5.6
CH	**11/1**	**13.6**	**12.6**	**3.3**	**12.3**
Max	11/6	14.6	13.9	6.1	15.8
Min	10/24	11.6	9.9	2.1	9.6

Table 3. Design and operating parameters for different in-bin drying systems found on several farms.

Farm	Bin Dimensions Diameter (ft)	Height (ft)	Grain Depth (ft)	Airflow (cfm/bu)	Drying Air Temperature (°F)	Stirrers
1	30	22	22	0.74	80	1
2	45	33	4	2.13	150-160	No
3	30	21	21	0.84	90	4
	27	18	18	1.12	80	2
4	30	29	29	0.86	100	No
5	27	18	18	1.2	136	2
6	27	27	27	1.01	100	2
	27	19	19	1.11	100	No
7	27	20	6	7.43	150-160	2

strategy is in the third year of experimental testing and shows promising results. For 28 years of computer-simulated data, the Variable Heat strategy minimized the overdrying of the bottom layer, the final moisture content (MC) range and the energy consumption. The final MC was closer to the target final MC (15%) than for the other two strategies investigated (Continuous Natural Air and Continuous Heat). The reduced overdrying of the bottom layer and the lower energy consumption allowed the Variable Heat strategy to minimize the total drying cost. In addition, Variable Heat was the strategy with the lowest variability in cost, final MC, MC range, and ending date (see Table 2). For more information on the variable heat in-bin low temperature drying and conditioning system, refer to current research projects at: www.GrainQuality.org

Medium Temperature Systems - Any bin dryer operated at air temperatures that keep grain kernel temperatures below 100-110°F for food grade corn (white and yellow hard endosperm corn) and below 130-140°F for high quality No. 2 yellow, waxy, high extractable starch, high amylose and high oil corn is considered a medium temperature in-bin dryer (see Grain Quality Fact Sheet #23 for more information). Whether a batch is dried and cooled in a shallow bed before moving it into the final storage bin, or dried and cooled using stirring machines, the biggest mistake in these systems is filling them too deep. If stirring machines are not used, the optimum bed depth is 2.5 to 4 ft; if stirring machines are used, the optimum depth range is from 6 to 9 ft. Drying capacity decreases disproportionately as depth is increased. For example, drying 26% moisture corn to 15% at 7.5 ft depth may take 41 hours, while doubling the depth increases the drying time to as long as 95 hours. Additionally, initial moisture content has a significant effect on drying time. For example, compared to drying from an initial moisture content of 26%, drying 22% moisture content corn to 15% cuts the drying time from 41 hours to about 27 hours at 7.5 ft.

In-bin drying systems found on several farms were analyzed with respect to food corn use in one Purdue University study using a computer simulation model. The parameter specifications are summarized in Table 3. The results indicate that the correct design and operation of the system are key factors for preserving grain quality and reducing drying costs (see Table 4). The two batch-in-bin drying systems (Farms 2 and 7) were operated at drying air temperatures in excess of those recommended to prevent stress crack formation in food corn (100-110°F). Although the lowest drying costs were achieved in one of these high temperature drying systems (Farm 2), the loss in quality premiums would offset those savings. The drying costs for the high temperature batch-in-bin drying system on Farm 7 were about double those of the system on Farm 2. This was the result of an oversized fan in combination with a shallow batch depth. Excessive drying costs and quality loss would make this system especially undesirable for food corn drying. Clearly, medium temperature in-bin drying at 90-100°F utilizing two stirring machines with an airflow of 0.75-1 cfm/bu will result in excellent food corn quality and low drying costs

Table 4. Drying times and costs for different in-bin drying systems found on several farms. The drying process was simulated using the STIRD model, which is a module of the Granary drying simulation programs (University of Florida).

Initial moisture content: 20%; final moisture content: 14.5%; LP gas cost: 60 cents/gallon; electricity cost: 7 cents/kW; minimum drying costs were calculated when ambient conditions were 60°F and 50% RH, maximum drying costs were calculated when ambient conditions were 40°F and 50% RH.

