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A TWO-FAN CROSSFLOW VENTILATION SYSTEM FOR UPRIGHT GRAIN STORAGES

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PREFACE

This publication reports some of the preliminary findings of a research project covering off-farm conditioning of grain in commercial storage.

Abilene Grain Co., Inc., made its facilities available for the tests, and the Hot Spot Products Division, Neptune Systems, Inc., cooperated by supplying material and assisting in the installation of the prototype ventilation system. Albert H. Graves, project leader, and Leo E. Holman investigations leader, Transportation and Facilities Research Division, Agricultural Research Service, contributed valuable suggestions and assisted in preparing the report.

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A TWO-FAN CROSSFLOW VENTILATION SYSTEM FOR UPRIGHT GRAIN STORAGES

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SUMMARY

A prototype two-fan crossflow ventilation system was installed in an upright grain storage bin, 140 feet deep and 17 feet in diameter. The system was developed to cool stored grain rapidly and to accomplish the small amount of drying needed to condition newly harvested grain having a moisture content 1 to 2 percent too high for safe storage.

In 3 years of tests with grain sorghum and wheat, the grain was cooled to near ambient air temperatures in 24 to 48 hours, and grain moistures were reduced 1 percent in about 100 hours.

Promising features of this system are satisfactory installation and maintenance of perforated and solid, vertical duct sections on the walls of an upright concrete bin; satisfactory airflow distribution through grain 110 to 140 feet deep; and an airflow rate as much as 10 times the normal rate that is practical for bins of similar size having floor-duct aeration systems.

Two 7-1/2 hp., vane-axial fans were used, one on the roof of the test bin to push air through the grain and one on the opposite side of the bin near the bottom to pull air through the grain and to exhaust it to the outside. The system provided airflow rates of about 1/2 c.f.m. per bushel with wheat or grain sorghum in the test bin. Horizontal airflow was reasonably uniform throughout the entire grain depth in the various tests.

BACKGROUND

Each year a considerable volume of tough wheat and grain sorghum may be received at country elevators in the Hard Winter Wheat area. This grain, with an excess of 1 to 2 percent moisture, must be rapidly cooled and the excess moisture must be removed to ensure safekeeping of the grain during storage. The yearly volume of such grain and the amount of moisture to be removed generally do not justify the expense of installing and operating commercial heated-air dryers.

Drying and rapid cooling of this tough grain in place in storage, with unheated forced air, would be advantageous. Conventional aeration systems in upright bins are not satisfactory for this purpose, however, because they are designed to move air vertically through the entire depth of grain, and the volume of air needed to do the drying job would require excessive fan power. Consideration was therefore given to use of crossflow aeration to condition newly harvested grain or other grain too moist for safe storage. With a crossflow aeration system, the air is moved horizontally across the bin instead of vertically through the much greater grain depth. With the shorter horizontal path, the airflow rate can be increased to 5 to 10 times the rate normally used for aeration without increasing the fan power required. To perform satisfactorily, a crossflow system must provide a reasonably uniform airflow throughout the entire depth of stored grain that is at different densities because of the varying degrees of packing that occur at different grain depths.

A number of crossflow aeration systems are in use in deep upright storages where the bin height is three or more times the bin diameter. In crossflow installations, air normally is distributed through the grain by use of two vertical, perforated ducts mounted opposite each other on the interior of the bin walls. Most crossflow systems currently in use are equipped with one fan to move air through the stored grain.

A series of tests was conducted in the Hard Winter Wheat area to determine the requirements for, and the limitations of, a two-fan crossflow ventilation system for conditioning warm grain sorghum and wheat having moisture contents 1 to 2 percent too high for safe storage when received at country elevators.

DESIGN OF THE TWO-FAN CROSSFLOW SYSTEM

Through a working agreement with a cooperator located at Abilene, Kans., a prototype two-fan crossflow system was installed in a 25,000-bushel bin in the headhouse of a 2-million-bushel concrete upright elevator. The depth of the test bin was 140 feet and the inside diameter 17 feet.

Two vertical semicircular perforated ducts of uniform cross section throughout their entire length were mounted opposite each other on the interior of the bin walls (figs. 1 and 2). The fans used were 7-1/2 hp. vane-axial fans of the crop-dryer type. One was placed on the bin roof (fig. 3) to push air down into one duct and then horizontally through the grain. The other fan was installed near the bottom of the second duct (fig. 4) to pull air horizontally through the grain, and then to exhaust it to the outside.

The ducts had a radius of 16 inches and were made of perforated, standard corrugated 14-gage metal. A solid section of corrugated duct, 15 feet long (fig. 5), was installed on top of the 117-foot-long perforated inlet duct to prevent short-circuiting of the air through the upper layers of grain in the bin. The exhaust duct (fig. 6) was 101 feet long.

The duct sections were securely anchored to the bin walls by 1/2-inch by 5-inch stud bolt expansion anchors set 2 to 3 inches deep into the concrete walls. Lead sleeves were solidly packed around the bolt heads set into the wall. The anchors were spaced approximately 21-3/8 inches, center to center.

