Dryeration: Better Corn Quality with High Speed Drying

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DRYERATION

BETTER CORN QUALITY
WITH HIGH SPEED DRYING

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DRYERATION—Better Corn Quality

by

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INTRODUCTION

Research on a new grain drying process termed “Dryeration” was begun in 1962. The first information was released on the research at the Purdue Farm Science Days, January, 1964. Laboratory and full scale research investigations have continued each crop year.

In 1964 and 1965, field observations of the Dryeration process on farms and at elevators were added to the research program. Performance was recorded by each cooperator, and the results summarized. The operators who followed the suggested procedure easily attained the performance predicted by the initial research. A summary of the field observations was presented at Purdue Farm Science Days in January, 1965, and again in 1966.

The Dryeration process appears equally adaptable to farm, country elevator and terminal drying applications. The information in this publication is directed toward farm and small elevator situations.

The Dryeration Process

What it is—The term “Dryeration” comes from the words drying and aeration. The process involves a combination of high speed, high temperature drying and slow cooling. Normally, grain is cooled in a batch dryer by shutting off the heat and running the fan through a cooling period or cycle. On continuous flow units the lower section of the dryer, usually approximately one third of the column or tray area, is devoted to cooling.

In the Dryeration process, illustrated in the schematic flow diagram in Figure 1, no cooling is done in the dryer. Corn is discharged from the dryer still carrying some excess moisture (usually 1 to 3 points) and hot (usually 120 to 140°F, kernel temperatures) and immediately transferred to a separate cooling bin. The hot corn is held without mechanical cooling for a tempering period where it steams in its own vapor. It is then cooled slowly to remove the 1 to 3 points of excess moisture before it is transferred, dry and cool, to storage or load-out.

How it works—In actual practice, a Dryeration system using one cooling bin would work as follows: Drying is started in the early morning and continued throughout the day, adding hot corn to the cooling bin. For best results, the cooling fan is not started until the last hot corn is put into the bin. This assures that the last corn added to the bin will have at least 4 hours of tempering time before the cooling zone reaches it. Cooling should always be delayed 4-6 hours after the first hot corn is put in.

The air is moved upward so that the first corn put in the bin will be the first corn cooled. This permits the tempering time to be satisfied either while the bin is being filled, in the case of the corn in the bottom, or while the cooling zone is moving up from the bottom, in the case of the last corn put in the bin. This overlapping or telescoping of the filling time, tempering time, and cooling
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time permits the process to proceed without taking additional time for tempering after the bin is filled. This is the main reason for recommending upward air movement.

The corn placed in the Dryeration cooling bin is cooled in 8-12 hours, usually overnight. It is unloaded the following morning. In a batch drying operation the cooling bin is unloaded while the first batch dries. With a continuous flow unit drying can be delayed until the cooling bin is unloaded. For continuous operation, two or more cooling bins are used in rotation.

What it accomplishes—The Dryeration process accomplishes two primary things: It reduces damage in high temperature, fast dried corn and it easily increases dryer output by 60 per cent for 10 points moisture removal. With less moisture removal and minimum down time to handle corn, dryer output may be increased up to 100 per cent.

Improved corn quality comes primarily from the reduction in "stress cracks." Stress cracks are fine hairline cracks or fissures that develop in the mealy (endosperm) portion of the corn kernel just under the seed coat. Stress cracks concern the grain trade because they are directly related to corn breakage in handling and result in excessive fine material causing the corn to be down graded. They also limit some corn processing, such as hominy production, where a whole corn kernel is essential.

FIGURE 1. Schematic flow diagram of the Dryeration process. Wet corn is placed in the dryer from a holding bin or transport vehicle. After drying, corn is transferred hot to the Dryeration cooling bin. Corn is accumulated without cooling for approximately 4-10 hours for tempering, then cooled slowly. Slow cooling takes approximately 10 hours and reduces moisture about 2 percent. Grain is unloaded cool and dry.
Stress cracks develop when rapid cooling follows rapid drying. The tendency toward stress crack formation increases as the grain dries to lower moisture contents. Most stress cracks form during cooling when the cooling follows immediately after at least 5 points moisture removal. With Dryeration the stress built up during drying is relieved in the tempering period. Tempering coupled with slow cooling gives a reduction in stress cracks.

Some typical patterns of stress cracks in corn are shown in Figure 2. Table 1 presents a comparison of checked kernels (the most severe stress crack category) and relative amounts of breakage in conventional drying versus Dryeration. More detailed information on stress cracks and breakage in dried corn was published in USDA Marketing Research Report No. 631 entitled, "Stress Cracks and Breakage in Artificially Dried Corn," available from USDA, Washington D. C.

The livestock farmer will look to Dryeration primarily for increased drying capacity, with corn quality a secondary factor. However, kernel breakage and fines contribute to storage problems and handling losses. The white dust frequently associated with fast dried corn tends to disappear with Dryeration.

The drying capacity increase in the Dryeration process comes from a combination of factors. These include 1) elimination of cooling in the dryer; 2) less moisture removal in the dryer; 3) increased drying efficiency; and 4) use of higher drying temperatures.

