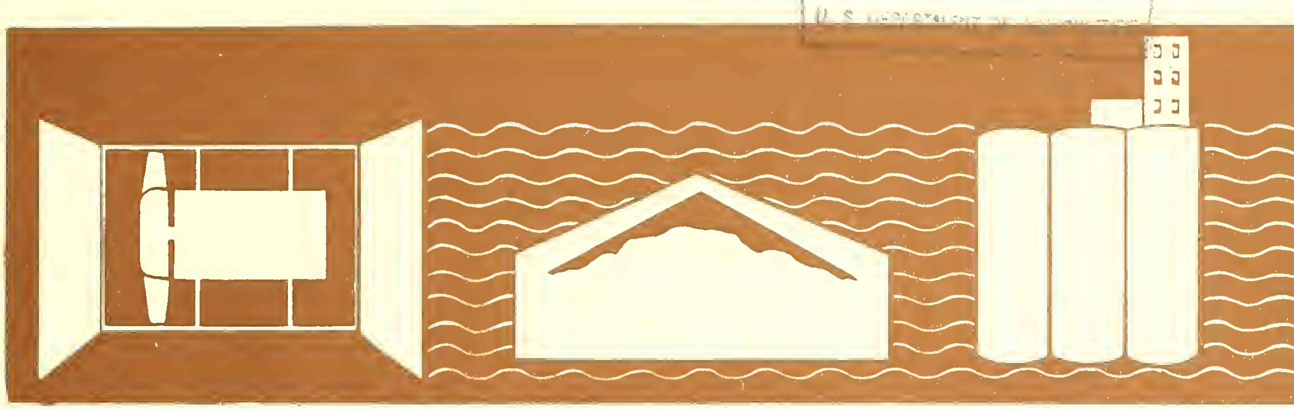

AERATION OF GRAIN

in Commercial Storages

Agricultural Marketing Service
Transportation and Facilities Research Division
in cooperation with Agricultural Experiment Stations
of Georgia, Indiana, Iowa, Kansas, and Texas

Marketing Research Report No. 178

UNITED STATES DEPARTMENT OF AGRICULTURE

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PREFACE

This report extends and brings up to date the information in Marketing Research Report No. 178, "Aeration of Grain in Commercial Storages," published in September 1957. The main purpose of this revision is to present new information obtained from research studies and industry experience since September 1957. Major revisions were made in the sections on ducts for flat storages to present information relating to designs of duct systems for the large, peak-loaded flat storages now in use. Some revisions were made in the recommended allowable air velocities within ducts and in the fan horsepower and static pressure charts. Additional examples of steps in designing aeration systems and some new illustrations were also added.

The original research was conducted in cooperation with the agricultural experiment stations of Georgia, Indiana, Iowa, Kansas, Michigan, and Texas. Studies in Iowa and Michigan have been discontinued.

This revised publication was prepared by the following agricultural engineers in the Handling and Facilities Research Branch, Transportation and Facilities Research Division, Agricultural Marketing Service:

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Reed S. Hutchison and David L. Calderwood, College Station, Tex.
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Herman F. Mayes, Watseka, Ill.
Lloyd L. Smith and Ralph W. Brown, Athens, Ga.
Dean W. Winter, Washington, D.C.

Many grain storage operators made their facilities available for the testing of experimental and commercial aeration systems and also offered helpful suggestions and criticisms. Acknowledgment is made to suppliers who loaned equipment for use in a number of the tests.

CONTENTS

AERATION OF GRAIN IN COMMERCIAL STORAGES

Compiled by Leo E. Holman, *Agricultural Engineer* [1]

Transportation and Facilities Research Division, Agricultural Marketing Service

SUMMARY

In the past grain storage operators periodically "turned" their stored grain—*moved it through the air*—to help maintain market quality. Aeration—*the moving of air through stored grain*—has become a generally accepted practice for maintaining market quality of stored grain without turning it. Aeration is applicable to all types of storages, but it is especially applicable to flat storages where it is difficult to move or turn the grain. In fact, without aeration longtime storage in flat structures is impractical. With aeration, market quality of grain is maintained without moving the grain, and wear and tear on both the grain and handling machinery is reduced. Aeration systems are also effective and efficient in applying fumigants to grain in storage.

An adequate duct system design is as important as a suitable fan. In large flat storages with "peaked" loading the design of adequate duct systems becomes even more important, and more complicated. It is always advisable to have a good engineering analysis of a proposed duct system and particularly so if the system is to be installed in a peak-loaded flat storage.