TEST PROCEDURES

The crossflow system was tested with newly harvested grain sorghum and wheat during three harvest seasons. The test bin was filled with grain and emptied each time by normal grain elevating and conveying equipment. The ventilation system was operated and grain was held in the bin for varying lengths of time. Operation of the system was manually controlled. Airflow resistance pressure and electric power requirements of the system were measured. Electric power requirements for the vane-axial fans were checked several times by using

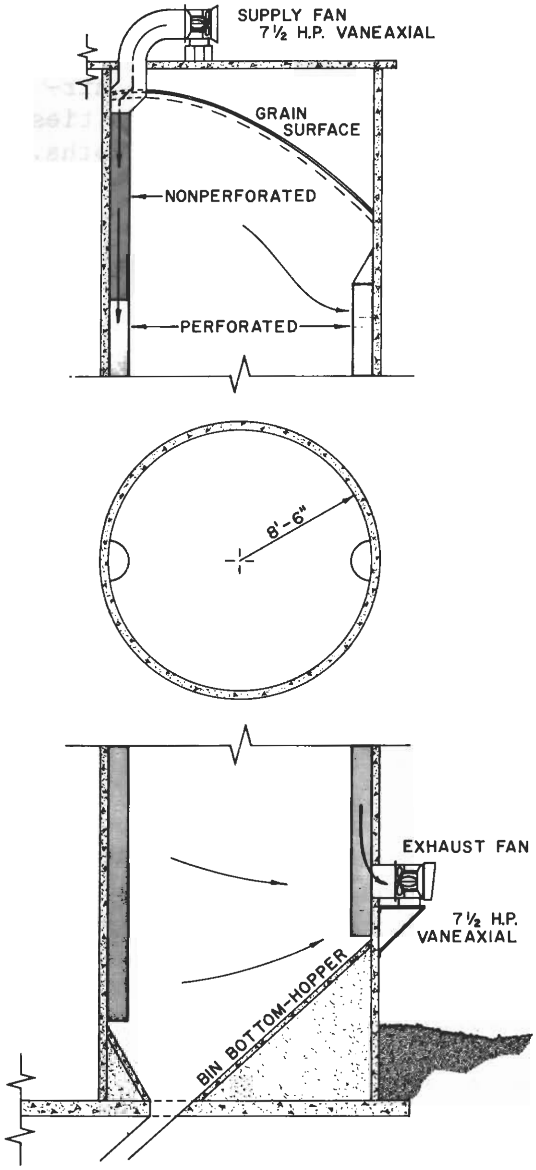

Figure 1.--Prototype two-fan crossflow ventilation system in bin 140 feet deep. Direction of airflow is indicated by arrows.

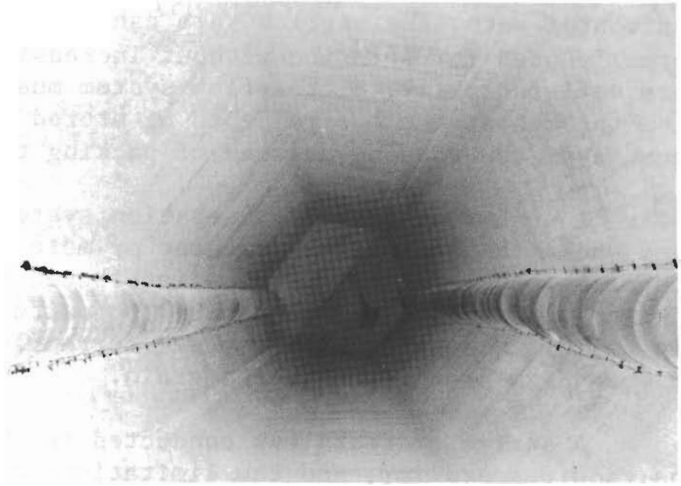

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Figure 2.--Vertical perforated crossflow ducts installed in the bin, as viewed from the top of the bin.

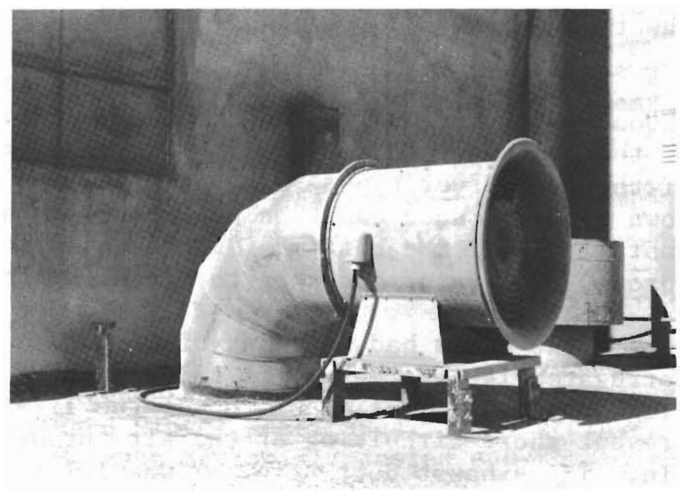

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Figure 3.--Inlet fan located on bin roof connected to a 23-inch diameter elbow and transition supply pipe.