Farm	**Bin Diameter (ft)**	**Drying Time (days)**	**Drying Costs (cents/bu)**	**(cents/bu/pt)**
1	30	11.5	4.1-7.7	0.8-1.4
2	45	1.3* (31 hours)	2.6-3.3	0.5-0.6
3	30	8	4.5-7.3	0.8-1.3
	27	7.5	4.4-8.0	0.8-1.5
4	30	6	3.7-5.5	0.7-1.0
5	27	3	4.9-6.3	0.9-1.2
6	27	5	4.5-6.8	0.8-1.2
	27	4.5	4.6-6.8	0.8-1.2
7	27	0.4* (9.4 hrs)	5.7-7.1	1.0-1.3

** Indicates Batch-in-bin drying.*

(0.8-1.5 cents/bu per point of moisture removed). These results are comparable to the Variable Heat low temperature drying strategy (1.4-1.6 cents/bu per point of moisture removed) especially when considering the difference in the assumed LP fuel cost (60 vs 80 cents/gal, respectively).

The addition of a power sweep auger can convert this system into a semi-continuous flow in-bin dryer. An automatic controller powers up the sweep auger every few minutes in order to remove a layer of dry grain from the bottom of the grain mass. In-bin continuous flow drying systems are generally sized with sufficient capacity to dry one day's harvest without the need for a separate wet holding bin. The main advantage of this system is that it allows for higher drying air temperatures because it relies on transferring grain at higher grain temperatures and moisture contents for bin cooling (see below under Combination Dryers). This increases drying capacity without exceeding the maximum allowable grain kernel temperature and overdrying of the bottom grain layers.

Another key item to look for while operating medium temperature bin dryers is condensation on the inside walls and underside of the roof. As the weather turns colder in late fall, water running or dripping back into the grain due to condensation can create significant spoilage problems during the storage season. When a batch is dried and moved to a final storage bin, condensation is less of a problem because rewetted kernels mix with drier kernels and tend to equilibrate. However, deep batches that remain in the bin are more susceptible to spoilage induced by condensation. Because most stirring machines do not reach all the way to the wall, adding air tubes that pipe warm air up along the inside walls of a bin helps to dry out wall condensation.

Also, adding additional roof vents, increasing the roof eave opening, and/or adding roof exhausters will help to allow moisture-laden air to exhaust more readily from the bin. The design recommendation of 1 square foot of vent surface area per 1000 cubic feet of air per minute is a minimum—more is better. Adding roof exhausters that move at least 125-150% of the drying fan inlet airflow will further help to alleviate condensation problems. Opening the center hatch of the bin can create problems, especially when a leg spout unloads into the bin and the support structure of the stirring machine is anchored there also. As the air exhausts from the center hatch it has plenty of opportunity to condense moisture on the cold steel of the hanging support structure. Keeping the center hatch closed and adding roof exhausters or additional vents to the roof reduces this problem.

High Speed Column Dryers

Any high speed column dryer operated at air temperatures that keep grain kernel temperatures below 100-110°F for food grade corn (white and yellow hard endosperm corn) and below 130-140°F for high quality No.2 yellow, waxy, high extractable starch, high amylose, and high oil corn is considered a medium temperature column dryer. Drying systems that exceed the maximum recommended grain kernel temperatures are considered high temperature dryers that cause poor quality corn (see Grain Quality Fact Sheet #23 for more information).

Batch - Only a few batch column dryers are sold new today. Most of the new high speed column dryers available are continuous flow dryers that allow for a batch mode if needed. Batch drying is inefficient, slow and takes too much supervision. Because batch dryers in operation today are generally quite old, the primary operational problem is with maintenance.

One common oversight is making sure the temperature sensor is installed at the proper location. It's a good idea to install more than one sensor, or at least to move the one built-in sensor to several locations in the plenum to determine the coldest and hottest spot. Having the sensor at the cold spot will create significantly hotter temperatures in the rest of the dryer, which causes overdrying and stress cracking of the corn. Placing the sensor in the hotter part of the dryer will assure that overdrying is minimized. Converting a column batch dryer to a combination dryer by eliminating the cooling step and transferring hot grain can significantly improve drying capacity and grain quality (see below under Combination Dryers).

Continuous - Operating a high speed column dryer without heat recovery increases the fuel costs by 20-30%. The potential savings in fuel costs in a late harvest and wet crop year could justify a new dryer purchase. Whether some air is recirculated back into the dryer through an external compartment, or whether the air is preheated by drawing it through the cooling section into the dryer, heat recovery always increases energy efficiency.