The small amount of air used for aeration is not costly to provide. The most commonly used airflow rates range from 1/20 to 1/10 cubic feet of air per minute (cfm) per bushel. These rates are generally adequate for reducing insect and mold activity and for holding moisture migration and accumulation within acceptable limits. Rates as high as 1/4 cfm per bushel are sometimes used in flat or shallow storages where more rapid cooling is desired. Airflow rates as low as 1/100 cfm per bushel were successful in preventing any appreciable moisture migration and accumulation in dry (12.2 percent moisture) shelled corn in the Northern Corn Belt. Recommended airflow rates for each area should be followed for best results.

The installed cost of aeration systems ranges from 1 to 5 cents per bushel capacity, depending on the size of the storage, the type of system, ease of installation, and other contributing factors. This cost can be prorated over a period of years. Normal operating (power and labor) costs range from 1/10 to 1/2 cent per bushel per year. Power and labor costs for turning grain 4 times a year range from 1/2 to 1 1/2 cents per bushel for the 4 turns.

Aeration usually is accomplished by pulling outside air downward through the grain and exhausting it through the fan. For summer cooling in Southern areas there may be some advantage in forcing the air upward through the grain; the heat trapped under the storage roof then is moved out without passing through the grain. There is little or no difference in power requirements and operating costs for pulling or pushing air through stored grain. Many fan assemblies can be changed on the aeration system to either pull or push air as the operator desires.

The fan horsepower required for aeration varies with the kind of grain, its stored depth, and the airflow rate per bushel. One horsepower will aerate up to 20,000 bushels of shelled corn 100 feet deep at 1/20 cfm per bushel. The same horsepower will aerate only about 5,000 bushels of wheat 100 feet deep at the same airflow rate.

Generally it is desirable to start cooling summer harvested grain as soon after storing as air temperatures will permit. Aeration to prevent moisture migration should be started early in the fall to keep the temperature of the grain close to the average temperature of the air throughout the fall season. A grain temperature not much below 45° to 50° F. generally is suggested if there is a chance that grain will be moved during the hot weather; otherwise, grain temperatures of 35° to 45° F. have been satisfactory.

The time required to cool a specific lot of grain by aeration depends on the airflow rate used, methods of operation, uniformity of airflow through the grain, and amount of evaporative cooling and other similar factors. Grain aerated at an airflow rate of 1/10 cfm per bushel, and under favorable conditions, can be cooled to near the existing air temperature in about 80 hours in the summer, 120 hours in the fall, and 160 hours in the winter. The total elapsed time, in days or weeks required, will depend on the daily hours of operation. Total aeration time per year for a lot of stored grain depends on the number of cooling stages.

It should not be assumed that aeration is an answer to all grain storage problems. Aeration may not completely eliminate all "turning" of stored grain but it should be considered in future grain storage programs. It can be an important practice in maintaining the market quality of stored grain and in minimizing handling costs.

[1] This report was compiled from material prepared by agricultural engineers who are listed in the Preface.

BACKGROUND INFORMATION

Preservation of grain quality has always been a problem to the grain warehouseman. This problem has increased as stocks of grain have accumulated in commercial elevators including flat storage annexes, converted oil tanks, airplane hangars, and other emergency storages. The storage period also has been lengthened. Aeration is being successfully used by many commercial storage operators to help solve this enlarged storage problem.

Grain storage operators have long followed the practice of "turning" grain—*moving it through the air*—when it is stored for more than a few weeks. To turn grain, conveying equipment and empty storage space are needed. During turning operations, considerable grain breakage and shrinkage generally occurs. As grain is in motion through the air for only a short time, ordinarily 1 minute or less, repeated turnings are necessary to accomplish satisfactory cooling of warm grain. Both research results and industry experience have demonstrated that aeration can accomplish results that are equal to or better than turning, and at less cost.

In some storages, a blast of cooling air is moved through the grain while it is run through a drier. This method is more effective than turning but it still involves moving the grain.

High moisture and caked grain can be removed by topping, although this generally does not solve the moisture accumulation problem as new layers of caked grain are likely to form again. Also the grain surface can be stirred periodically but this is a costly and questionable measure for preventing surface spoilage.

PURPOSE

This publication covers: (1) The design, selection of equipment, and installation of grain aeration systems; (2) the operation of such systems; (3) ownership and operating costs; and (4) examples of installations.