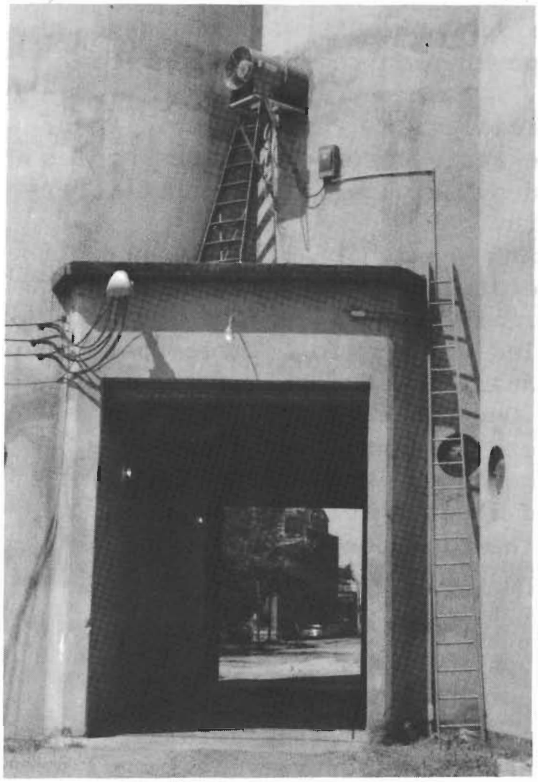

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Figure 4.--The 7-1/2 hp. vane-axial crop-dryer fan installed in an exhaust position on the exterior wall over the head-house driveway.

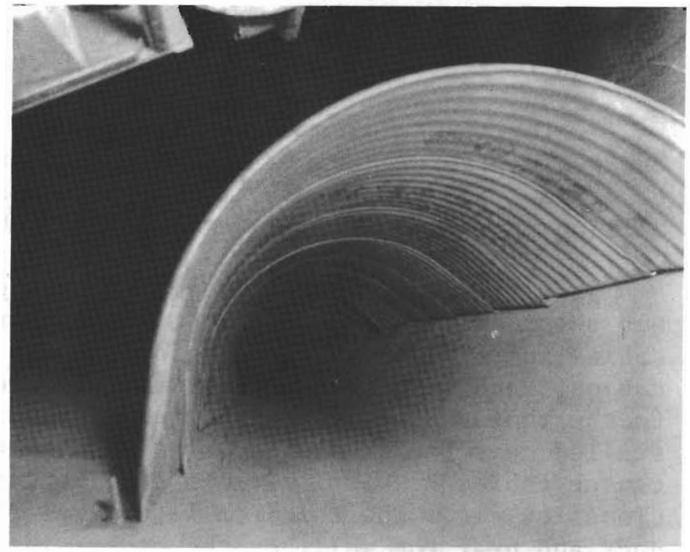

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Figure 5.--Installed solid sections at top of the inlet duct. A transition supply pipe and elbow were used to connect inlet duct to fan on roof.

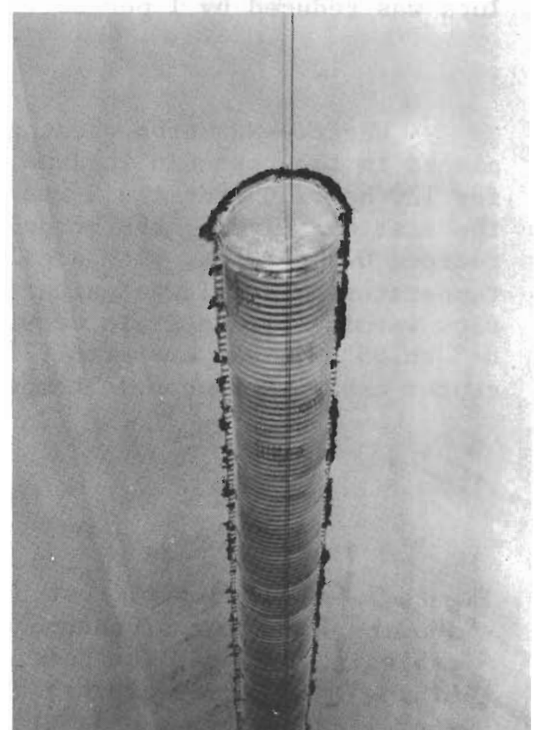

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Figure 6.--Inside surface of bin wall showing the upper end of perforated exhaust duct and a cone-shaped closure section.

an electric power analyzer. The 3-phase power line circuit was connected through the instrument to check the electric power requirement of each fan.

The moisture content, temperature, official grade, and fat acidity of the grain were determined before and after the tests, from composite samples of grain. The composite samples were obtained by sampling at 5-minute intervals during the filling and emptying of the bin.

The temperature of the grain during operation of the ventilation system was recorded by an electronic multipoint recorder connected to thermocouple cables installed in the bin before it was filled with grain. Three thermocouple cables, each with 18 junctions spaced 7 feet apart on the cable, were fastened to the roof and let down into the empty bin. One cable, A (fig. 7), was installed near the exhaust duct and about 14 feet from the inlet duct. The center cable, B, was located midway between the ducts in the direct path of crossflow air. The third cable, C, was placed about 7 feet from the inlet duct and near the wall, on the other side of the bin from cable A.

