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Aeration for Grain Storage

James
J. L. Halderson
Agricultural Engineer

Larry
L. E. Sandvol
Entomologist

Aeration is a practice of forcing small volumes of ambient air through stored grain at low flow rates to prevent deterioration of grain quality. The low airflow rates result in the most efficient use of energy. The practice of moving or "turning" grain to reduce "hot spot" formation can be successfully replaced by aeration in most instances. Risks of storage loss can be reduced by cooling grain and maintaining uniform temperature and moisture conditions throughout the grain.

This publication provides detailed information on specifications for aeration and monitoring equipment. The emphasis is on farm-located round steel storage bins, the most common type in Idaho. However, the principles discussed are applicable to flat storage as well as storage in round bins. Factors considered are: (1) sizing ducts and fans, (2) duct and fan location in bins, (3) operation of fans and (4) thermocouples for temperature monitoring.

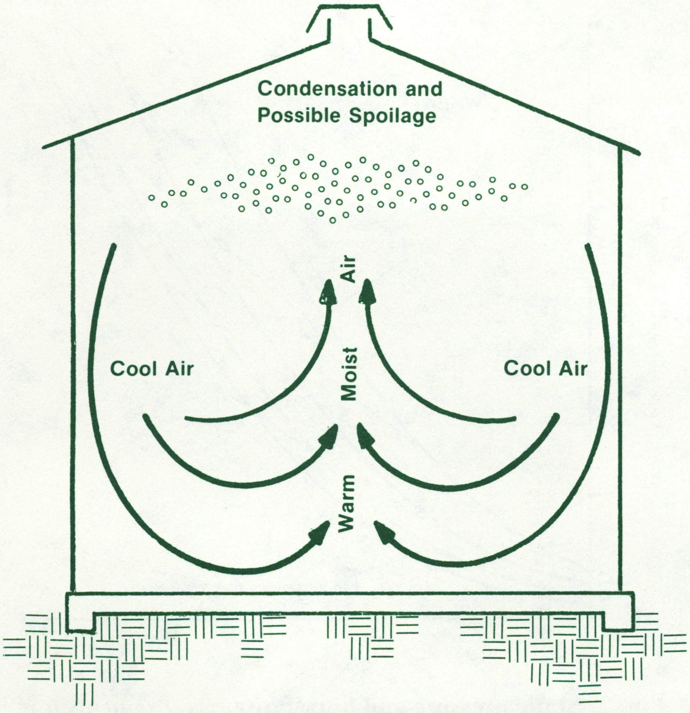

Fig. 1. Cooling of bin exterior causes air circulation and moisture movement (3).

Reason for Aeration

Insect activity, fungal growth and moisture migration are reasons why grain spoils or deteriorates while in storage. Moisture in the grain kernel is related to moisture in the air within the grain bulk. Changes in outside air temperature cause this relationship to change. When grain is first placed in storage, it has a given kernel temperature. However, as winter approaches, the exterior grain cools while the insulating properties of dry grain cause the innermost grain to remain warm (see Fig. 1). The settling effect of the heavier exterior air plus the buoyant effect of the lighter center air causes slow air circulation within the bin by convection. Warm air can contain more moisture than cool air. As the center air rises, it is cooled by the surface grain. Moisture from the cooling air moves into the surrounding grain and slowly increases its moisture content. In bins sufficiently large to maintain convective air movements for some time, the uppermost grain can become moist enough to cause germination, heating, insect propagation and mold growth.

This movement of moisture is called moisture migration. It can occur with harmful results even though the average moisture content of grain in the bin is 12% or under. To counteract convective currents, temperature variations within the bin should be reduced by aeration to approximately 15°F or less.

Insects that inhabit grain bins are mostly subtropical in nature and have optimum growth temperatures in the range of 80 to 90° F. Lowering the grain temperature to 60° F or less can interrupt many of the egg laying phases of the insect's life cycle (Table 1). Therefore, if grain is cooled to 60° F or less, some insects already within the grain will not be able to reproduce to increase in numbers. Further lowering of grain temperatures can cause even greater restrictions on the insect's life cycle. The feeding of most adult insects can be stopped with temperatures of 50° F or less.