One of its purposes is to provide information on the design, selection, and installation of aeration systems for use by commercial grain storage operators who are considering the installation of aeration equipment or modification of existing systems. This information also should be useful to design engineers, equipment suppliers, and others who may assist storage operators in designing, selecting, and installing equipment. The data on operating criteria should be of interest and value to those who now have aeration systems as well as those who plan to install such systems. The same is true of the material costs. Examples of installations are given to suggest steps that should be helpful to engineers and others in designing and installing aeration systems.

This publication is not intended to cover farm storage installations. However, some parts of the report may be of value to those interested in the storage of grain on farms.

DEFINITION OF TERMS

Terms generally familiar to the grain trade are not defined or explained. Certain terms which may be unfamiliar to some readers, and terms used in a special sense, are defined below:

Aeration.—The moving of air through stored grain at low airflow rates (generally between 1/20 and 1/10 cfm per bushel), for purposes other than drying, to maintain or improve its value.

Duct.—A chamber in the grain through which air is moved into or out of the grain. This chamber also is commonly referred to as a collector, tunnel, aeration duct, air duct, plenum chamber, etc.

Supply pipe.—A tight-walled pipe or tube for conveying air between the fan and duct.

cfm.—An abbreviation used in expressing "cubic feet of air per minute," the designation for the volume of air being moved.

Static pressure (S. P.).—A measure of the force or pressure that must be exerted on air to move it through grain and the aeration system. It is used in determining fan and horsepower requirements and in fan ratings furnished by fan manufacturers. Static pressure usually is measured in inches of water. See Appendix.

Upright storage.—Any storage where the height is greater than the diameter or width. This type of storage also is commonly referred to as a deep bin, tank, silo, cell, or vertical storage.

Flat storage.—Any storage where the height is less than the diameter or width. These storages also are referred to as horizontal storages.

Grain.—All cereal grains, oil seeds, and other seeds unless otherwise designated.

Cooling zone.—That portion of the grain mass in a storage where the temperature is falling during aeration.

Cooling stage.—The time required to move a cooling zone entirely through a lot of stored grain.

USES OF AERATION

COOLING STORED GRAIN TO PREVENT OR MINIMIZE MOLD GROWTH AND INSECT ACTIVITY

Cooling stored grain to prevent mold growth and insect activity includes removal of both natural heat and heat from artificial drying. Aeration for these purposes is widely used in the areas of summer harvest. In the summer, grain often goes into storage at 90° F. or higher and should be cooled as soon as atmospheric conditions permit. Grain going into storage during the fall months also should be cooled.

There is no one optimum storage temperature for grain. The moisture content of the grain, its probable use (for food, feed, oil, seed), and the length of the storage period (weeks, months, or years), are factors that determine the desirable storage temperature.

Most grain molds grow slowly or not at all below 70° F. when grains have moisture contents in line with those shown in table 4.[2] Insect reproduction is stopped, or nearly so, at temperatures below 60° F. Moreover, many insects die from starvation when grain temperatures drop to 40° F. for any length of time. Most species, excluding moths, are killed in 2½ months' time at a temperature of 35° F.[3] (Although aeration is useful in providing lower grain temperatures that help to prevent serious insect infestation and consequent grain loss, it will not entirely replace fumigation and other direct means of insect control.)

EQUALIZING STORED GRAIN TEMPERATURES TO PREVENT MOISTURE MOVEMENT FROM WARM TO COOLER GRAIN

Temperatures of stored grain are equalized to prevent moisture from moving from warm to cooler grain. This moisture movement is normal in any storage where appreciable variations in grain temperatures exist, but it is most pronounced in the colder, northern areas of the United States. During the fall and winter months grain located near exposed walls and upper surfaces cools more rapidly than that in the center of the bin. This temperature difference causes slow convection currents in the bin with the warm air, which rises through the center of the grain mass, carrying moisture from the warmer grain to the colder surface grain. Moisture accumulation may be serious enough to cause molding and crusting on the grain surface and spoilage in other parts of the bin. In stored grain having uniform temperatures, moisture migration does not take place.

REMOVING ODORS FROM STORED GRAIN

The "fresh" grain smell is one of the most striking characteristics of aerated grain. Molding and rancidity of grain causes common storage odors. This condition is minimized by cooler grain temperatures and aeration will either remove or reduce such odors. Some odors can be rapidly dissipated with only a few air changes, while others are more persistent and require longer periods of aeration. Some odors are removed only temporarily or reduced in intensity by aeration. Sour or fermented odors are seldom removed entirely by either aeration or drying. Also, the dissipation of odors from stored grain does not assure freedom from molding and rancidity.