Although the first reaction to handling higher moisture grain and maintaining drying capacity is to increase the drying air temperature, quality deterioration results, due to increased stress cracks and breakage susceptibility. It is important to note that grain kernel temperature is not the same as the drying air temperature. The design of the dryer and its operation has a significant effect on the relationship between the drying air temperature and grain temperature. Utilizing a range of drying air temperatures such as 200-220°F in the top of the dryer for the wettest grain, and 170-190°F in the bottom of the dryer for the driest grain can keep grain kernel temperatures below maximum allowable levels especially if corn is transferred hot (110-130°F) and moist (17-18% moisture content). Being able to operate a high-speed column dryer both in the heat and cool, as well as the full heat mode, provides the greatest flexibility for optimizing quality, capacity, and fuel costs.

Reducing the drying air temperature significantly below 170-190°F does not improve energy efficiency. As a matter of fact, total energy consumption increases sharply for high-speed dryers that generally operate with 75 cfm/bu or more (see Figure 1). The dilemma for the operator is having to choose between lower fuel cost and grain quality versus higher fuel cost and quality. Rapid drying followed by immediate cooling without tempering of grain kernels causes most of the stress-crack formation. Equipping high-speed column dryers with tempering sections before the cooling stage should be a standard modification. Tempering allows the moisture gradient that develops inside each kernel to equilibrate and the built-up internal kernel stresses to relax. Turning a grain column inside out along the drying section helps to minimize the inherent moisture gradient that develops across the column. In addition, stacked dryers with multiple burners are preferable because they allow operators to decrease drying air temperatures stepwise from top to bottom as the grain moisture content is reduced.

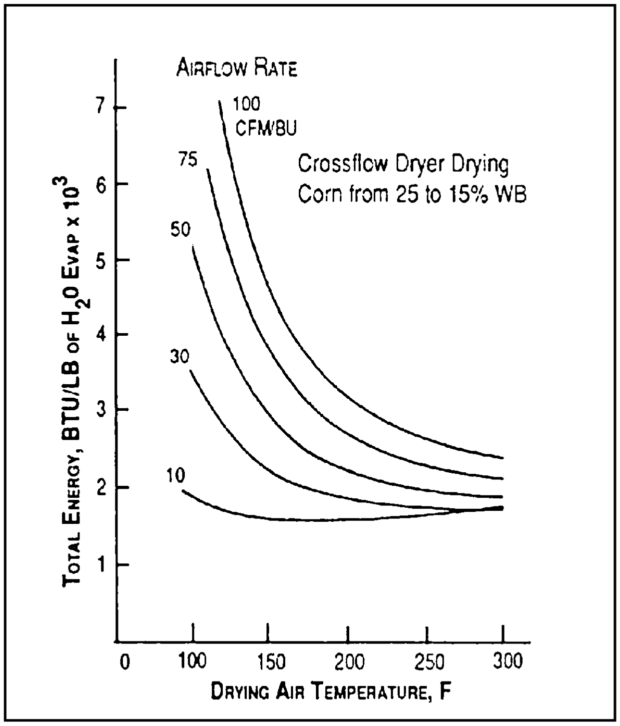

Figure 1. Energy requirements of a conventional crossflow dryer as a function of drying air temperature and airflow rate. (Univ. of Nebraska, 1975).

Combination Dryers

Combination drying systems combine medium temperature drying with slow cooling and drying in bins. Medium temperature drying can occur in a continuous flow, automatic batch, or bin dryer. Potential advantages of combination drying include the following:

- better grain quality
- higher drying capacity
- reduced fuel costs
- more operational flexibility

Because operating these drying systems involves transferring hot grain, one of the most common mistakes involves not measuring grain moisture content accurately (see Grain Quality Fact Sheet #14 for a proper procedure). Transferring corn at too high a moisture content can lead to spoilage problems during the storage season. Another mistake involves not equipping the cooling bin with a full floor to assure even air distribution and properly sized fans to achieve the design airflow rate for cooling of hot corn (see below). Too low of an airflow rate will result in grain spoilage because the cooling front will move too slowly through the warm grain mass. Too high of an airflow rate will cool grain too quickly, which will lock moisture in the kernels and require the much slower natural air drying process to remove the last few points of moisture.