Air Volume

Aeration rates in the range of 1/10 to 1/20 cubic feet of air/minute/bushel (cfm/bu) are normally enough for grain storage. At these rates, sufficient air is moved through the grain to cool it and flow rates are low enough to avoid high friction losses. To double a given airflow rate requires 1.5 times the fan pressure. Since fan horsepower is a function of air quantity as well as pressure, doubling the flow increases horsepower requirements by 3 times. Fig. 2 shows static pressures and horsepower requirements necessary for moving air through wheat at different flow rates. Barley requires approximately one-half the static pressure of wheat for the same air volume.

Direction of Airflow

Either upward or downward air movement can be used in grain storage. Normally, downward movement can achieve satisfactory results with a lower airflow rate since the air being discharged has not been allowed to cool within the bin. Upward air movement must be at somewhat higher rates to keep the top grain from cooling. If the grain surface cools, the air will also be cooled just before discharge and moisture will be released. Condensation on cold roof sheets can be a problem especially if the grain is warm and the weather is cold. A small space between grain and roof accentuates this problem. High-velocity air will not release moisture when going through the surface grain. Ground-level fans are sometimes difficult to protect against ingesting blowing snow when the fan is set up to blow air into the bin. Downward air movement is not well suited to a system where cooling is started on a partially filled bin and more warm grain is placed in the bin. In this instance the heat from the upper grain must be moved through the lower cool grain so cooling takes much longer.

Uniform Distribution

If uniform airflow rates can be achieved throughout the grain, then minimum energy is used to do the cooling. Several factors can affect the distribution of air. Fine material such as chaff, broken straw, weed seeds and dirt can cause a tightly packed core or spoutline directly under the filling point. The fine material blocks air movement and often contains more moisture than the grain. There is no remedy for this condition except mechanical movement of the grain. Distributors are sometimes used to spread grain as it enters the bin. This generally

Table 1. Insect life cycle phases as affected by temperature (5).

	Adult dormant	No mating	No egg laying	No larval development	Optimum development
Rice weevil	45	53	—	60	84 to 88
Granary weevil	35	55	—	60	82 to 86
Confused flour beetle	—	—	60	64	95 to 100
Red flour beetle	—	—	60	68	97
Saw-toothed grain beetle	—	—	60	—	93
Lesser grain borer	—	—	—	—	90

Note: According to Christensen (4), temperatures less than 63° F provide safe storage except for hot spots.

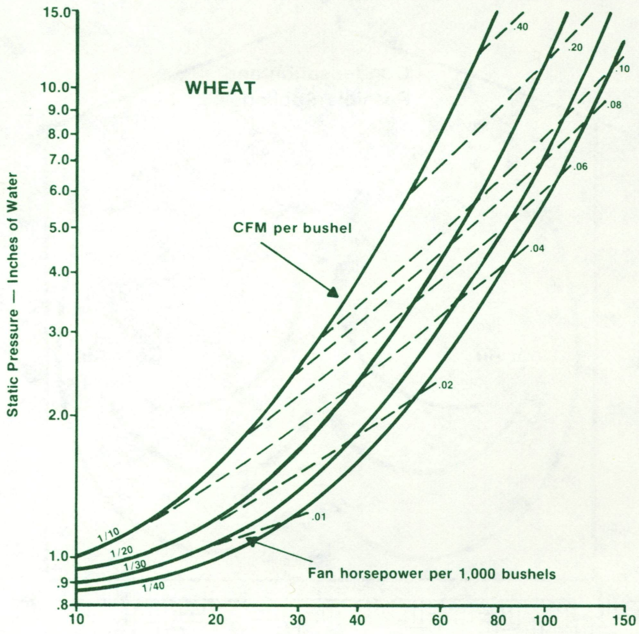

Fig. 2. Static pressure and horsepower requirements for various aeration rates and depths of wheat (2).

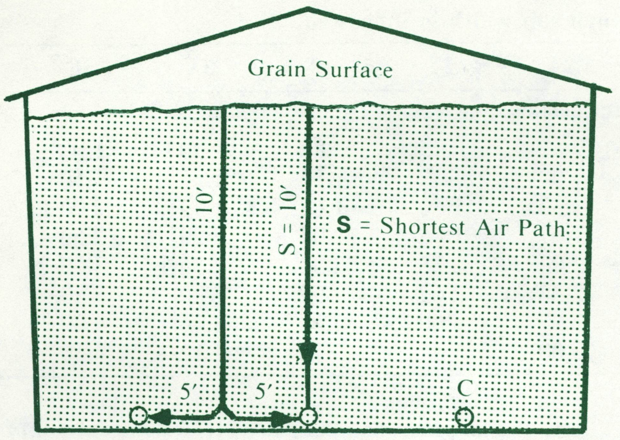

Fig. 4. Layout and spacing of lengthwise ducts in a flat storage. Ducts located so that the longest air path is not more than 1.5 times the shortest path for any duct (2). S equals shortest air path.