Although little factual information is available in regard to the operational requirement for removing odors, fans usually are operated from 30 minutes to 1 hour, or longer, once every 2 to 4 weeks, or whenever the operator thinks it desirable. With airflow rates recommended for aeration, from 5 to 20 minutes are required for one complete change of air in the stored grain.

APPLYING FUMIGANTS TO STORED GRAIN[4]

The introduction of fumigants through an aeration system is a practical method of fumigating grain. The distribution of fumigants is usually more uniform, and the dosage required less, than for gravity methods. The fumigants may be purged from the grain after a prescribed exposure period by operating the fan for a few hours.

With uniform airflow the fumigant can be introduced into the grain in about the time required for one air change. It is desirable to allow from 10 to 20 minutes to meter the fumigant into the airstream, which requires an airflow rate of from 1/20 to 1/10 cfm per bushel. Higher airflow rates can be used in a closed system where the fumigant can be recirculated through the grain.

Optimum grain temperatures for effective and economical application of fumigants differ according to the method of application. When applied with no aeration to the surface of stored grain the grain temperatures should be at least 65° F. This is necessary for gravity penetration of fumigant to the bottom of the grain bulk in killing concentrations. Grain temperatures are less important when fumigants are applied with aeration. The fumigant can be effectively distributed to all portions of the grain bulk under a fairly wide range of grain temperatures.

HOLDING MOIST GRAIN IN STORAGE FOR BRIEF PERIODS

Aeration reduces the hazard of spontaneous heating when it is necessary to hold moist grain in storage for brief periods. Continuous aeration removes heat generated by mold growth, the principal source of heat, and also helps to

[2] Carter, Edward P., and Young, George Y. Effect of Moisture Content, Temperature, and Length of Storage on the Development of "Sick" Wheat in Sealed Containers. Cereal Chem. 22:418–428, Sept. 1945. Tables 1 to 5.

[3] U.S. Department of Agriculture. Control of Insect Pests of Grain in Elevator Storage. Farmers Bulletin 1880.

[4] Phillips, G. L. Grain Fumigation, Agr. Chem. X(1): 55–56, 117–121; X(2): 41–43, 133–135, Jan., Feb., 1955.

Phillips, G. L. Experiments on Distributing Methyl Bromide in Bulk Grains with Aeration Systems, AMS–150, 1957.

Phillips, G. L. Experiments on Distributing Liquid Grain Fumigants in Bulk Grains with Aeration Systems. AMS–151, 1957.

Phillips, G. L., Experiments on Distributing HCN in Bulk Grain with Aeration Systems, AMS–152, 1957.

Phillips, G. L., Whitney, W. K., Storey, C. L., and Walkden, H. H. Bulk Cocoa Bean Fumigation for Tobacco Moth: Gravity Penetration vs. Recirculation Pest Control 6(27): 39–42, 44, June 1959.

Redlinger, L. M. Studies on Fumigating Rice in Flat Storage by the Forced Circulation Method Rice Jour., 60(3): 18–23, March 1957.

slow down mold growth and other deterioration by reducing grain temperature. However, definite upper limits of moisture and temperature have not been established for moist grain under aeration.

Aeration may be used during periods of heavy receipts of moist grain. By providing safe holding conditions, the load on the drier can be spread out and more grain handled during a given harvest period.

DESIGN, SELECTION OF EQUIPMENT, AND INSTALLATION OF AERATION SYSTEMS

The principal parts of an aeration system and their functions are: (1) One or more fans to supply the necessary air at the required static pressure; (2) ducts to move air into or out of the stored grain; (3) supply pipes to connect the fans and ducts; (4) a motor to operate each fan; (5) controls to regulate the operation of the fan; and (6) the storage in which the system is installed.

Before designing a system and selecting aeration equipment, the operator should consider: (1) What types of grains are to be aerated; (2) the kinds of storage structures in which the system is to be installed; (3) the airflow rate per unit (bushel, barrel, etc.) to be provided; and (4) the number of storages or the quantity of grain to be serviced by each fan. After these points have been considered determinations should be made as to: (1) Total air volume to be supplied; (2) the static pressure against which the fan must operate; (3) size and type of fan and motor needed; and (4) the kinds of ducts and supply pipes needed. The following information on types of systems and airflow, fan, duct, and power requirements is provided to help in making these determinations.

TYPES OF SYSTEMS

Several combinations of fans and ducts can be used to supply and distribute the air needed for satisfactory aeration of grain in upright and flat storages.