The cooling is transferred from the dryer to the Dryeration bin. This reduces the batch time by 30 to 45 minutes in a typical 300 to 500 bushel dryer. A comparable capacity increase is accomplished in continuous flow dryers. Normally, the lower 1/3 of the dryer is devoted to cooling. If this section is converted to additional heat area, 50 per cent more heat can be used and gain 50 per cent in drying capacity.

The second source of increased capacity in Dryeration comes from discharging the grain from the dryer carrying about 2 points of excess moisture. This moisture is removed during the cooling process, the amount depending primarily on the corn temperature.

Consider a sample of 25 per cent corn to be dried to 15 per cent. In a conventional drying procedure, the corn would be heat dried to 16 per cent and then cooled with possibly 1 per cent further moisture reduction to 15 per cent with
fast cooling. In the Dryeration process, the corn would be dried to 17 per cent in the dryer, and immediately transferred to the cooling bin. Under slow cooling, the corn will continue to dry to about 15 per cent. Since we get 1 per cent more drying out of the residual heat leaving the dryer and since the last point or two is the hardest to get out, we could expect a 10-20 per cent increase in efficiency. This reduces both time and fuel costs.

The drying done during Dryeration cooling proceeds with a very high moisture removal per unit of air. The air leaving the hot grain is saturated, with a temperature essentially equal to that of the hot corn (normally 120-140°F.). To get an exhaust air condition equivalent to this in a deep layer bin drying system, the air would have to enter the grain at nearly 500°F. This is to say that the moisture holding capacity of the air is increased the same as though it were heated to 500°F. This is one of the reasons that the outside air conditions have very little effect on Dryeration cooling.

Higher drying temperatures are permitted with Dryeration and account for some of the increased dryer output. Maximum drying temperatures are controlled by the limits of kernel temperature acceptable in corn for milling and other uses. This kernel temperature limit has been established at about 140°F. Since with Dryeration the corn is discharged at a moisture 1-2 per cent greater than with conventional drying, the kernel is cooler. This permits an increase in input air temperatures without exceeding the allowable kernel temperatures. Drying temperatures up to 240°F. can be used.

The sources of capacity increase on batch and continuous flow dryers are summarized schematically in Figure 3.

**Cooler corn into storage**—The corn temperature into storage from the cooling bin is generally 10-20°F. below that in conventional drying, since most of the cooling is done with colder night-time air. The result should be fewer storage problems, which are directly related to grain temperature.

**FIGURE 3.** Sources of capacity increase with Dryeration. The capacity increase from all factors will normally reach 50-60 percent in drying corn 10-12 points. As the amount of moisture to be removed is reduced, the capacity increase from Dryeration will be greater, possibly reaching 100 percent. The large increase from eliminating cooling in the dryer depends on by-passing the cooling period in batch dryers or converting the cooling section of continuous flow units to additional heat section.
Dryeration Cooling Specifications

Cooling bins—The cooling bin for Dryeration can be any normal grain storage bin with provisions for adding adequate aeration. Both hopper or flat bottom bins have been used satisfactorily. The duct arrangement detailed in Figure 4 has been used satisfactorily in several installations.

Flat bottom round metal bins with either a complete or partial perforated floor can be used as the cooling bin, as shown in Figure 5. An adequately sized aeration duct above the floor can be used, provided a satisfactory unloading arrangement can be made.

Dryeration cooling bins may also be adapted from ear corn storages. Two possible forms are suggested in Figures 6a and 6b. In both cases, all or part of the sloping floor can be perforated, using the lower enclosure as an air plenum. Special ducting to the outside, or the use of low pressure exhaust fans above the bin, may be necessary when the cooling bin is within another building.

Bin unloading—Fast and easy cooling bin unloading is important, since it will generally be done every 24 hours. Gravity flow from hopper bins gives complete storage unloading and presents no problem.

In flat bottom bins, the grain left on the floor after gravity unloading can be removed with a sweep unloader. The sweep should have a grain shield behind the screw, as shown in Figure 7. The shield assures a more constant rate of delivery, and the possibility of a high handling rate. A shielded sweep will complete unloading in one trip around the bin.

You can also choose to let the corn form its own hopper by leaving in the bin the grain that will not run out by gravity. Provided this grain remains dry, cool, and in good condition, repeated fills of hot corn are permissible without complete emptying. The “grain hopper” should be removed before the bin is filled for long term storage. It should also be checked regularly for heating or air blockage due to fines accumulation.

Sizing the cooling bin—The cooling bin must be large enough to hold the daily Dryeration output. If a 500 bushel batch dryer has been delivering three batches or 1,500 bushels per day with cooling done in the dryer, the cooling bin should hold a minimum of 2,400 bushels to accommodate the 60 per cent capacity increase with Dryeration.
FIGURE 5. Flat bottom round metal bin adapted for Dryeration cooling. The bin may have either a completely perforated floor or partially perforated ducts set flush with the floor surface as in insets 5A and 5B. Ducts above the floor can be used if a satisfactory bin unloading method can be found. Leaving shelled grain that will not run to the center outlet in the bin may be an alternate to use of a sweep unloader.

