Using controlled aeration for insect and mould management in the south-western United States

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Abstract

The use of controlled aeration systems as an integrated pest management (IPM) tool has been studied continuously in Oklahoma since the mid-1980s. Field research and demonstrations in storage bins and silos at farms and commercial elevators were used to test the principles of grain and headspace air temperature manipulation to minimise insect populations. This work was an extension of research studies by Evans and other Australians in the 1970s and early 1980s, adapted to Oklahoma's high risk storage environment for hard red winter wheat.

An extension fact sheet on use of aeration for insect management in stored grain was developed in 1987 (revised in 1990) by leaders of the OSU Stored Grain IPM Committee, formalising a step-by-step management procedure for use in pest management. This process uses an inexpensive ($US400-$US1000) custom-made aeration controller to operate aeration blowers on grain silos or tanks at preset temperatures. An elapsed time hour meter accumulates blower(s) operating time to provide aeration management operating time data. Aeration controllers usually pay for themselves in less than one year.

Aeration systems ranging from one blower per small tank or silo, to large elevator storage complexes with as many as 24 blowers on two large steel tanks operated by one aeration controller were developed. Electro-mechanical aeration controllers and electrical circuits are illustrated with component costs in U.S. dollars.

Stored-Grain Pest Management

Stored-grain pest management is the organised, long–term approach to maintaining the quality of the grain, minimising chemical control inputs, and preserving the integrity of the grain storage system. To implement an effective management program and integrate control practices, operators must understand the ecology of the storage system. Through this understanding, techniques can be integrated into grain storage systems to prevent or minimise losses. These management techniques must focus on factors that influence storability, including:

- grain temperatures throughout the mass;
- grain moisture and seed interstice relative humidity;
- grain condition (peaked, fines and foreign material);
- storage structure and conditions;
- storage timing;
- aeration timing; and
- sources of grain insects and moulds.

Grain temperature — a pest management tool

Grain temperature is a major stored–grain management tool. Insects and moulds are regulated by temperature. Harvest temperatures vary widely for grain crops across the U.S. In northern states, grain is generally harvested later, can be stored at higher moisture levels, and can be cooled much sooner after harvest than grain in central and southern locations (Table 1).

Insects and moulds are poikilothermic — the higher the temperature (within limits), the greater the development. Most grain insect activity begins to slow above 35°C (95°F). Thus, the ability to maintain grain temperatures at or above 35°C for considerable periods of time is a useful grain insect management tool. Also, since most grain insect and mould activity is greatly reduced at grain temperatures below 15°C (60°F), rapidly cooling grain from the 30 to 35°C range to about 15°C or lower, provides an added grain insect management option. Thus, planned temperature reductions by controlled aeration can significantly reduce insect and mould populations (Fig. 1).

Grain moisture — storage and marketing problems

Grain moisture is another critical factor that regulates storability. The higher the levels of grain moisture, the greater the potential for high populations of stored–grain insects and moulds. Table 1 illustrates safe grain storage moisture levels for southern, central, and northern U.S. storage regions. As shown by these data, grain is at higher risk in southern states than in central and northern states due to longer periods of warm temperatures and higher relative humidity between harvest and aeration cooling. So, recommended storage moisture levels are lower in the South.

During aeration, grain moisture content is reduced by an estimated 1/3 to 1/2 percent during one fall aeration cooling cycle, and 1/4 to 1/3 percent during one winter cooling cycle. Insects and moulds can be managed by strategically using aeration to lower and equalise grain temperature. Fall grain cooling is critical in eliminating moisture migration and reducing insect and mould risks.

Effects of Temperature and Moisture on Insect Populations

Stored–grain insects and moulds are like other biological organisms—the longer the amount of time under favourable conditions, the more they develop. Figure 2 gives data projections by Hagstrum and Flinn (1990) showing expected effects of grain moisture and grain temperature on insect populations in grain aerated by selected target dates. This figure illustrates

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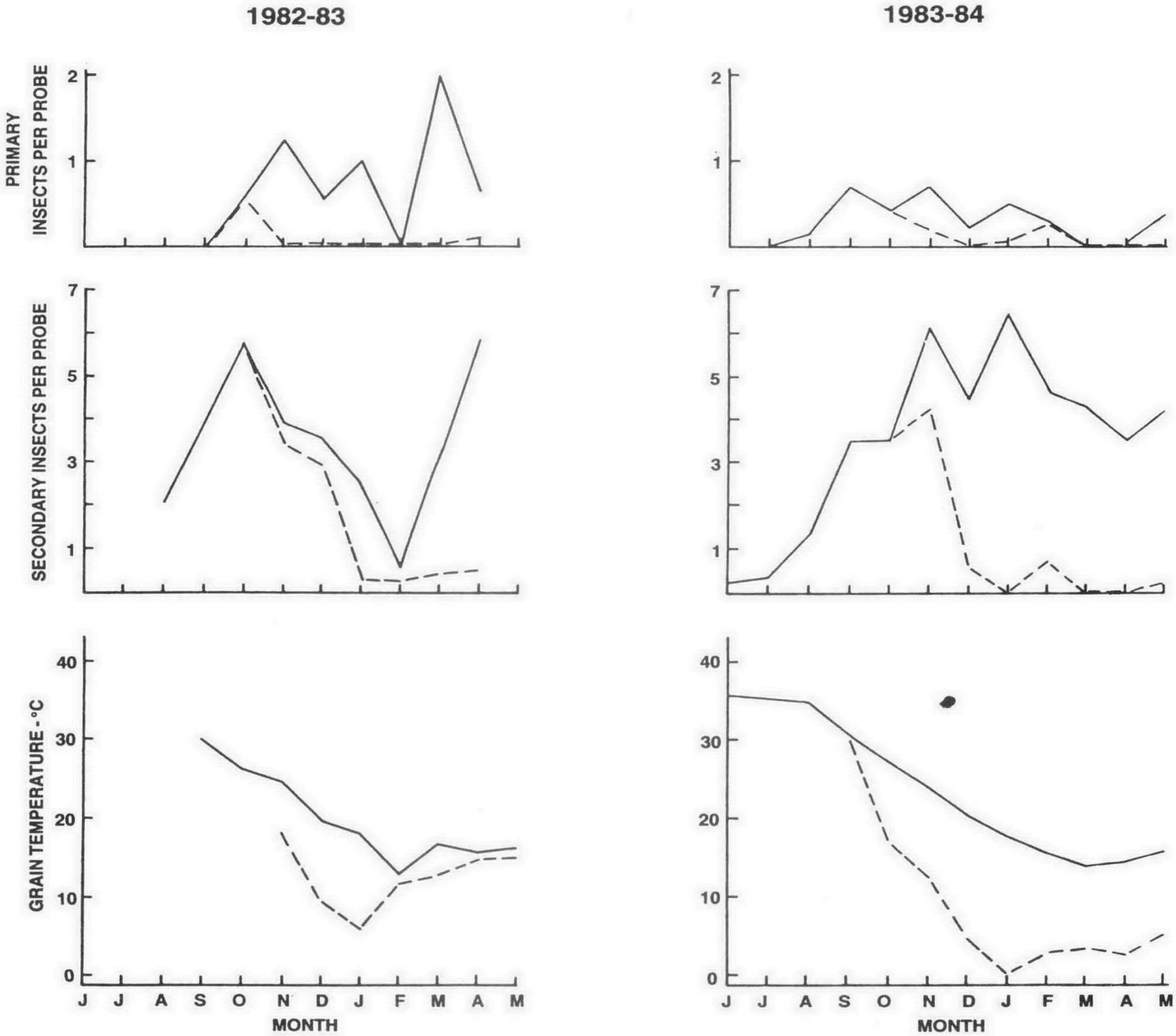


Fig. 1. Comparison of aerated to unaerated wheat storage effects on insect populations: solid line, unaerated; broken line, aerated.

predicted relationships between two grain temperatures and two moisture levels with insect frequencies when aeration is completed by 1 October.

These projections closely model field experience during the past decade in southern high plains wheat storages. This prediction system involves exponential population development. If temperature and grain moisture levels are favourable, stored–grain insects and moulds will increase in an exponential (non–linear) fashion. Managers must be aware of the risk based on the time the product has been stored when grain temperatures and moisture levels are conducive to growth.