A **fixed fan** for each storage or for each duct in a storage is simple, versatile, and efficient (fig. 1). However, this method is relatively expensive since several small fans and motors cost more than a single fan and motor delivering the same volume of air. The cost of electric wiring will also be greater. Another disadvantage is that fumigants must be introduced into each individual storage unit.

In a **manifold system** one fixed fan can be connected to two or more storages or ducts with one manifold (fig. 2). This system is flexible, as the bins connected to the manifold can be aerated all at one time, severally, or singly by using slide gates or dampers in the supply pipes. This type of installation should cost less and is more convenient because only one switch is required. However, such installations may result in the inefficient use of a relatively large fan and motor when all units on the system are not being aerated. Also, some loss in air pressure usually occurs around the slide gates or dampers in the supply pipes. The loss of pressure due to friction in the long manifold reduces the volume of air delivered by the fan. A return pipe for distributing fumigants usually can be added to this system. Fumi-

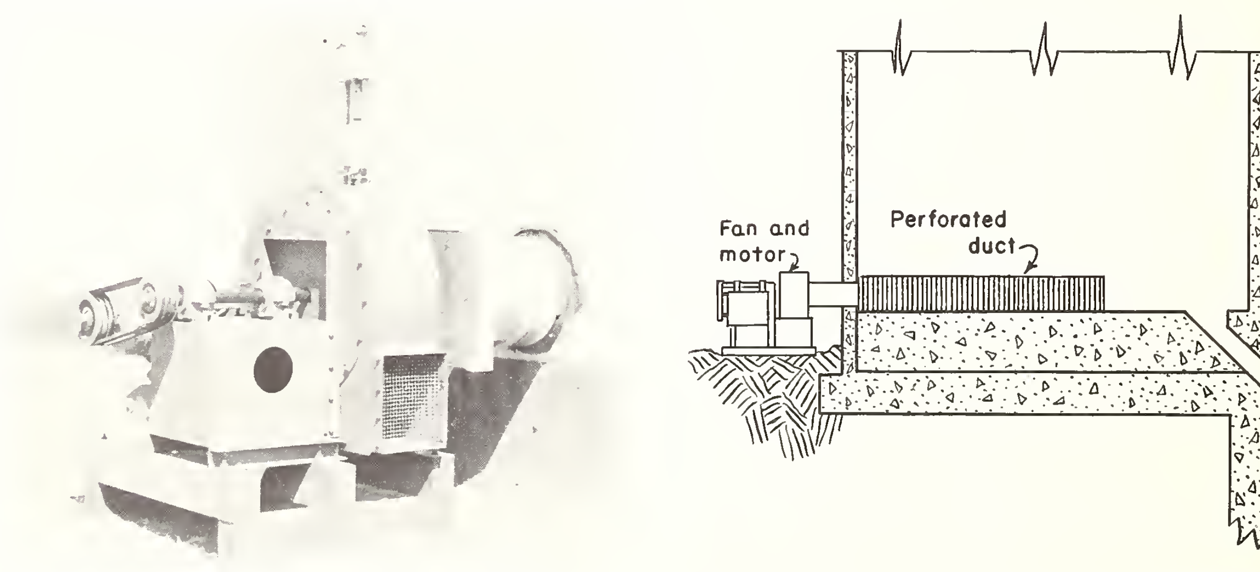

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FIGURE 1.—Aeration system for upright storage with flat bottom. A single aeration duct is shown.