FIGURE 6. Two cross-sections showing methods of adapting an ear corn crib for Dryeration cooling. Sloping floor may be partial or completely perforated depending on airflow requirements. Figure 6b shows air discharge at top blocked and an exhaust fan (low pressure type) added to remove moist air from building. Provision may be made for air flow to both sides of the unloading auger of the bin in Figure 6b by locating the fan at the end of the crib. The top fan in 6b might be the Dryeration cooling fan, thereby eliminating one fan and simplifying the system.
FIGURE 7. Two examples of sweep unloaders with gathering or collector shields behind the screw. The sweep unloaders are used in flat bottom storage bins to remove grain that will not gravity flow to a center outlet. Note that both units have a wheel on the outer end. This wheel is normally larger than the screw and acts as a support and drive. It spins on the floor or drags on the conveyor shaft to push the unit forward into the grain pile.

Shielded bin sweeps are not normally designed to start under the grain pile. The drive wheel end is either supported above the angle of the cone of the grain that will remain, or the entire unit is removed from the bin before each refill. Started on top of the cone of grain, a shielded sweep travels essentially straight downward to the floor. It then moves forward into the pile and will complete unloading in one trip around the bin. The amount of grain remaining on the floor depends on the shield-to-floor clearance, usually less than one inch. The delivery rate of the unloader is essentially constant once the horizontal position is reached.
Actually, the Dryeration cooling bin should be sized for the long range farm needs for drying capacity, rather than to fit a particular dryer. Addition of Dryeration to a dryer barely able to keep up with a 2 row corn harvester can put the drying capacity in the 4 row corn harvest range. If the operator later changes dryers, chances are that the basic drying capacity will be increased to match current and future production increases. A cooling bin bought today might well include capacity for the maximum 4 row harvest-dryer-Dryeration combination.

Remember that the grain left in a flat bottom bin to form a “corn hopper” reduces the holding capacity of the bin. For bins under 30 feet sidewall height, this can be 15-20 per cent of the volume.

Air flow and fan requirements—Airflow rates for Dryeration cooling should be between $\frac{1}{2}$ and one cubic feet per minute per bushel (cfm/BU). A design calling for $\frac{1}{2}$ cfm/BU when the cooling bin is full will provide higher airflow rates for smaller grain quantities, but probably not in excess of one cfm/BU. These airflow rates will normally cool the corn in 6-12 hours, and still hold air velocities through the grain sufficiently low to get a high moisture saturation of the exhaust air.

Cooling airflow rates for Dryeration is a case where if “an inch is enough, don’t give it two.” Increasing airflow will speed the cooling process, but will force the heated air out of the corn before it has time to pick up a full moisture load. Faster cooling may also increase stress crack formation.

Fan horsepower, static pressure and duct requirements are given in Table 2 for cooling airflow rates of $\frac{1}{2}$, $\frac{3}{4}$ and 1 cfm/BU in bin sizes of from 900 to 18,000 bushels. Larger diameter bins require that fan and duct sizes be increased in proportion to the added bushel capacity. Grain depths greater than 50 feet require excessive fan horsepower unless provisions are made for cross-flow rather than bottom to top air movement.

Test observations have indicated that under some conditions hot, sweaty corn has a greater resistance to airflow than dry corn. Some allowance was made for this in the static pressure values given in Table 2.

It has been observed that uneven cooling leading to longer than expected cooling time occurs more frequently with shallow grain depths. The airflow rate can be increased with a small increase in fan horsepower at grain depths of 10-15 feet. This suggests favoring the higher airflow rates when cooling is done in shallow bins. On the other hand, selecting the lower range of airflow rates makes more sense in the case of the deeper bins.

Note from Table 2 that fan horsepower is increased roughly 5 times when the airflow rate is doubled from $\frac{1}{2}$ to 1 cfm/BU.

Perforated floor and duct area—The perforated area should be sufficient to keep air velocities entering the grain to 30 feet per minute (fpm) or less. This area is determined by dividing the total air flow rate by 30. Assume 3,000 bushels of hot corn to be cooled at one time with air flow rate of $\frac{1}{2}$ cfm/BU. The duct or floor surface area that should be perforated is: 3,000 bu x $\frac{1}{2}$ cfm/BU = 1,500 cfm ÷ 30 fpm = 50 square feet (ft²). In circular ducts, only 80 per cent of the surface is considered when it lays on the floor or against a wall. Thus a round duct with a 16 inch diameter and 15 feet long or a flat perforated strip 2 feet x 25 feet would be adequate. (See Table 2.)

In general, air velocities in ducts and sub-floor tunnels should not exceed 1,500 fpm. Dividing the total air flow in cfm by 1,500 fpm gives the cross sectional area in square feet. Air transitions and entrance collars should not restrict the air flow.