RESULTS

1963 Tests

Table 1 shows the official grade, moisture content, fat acidity, and temperature of four lots of grain sorghum held for periods varying from 1 week to 2 months and ventilated for 65 to 186 hours in the test bin. The official grade of each lot was maintained or improved. Moisture content of two of the lots was reduced by 1 percent.

1964 Tests

Wheat.--New crop wheat grading no. 1 HW (Tough) (lot A in table 2) was placed in the test bin in June 1964. Beginning June 23, the fans were operated for 120 hours during the 2-week test, mainly during the day. At completion of the test on July 10, the grade was No. 1 HW (table 2). Moisture content was reduced 0.9 percent, with a calculated weight loss of 7 tons of water. Grain temperatures were lowest after 25 to 30 hours of fan operation; after 60 hours, slow warming of the grain occurred. The initial grain temperature ranged from 84° to 95° F., and averaged 92° F. After 30 hours of fan operation, all center cable thermocouple temperatures were below 80° F.

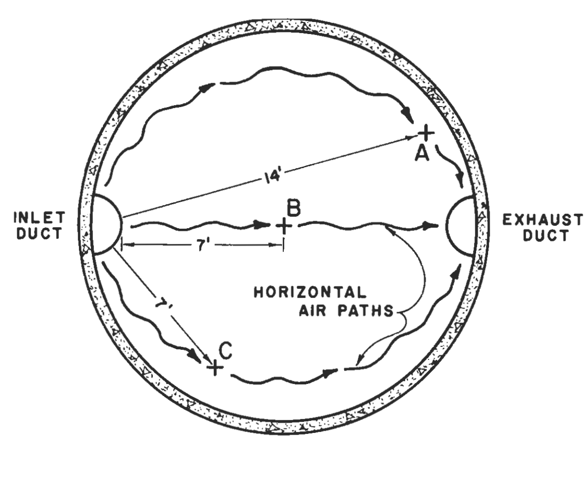

Figure 7.--Plan view of test bin showing locations of thermocouple cables A, B, and C for determining grain temperatures; horizontal paths through the grain are also shown.

Table 1.--Moisture content, temperature, and quality of grain sorghum in 4 tests of crossflow ventilation in a deep bin, fall 1963

Item	Test lot A Fan operation, 65 hours; 79° F., av. outside temp., 64% relative humidity		Test lot B Fan operation, 159 hours; 75° F., av. outside temp., 38% relative humidity		Test lot C Fan operation, 186 hours; 75° F., av. outside temp., 45% relative humidity		Test lot D Fan operation, 160 hours 1/	
	Start Sept. 12	Stop Sept. 20	Start Sept. 21	Stop Oct. 4	Start Oct. 5	Stop Oct. 28	Start Oct. 29	Stop Dec. 30
Moisture content--percent..........	15.0	14.6	14.7	13.7	13.8	12.8	14.0	13.2
Official grade--number...........	3 Yel.	3 Yel.	3 Yel.	2 Yel.	2 Yel.	2 Yel.	2 Yel.	2 Yel.
Temperature, representative grain--degrees F.	87	78	82	68	89	67	73	46
Temperature, exhaust air from grain--degrees F.	85	75	79	62	77	69	73	44
Fat acidity--units...........	22.8	22.2	24.6	28.1	--	--	38.3	40.2

1/ Average outside air temperature and relative humidity were not obtained.

Table 2.--Moisture content, temperature, and quality of wheat in 3 tests of crossflow ventilation in a deep bin, summer 1964

Item	Test lot A Fan operation, 120 hours; 86° F., av. outside temp., 42% relative humidity		Test lot B Fan operation, 24 hours; 86° F. av. outside temp., 35% relative humidity		Test lot C Fan operation, 24 hours; 68° F., av. outside temp., 48% relative humidity	
	Start June 23	Stop July 10	Start July 14	Stop July 15	Start Aug. 1	Stop Aug. 2
Moisture content--percent	14.2	13.3	12.2	11.9	12.4	12.4
Temp., representative grain--degrees F.	92	82	92.5	84	87.5	72
Temp., exhaust air from grain--degrees F.	92	80	92	85	89	74
Official grade--number	1 HW Tough	1 HW	1 HW	1 HW	1 DHW	1 DHW
Protein--percent	11.25	12.00	11.80	12.00	12.60	12.75
Sedimentation--value	43	44	41	39	55	50
Fat acidity--units	11.3	13.3	14.6	15.3	--	--

The bin was filled with another lot of new crop wheat (lot B) on July 14, 1964. This wheat ranged in moisture content from 11.4 to 13.0 percent and averaged 12.2 percent. The grain temperature ranged from 82° F. to 104° F. and averaged 92.5° F.