Once a warming change is started, it should be completed as soon as possible to prevent condensation. Cooling is not quite so critical, especially for upflow systems since the warm-cool interface within the grain is not so sharp. Generally, however, aeration should be completed, once it is started, whenever ambient air conditions permit. Sometimes cooling can be safely accomplished with very high air humidity if the grain is considerably warmer than the air. This occurs because the warm grain raises the air temperature and the relative humidity decreases, usually approximately twice as much in magnitude as the rise in air temperature for Idaho nighttime conditions. For a discussion of this, see Current Information Series No. 518 (6). Returning moisture to grain takes much longer than removing it.

Fans can be operated manually, on a partially automatic system such as a time clock or on a fully automatic system of "high" and "low" thermostats and "high" and "low" humidistats. Because most controls have a limited amount of current-carrying capacity, a magnetic starting switch is usually advisable for motors over one-half horsepower. However, manufacturers' ratings for controls should be consulted.

For dry grain storage, the following steps are recommended:

1. Aerate grain as soon as the bin is filled in downflow systems to remove field heat. For upflow systems, aeration can be started in a partly filled bin.
2. Aerate again when outside temperatures average 15 to 20° F different from the grain or whenever temperatures within the grain vary more than 10 to 15° F.
3. Use temperature probes or prelocated thermocouples to check grain temperatures every 7 to 10 days. Additionally, inspect grain for mold and insects, especially in the top 3 to 6 feet.
4. Keep grain within 15° F of the average outside air temperature in cooling to 35 to 40° F in the fall and warming to 50 to 60° F in spring and early summer.

Temperature Sensing and Equipment

One of the best ways to check grain temperatures is to install thermocouples in the bin before it is filled. Ropes can be attached to the bin wall with eye bolts and turnbuckles so that thermocouples can be located properly. Vinyl electrical tape is suitable for attaching thermocouple wire to rope so that grain pressure will not pull wires loose. Lines should be pre-measured and assembled before hanging to avoid the need of a scaffold. Turnbuckles on either end of the rope permit tensioning.

Wires should be fed to a common location so temperatures can be read rapidly. Since the top few feet of grain and the bottom few feet are most indicative of changes, several thermocouples should be located at each of these locations. Spacings of 3 feet along the rope are suitable. Bottom-located thermocouples should be high enough to avoid sweep augers or cause bin access problems. An extra set of thermocouple wires costs very little to install with the initial job but can be very handy if some units are damaged during bin filling. A rotary switch is a convenient way of rapidly connecting thermocouple wires to readout devices. Several manufacturers have assembled thermocouple kits for bin systems. Various options can be obtained to satisfy the needs of almost any installation.

Mercury bulb thermometers can also be probed into the grain for temperature indications. A piece of electrical conduit can be used as a probe, with the thermometer suspended on a string in the conduit. The thermometer must be given time to stabilize after it is inserted.

THERMOCOUPLE WIRE

Thermocouple wire comes in numerous types of conductors and insulations as well as conductor size (7). A suitable kind for grain bins is 24 gage, copper-constantan conductors with polyvinyl covering. It costs about 10 cents per foot. This kind responds well for the temperature ranges normally encountered in stored agricultural products. The vinyl insulation resists most atmospheres found in

Table 3. Rectangular ducts — effective cross-section areas*.

Depth (inches)	Duct area in square feet when top width in inches is: 9	12	15	18	21	24	27	30	33	36
	(square feet)									
4	0.25	.33	.41	.50	.59	.67	.75	.88	.90	1.00
6	0.38	.50	.62	.75	.88	1.00	1.12	1.24	1.36	1.50
8	0.50	.67	.83	1.00	1.17	1.33	1.50	1.67	1.83	2.00
10	0.62	.83	1.04	1.25	1.46	1.67	1.88	2.08	2.29	2.50
12	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
14	0.88	1.16	1.46	1.75	2.04	2.33	2.62	2.92	3.20	3.50
16	1.00	1.33	1.67	2.00	2.33	2.67	3.00	3.33	3.66	4.00
18	1.12	1.50	1.88	2.25	2.62	3.00	3.38	3.75	4.12	4.50

*Table from Noyes (1).