Table 1 lists safe storage moistures for 10 grain and seed crops in the U.S. by general latitude location. Table 2 lists the approximate time that maize (shelled corn in the U.S.) can be expected to remain in storage before it deteriorates (loses 1% dry matter) enough to change at least one market grade level based on storage moisture and temperature of the grain in storage. Recommended airflow rates by crop for several moisture levels are listed in Table 3.

Storage Time vs. Moisture and Temperature

Grain moisture and temperature interact significantly; both must be interactively managed. Table 2 lists estimates of allowable time that maize or shelled corn can be stored in aerated storage at various moisture contents and grain temperatures before the product loses 1% dry matter, reducing maize one market grade or more, depending on other grading factors in a sample.

Table 2 does not account for significant differences in hybrid seed varieties, variations in moisture tester or meter accuracy, and other important management conditions, such

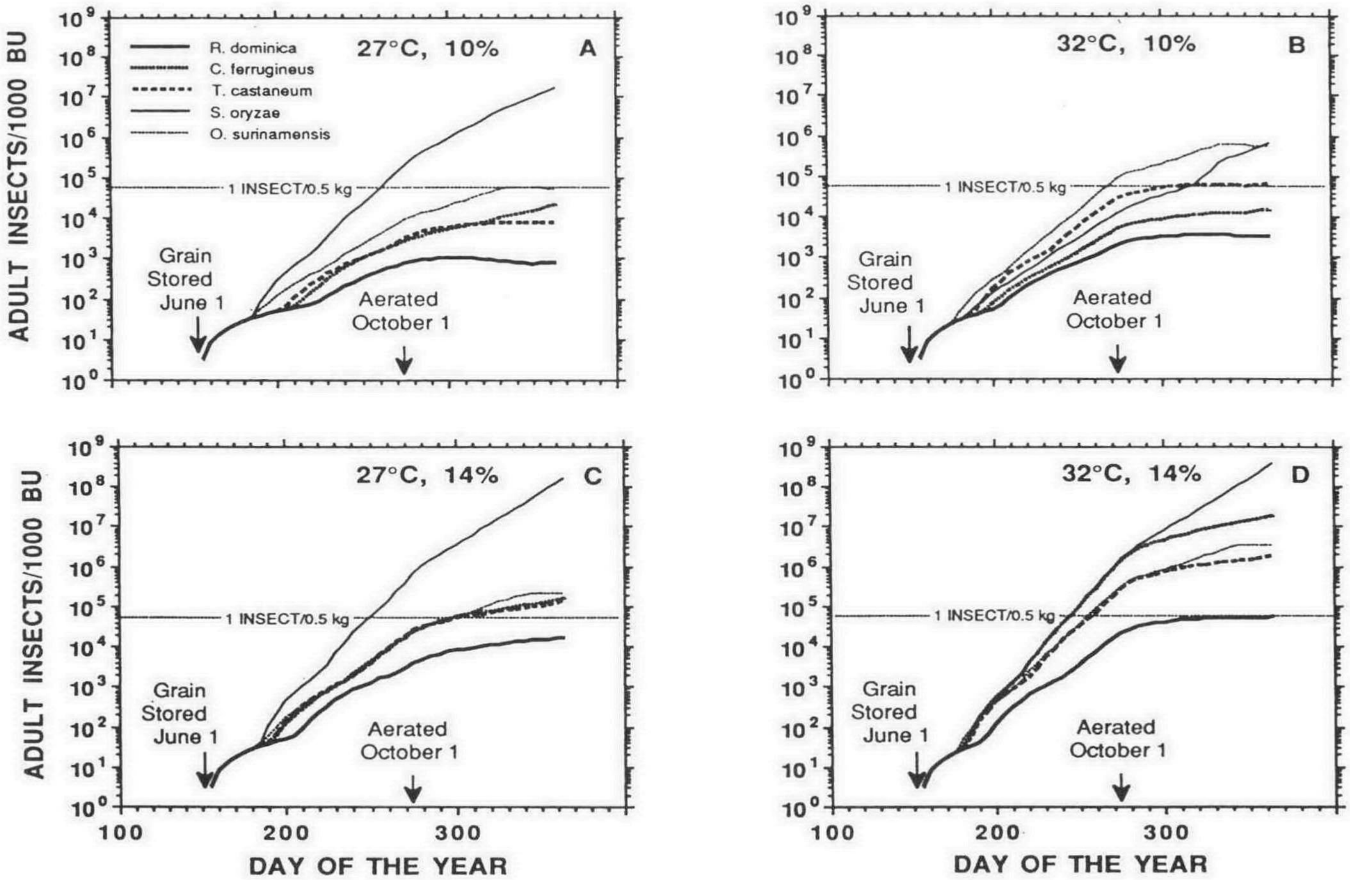


Fig. 2 Predicted effects of aeration temperatures and grain moisture levels on the growth of five stored-grain insect species with aeration completed on October 1.

as solar radiation on the side of storages, that can radically change localised grain temperature and cause spoilage due to rapid mould development when the grain is held in storage in a very moist condition. That is why aeration is necessary when holding grain above the safe storage levels listed in Table 1.

Moisture Migration

Grain that contains acceptable moisture levels and uniform temperatures can be stored safely. Maintaining uniform grain temperatures requires close management or thermally insulated storage. When grain is stored at safe moisture levels but is not aerated properly, uneven grain temperatures can cause movement of moisture through the grain mass, called moisture migration.

In cold weather, temperatures in the outer two to three feet (sides and top) of grain cool much faster than grain near the centre. Cold dense air settles by gravity through the outer grain to the floor, moves inward near the bottom of the storage. As air warms and becomes lighter, it expands and rises in the centre grain (Fig. 3), and its relative humidity drops.

For each 11°C (20°F) rise in air temperature, the percent relative humidity is cut in half. Air at 4.4°C (40°F) with 80% r.h. will drop to 40% r.h. when it warms to 15.6°C (60°F); this air is below the equilibrium relative humidity of most dry grain and will absorb moisture from the grain. When air moves through grain and warms to 11°C (20°F), it is typically below grain equilibrium moisture and absorbs moisture. As warm moist air reaches cold surface, it condenses moisture on the cold grain. Periodic warming of headspace air activates moulds, causing grain to crust and seal over. Moisture migration, also called top crusting (Fig. 3), can occur even in safe grain moistures of 9–11% when grain is not properly managed and aerated.

Controlled Aeration — Stored Grain Pest Management Tool

Aeration is used to manage grain temperature by cooling grain to uniform temperature levels in the fall and winter. The general principles of controlled aeration for grain received at safe storage moistures are as follows: 'Harvest heat' should be left in the grain as a barrier to insect entry during the warm summer months. Insect populations will increase in the early fall when grain surface temperatures begin to lower. (Populations may build earlier if grain is cooled during the summer to temperatures that are ideal for insect reproduction and growth.) When a strong (3–5 day) weather front develops with air temperatures that will allow cooling grain to 13–18.5°C (55–60°F), aeration systems should be operated. The objective is to quickly cool the grain mass across the optimum range of insect feeding and breeding, 21–32°C (70–90°F), to temperatures below 13–18.5°C (55–60°F).