The fans were started at noon on July 14 and operated continuously for 24 hours. Figure 8 shows the temperature at three locations in the grain and the temperature of the outside air during this period. Atmospheric conditions were fair to cloudy during the period, and the average relative humidity was 35 percent. Grain temperatures at the end of 24 hours of operation ranged from 76° to 92° F. and averaged 84° F. Air temperature at the exhaust from the grain was near 91° F. during the first 10 hours of the test. After 12 hours

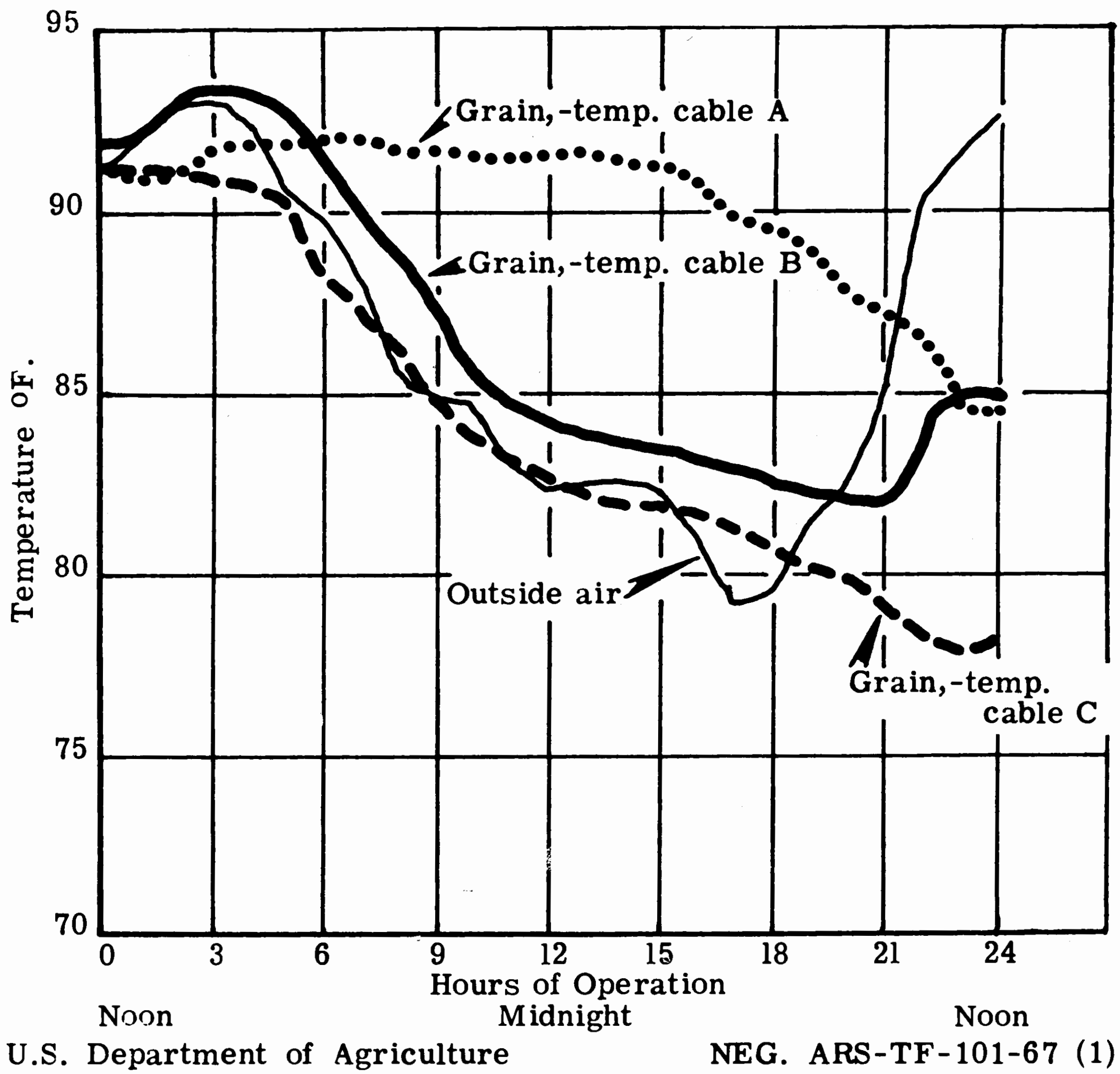

Figure 8.--Wheat and air temperatures during 24 hours continuous operation of the crossflow ventilation system, July 1964.

(at midnight), the exhaust temperature was 90° F., and it decreased gradually to 85° F. at 8:00 a.m. where it remained until noon when the fans were turned off. There was no appreciable change in moisture content during the 24-hour test.

New crop wheat was transferred to the test bin from an annex storage bin for the third test (lot C). This good quality new crop wheat grading No. 1 DHW had an average moisture content of 12.4 percent. The initial grain temperature averaged 87.5° F.

The fans were run continuously for 24 hours when air temperatures averaged about 68° F. and the relative humidity about 48 percent. At the end of 24 hours the average grain temperature was 72° F., with a range from 65° to 78° F. This was an average reduction of 15.5° F. in grain temperature (fig. 9). There was no measurable change in the moisture content of the wheat.

Grain Sorghum.--In October, 25,000 bushels of new crop grain sorghum averaging over 14 percent moisture (range 12 to 18 percent) and 74° F. were used in a test. After 62 hours of fan ventilation the grain temperature averaged 61° F. and the moisture content 13.6 percent.

In November, a second lot of new crop grain sorghum having an initial average moisture content of 13.4 percent and an average temperature of 73° F. was ventilated. After 64 hours of fan operation the average temperature was 53° F. and the moisture content 12.8 percent.