Process Design Considerations

Condensation problem—Moisture will condense on the cold bin walls and roof during the tempering and cooling period until the hot corn is cooled to near outdoor temperatures. (This is the same phenomenon that causes condensation on a plate under a hot piece of toasted bread.) A layer of corn one to two kernels thick near the bin wall often becomes saturated. Not all of this excess moisture is removed during cooling, and some wet corn will be mixed with the dry corn or stick on the walls when the bin is emptied. This wet corn has not caused any noticeable trouble when mixed with the larger amount of dry corn. The problem of the wet corn is the reason for recommending that the corn be moved out of the bin where it was tempered and cooled and stored elsewhere.

Tempering and cooling in the storage bin—Many have asked about tempering and cooling the corn in the storage bin and leaving it there. This practice would eliminate 1) need for a special tempering bin, and 2) an extra handling of the corn.

If done in the storage bin, the tempering and cooling need not keep pace with the dryer. There would be ample time to temper the last corn put in the bin after the bin is filled but before the cooling fan is started. Under these conditions, the cooling air may be pulled downward through the
Table 2. Equipment design for Dryeration cooling

<table>
<thead>
<tr>
<th>Bin Dia.</th>
<th>Grain Depth</th>
<th>Grain Volume</th>
<th>Design Requirements for Air Flow Rates of ( \frac{1}{2}, \frac{3}{4} ) and 1 cfm/bu.</th>
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\(^a\) ASAE standard data for clean dry corn increased 50% for fine material and compaction plus 0.5 inch allowance for duct loss.

\(^b\) Calculated on basis of 50% "installed" fan efficiency.

\(^c\) Minimum perforated area of the duct surface based on an air velocity of 30 fpm entering corn.

\(^d\) Requirements are above practical limits.

Grain and exhausted from the bottom. Downward air movement will eliminate some of the problem of moisture condensation on the roof and bin walls.

Iowa researchers\(^1\) report successful cooling of hot corn in storage bins with downward air flow. They took one week or more to cool the corn using air flow rates as low as 1/50 cfm/bushel. They reported no moisture condensation problem where the air was pulled down through the warm corn into the duct and exhausted before it could cool appreciably. However, their hot corn went into the cooling bin with about 4 percentage points less moisture and at a somewhat lower temperature than recommended for the Dryeration process. Under these conditions, condensation may not be the problem that it is with the wetter and hotter corn.

\(^1\) R. A. Norton in *Iowa Farm Science*, October 1963.
One drawback to downward air movement comes when drying is stopped with a bin only partly filled with hot corn. If this corn is cooled before more hot corn is added on top, all the heat and moisture from the second layer of hot corn must be moved through the cool corn underneath. In effect, the corn previously cooled is reheated and rewet and much more time is required to complete the cooling than if the heat and moisture of the second layer had been pushed on out the top.

Another difficulty with downward air flow occurs when cooling is intermittent or interrupted. A bin full of hot corn acts much like a chimney and draws cool air in the bottom when the fan is not running. Hot corn near the floor or ventilating duct may cool enough between periods of fan operation that water will condense on it when fan operation is resumed and warm moisture laden air hits the cooled area. In extreme cases, this condition has essentially sealed off the ventilation duct. Thus, with downward movement of cooling air, it is important to have continuous fan operation until all of the corn in the bin is cooled.

Some Indiana users of Dryeration have experimented with leaving their corn in the bin where it was tempered and cooled. Several have done this with their last fill of the tempering bin for the season. They ran their aeration fans a few days after cooling was completed to help remove the excess moisture near the bin wall. No trouble was reported with this procedure, probably because the outdoor temperature was fairly low at the tail-end of the season. This practice may be more hazardous during early fall when the weather is warmer. It is safer to move the corn out of the tempering bin. The mixing and blending assures corn of more uniform temperature and more uniform moisture going into storage.

Recent tests have shown that insulated bins reduce the moisture condensation problem. Downward airflow used in an insulated bin proved satisfactory for cooling and storing corn in the same bin without moving where aeration was continued all winter during favorable weather.

Another alternative for utilizing the tempering bin for storage at the end of the season is to fill it with corn that has been cooled in the dryer in the conventional manner.

Coordinate handling—The Dryeration process with a separate cooling bin adds a “handling loop” to the grain flow path. In a typical high capacity, high temperature drying process, the wet grain is delivered to a holding bin. It may flow by gravity to the dryer, or be re-elevated from ground level to load the dryer. With Dryeration, the hot grain is again elevated out of the dryer to the cooling bin. From the cooling bin it will be re-elevated to storage or load-out. If it goes into storage, it will be elevated later in load-out.

These four or five handleings may at first seem excessive. However, it should be recognized that the volume of grain that tends to require high speed, high temperature drying, also requires a well-coordinated ready-to-go handling system. Hence, although the Dryeration process adds to the handling operations, it also tends to fit the circumstances that force a good handling layout, whether Dryeration is used or not.

Handling rates—Dryeration steps up the grain handling rate needed in proportion to the increased drying capacity. The bottleneck often comes in unloading the cooling bin. In general, the unload rate must be high enough to clear the bin by the time the first hot grain of the day is ready for transfer. Assuming a 2,500-3,000 bushel per day total Dryeration capacity the handling equipment should be capable of transferring this grain in two hours or less. This handling rate may become more critical in a 24-hour continuous operation when two or more cooling bins are used.