These ideal aeration weather patterns in Oklahoma and the south–west U.S. are the result of major fall air temperature changes. Figure 4 shows the average amounts of 55°F available in Oklahoma during the months of October–November based on 30–year weather data. Cold weather fronts begin arriving in Oklahoma and the south–west during mid to late September. Aeration systems with medium airflow, 0.15–0.30 m^3/minute/m^3 (0.20–0.40 cfm/bu Table 6), can cool the entire

Table 1. Maximum moisture contents for aerated grain storage

Grain type and storage time	Maximum moisture content for safe storage (percent wet basis)		
	South	Central	North
Shelled maize and sorghum			
Sold as #2 grain by spring	14	15	15
Stored 6 to 12 months	12	13	13
Stored more than 1 year	12	13	13
Soybeans			
Sold by spring	13	14	14
Stored 6 to 12 months	12	12	13
Stored more than 1 year	11	11	12
Wheat, oats, barley, rice			
Stored up to 6 months	12	13	14
Stored 6 to 12 months	11	12	13
Stored more than 1 year	10	11	12
Sunflower			
Stored up to 6 months	10	10	10
Stored 6 to 12 months	9	9	9
Stored more than 1 year	8	8	8
Flaxseed			
Stored up to 6 months	9	9	9
Stored more than 6 months	7	7	7
Edible beans			
Stored up to 6 months	13	14	15
Stored 6 to 12 months	12	13	14
Stored more than 1 year	10	11	12

Notes: 1. Values for good quality, clean grain and aerated storage. 2. Reduce one percent for poor quality grain, such as grain damaged by blight, drought, etc. Reduce each entry by two percent for nonaerated storage.
Adapted from Anon. (1987).

grain mass in 36–72 hours. Thus, an operator can take advantage of those 3–5 day periods of cold air to gain earlier control of insects by rapidly cooling the grain. But, even if only 50–60% of the grain is cooled during the first cold front, cooling may be completed with the next cold weather in the next week or two, and the entire storage is placed in safer insect and mould conditions.

During one aeration cycle, the grain temperature will typically be reduced from 26.7-32.2°C (80-90°F) to 12.8-18.3°C (55-65°F), a reduction of 8-19°C (15-35°F). Grain that is not cooled in early to mid-fall (mid-September through early November) will develop various stages of moisture migration or top crusting. Early fall aeration eliminates most if not all of this temperature differential. Data needed to manage an aeration system are listed in Tables 1-6.

Aeration controller thermostats monitor ambient air temperatures and start the blower(s) automatically at preset temperatures that are ideal for grain cooling. The controller also stops the blower(s) if the air temperature rises above the thermostats preset upper temperature limit. It will precisely repeat these blower start/stop conditions at any time and as many times as the outside air temperature moves below or above the thermostat setting. The aeration controller makes sure that the cooling air is at least as cool or colder than the thermostat setting before the blower will operate.

An hour meter accumulates the hours of operation each time the blower runs. This provides the grain manager with the exact amount of aeration time since aeration is started. Based on blower airflow rates, and the data from Table 6, managers can predict the amount of aeration time needed to finish a cooling front. As the hour meter approaches the calculated shut off time, the grain mass temperatures should be checked to see if the cooling front has moved through the grain. Aeration can be used to manipulate grain temperatures for insect management if a properly designed aeration controller is used for precise cooling of the grain.

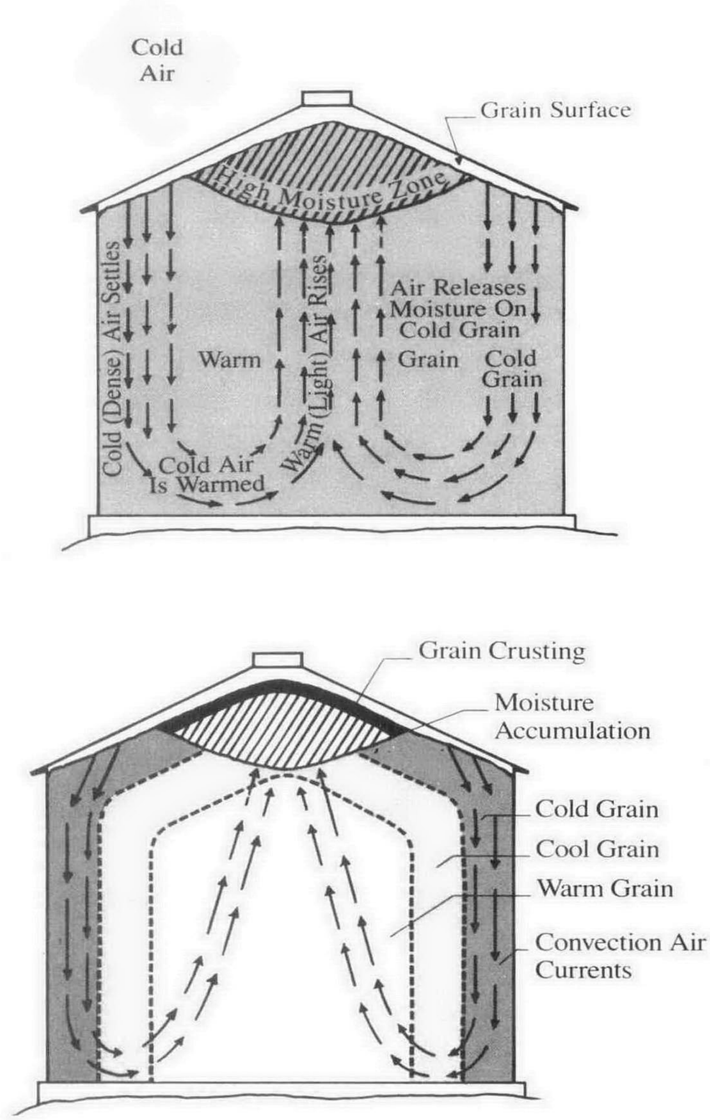


Fig. 3. Example of moisture migration or top crusting in summer-harvested grain stored several months without aeration.

Aeration System Management Problems

Data from throughout the U.S. indicate that many grain managers do not operate aeration systems properly. Mistakes include waiting too late in the fall to begin aeration, not operating aeration blowers under optimum temperature conditions, missing favourable weather pattern air temperatures, running blowers continuously night and day in temperatures that rewarm the grain, failing to operate blowers the required number hours to move a cooling front completely through the grain mass, or operating blowers excessively and removing excess grain moisture (reducing market weight). Timing and duration of early and mid-fall cooling fronts are difficult to predict. Thus, manual operation of aeration systems is difficult if not impossible to manage satisfactorily.

Aeration Controller Trials in the South-western U.S.

In Oklahoma, grain harvested in June is typically stored at safe storage moisture levels at temperature levels of 35–38°C (95–100°F), and often reaches storage temperatures of 40.5°C (105°F) or more. Dry wheat (11–12% moisture, wet basis) will store satisfactorily at 40.5–43.3°C (105–110°F). If aeration is used to cool wheat during the summer, the wheat is placed in a condition that favours insect infestation. Steel tank storage headspace day-time temperatures typically range between 45 and 57°C (113–135°F). During nights the headspace air varies between 29.5 and 35°C (85–95°F). Thus, steel tank surface grain temperatures cycle between these temperature extremes, a thermal environment that is not conducive to insect entry, but does cause protectants to degrade. Concrete silo sidewalls and roofs provide a thermal lag, so headspace temperatures change much more slowly in concrete than steel structures.

For Oklahoma, central and north Texas and southern Kansas, aeration systems should be prepared for operation by early September. National weather reports should be monitored closely to determine when the first usable cold weather will enter the storage region. From Kansas to south Texas, thermostats require different settings. Weather fronts of at least 3–5 days duration with temperatures in the 15–21°C (60–70°F) range can be used effectively. For these temperatures, upper limit thermostats should be set to switch when air temperatures drop to 15–18°C (60–65°F) for Oklahoma and Kansas; in central to south Texas, settings of 19–21°C (65–70°F) may be necessary to capitalise on early favourable cooling weather.

As the actual temperatures in a cooling front are determined, the controller thermostat should be set on the upper acceptable limit to achieve maximum cooling. If night temperatures drop to 12–13°C (53–55°F) and day-time peak temperatures are 22–24°C (72–75°F), consider setting the thermostat to minimise off time. In Oklahoma, early fall cold weather fronts typically last 3–5 days. In some years, several fronts may come during September a few days apart, but in other years, there may be 2–3 weeks before the second cold weather arrives. Figure 4 shows the available hours of 13°C (55°F) temperatures available in October and November, based on 30-year U.S. Weather Bureau data for Oklahoma. About 90% more hours are available each month at 15.5°C (60°F) than at 13°C. So, instead of setting the controller at 15.5°C (60°F), the ideal upper limit, grain managers may gain 50–75% more fan time by operating the blowers at temperatures 2–3°C higher just to get the overall cooling front completed before a cold weather front recedes.