In December and January a third lot, having an initial moisture content of 14 percent and a temperature of 40° F., was used. After 45 hours of ventilation grain temperatures averaged 25° F. and after 112 hours the moisture content averaged 13.6 percent.

1965 Tests

Wheat.--The test bin was filled and used for three 25,000-bushel lots of new wheat grading Tough. The first lot had an initial moisture content of 14.1 percent before ventilation and 13.3 percent afterwards; the calculated amount of moisture evaporated was 11,400 pounds. The fans were operated 124 hours during daylight working hours. The initial cooling front moved through the wheat directly between the inlet and exhaust ducts, where the air path was the shortest, in 22 hours, but it required 30 hours for the front to move through the wheat near the bin walls, where the air paths were much longer (see fig. 7).

The second lot contained 14 percent moisture before ventilation and about 13 percent afterwards. Fans were operated continuously for 8 days to obtain 178 hours of ventilation. The calculated amount of moisture evaporated was 16,200 pounds. The initial average grain temperature was 91° F. and the final average was 73° F., a reduction of 18° F.

The third lot of tough wheat was loaded into the test bin on July 31 for cooling and storage until transfer to a flour mill. The grain had an average initial temperature of 87° F. and was cooled to an average temperature of 76.5° F., using 88 hours of fan operation.

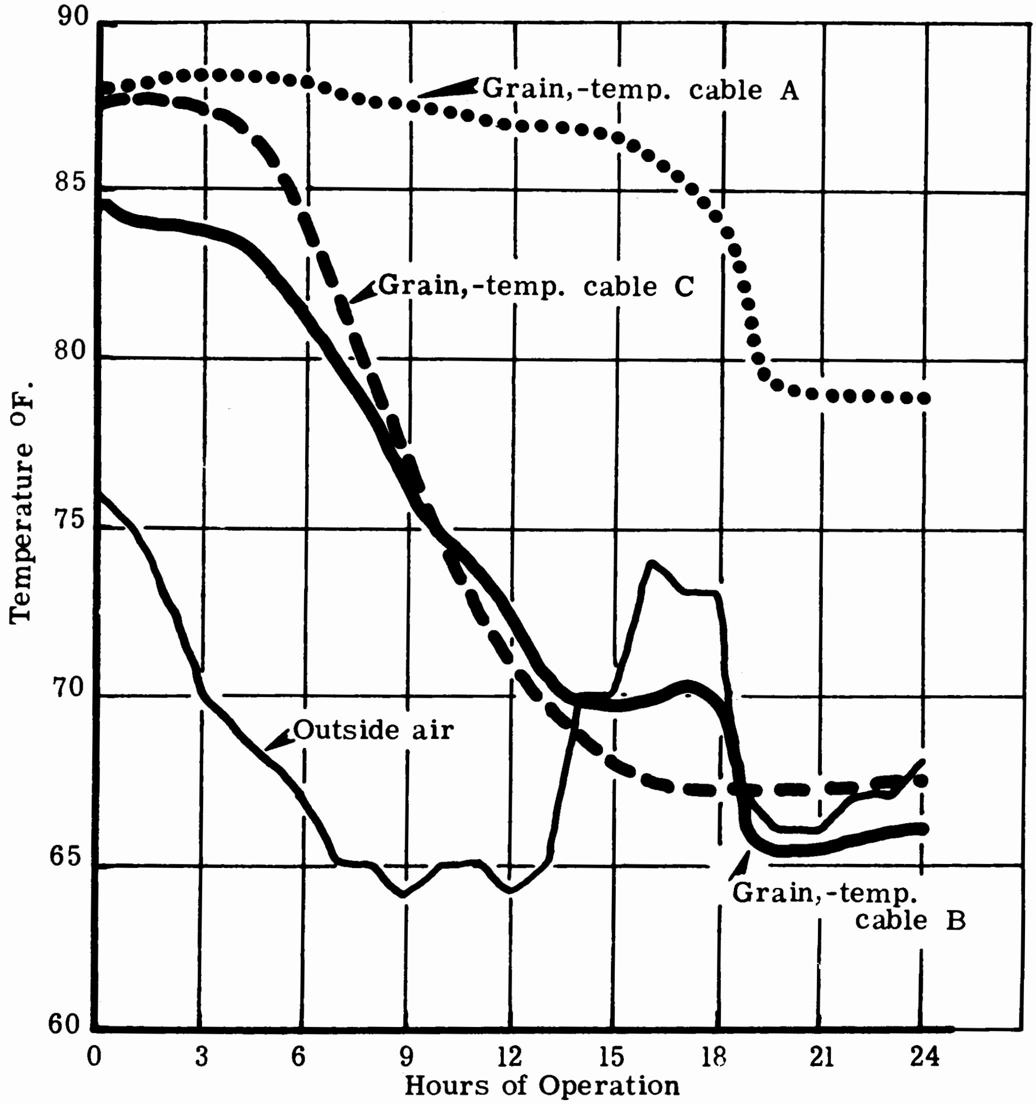

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Figure 9.--Wheat and air temperatures during 24 hours continuous operation of the crossflow ventilation system, August 1964.