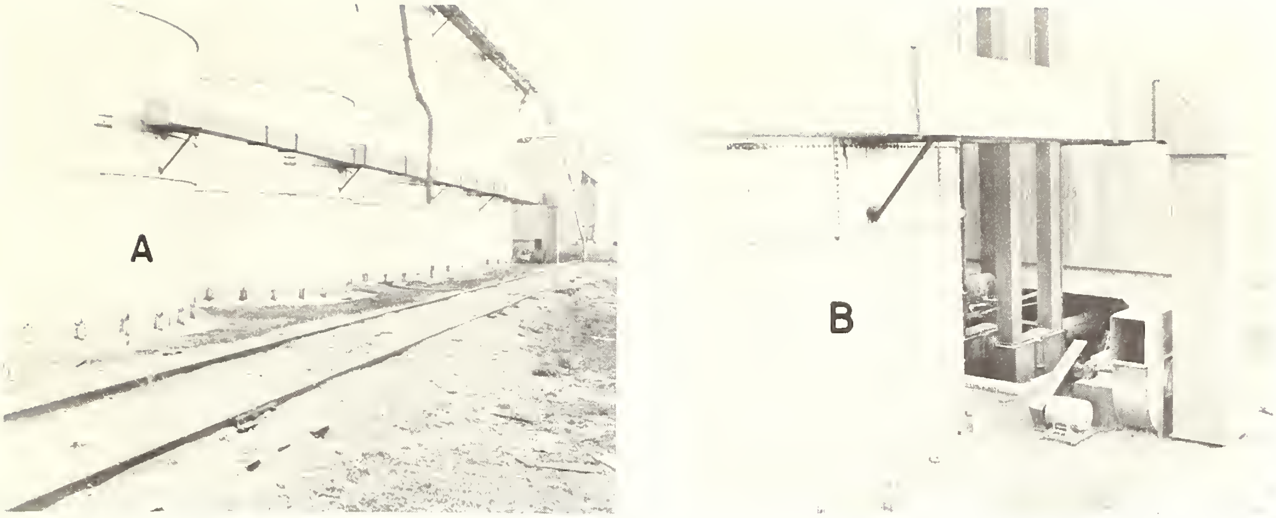

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FIGURE 2.—Manifold system for upright storage (*A*), closeup of fan (*B*).

gants can be introduced into several storages simultaneously.

A **portable fan** can be used to aerate several storages or parts of storages at a smaller initial cost (fig. 3). Even with the fan and motor mounted on wheels, however, this type of installation is inconvenient as it will have to be moved about frequently. A well-designed metal connector, adjustable to any angle and with a telescoping joint permitting adjustment in length, should be used for connecting the fan to the supply pipe.

There is a limit to the number of storage units that can be aerated effectively by one portable fan. Warm grain may mold or moisture migrate in some storages before aeration is completed in others. One portable fan is seldom used for aerating more than 3 or 4 bins where the fan is connected to but one bin at a time. It should be remembered that aerating 4 bins, one at a time, with an airflow rate of say 1/10 cfm per bushel will not completely aerate them any faster than supplying 1/40 cfm per bushel to all 4 bins at once.

AIRFLOW REQUIREMENTS

Airflow rates suitable for the aeration of stored grain are given in table 1. They are based on the results of four years of research and industry experience in six different areas of the United States. In designing an aeration system these rates can be used as a basis for estimating fan and motor sizes and capacities, duct sizes and spacing, and supply pipe sizes.

It must be recognized, however, that some nonuniformity of airflow exists in most aerated storages. Some grain is aerated at a higher airflow rate than other portions of the grain mass. Therefore, in selecting an airflow rate, careful consideration must be given to the *lowest* rate that can be permitted in any portion of the stored grain. This is most important, as the time required for successful aeration will be determined by the lowest airflow rate in a mass of grain. (For design purposes, small portions of grain which cool by conduction or by other means may be disregarded in determining the lowest permissible airflow rate).

In well-designed aeration systems for upright storages the lowest airflow rate in any part of the storage usually is not less than 90 percent of the selected rate. On the contrary, in well-designed systems for flat storages the lowest airflow rate

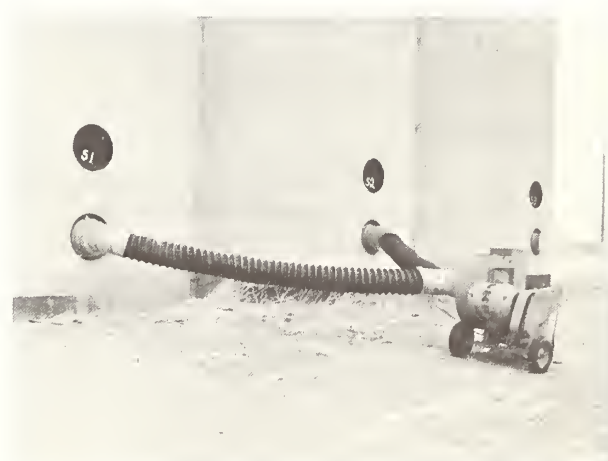

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FIGURE 3.—Portable fan and motor used to aerate 2 storages at one time. Fan is moved to adjoining storages when aeration is complete.