Airflow Rates vs. Cooling Time

Completing the aeration cooling cycle in minimum time is very important for insect and mould management. The highest aeration airflow rates that can be justified economically should be used. Typical commercial aeration airflow rates are 0.04–0.08 m^3/minute/m^3 (0.05–0.1 cfm/bu). At these rates, completing one cooling cycle in the fall typically requires 150–300 hours at 0.08 at 0.04 m^3/minute/m^3. Blowers that deliver 0.20–0.40 m^3/minute/m^3 (0.25–0.5 cfm/bu) will reduce cooling time to about 40–80 hours. The 0.20 m^3/minute/m^3 flow rate would allow the grain manager to cool a storage in 80 hours, or just over 3 days of continuous operation. Tables 4 and 5 list approximate aeration blower power (kW) per 100 m^3 (2823 bushels) at specific airflow rates for a range of storage depths for wheat, maize, grain sorghum, soybeans and other grain crops. Table 6 lists approximate cooling hours required for aeration at specific airflow rates.

It costs more money to go fast. Increasing from 0.08 to 0.20 m^3/minute/m^3 involves an increase of 2.5 times the airflow, but about 6 times the power. Pressure (and thus power) increases as a function of the square of the airflow rate increase. Electric power delivery wiring and controls may also require expensive modifications. Local power company engineers should be consulted.

The cost of insect damage may easily offset a significant increase in power costs. Changes in blower size and power should be evaluated carefully. One replacement cost strategy for a storage facility with a variety of storage and blower sizes is to move large blowers to smaller storages to increase the airflow, then purchase and install bigger blowers on the larger storage.

If all storage units can be completely cooled with the first cold weather by using 0.20 m^3/minute/m^3 airflow rate rather than partially cooling it using 0.08 m^3/minute/m^3 airflow, the manager does not have to wait several days or weeks to complete cooling. Control of insect populations is established early. When the entire grain mass is cooled rapidly, from warm to cold temperatures in 2–5 days, insects will die in

Table 2. Estimated storage durations for shelled maize held at specific moistures and temperatures during which one percent dry matter loss occurs[a]

Temperature		Days				
°C	°F	14	15.5	17	18.5b	20b
		Moisture content (wet basis)				
10.0	[50]	256	128	64	32	16
15.6	[60]	128	64	32	16	8
21.1	[70]	64	32	16	8	4
26.7	[80]	32	16	8	4	2
32.2	[90]b	16	8	4	2	1
37.8	[100]b	8	4	2	1	0

Source: H. J. Raney et al. (1987).
[a]Conditions during which one percent dry matter loss occurs and quality is reduced by one market grade.
[b]Continuous aeration is required at moisture levels of 18 to 20 percent with grain and/or air temperatures above 80 °F.

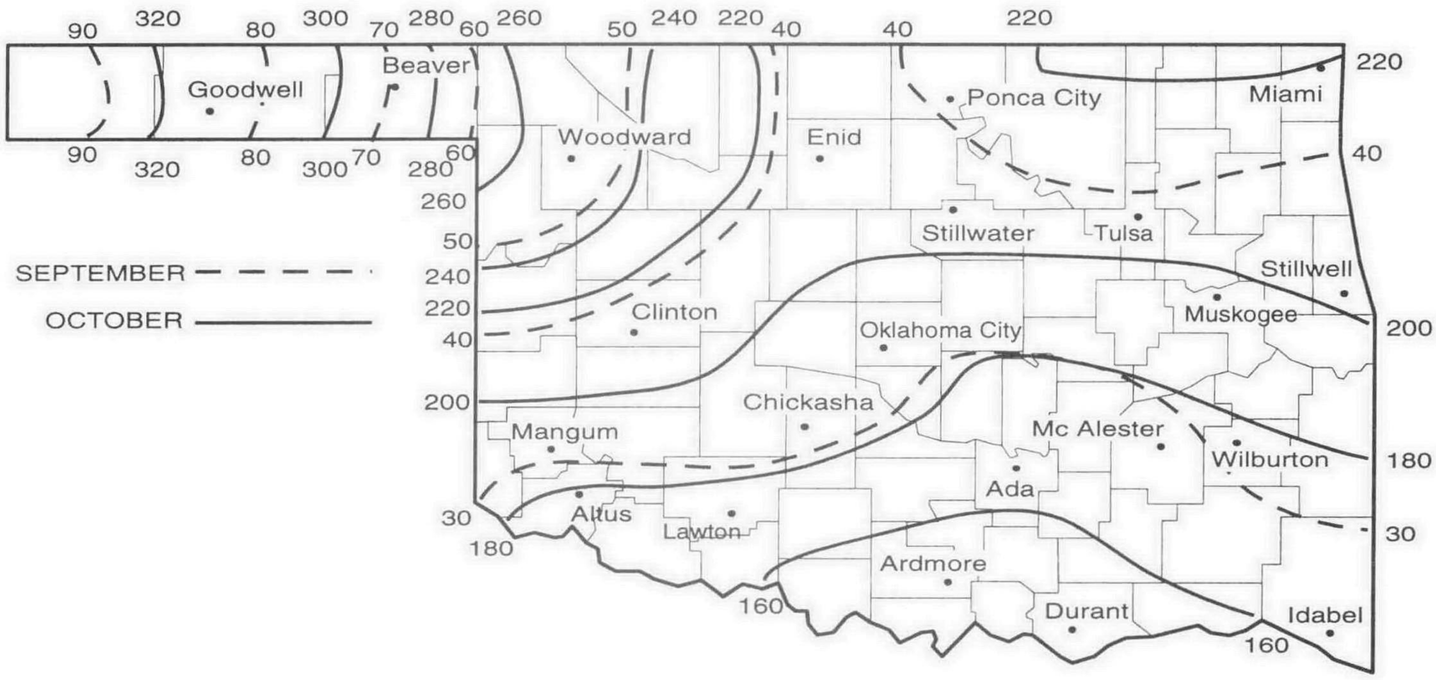


Fig. 4. Hours of 12.8°C (55°C) weather available annually in Oklahoma during September and October (30 year weather data).

Table 3. Recommended minimum airflow rates for aeration

Crop	Moisture content	Cfm/bu range
Shelled maize,	14 percent and below	1/10 to 1/4
Sorghum	15 to 16 percent	1/4 to 1/2
	18 percent +	1/2 to 1
Wheat, Oats,	13 percent and below	1/10 to 1/4
Barley, Rice	14 to 16 percent	1/4 to 1/2
	17 percent +	1/2 to 1
Soybeans	10 to 11 percent	1/10 to 1/4
	12 to 13 percent	1/4 to 1/2
	14 percent +	1/2 to 1
Sunflowers	8 to 9 percent	1/10 to 1/4
	10 to 11 percent	1/4 to 1/2
	12 to 13 percent	1/2 to 1

Source: Stored Grain Management Handbook, Agricultural Engineering Department, Kansas State University, Manhattan, Kansas, USA.

about 2 weeks (Khan 1990). Then, not only has fumigation been replaced by grain temperature manipulation and management, but aeration for mould control has been completed, placing the grain in a safer condition against *moisture migration* and mould.

OSU Aeration Controller Designs

Aeration controllers have been developed at Oklahoma State University (OSU) for a wide range of grain storage facilities in State. These systems range from small corrugated steel 100–250 t (3500–10000 bushel) tanks with one vane axial blower per tank on farms, to a commercial grain facility with two 8000 t (30000 bu) steel tanks with 12 blowers per tank and another elevator with four 2250 t (80000 bu) concrete silos with 3 blowers per silo, or 12 blowers on one controller.

The aeration controller on the two 8000 t steel tanks operated eight 6 kW blowers mounted on base aeration ducts and four 2.5 kW roof exhausters on each tank, or a total of 24 blowers. Each tank has a separate control circuit panel for 12 blowers, but all 24 blowers operate from one set of thermostats in the *master* control box. Either tank can be operated independently of the other, or both can be operated simultaneously. Blowers are grouped with two 6 kW and one 2.5 kW blower operated as a unit by each time delay relay, with four groups of blowers on each tank. Blower groups are started at 7 second intervals; the entire system is on-line in 56 seconds.