Grain Sorghum.--In 1965, the crossflow system was also used for four lots of new crop grain sorghum which were too wet for storage without aeration or drying. An average of nearly 370 pounds of water per hour was removed during the first 24 hours of fan operation, and only 25 pounds per hour after 60 hours of operation when the grain temperature was near the air temperature.

SYSTEM PERFORMANCE

The duct system has remained securely in place after three seasons of operation of the system. During this period the bin has been filled about 18 times with wheat and grain sorghum, totalling around 475,000 bushels.

Airflow resistance pressures measured in the duct system with the bin filled with wheat are shown in figure 10. Pressures were measured during operation of the system for full bins of wheat and of grain sorghum. The difference in pressure between the two grains was small. With two fans operating, the total working crossflow pressure ranged from 4 inches water gage in the top 20 feet of the bin to 5 inches toward the bottom of the bin. The pattern of horizontal air path through the stored grain approximated that shown in figure 7.

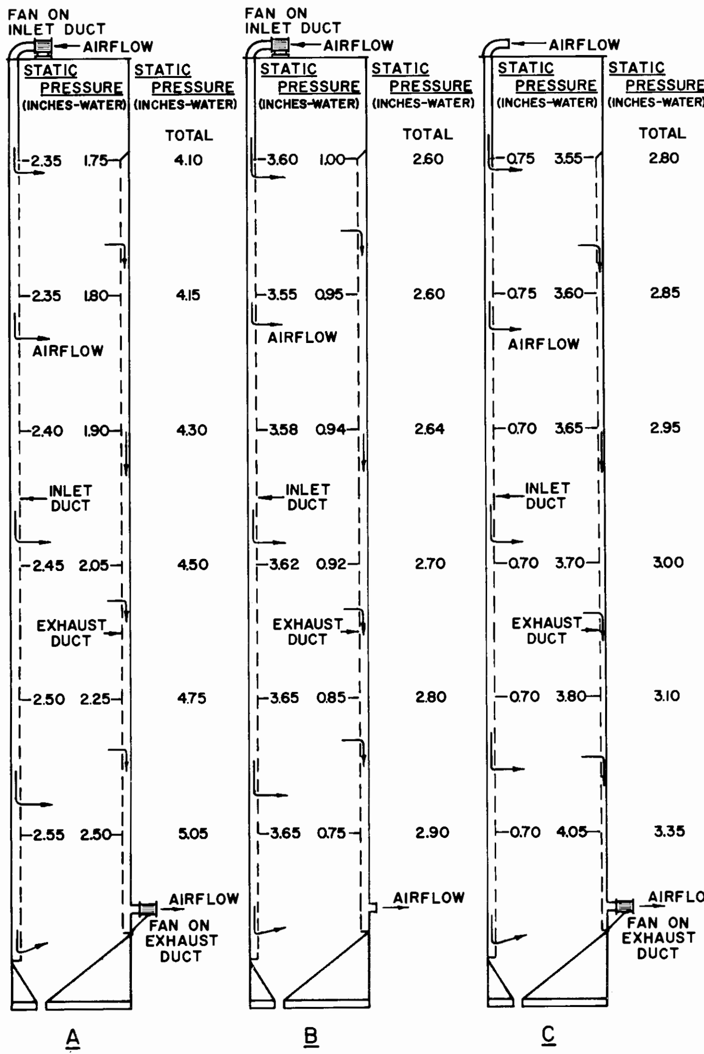

Figure 10.--Static air pressures measured at 20-foot intervals in vertical duct system of test bin filled with wheat: (A) both fans operating; (B) inlet fan only operating; (C) exhaust fan operating. (Bin diameter, 17 feet, height, 140 feet.

According to certified fan performance ratings of the manufacturer, airflow through the system was approximately 10,000 cubic feet per minute, for an average of nearly 1/2 c.f.m. per bushel.

Data on electric power requirements of the fans were obtained for both test grains with one fan running and with both fans running (table 3). Readings were taken on individual fans, but normal operation of the system, for both wheat and grain sorghum, was with both fans running. Power consumption was about 13 kilowatts per hour.

The effectiveness of the system for crossflow movement of air in a deep bin was determined by grain temperature changes during continuous fan operation tests. All tests showed excellent temperature uniformity vertically along each temperature cable throughout the depth of the grain. Grain located horizontally the greatest distance from the inlet duct along the radial air paths was the slowest to cool and required about 18 hours of fan operation before any appreciable temperature changes were noted (figs. 8 and 9).

INSTALLATION AND OPERATING COSTS

The estimated cost for material, equipment, and installation of the prototype two-fan crossflow system in a 25,000-bushel bin at Abilene, Kans., in 1964 was $5,400. 1/ This included the required steel corrugated duct sections and stud bolt anchors, two 7-1/2 hp. vane-axial, grain-drying fans, electric wiring and motor starters, labor and installation charges, and other necessary miscellaneous charges. It is not known how this estimate would compare with the cost of a similar two-fan system supplied and installed as a package unit by grain aeration companies. However, such information should be available from the companies for similar installations for upright storages of various sizes and capacities.

The $5,400 represents an investment cost of 21.6 cents per bushel of storage. The system can be used for at least 10 lots of grain annually, or 250,000 bushels, to make a proportional investment of about 2 cents per bushel.