Hot corn handling rates are somewhat lower for a continuous flow than for a batch process. The continuous flow unit delivers a constant flow of grain to the cooling bin. The batch dryer, in contrast, is shut down to transfer corn. A high handling rate is essential to reduce the down time.

Actually, the handling rate for a given farm is a composite of the needs for corn receiving, dryer loading, hot corn transfer, Dryeration bin unloading, and transfer to storage or load-out. A handling rate in the 1,500 to 3,000 bushels per hour range seems to work well on many farms with a volume sufficient to include Dryeration. This handling rate will permit use of 6 inch augers on dry grain, and 8 inch augers on both wet and dry material alone or in combination with a vertical bucket or auger elevator. On-farm handling rates in excess of 3,000 bushels per hour can seldom be justified.

Converting the dryer for Dryeration—There is no problem in adapting a batch type dryer to the Dryeration process. The cooling period is simply omitted. On automatic units, the controls are set to by-pass cooling by cycling direct from heat to unload.

Continuous flow dryers are adapted to Dryeration by converting the cooling section to a heat section. It is also frequently desirable to return the dryer to conventional operation (cooling in the dryer), especially on farm units. This is for drying other grains, small quantities of seed or custom grain, or end-of-season drying when the cooling bin is filled for long-term storage.
FIGURE 8. Typical single and multiple fan continuous flow grain dryers. Units a and b are horizontal two-fan and single-fan models respectively, and units c and d are double and single-fan tower-type models. Adapting continuous flow dryers for Dryeration involves converting the cooling section to additional heat-section. Since the cooling section is approximately one half the size of the original heat section, the heat input needs to be increased about 50%. Little is gained capacity-wise by simply not using the cooling system.

In single-fan continuous dryers, the partition between the heating and cooling sections of the column may be removed, and more heat added to take care of the air formerly used for cooling. This normally requires an additional burner or replacement with a larger burner since existing burners seldom have 50 percent reserve heating capacity. The same conversion procedure may be used for two-fan units if the air from both fans may be directed past the burner. For two-fan units, it is usually better to add a separate burner and controls for the cooling fan. This permits return to normal operation by simply shutting down the added burner.

Any modification of a dryer for adaptation to Dryeration should be done by the manufacturer or under his direction.
There are basically two types of continuous flow dryers, single fan and multi-fan (usually 2 fans) units. The basic designs, with alternates, are shown in Figure 8. The single fan units normally employ a vane or deflector in the air stream to direct a portion of the air into the cooling section. The fan may be either on the pressure or suction side of the grain column. The cooling air plenum is separated from the hot air plenum by a partition.

The vane or deflector can be moved on many designs to vary the amount of cooling needed under different drying situations. The heat unit is located in the air stream beyond the point at which the cooling air is diverted. Modification for Dryeration sometimes requires only removal of the diverter. As an alternate, a second burner in the cooling air stream not only adds the additional heat needed, but also simplifies changing back and forth from Dryeration to conventional operation.

A second burner also works best for converting two-fan continuous flow dryers. Some units can be adapted by eliminating the cooling fan and simply ducting the hot air to the cooling section. However, air flow from the original hot air fan, applied to both the heating and cooling section may not be sufficient. Too, the original burner output, when applied to the greater air flow of the increased dryer area, or to that of a substituted higher output fan, may be inadequate. A continuous flow dryer conversion for Dryeration should be done by the manufacturer, or at his direction, to protect warranties, dryer performance and insure safety in control and operation.

Gravity spouts—Storage and cooling layouts using gravity spout connections to the top of all bins will require some way to keep hot vapor from entering spouts. The vapor laden exhaust air will travel up the fill spout and into the distributor and elevator head. It will usually condense somewhere along its route and may either run back into the cooling bin or down the spout to a storage bin that has already been filled, or drip out of the load-out spout. In cold weather, condensate may freeze.

A flap valve in the grain pipe, opened by the flow of grain, might be an answer but may freeze shut. A bypass valve in a “Y” on top the bin, a removable pipe section, or a manual or gravity operated flap valve on the end of the pipe are possibilities. Sketches of these alternates are shown in Figure 9. A downward air velocity in the gravity pipe should also work. This could be done with an exhaust fan in the top of the cooling bin, or a pressure fan forcing air into the leg or distributor head. The important point is to recognize that the condensate in spouts can be a problem and to reckon with it in your design.

Safe storage—Distributing fine materials in the Dryeration bin is important. The hot fine material is usually sticky and accumulates and packs under the grain spout worse than cool, dry material. A grain distributor is needed to avoid a hard core of fine material.

Distribution or removal of the fines, having the grain cool and keeping it uniformly cool with an adequate and correctly operated aeration system should permit storage of 14 per cent moisture corn on a long-term basis. The idea of overdrying 1 to 2 points “to be safe” does not make sense with an experienced operator using modern grain storage equipment and technology. Each point grain is overdried causes slightly more than 1 per cent weight loss when drying to 12-14 per cent moisture range. With corn worth approximately 2¢ per pound, the cost is virtually 2¢/bu for each point of overdrying.