All controllers use recording hour meters to log the continuous hours of blower operation time. Figure 5 shows an aeration controller used on commercial storage structures with multiple large power blowers. Each controller has a control selector switch for manual, off, automatic operation. The manual selector switch position is used for blower maintenance and service work, or to test various functions of the aeration system. It operates the blower motors directly. The automatic switch position sets the circuit for automatic thermostat on/off blower control, based on the set-point temperature. The hour meter records the time the blowers run, regardless of whether manually or automatically controlled.

Some aeration controller circuits use both high and low temperature thermostats. Two thermostats are used to limit the range of cold air temperatures forced into the grain, such as an upper limit setting of 15.5°C (60°F) and a lower limit setting of 4.4°C (40°F), to control grain temperatures precisely within an 11°C (20°F) band. Either high or low temperature switch opening will interrupt blower operation.

Figure 5 illustrates a typical commercial grain facility controller which uses only a high or upper temperature limit thermostat. This system was designed to operate multiple blowers on two grain tanks where the operator wanted separate hour meters for each set of blowers. Two relays and one time delay relay control the blower groups in this installation. In multiple blower systems, time delay relays are used to

Table 4. Approximate blower power, kW/100 m^3 [HP/1000 bushels]-- wheat/sorghum.

Grain depth		Airflow rate m^3/minute/m^3 [(cfm/bu]											
m	[ft]	0.8	[1]	0.6	[3/4]	0.4	[1/2]	0.2	[1/4]	0.08	[1/10]	0.04	[1/20]
4.6	[15]	3.5	[1.65]	2.3	[1.11]	1.0	[.47]	.23	[.11]	.08	[.040]	–	–
6.1	[20]	6.3	[2.99]	4.0	[1.91]	1.66	[.79]	.42	[.20]	.10	[.050]	.04	[.020]
7.6	[25]	14.3	[6.80]	7.0	[3.33]	2.65	[1.26]	.63	[.30]	.14	[.065]	.05	[.024]
9.1	[30]	20.0	[9.50]	11.0	[5.22]	4.04	[1.92]	.95	[.45]	.17	[.080]	.06	[.029]
10.7	[35]	29.2	[13.88]	14.9	[7.08]	5.88	[2.79]	1.37	[.65]	.21	[.10]	.07	[.034]
12.2	[40]	–	–	20.0	[9.51]	7.75	[3.68]	1.83	[.87]	.30	[.14]	.08	[.040]
13.7	[45]	–	–	–	–	10.87	[5.16]	2.44	[1.16]	.34	[.16]	.10	[.048]
15.2	[50]	–	–	–	–	13.33	[6.33]	2.82	[1.34]	.40	[.19]	.12	[.057]
18.3	[60]	–	–	–	–	20.1	[9.55]	4.33	[2.06]	.59	[.28]	.16	[.076]
21.3	[70]	–	–	–	–	–	–	5.94	[2.82]	.82	[.39]	.20	[.096]
24.4	[80]	–	–	–	–	–	–	7.67	[3.64]	1.05	[.50]	.27	[.13]
27.4	[90]	–	–	–	–	–	–	10.43	[4.95]	1.39	[.66]	.36	[.17]
30.5	[100]	–	–	–	–	–	–	–	–	1.66	[.79]	.42	[.20]

Sources: Anon. (1962, 1988),

Table 5. Approximate blower power kW/100 m3 [hp/1000 bushels] — maize/soybeans.

Grain depth		Airflow rate m^3/minute/m^3 [(cfm/bu]											
m	[ft]	0.8	[1]	0.6	[3/4]	0.4	[1/2]	0.2	[1/4]	0.08	[1/10]	0.04	[1/20]
4.6	[15]	1.3	[0.61]	0.65	[0.31]	0.27	[.13]	0.08	[.04]	0.042	[.020]	–	–
6.1	[20]	2.5	[1.20]	1.2	[0.57]	0.5	[.24]	0.13	[.06]	0.048	[.023]	–	–
7.6	[25]	5.3	[2.50]	2.0	[0.95]	0.8	[.39]	0.21	[.10]	0.059	[.028]	0.021	[.010]
9.1	[30]	8.0	[3.80]	3.2	[1.54]	1.2	[.58]	0.29	[.14]	0.070	[.033]	0.023	[.011]
10.7	[35]	11.6	[5.50]	4.6	[2.20]	1.8	[.84]	0.42	[.20]	0.080	[.038]	0.027	[.013]
12.2	[40]	–	–	6.5	[3.10]	2.3	[1.11]	0.53	[.25]	0.090	[.043]	0.032	[.015]
13.7	[45]	–	–	–	–	3.3	[1.55]	0.67	[.32]	0.110	[.052]	0.036	[.017]
15.2	[50]	–	–	–	–	4.0	[1.90]	0.86	[.41]	0.135	[.064]	0.040	[.019]
18.3	[60]	–	–	–	–	6.0	[2.86]	1.3	[.61]	0.204	[.097]	0.048	[.023]
21.3	[70]	–	–	–	–	–	–	1.9	[.90]	0.284	[.135]	0.063	[.030]
24.4	[80]	–	–	–	–	–	–	2.6	[1.25]	0.379	[.18]	0.080	[.038]
27.4	[90]	–	–	–	–	–	–	3.5	[1.65]	0.484	[.23]	0.097	[.046]
30.5	[100]	–	–	–	–	–	–	–	–	0.653	[.31]	0.114	[.054]

Sources: Anon. (1962, 1985).

sequence the startup of all blowers or groups of blowers at approximately 6–8 second intervals.

An electrical circuit schematic diagram for two simple controllers is illustrated in Figure 6. A more complex controller circuit diagram is shown in Figure 7. Both circuits use a basic 'ladder' diagram for wiring and circuit analysis. All aeration controllers are set up so the original blower motor starter manual operating switches can still be used for controlling individual blowers when the aeration controller is set to the off position.

A typical component parts list for an aeration control with time delay relays that can operate 4 blower motors or groups of motors is shown in Table 7. Prices of the materials for the controller are 1990 US$. After building one or two units, an experienced electrical technician can assemble, wire and test these boxes in 1–2 days, depending on the complexity of the system and diagram (Noyes, et al. 1992a,b).

Electromechanical aeration controllers built from standard off-the-shelf components are reliable, easy to troubleshoot and repair, and are relatively inexpensive. Aeration controllers usually pay for themselves in less than one year. An electrician's labour costs US$30/hour for 8 hours assembly time, or US$240 labour per controller, parts are US$318 (Table 7) and it costs US$120 for installation: that's US$678 for a unit that will operate all blowers reliably and accurately in a 1–3 tank complex. Compared to computerised controllers that cost US$3500 without installation, and require considerable learning to operate effectively, the OSU electro-mechanical controller is a good investment. If a relay, timer, thermostat, switch or hour meter fails, pull it out and plug in a new one, purchased locally. Computers and microprocessors are wonderful for complex processes. Aeration management need not be a complex process.

OSU's Aeration Management System

Aeration is part of the overall stored-grain management plan. Developing an aeration controller system to operate aeration blowers without including other 'best management storage practices' does not constitute an effective insect control program. Individual grain management systems require different levels and amounts of management input and time.