The power cost per 25,000 bushels of grain is determined by the total hours of fan operation. The fans require about 13 kilowatts per hour; at 4 cents per kilowatt, the cost per hour would be about 50 cents. Assuming 100 hours of operation for a bin of newly harvested grain, the power cost would be $50 for 25,000 bushels or 0.2 cent per bushel.

DISCUSSION

The many tests conducted with this prototype two-fan crossflow system have demonstrated its potential application for conditioning moist, warm grain in deep storages. The well-anchored, perforated corrugated duct sections were found to be sufficiently strong to withstand both the static and dynamic pressures of the grain during the many loadings and unloadings involved in

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1/ The cost in 1967 would probably be 8 to 10 percent higher.

Table 3.--Electric power requirement of the fans, crossflow ventilation system, in tests with the bin filled with grain.

Test grain and operation	Inlet fan			Exhaust fan			Both fans, power consumption rate
	Current	3-phase voltage	Power consumption rate	Current	3-phase voltage	Power consumption rate	
	Amperes	Volts	Kilowatts	Amperes	Volts	Kilowatts	Kilowatts
Wheat:							
One fan.......	7.98	472	5.68	8.45	475	5.95	---
Both fans.....	8.17	468	5.88	8.82	475	6.18	12.06
Grain sorghum:							
Both fans.....	8.47	480	6.25	8.95	475	6.25	12.50
Wheat:							
One fan.......	8.34	490	6.00	8.22	485	6.14	---
Both fans.....	8.78	490	6.38	8.55	490	6.25	12.63

conducting the tests. This two-fan, crossflow system, requiring not more than a maximum static pressure of 3 inches water gage per fan unit, permits use of economical vane-axial fans. At these relatively low pressures, this type of fan delivers a greater volume of air per horsepower than a more expensive centrifugal fan of the same horsepower. Tests demonstrated reasonable fan efficiency.

Static pressure data obtained show good horizontal and vertical distribution of airflow across the bin. The data indicated that the two-fan system provided reasonably uniform positive pressure throughout the length of the inlet duct and fairly even suction pressure in the exhaust duct. The design was adequate to limit duct pressure and duct frictional losses to a reasonable minimum.

Totally enclosed electric motors were used in this installation to meet the standards of construction and performance required by the National Electrical Code for conditions of atmospheres with combustible grain dust in Class II, Group G. Operating experience gained during the tests demonstrated the necessity for using a fan wheel or propeller with enclosed hubs. Since dust flows past the idle fan wheel during handling operations such as filling the bin, an enclosed fan wheel hub must be used to prevent dust from settling and causing the wheel to be out of balance when started. Such a fan is already available commercially and is used in the rice industry.

The two-fan crossflow system has all the advantages of a single-fan crossflow system over a floor-duct system for conditioning newly harvested grain. These advantages are:

1. Faster cooling rates are possible with the crossflow systems because of the higher airflow rates obtained. For example, grain in a full bin (25,000 bushels) was cooled to near atmospheric temperatures in 24 to 48 hours of continuous operation. By moving air across the bin, an airflow rate of about 1/2 c.f.m. or more per bushel was obtained.

2. The storage manager has an unheated air ventilation system suitable for removing small amounts of grain moisture (1 to 2 percent) and for equalizing moisture in the grain mass.

3. Wet grain can be held in the bin for several weeks with minimum mold damage, as an alternative to repeated turning until the grain can be moved to a dryer or blended with dry grain.

4. For some grains, the capacity of heated-air commercial dryers may be increased at harvesttime by using the crossflow system for cooling warm grain from the dryer.

5. Uniform grain temperatures can be established in 2 or 3 days.

6. An aeration cooling stage may be completed for a lower power cost per bushel than with a floor system; for example, 25,000 bushels were cooled in 30 hours at 50 cents per hour for electric power, for a total of $15 or 0.06 cent per bushel.

Data obtained from the tests conducted with the two-fan system indicate the following advantages over a one-fan system:

1. Airflow rate through the denser grain near the bottom of the bin is improved. Static pressure data obtained in the tests showed higher static pressures at the lower end of the inlet duct farthest from the inlet fan and in the exhaust duct nearest to the exhaust fan. Thus, the highest total net static pressures are available for producing a flow of air through the more dense grain in the bottom portion of the bin. Figure 10A shows an increase of nearly 1 inch in total static pressure from the top to the bottom of the bin to produce airflow through the denser grain.

2. The static pressure in the inlet duct at the point below the solid duct section, where air first enters the grain (fig. 10), is considerably lower with two fans than with one fan operating on the inlet duct, assuming the same total air volume. For example, at this level the total pressure available to move air through the grain is about 4 inches of water, but at the air entrance the measured pressure was 2.35 inches. With one fan supplying an equal volume of air into the inlet duct, the static pressure required at the air entrance point would be 4 inches plus the pressure due to the resistance in the duct. It is estimated that the total pressure required would exceed 5 inches. This added pressure would increase the problem of air short-circuiting to the upper grain surface.

3. Using two fans provides considerable flexibility in the airflow rates used for aeration or ventilation. The two fans can be used for fast cooling and removal of 1 to 2 percent of moisture from warm, moist grain, or, when fast cooling is not essential, either fan can be used individually for slower cooling of dry grain.