**Effective surface area of flush-floor duct = top width (ft.) × length (ft.). Effective surface area of on-floor duct = [top width + 2 (depth)] (ft.) × length (ft.). All surfaces exposed to grain should have 10% openings or more.

DUCTS

Ducts are designed primarily with three factors in mind. The perforated surface area should be 1 foot square (ft^2) for each 25 cfm of air and the cross sectional area of the duct should be chosen to keep air velocities at 2,000 feet per minute (fpm) or less. Additionally, duct spacing should not be excessive. Ducts built into the floor have the advantage of not interfering with bin unloading equipment.

In the example bin, to supply 1,900 cfm air, 76 ft^2 of perforated duct would be needed and the duct cross section should be a minimum of 0.95 ft^2 (i.e. 1,900 cfm ÷ 2,000 fpm). Table 2 shows that a 14-inch diameter round duct fits this requirement since it has a cross section of 1.07 ft^2. This duct contains 2.94 ft^2 perforated surface per foot of length, so a total perforated duct length of 26 feet is required. The surface area of circular perforated ducts is usually considered to be about 80% effective when resting on the bin floor whereas square ducts resting on the floor have an effective surface area of the top and both sides (Table 3).

Ducts should be spaced to provide uniform airflow through the grain. Fig. 3 shows several duct arrangements for round bins. Arrangement A is suited for smaller bins while B is best suited for large bins up to 40 feet in diameter. Round bin ducts should be arranged so that grain at the floor level is no more than 6 feet from a duct. For flat storage, ducts should be arranged so the longest path of air through the grain is not greater than 1.5 times the shortest path (Fig. 4).

Fan Operation

Fans can be operated whenever ambient air conditions are suitable. Whether cooling or warming, the temperature of the outside air should be at least 10 to 15° F different from temperature of the grain. To reduce the moisture content of the grain, the humidity of the inlet air should be less than approximately 70 to 75%. Large temperature changes can be made when cooling but relatively small, frequent changes should be made when warming to prevent condensation on cold grain.

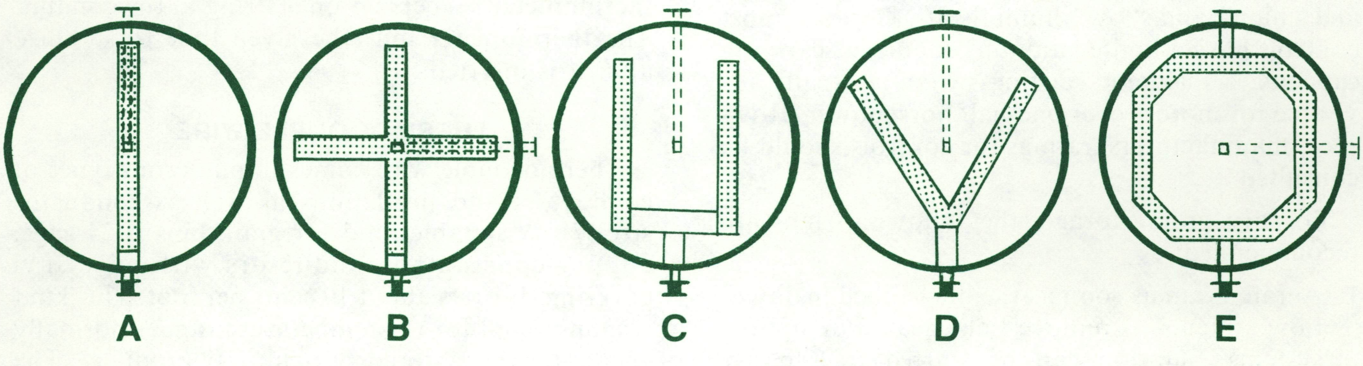

Fig. 3. Duct arrangements for various sizes of round bins (1).

Table 2. Circular ducts — effective cross-section and surface areas*.