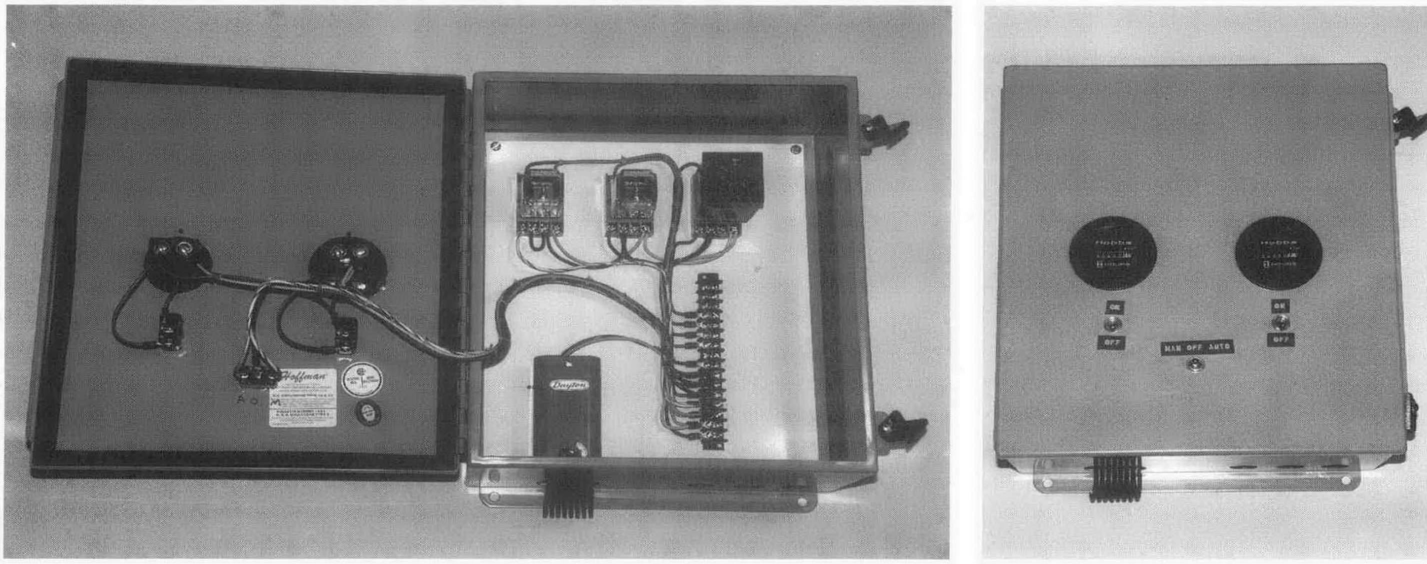


Fig. 5. Typical electro-mechanical aeration controller used for commercial elevators.

Producers and elevator operators must develop stored-grain management strategies depending on their location, facility, product, and harvest time (Noyes et al. 1989a,b; 1990).

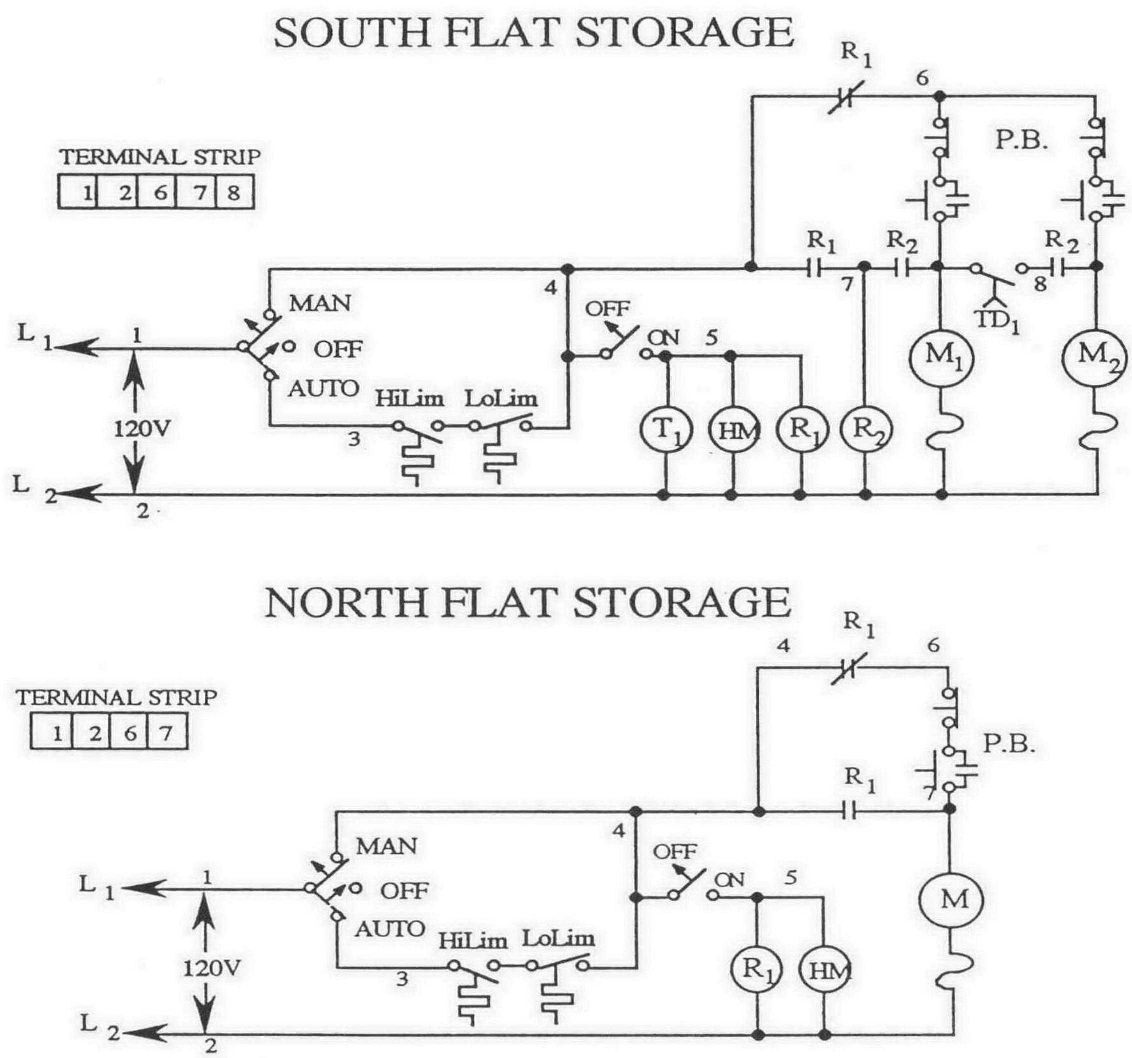
Stored grain aeration management strategies include the following:

- planned aeration using automatic aeration control—an aeration controller using one thermostat system (both high and low temperature settings on some systems) operating at preset temperatures controls all blowers on multiple tanks or silos in sequence
- maintaining grain temperatures above or below the optimum insect feeding and breeding range of 21–32°C (70–90°F)
- high airflow — using higher than the normal airflow rates of 0.08 m^3/minute/m^3 (0.1 cfm/bu) allows shorter aeration times (see Table 6); instead of 120 hours for a complete cooling cycle at 0.08 m^3/minute/m^3 (0.1 cfm/bu), using 0.20–0.40 m^3/minute/m^3 (0.2–0.5 cfm/bu) would reduce cooling time to 25–60 hours
- maximum use of available favourable cool or cold weather systems, using high airflow rates
- sealing tank, bin or silo base openings — keeps cold air from draining out of grain mass and pulling in warm air, and keeps insects from entering at base; grain managers can monitor insects in the grain storage headspace
- roof blowers/vents open except when fumigating — allows air exchange that minimises humid air buildup in headspace and roof condensation
- housekeeping/cleanup—thoroughly clean bin aeration ducts and unload auger trenches (where insects thrive on grain dust and foreign material) as well as other areas of storage
- empty tank or silo pesticide spray and/or fumigate— to remove initial insect populations before fresh harvested grain is stored; very important if aeration ducts and unload augers are not thoroughly cleaned or vacuumed
- grain cleaning—removes grain dust and fines that insects thrive on, and improves aeration; clean grain provides less insect attraction. Aeration is much more productive — blower operating times are typically 25–50 % less for clean grain than grain with significant levels of trash and foreign matter
- grain spreading/leveling, or pulling core of fines from silo or tank by running centre unload conveyor — improves management inspection and sampling, aeration (eliminates core of fines and foreign material under fill point), grain temperature maintenance, fumigation

Table 6. Airflow rate, m^3/minute/m^3 vs. cooling time, hours[a]

Season	Low aeration (hours)		Medium aeration (hours)			High aeration (hours)			
	0.04	0.08	0.16	0.24	0.32	0.4	0.5	0.6	0.8
Summer	180	90	45	30	24	18	15	12	9
Fall	240	120	60	40	30	25	20	15	12
Winter/Spring	300	150	75	50	40	30	25	20	15

[a] Assumes clean grain at safe storage moisture. Grain that is peaked and has foreign material concentrated under the fill point(s), cooling may require 50% additional time or more.