Pattern Layouts for Dryeration

Several pattern layouts for drying facilities including Dryeration are shown in Figures 10 to 14. Figures 10 and 11 outline plans for new facilities using one or two flat bottom bins for cooling. Figures 12 and 13 show the same basic layouts using grade level discharge hopper bottom cooling bins. Figure 14 presents a Dryeration adaptation of a double ear corn crib converted to shelled grain as a handling center.
FIGURE 10. Pattern layout for Dryeration using one flat bottom cooling bin. Hot corn may be conveyed direct to the Dryeration bin adjacent to the dryer or returned to the vertical elevator inside the center building, and hence to the tempering-cooling bin. The wet grain holding bin behind the dryer may be elevated for gravity discharge into the top of the dryer, or the grain returned to the elevator leg to fill the dryer. Offsetting the center building to bring the leg and dump position to one end permits the dryer location close-in for fast wet grain handling, trucks can hoist outside the building and dump inside, and the elongated building drive will permit a scale location.

FIGURE 9. Methods of stopping or bypassing gravity grain spouts to reduce moisture travel up the pipe. Ample exhaust air outlets in the bin roof will reduce pressure tendency for air to flow up gravity spouts. All methods should open automatically when grain flows through the pipe.
FIGURE 11. Pattern layout for Dryeration using two flat-bottom bins. The two Dryeration bins can be filled directly from the dryer by either inclined conveyors such as illustrated in Figure 10, or by a short, hot or dry corn bucket elevator located between the Dryeration bins, next to the dryer. The latter arrangement works especially well with a continuous flow dryer, since the hot or dry grain handling rate needs are relatively low. For a batch drying process requiring high handling rates, hot or dry corn may be returned to the main leg inside the center building and hence to the Dryeration bins.

The wet grain holding bin shown is a hopper bottom unit elevated above the dryer for gravity outflow. Grade level units may be used and the grain re-elevated to load the dryer. The center building may be offset as in Figure 10.

FIGURE 12. Dryeration pattern layout using one or two hopper bottom units as cooling bins. Height of the relatively small diameter hopper tanks will generally force the use of a vertical elevator for filling. This may be a special hot corn elevator located in the interspace of the three hopper bins, or the grain may be returned to the main elevator for conveying to cooling bin. The gravity fill to dryer from the wet grain bin is optional.
FIGURE 13. Dryeration pattern layout for one or two hopper bottom cooling bins. Any combination of the bins to the left of the center building can be used for Dryeration. The dryer position can also be on the layout center line, in place of the second Dryeration cooling tank. For large volumes both dryer positions, or two units side by side, may be desirable.

FIGURE 14. Dryeration pattern layout utilizing a converted double crib. Dryeration cooling may be done in any combination of flat bottom or hopper bins outside the building, or in converted crib sections inside. All return conveyors cross on top of crib floors to bring grain to the inside elevator. Return conveyors normally use the same drive unit, which is shifted. The wet grain holding bin may discharge at grade level, either toward the dryer for self-loading models or toward the drive for loading via the main leg. The wet bin may also be elevated for gravity or horizontal conveyor discharge directly into the top of the dryer. Elevated bin over the drive may be substituted for wet grain holding where horizontal conveyor filling of the dryer or respouting to the main leg is used.
Operating and Managing a Dryeration Process

Some method of measuring in-process moisture contents and grain temperatures is essential for efficient operation and management of the Dryeration process. The dryer is unloaded when the moisture content is low enough so that the grain will finish drying during the slow cooling. You want the grain temperature to be as high as possible, still maintaining quality, so that the amount of heat available for drying during cooling is as great as possible.

Moisture measurement—The problem in measuring in-process moisture contents is the high grain temperature. Workable accuracy is difficult with moisture meters on hot grain. The temperature of the corn at the instant of reading after exposure to air, cold weigh pans, cold meter surfaces, and several pouring operations, cannot be determined accurately.

One solution is to fast cool the grain sample to near the meter calibration temperature, (usually 70-80°F) and then measure moisture. If the sample is fast cooled immediately after it is removed from the dryer, it will lose little moisture.

Two units for fast cooling grain are shown in Figure 15. Almost any small fan will do the job, including household ventilation and air circulation fans. A 1 pound sample can be cooled in 3-5 minutes. To speed cooling, the sample may be stirred while in the air stream.

A small correction factor may need to be applied to the moisture reading on the fast cooled sample. Also, some moisture meters tend to read freshly dried corn too low. The most accurate way to determine the moisture of hot corn is to seal a sample in a moisture tight container, such as a glass fruit jar and read the moisture 24 hours later. This will give you a correction factor for any moisture lost in fast cooling the corn sample plus any error correction needed for freshly dried corn. It is important to get a representative sample of the grain. If samples are taken from the dryer, they should be pulled from across the entire grain column, and blended. At least three samples should be taken during unloading, preferably spaced to coincide with the first, middle and last third of the dryer quantity.