Diameter	Cross-section area		Surface area	
	Round	Half-round	Round**	Half-round
(inches)	(square feet)		(square feet/feet of length)	
6	0.20	0.10	1.26	0.79
8	0.35	0.18	1.67	1.05
10	0.54	0.27	2.09	1.31
12	0.78	0.39	2.52	1.57
14	1.07	0.54	2.94	1.83
16	1.40	0.70	3.34	2.10
18	1.77	0.88	3.78	2.36
20	2.18	1.09	4.18	2.62
22	2.64	1.32	4.60	2.88
24	3.14	1.57	5.02	3.14

*Table from Noyes (1).

**Round duct surfaces considered 80% effective.

results in tighter packing which reduces airflow rates. In some instances, distribution of the fine material throughout a larger volume is not sufficient to offset increased static pressure. Auger distributors will generally give uniform fines distribution but they are costly to purchase and install.

Filling a bin completely to the roof also causes poor air distribution because air has a longer pathway at the peak of the pile. The longer pathway usually coincides with the location of a greater amount of fines to compound the problem. An unrelated but important reason for not filling the bin much above the sidewalls is that inspection is difficult, at best, and grain cannot be readily fumigated if an insect problem is encountered.

Ducts for distributing the air must be properly sized and properly located to obtain uniform distribution. Ducts and fans are discussed in detail in a later section.

When to Aerate

Since nighttime air temperatures are relatively low in Idaho, aeration can generally be started as soon as the bin is filled. Whenever outside air temperatures are approximately 15°F cooler than the grain, fans can be operated. Once cooling is started, it should not be stopped for long since moisture can migrate to the warm-cool interface. Grain should be cooled to about 40°F before the winter cold period of December through February. It should be aerated again to equalize temperatures throughout the bin whenever air temperatures vary from grain temperatures by 20°F or more for periods of several weeks. Grain bin temperatures should be checked every 10 days at several locations in the top 3 feet of the bin. That is where most problems arise and temperature increases will first be noticed. The temperature readings should be recorded. Gradual changes can forecast impending trouble in time to allow for corrective aeration before damage occurs.

Size of Fan and Ducts

FAN

Airflow rates of 1/10 to 1/20 cfm/bu are recommended for both manually and semi-automatically controlled aeration systems. These rates will provide sufficient cooling while keeping operating costs low.

One need only know the bin capacity (to the eave) to determine fan capacity. Bin capacity multiplied by 1/10 and 1/20 determines the range of capacity in which the fan must operate. To determine bin capacity in bushels, multiply the bin diameter by itself, then by 0.785, then by the sidewall height, and then divide this product by 1.25 (the number of cubic feet in one bushel). For example, a bin with a diameter of 35 feet 6 inches and sidewall height of 24 feet will have this capacity in bushels:

$$\frac{35.5 \text{ ft} \times 35.5 \text{ ft} \times 0.785 \times 24 \text{ ft}}{1.25} = 18{,}994.49 \text{ bu}$$

For this bin, the fan airflow rate should be no greater than 1,900 cfm (1/10 cfm/bu) and no smaller than 950 cfm (1/20 cfm/bu).

The next step in fan selection is to determine the pressure at which the fan must operate to move the required volume of air through the grain. Fig. 2 shows the relationship between static pressure and depth of wheat in this case. If the example bin above was filled with wheat, Fig. 2 shows that approximately 1.95 inches of water pressure would be required for 1/10 cfm/bu and 1.4 inches water pressure for 1/20 cfm/bu. Fan performance charts can be used to choose a fan which falls into this performance category.

storage units. The sensing portion of the wire is made by stripping off about ¼-inch of insulation at the end, twisting the bare wires together for one turn or so, soldering them together with resin-core solder and then installing this tip whenever one wants to determine temperatures. The wire at the other end can be terminated with a specially made thermocouple plug or by connecting to a rotary switch if numerous thermocouples are used at one facility. Reference 7 shows rotary switches available from one manufacturer but there are others as well.

TEMPERATURE READOUTS

Instruments that indicate the temperature to which the thermocouple is exposed are varied, both in ease of determining temperature and in cost. The simplest units are meters which have scales directly calibrated for temperature. More expensive units give digital indications for temperature or can provide a chart recording of temperature. Regardless of how temperature is determined, a graph should be made of temperature vs. time. Knowledge of the long-term temperature trend is useful because it allows corrective action to be taken in time to avoid decreased quality. Reference 7 shows typical readout devices.

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