GLOSSARY:

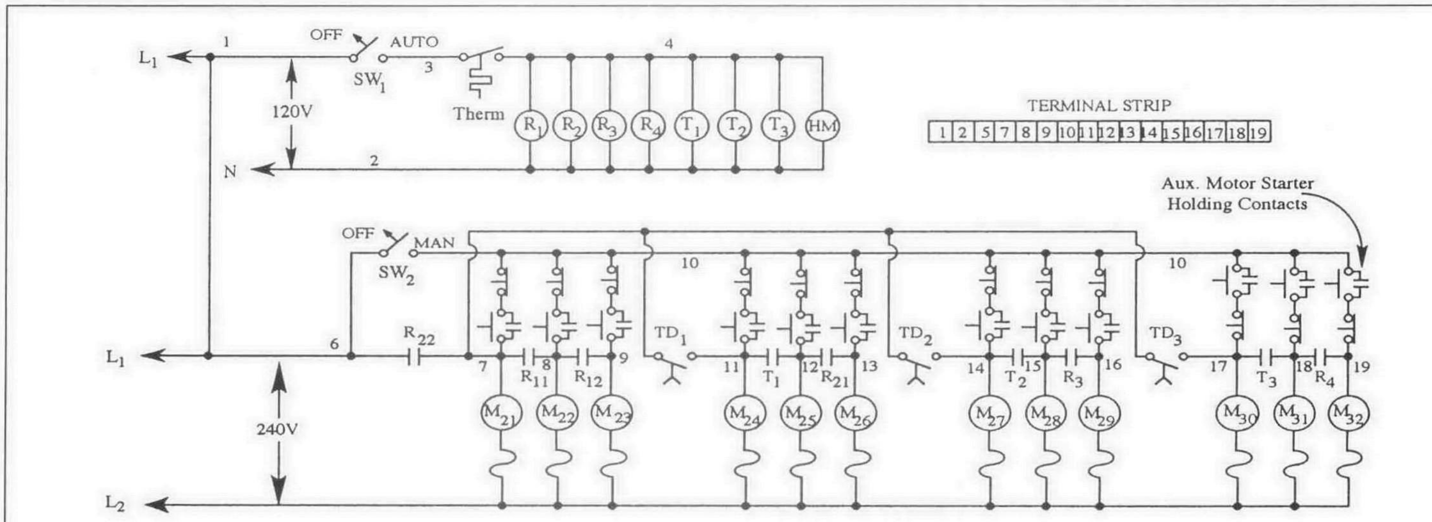
AUTO = Automatic Position on 3 Position Selector Switch
MAN = Manual Position on 3 Position Selector Switch
Therm = High Limit Thermostat
HM = Hour Meter
M = Blower Motor Starter Coil
T = Time Delay Relay & Instantaneous Timer Contacts
TD = Time Delay Relay Timed Contacts
R = Control Relay
PB = Push Button Switch, Start/Stop
SW = Two Position Selector Switch, ON/OFF

Wiring Color Code
1 - white
2 - black
3 - yellow
4 - orange
5 - green
6 - pink
7 - lt. blue
8 - grey

Fig. 6. Wiring schematic diagram for aeration controller circuits using high and low temperature thermostats to control one or more blower motors.

- temperature cable thermocouple reading/recording — provides periodic grain mass thermal profile, a valuable management asset
- grain monitoring/sampling — provides grain moisture and temperature, and insect and mould management data
- fumigation — is a backup system if grain has infestation at or above economic population thresholds and weather for grain cooling is not available; storage prepared for controlled aeration management by sealing roof vents and blowers, and fill points is ready for fumigation.

When properly coordinated, these management practices will help maintain grain quality, reduce inputs, and preserve grain quality. To effectively store grain, it must be managed from a total systems approach. Stored grain should be inspected regularly. Key management components including grain moisture and temperature, insect and mould population



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Timer Settings
T_1 = 7 sec
T_2 = 14 sec
T_3 = 21 sec

Wiring Color Code

1 - white	11 - white/purple
2 - black	12 - white/red blue
3 - yellow	13 - yellow/brown
4 - orange	14 - red/black
6 - pink	15 - grey
7 - lt. blue	16 - pink/purple
8 - drk blue	17 - orange/purple
9 - purple	18 - white/purlpe
10 - green	19 - grey/purple

Fig. 7. Wiring schematic diagram for aeration controller circuits using a high temperature thermostat to control 12 blower motors.

levels, and the storage structure should be checked. The following sections discuss selected grain management strategies.

Aeration Management Data

Data from throughout the U.S. indicate that many producers and grain managers do not operate aeration systems properly and do not run their blowers the correct number of hours. This may be because they do not have the correct management data at their disposal. The use of automatic aeration controllers with hour meters to optimise aeration blower time should be a priority stored-grain management strategy. Grain should be aerated during major seasonal air temperature changes in the fall and winter to prevent moisture migration. Some of the data needed to manage an aeration system properly are listed in Tables 1–6. Seal Storage Base and Sidewall Openings

Seal all tank and silo base and sidewall openings, including aeration blowers, augers, slide gate push rods, U-trough covers, foundation cracks, missing bolt holes and sidewall doors or access ports. This sealing process must be extremely thorough. Insects can and will enter any small access opening. Sealing the base restricts insect access to the top of the structure where it can be more easily monitored. Sealing auger and blower or blower inlet or outlet openings will prevent cold air from leaking out of the storage and warm convection air currents from moving up through the storage, removing grain moisture. Use professional fumigation sealing materials. Seal for non-leak fumigation, then leave storage openings sealed except when in use or when cleaning.

Note: Do not seal roof aeration exhaust or inlet vents except for fumigation. The storage head space must have free air movement to minimise humid air buildup and roof condensation.

Level vs. Peaked Grain Surfaces

Level grain is much easier to manage than peaked grain. Peaked grain, shown in Figure 8, is difficult to manage because of several problems:

- peaked grain is very difficult to cool; after cooling, peaked grain rewarms rapidly — temperatures can not be controlled
- at least 25–50% more aeration time is required to cool peaked grain compared with storages with grain surfaces that are level or slightly rounded
- grain protectants deteriorate more rapidly in hot, peaked grain
- peaked grain has a much larger surface area than level grain (visualise the outer surface of a cone vs. the base area of the cone); grain rewarms rapidly in peaks due to warm head space temperatures, which allows insect and mould populations to accelerate
- fumigation of peaked grains is more difficult and generally not as effective
- grain that is peaked usually has a core of foreign material down the centre of the grain mass; this core is difficult to cool, and attracts and harbours insects populations.

An effective method for cleaning out centre concentrations of fines and trash from peaked grain is to unload the centre grain from each 0.6–1.2m layer as tanks or silos are being filled or loaded. After the final fill layer, remove the peak grain to an inverted cone approximately half the bin diameter across the top (Fig. 9), then level the grain or leave the shallow depression. Even when a tank or silo is completely filled before removing grain, running the centre unload conveyor to pull the peak out will remove a core of grain about 25–50 cm in diameter that contains a high concentration of grain fines. This action will open the centre and loosen the grain mass, allowing