Measuring hot grain temperatures—A simple way to measure corn temperatures is to place a sample in a large mouth thermos bottle with a thermometer that will read up to 200°F (such as a candy thermometer). The thermos is quickly filled, the thermometer inserted, and the temperature read as soon as the reading stabilizes. The
hot grain is left in the thermos until immediately before the next sample is taken. This keeps the thermos warm and reduces the heat drawn from the new sample. Generally the sample for moisture content and temperature is taken at the same time.

Estimating dryer heat time—The heat time for corn can be calculated if we know the amount of moisture to be removed and the heat delivery rate of the dryer. The amount of moisture to be removed can be calculated from Table 3 by taking the difference between the amount of water per bushel at the two moisture contents. This water removed per bushel, multiplied by the original number of bushels, is the total water to be removed. Multiplying the total weight of water in pounds by 2,000 BTU/pound (the average amount of heat that must be supplied to evaporate one pound of water at average drying efficiencies) we get total heat required;

\[
Pounds \text{ Water Removed} \times 2000 \text{ BTU/LB} = \text{Heat Required (BTU)}
\]

The heat input of the dryer can be estimated by multiplying the air flow in cfm (from manufacturer's rating) times the temperature rise (difference between outside temperature and temperature in dryer). The following equation is a good estimate of the BTU's being delivered per hour;

\[
\text{Air Supplied (CFM)} \times \text{Temperature Rise (OF)} = \text{BTU/hour}
\]

Dividing the total BTU's required by the BTU's per hour will give the estimated number of hours to dry the grain. Drying time can also be estimated as follows:

\[
\text{Drying Time (hr)} = \frac{\text{Water Removed (LB)} \times 2000 \text{ BTU/LB}}{\text{Air Supplied (CFM)} \times \text{Temperature Rise (OF)}}
\]

If the final answer does not correspond to actual times experienced, be suspicious that the air flow estimate may be too high or low. Also, the 2,000 BTU per pound of water can be too high in warm, dry weather conditions, possibly a little low in wet, cold weather.

Estimating the drying during cooling—The amount of drying that will occur during the cooling process depends on the amount of stored heat in the corn and how efficiently this heat is used. Theoretically, corn at 140°F has enough stored heat to remove a maximum of 3 points of moisture when cooled to 60°F. In actual tests the moisture loss was about two-thirds of this maximum. The moisture loss observed in six tests with three corn temperatures are shown in Table 4.

<table>
<thead>
<tr>
<th>Grain Moisture content</th>
<th>Shelled corn and grain sorghum (lb. of dry matter/bu=47.32)</th>
<th>Wheat and soybeans (lb. of dry matter/bu= 51.6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent</td>
<td>Pounds</td>
<td>Pounds</td>
</tr>
<tr>
<td>35°</td>
<td>25.4</td>
<td>27.8</td>
</tr>
<tr>
<td>32</td>
<td>22.2</td>
<td>24.2</td>
</tr>
<tr>
<td>30</td>
<td>20.2</td>
<td>22.1</td>
</tr>
<tr>
<td>28</td>
<td>18.4</td>
<td>20.1</td>
</tr>
<tr>
<td>26</td>
<td>16.6</td>
<td>18.2</td>
</tr>
<tr>
<td>24</td>
<td>14.9</td>
<td>16.4</td>
</tr>
<tr>
<td>22</td>
<td>13.3</td>
<td>14.6</td>
</tr>
<tr>
<td>20</td>
<td>11.8</td>
<td>12.9</td>
</tr>
<tr>
<td>18</td>
<td>10.4</td>
<td>11.4</td>
</tr>
<tr>
<td>16</td>
<td>9.0</td>
<td>9.8</td>
</tr>
<tr>
<td>14</td>
<td>7.7</td>
<td>8.4</td>
</tr>
<tr>
<td>12</td>
<td>6.5</td>
<td>7.0</td>
</tr>
</tbody>
</table>

\* A bushel is defined here as the amount of grain required to yield 56 pounds of shelled corn or grain sorghum at 15.5% moisture, 60 pounds of wheat or soybeans at 14% moisture.

\* To determine the number of pounds of grain required to make a bushel at a given moisture percentage, add the pounds of water to the pounds of dry matter (shown at head of column). For example: To obtain the weight of corn, at 28% moisture content, to make a bushel, add the pounds of water (18.4) to the pounds of dry matter per bushel (47.32). This totals 65.7 pounds. It requires 65.7 pounds of corn at 28% moisture content to make a bushel (56 pounds) of 15.5% corn.

\* Water content for moisture values not shown can be estimated from an average of the data for two adjacent moisture values.

Table 4. Corn moisture reduction during cooling at 1/2 cfm/bu.