TABLE 1.—*Airflow rates for aeration of stored grain in specified areas* [1]

Type of storage	Airflow rate per bushel of grain	
	Northern States	Southern States
	cfm	*cfm*
Flat	1/20 to 1/10	1/10 to 1/5
Upright	1/40 to 1/20	1/30 to 1/10

[1] Rates are based on intermittent fan operation when air conditions are suitable.

in some portions of the grain may be one-half, or less, the selected rate. For example, with a selected rate of 1/10 cfm per bushel some grain may be aerated at a rate of 1/20 cfm per bushel. This is one reason why airflow rates selected for a flat storage usually are about double those for upright storages (table 1).

The aeration system for the entire storage, and the plans of operation and management, must also be considered in selecting an airflow rate. Many systems provide sufficient fan capacity to aerate all parts of a storage unit simultaneously. However, portable fan systems, and some manifold systems, aerate only a part of the storage unit at one time. As much time will be required to aerate two bins, one at a time, at an airflow rate of 1/10 cfm per bushel as would be required to aerate both bins simultaneously at an airflow rate of 1/20 cfm per bushel.

Airflow rates measured in grain soon after storage usually will be higher than those measured after several months of storage. The stored grain packs and causes increased resistance to airflow. (See section on Estimating Fan Horsepower and Static Pressure Requirements for Aerating Grain.)

DIRECTION OF AIRFLOW

Fans are usually operated to draw air downward for cooling stored grain. This is done for two reasons: (1) The natural tendency for air to move upward from the warm grain toward the cool upper surface is in part offset; and (2) the exhaust air, which is usually comparatively warm and moist, is expelled through warm grain in the lower part of the bin and not through the colder upper grain surface where some condensation might occur.

In the warmer Southern areas there may be some advantage in forcing air upward through the grain. The chief advantage of this "reverse flow" is that heat trapped under the roof can be forced out at the top rather than being pulled down through the grain. Also, the warmer grain at the top may be cooled without moving the warm air through the cooler grain at the bottom. This may shorten the cooling time and thereby reduce the cost.

There is also some advantage in upward airflow from the long duct systems used in many flat storages. An analysis of airflow in selected systems showed a more uniform airflow with air moving upward through the grain. Uniform airflow is desirable as it is directly related to uniform cooling of the grain.

There are, however, some hazards in using upward airflow, particularly in areas where subfreezing air temperatures occur. Warm air moving upward through the grain passes through the cooler grain at the top surface. During freezing weather, the warm air may be cooled enough for moisture to condense on the cold grain and possibly on the underside of the bin roof. A substantial layer of damp, moldy grain may form as a result of the condensation. To prevent this harmful condensation, grain temperatures should be kept within 10° to 15° F. of the cooling air temperatures. Other recommendations for operating aeration fans in each area also should be followed.

FAN REQUIREMENTS

The selection of a fan for aeration depends on: (1) Volume of air to be delivered; (2) the static pressure at which the fan must operate to move the air through the grain and aeration system; and (3) noise level of fan. Static pressure will vary with airflow rate; depth of grain; kind, size, and condition of grain; and the resistance of the aeration system. Noise is associated mainly with fan speed.

Kernel size, moisture content, and the amount of foreign material in grain affect the resistance of grain to airflow. The resistance of wheat is greater than that of rough rice or grain sorghum and several times that of shelled corn. To illustrate, in moving 1/10 cfm per bushel through 100 feet of shelled corn the static pressure would be about 7½ inches of water.[5] In comparison, to obtain the same airflow rate through 100 feet of wheat, the static pressure would be over 25 inches of water or more than 3 times as great as that for corn.

TABLE 2.—*Resistance of wheat and aeration system to airflow at specified rates of flow when wheat is stored in a bin 18 feet in diameter and 100 feet deep*

Airflow rate (cfm./bu.)	Static pressure	Power requirements for fan
	Inches water	*Horsepower*
1/10	26. 0	17. 5
1/20	12. 4	4. 2
1/30	7. 8	1. 8

[5] The static pressure being developed by the fan in moving the air indicated is equivalent to the pressure that will lift a column of water 7½ inches.

The resistance of most grains to airflow increases almost directly in proportion to the depth. Varying the airflow rate for any grain also affects the static pressure and power required (table 2).

Most aeration systems in use in upright storages in 1959 were designed for static pressures not exceeding 15 inches of water. However, systems operating at static pressures of 10 inches or less were more common.

TYPES OF FANS

Both axial flow (propeller) and radial flow (centrifugal) fans are used for aeration. Either type is used where the static pressure of the grain and the system are not more than about 4 inches of water. Centrifugal fans are commonly used for higher pressures. In 1959 propeller fans were generally used in flat storages and centrifugal fans in upright storages.