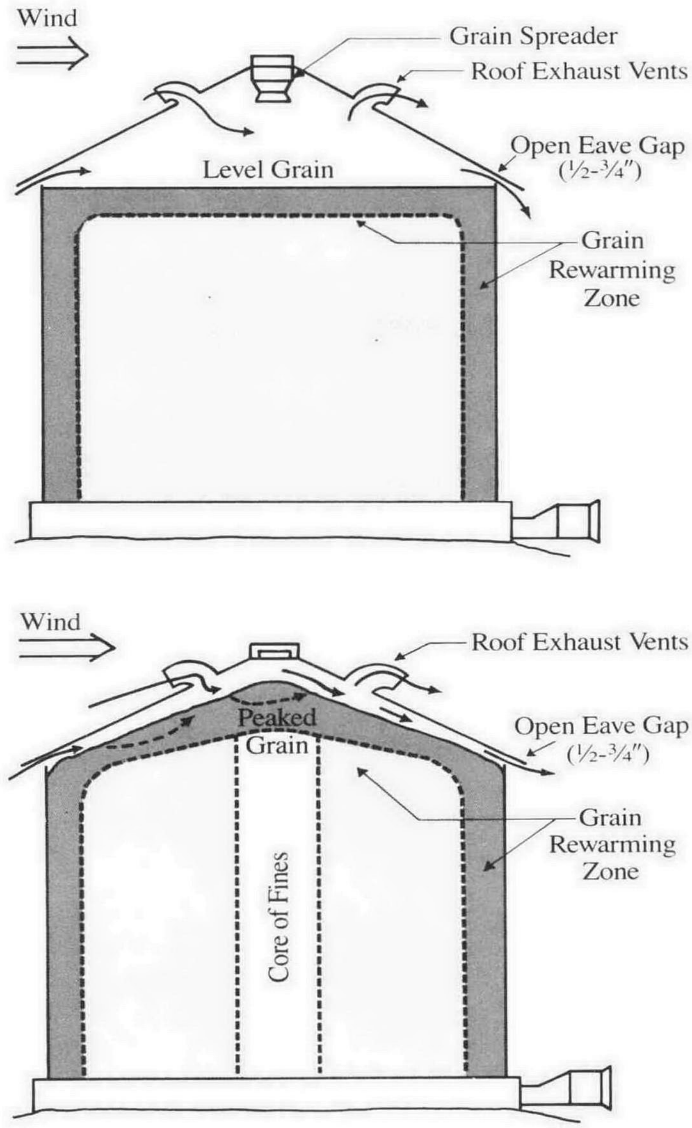

Fig. 8. Peaked grain vs. level grain surface in storage bins.

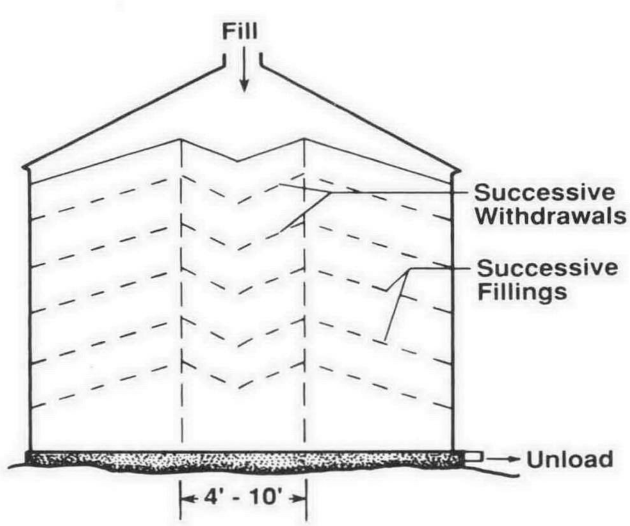

Fig. 9. Withdrawing layers of grain during filling to remove most fines and foreign material from a 1–2 m centre core.

improved air penetration of the centre of the grain mass, especially with the peak depth removed.

To determine when the peak grain has been pulled out, place confetti or newspaper shreds in the grain at the top and scatter them in continuously from the peak about half way down the slope. Observing when the confetti or pieces of paper stop coming out will indicate when the grain surface cone is about half the storage tank diameter.

Monitoring and Sampling

Monitor grain and sample for insects every 3–4 weeks throughout the storage period. Fumigate if insects exceed economic threshold levels — population levels of insects that will likely cause significant economic losses if not treated. If a storage has an area of warm grain that is infested, complete fumigation may be required if grain cannot be turned. Deep cup probes or vacuum samplers can be used to determine the extent of insect infestations.

Probe traps are recommended and can be used to monitor populations and make treatment decisions. Economic thresholds for probe traps need to integrate grain temperature, insect species and market destination criteria. (Fargo et al. 1989, 1994). Close monitoring during late August–early September allows managers to determine whether aeration may occur soon enough or if they may need to fumigate.

Aeration with cold air can help control insect populations if detected early before they reach economic threshold populations. However, insects generally infest peaked grain and cores of fines or wet areas below fill points where moisture condensation has occurred. These areas are often dense and sometimes crusted over with mould which restricts or blocks forced air movement.

Summary

Controlled aeration is a major management tool for elevators and grain storage facilities in the south-west United States. Many of the grain management principles discussed in this paper can be applied in other areas of the world, especially in regions where climatic conditions are similar. Principles such as sealing storage to keep insects from entering storage bases and using head space temperatures and retaining 'harvest heat'can be used to deter insect infestation as long as grain is stored at safe moisture levels and is monitored for pest problems.

References

Anon. 1985. Grain Storage Management Workshop Handbook, Farmland Industries, Inc., Kansas City, Missouri, USA.

Anon. 1962. Aeration in country elevators. Marketing Research Report No. 178, Agricultural Marketing Service, United States Department of Agriculture, Washington, D.C., USA.

Anon. 1987. Managing dry grain in storage, Publication No. AED-20, Midwest Plan Service, Iowa State University, Ames, Iowa.

Cuperus, G. W., C. K. Prickett, R. D. Bloome, and J. T. Pitts. 1986. Insect populations in aerated and unaerated grain storage in Oklahoma. Journal of the Kansas Entomological Society, 59:620–627, Kansas State University, Manhattan.

Cuperus, G. W., R. Higgins, and E. Williams. 1989. Integrated pest management, In: 1989 Oklahoma grain elevator workshop manual, Circular E-881, Cooperative Extension Service, Oklahoma State University, Stillwater.

Fargo, W.S., G.W. Cuperus, E.L. Bonjour, W.E. Burkholder & R.T. Noyes. 1994. Influence of probe trap type and attractants on the capture of four stored-grain coleoptera. Journal of Stored Products Research (In press).

Fargo, W.S., D.R. Epperly, G.W. Cuperus, B.L. Clary & R.T. Noyes. 1989. Influence of temperature and duration on the trap capture of four stored grain insect species. Journal of Economic Entomology. 82: 970–973.

Hagstrum, D. W., and P. W. Flinn. 1990. Simulations comparing insect species differences in response to wheat storage conditions and management practices, Journal of Economic Entomology, 83:2469–75.

Harner, J. P., and R. T. Noyes. 1988. The principles of grain aeration, Section 6, In: Stored grain management, Kansas Cooperative Extension Service, Kansas State University, Manhattan.

Khan, N. I. 1990. The effects of various temperature regimes and cooling rates on the mortality and reproductive abilities on two stored grain insect species. Thesis, Oklahoma State University.

Noyes, R. T., D. R. Epperly, B. L. Clary and G. W. Cuperus. 1992. Elevator managers summary report—Oklahoma wheat elevator electrical energy reduction demonstration project, OSU Grant No. 3881 OIL/SECP 88, Oklahoma Cooperative Extension Service, Oklahoma State University, Stillwater, 28 p.

Noyes, R. T. 1991. Aeration of Texas coastal region grain storage: critical management considerations, In: Proceedings, South Texas grain quality conference, Corpus Christi, Texas, May 22–23, 32p.

Noyes, R. T. 1990. Aeration of grain storage. In: Proceedings, 3rd national stored grain pest management training conference, Kansas City, Missouri, Oct. 20–25.

Noyes, R. T. (ed.), and B. L. Clary. 1989 a. Aeration of commercial grain storage, In: 1989 Oklahoma grain elevator workshop manual, Circular E-881, Cooperative Extension Service, Oklahoma State University, 135 p.

Noyes, R. T., B. L. Clary, H. A. Cloud, and B. A. McKenzie. 1989 b. Aeration of stored wheat, In: Wheat pest management handbook, USDA Extension Service, Washington, D.C., 68p.

Noyes, R. T., B. L. Clary, and G. W. Cuperus. 1990. Maintaining quality of stored grain by aeration. OSU Extension Facts No. 1100, Oklahoma Cooperative Extension Service, Oklahoma State University, Stillwater, 4p.

Raney, H. G., et al. 1987. Management of on-farm stored grain, Cooperative Extension Service, University of Kentucky, Lexington, 98p.