<table>
<thead>
<tr>
<th>Hot corn temperature</th>
<th>Moisture reduction (6 tests)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Range</td>
</tr>
<tr>
<td>128</td>
<td>1.7 1.5—1.9</td>
</tr>
<tr>
<td>142</td>
<td>2.1 1.7—2.3</td>
</tr>
<tr>
<td>152</td>
<td>2.5 2.0—3.1</td>
</tr>
</tbody>
</table>

Determining when grain is cool—How do I tell when the grain is cool? When the cooling air exhausts at the top, measuring grain temperatures in the upper layer with a temperature probe or thermometer is recommended. Some installations have permanent thermocouple systems to monitor grain temperatures throughout the bin. It is a good idea to check the grain temperature as it is transferred.
Table 5. Typical costs of components for Dryeration bins

<table>
<thead>
<tr>
<th>Round Metal Bins</th>
<th>Typical sizes</th>
<th>Storage cost/bu.</th>
<th>False floor cost/bu.</th>
<th>Duct or aeration Strip</th>
<th>Fan</th>
<th>Grain distributor</th>
<th>Sweep unloader</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dia. feet</td>
<td>Ht. feet</td>
<td>Capacity bushels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hopper bottom</td>
<td>12</td>
<td>30</td>
<td>2500</td>
<td>$1/bu</td>
<td>none</td>
<td>$100.00</td>
<td>$150.00</td>
</tr>
<tr>
<td>Flat bottom</td>
<td>18</td>
<td>16</td>
<td>3300</td>
<td>.40</td>
<td>.10</td>
<td>100.00</td>
<td>150.00</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>18</td>
<td>4400</td>
<td>.35</td>
<td>.10</td>
<td>125.00</td>
<td>225.00</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>16</td>
<td>6500</td>
<td>.30</td>
<td>.10</td>
<td>150.00</td>
<td>200.00</td>
</tr>
</tbody>
</table>

What constitutes cool grain? Consider grain cool when it is at least as cold as the air temperature was, when the fan was started some 10-12 hours earlier. Don’t expect all of the grain to be at air temperature when you come out to check it on a frosty morning! The temperature at the moment might have existed only for the previous hour or so. You would hardly expect all of the grain to be at this temperature since the cooling rate is relatively slow. In the fall of 1964 and 1965, farm and elevator operators generally were able to cool their corn to temperatures of 50-60°F.

Safety in the cooling bin—Saturated air exhausted from cooling bins at 120-140°F may be oppressive, if not dangerous to breathe. If you must enter a bin, you should have another person stand by in case help is needed. Entering any grain bin during unloading is dangerous. The suction of the flowing grain coupled with the normal foot and leg penetration in the dry grain frequently makes it impossible for the person “caught” to work free. He can be drawn under the grain and suffocated or into the conveying equipment and injured.

Estimating Costs of Dryeration

The primary costs of a Dryeration process will be the investment in the cooling bin, the aeration system, and any additional grain handling equipment needed. The cost of operating the system will be relatively insignificant. Table 5 lists the costs for typical components.

The cooling bins listed in Table 5 are also storage bins at the end of the season. If this storage capacity is needed, whether Dryeration is used or not, then most of the bin cost should be considered as storage, not a Dryeration cost. The only cost items chargeable to Dryeration are those which have to be added to make the process work. These include the special mechanization, air entrance and wiring.

The cost of mechanizing grain handling in Dryeration is virtually impossible to estimate because of the variation in layouts. Assuming flow rates to and from the bin at 1,500-2,000 bushels per hour and a basic handling system matched to this rate already in use, cost of the mechanization added to accommodate Dryeration will usually run $500-$1,000.

The cost of power to run the Dryeration cooling fan and the handling equipment to load and unload the bin is small. Assuming a 1-hp fan running 10 hours and a 2-hp 20-foot transfer of grain at 1,500 bushels per hour to and from the cooling bin, combined power costs would be 30-40¢/fill. This is based on 2¢ per kilowatt-hour for power and 2,500 bushels of grain per day.

Drying capacity attained by using an existing dryer and adding Dryeration, versus buying a new, larger dryer and operating without Dryeration, is a key cost comparison. Grain dryers, whether bin or high-speed units, normally cost about $3,000 per 1,000 bushels of daily drying capacity. Assume Dryeration increases the capacity of a 1,500-bushel-per-day dryer by 60 per cent. The 900 bushels of added capacity might have a value of roughly $3,000 in terms of new dryer cost. The new dryer cost can be weighed against the cost of equipping for Dryeration as an alternate method of increasing capacity.

It should be emphasized that the above discussion does not consider a primary benefit of Dryeration—that of improved product quality. And, Dryeration is not limited to increasing the output of existing dryers—it is equally applicable to new dryers, whether batch or continuous flow.
SUMMARY

The Dryeration process has been studied in both the laboratory and the field. Field performance has fulfilled research predictions. The process is applicable to high temperature, high capacity drying systems where the kernel temperatures are high enough to accomplish adequate tempering and drying in the cooling bin. The process is readily adaptable to either continuous flow or batch dryers. In the former, the cooling section is converted to a heat section to get maximum gain in capacity. In the batch process, the cooling cycle is eliminated. The capacity increase has generally been at least 60 per cent with 100 per cent increases possible. Good handling facilities are essential to achieve the optimum capacity.

The tempering period coupled with slow cooling of the corn has reduced the stress cracks and kernel breakage by 50 per cent.

In short, the potential gains from Dryeration in improved grain quality, higher drying capacity, and improved drying efficiency are so consistent and significant that it must be evaluated for farm, country elevator, and terminal elevator drying. The process has essentially equal performance opportunities in both existing and new drying installations.