Hot corn transfer can cause significant condensation problems in the grain transfer system between the dryer and the cooling bins. Wet fines, dust and bees wings build up can be excessive in mechanical handling equipment such as screw and drag conveyors and bucket elevators. Pneumatic conveying systems are preferred because condensation is usually not a problem inside the transfer pipes. When designed and operated properly, pneumatic conveyors do not cause more damage than mechanical conveyors as long as decelerators are used at the end of each pipe before dropping hot grain into the cooling bins.

Dryeration - Medium temperature drying followed by transferring hot grain (110-130°F) at 17-18% moisture content into a steeping bin is known as dryeration. The critical operational procedure involves steeping the hot corn for 6-12 hours followed by cooling with ambient air at 0.5-1.0 cfm/bu, during which the extra 2-3 percentage points of moisture are removed. After a cooling time of 10-20 hours the corn is moved into a final storage bin equipped with regular aeration fans. Cooling the hot corn too quickly because of insufficient steeping time or too much airflow will not reduce the moisture content below the 15% safe storage level. Condensation in the steeping bin is significant. However, because the cooled corn is transferred to a final storage bin, wetter kernels are mixed and will tend to equilibrate during aeration in storage. Research conducted at Purdue University shows that dryeration can increase drying capacity by over 150% compared to conventional high temperature drying, while reducing drying costs by more than 10%.

In-bin Cooling - Medium temperature drying followed by transferring hot grain (110-130°F) at 16-17% moisture content into a storage bin is known as in-bin cooling. Because no extended steeping takes place, the fan is turned on as soon as a few feet of hot corn cover the perforated floor.

Cooling occurs over about 48 hours with ambient air at a full bin airflow rate of 0.5-1.0 cfm/bu. Cooling the hot corn too slowly because of undersized fan capacity can lead to spoilage. Also, condensation can become a storage problem because the corn remains in the bin and wetter kernels are not remixed. Thus, it is recommended to avoid removal of more than 2 percentage points of moisture if the cooled corn is left in the same bin for storage. Condensation can be managed using additional roof vents, larger bin eave openings, roof exhausters, and perforated air tubes along the sidewalls.

Medium-Low Temperature (2-stage) Drying - Medium temperature drying followed by transferring hot grain (110-130°F) at 19-23% moisture content into a natural air drying bin appears to be a little known practice. The hot corn is cooled in the bin as the low-temperature drying front is started. Cooling will remove about 1 point of moisture. Sizing the fans to the proper airflow and operating the fans continuously until the top layer drops below 18% moisture and 35°F is critical (see Table 5). According to research conducted at Purdue University, two-stage drying can increase drying capacity by over 70% compared to conventional high temperature drying, while reducing drying costs by more than 10%. The main disadvantage can be overdrying of the bottom grain layer due to the difficulty of controlling the natural-air drying process. If moisture shrink losses become too great, combination medium-low temperature drying will be uneconomical. The new variable heat in-bin drying strategy described above may provide the ideal solution for controlling overdrying and reducing costs in two-stage drying systems.

Table 5. Recommended airflow rates for corn transferred hot into a natural air drying bin.

Airflow (cfm/bu)	Hot Corn Moisture Content (%)
0.75	19-20
1.00	20-21
1.25	21-22
1.50	22-23

Specialty Grains

Specialty grains such as food-grade white (see Grain Quality Fact Sheet #34) and yellow as well as waxy, high-amylose and high extractable starch corn have to be handled much more delicately than regular commercial corn. Operating conventional drying equipment with high temperature settings assures poor product quality and destroys its end use potential. Field drying below 20% moisture and applying as little heat as possible during artificial drying (using low and medium temperatures) are musts to minimize stress-cracking, gelatinization of starches, and/or denaturization of proteins. In addition, combination drying and multistage drying should be implemented as the preferred drying methods (see Grain Quality Fact Sheet #23 for more information). Recent Purdue University research indicated that high oil corn is not as sensitive to end use destruction as other specialty grains and can be dried similarly to good quality No.2 yellow corn (see Grain Quality Fact Sheet #35)

Note: This Grain Quality Fact Sheet was originally published on September 24, 1993. This current version contains new research information and has been significantly revised by the authors.

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