Three types of centrifugal fans are shown in figure 4. The "forward-curve" fan, figure 4–A, has a large number of blades and operates at a relatively slow speed. One objection to this fan is that the motor may be overloaded if the static pressure is decreased so the fan delivers additional air.

A centrifugal fan with straight blades, figure 4–C, is often referred to as a pressure fan or industrial exhauster. This type of fan is widely used in aerating grain in upright storages. It also overloads when the static pressure is reduced but not as much as a forward curve fan.

A "backward-curve" centrifugal fan, figure 4–B, has about 12 blades and is a high-speed fan. It is slightly more efficient, but more expensive, than a forward-curve or straight-blade fan. It has a self-limiting horsepower characteristic. If the motor size is adequate for fan operation near the point of greatest efficiency there will be no danger of an overload.

Three types of axial flow fans are shown in figure 5. While essentially considered as low pressure fans, certain designs are suitable for the higher pressures.

Fans should be selected on the basis of performance ratings supplied by the manufacturer. A performance rating specifies the volume of air delivered by the fan over a range of static pressures. Reliable performance ratings are assured if the fans selected are rated in accordance with the testing code of the Air Moving and Conditioning Association (formerly the National Association of Fan Manufacturers).

FAN CONNECTIONS

Although the remainder of the aeration system may be adequate, the system will not perform at its best unless the fan is properly connected. A poor fan connection may reduce the airflow by as much as 25 percent, and possibly more.

Air should enter a fan in as near a straight line as possible. Short inlet elbows restrict the fan output (fig. 6–A). Elbows with a larger throat diameter are much better (fig. 6–B).

Attaching a short elbow to the fan outlet as shown in figure 7–A is bad practice. A longer elbow installed as shown in figure 7–B is a much better installation. Abrupt changes in pipe sizes also cause reductions in air delivery.

TYPES OF DUCTS

Ducts may be circular, semi-circular, arched, rectangular, or of an inverted V-shape or U-shape. Perforated false floors are seldom used for aeration because of their relatively high cost. Ducts, which are less costly, have proved satisfactory, although they permit some non-uniformity of airflow.

Perforated ducts have air openings or perforations uniformly spaced over their surfaces to permit passage of air through the duct surface. The area of the perforations should equal at least 10 percent of the total duct surface area.

Each opening must be small enough to exclude the grain that is to be aerated. For example, round holes $\frac{3}{32}$ inch in diameter or slots $\frac{5}{64}$ inch wide will not pass normal-sized kernels of wheat. Larger openings may be used for shelled corn, soybeans, and other larger seeds.

Perforated ducts are commonly made of punched or expanded metal. A steel frame covered with expanded metal which in turn is covered with screen wire is also used. Screen wire for this purpose is not considered a permanent material and in some deep storages has failed to withstand the grain pressures.

Tight-wall ducts of metal or wood with one side open, and facing downward, are also used as aeration ducts. The inverted V is one of the simpler shapes.

Important dimensions of a duct system are: (1) The size—cross-sectional area—and the length, which influence the air velocity within the duct and the uniformity of airflow through the grain. (2) The surface area—circumference or perimeter—of the duct which effects the static pressure losses in the grain surrounding the duct. (3) The distance between the ducts—duct spacing—which influences the uniformity of airflow through the grain between the ducts.

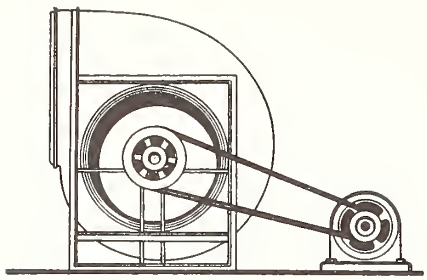
DUCT CROSS-SECTIONAL AREA

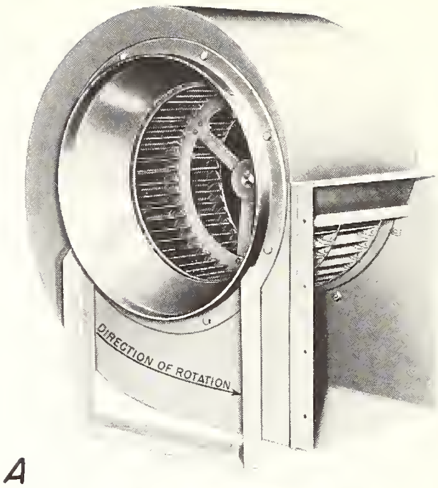
The required cross-sectional area of a duct can be determined by dividing the total air volume to be carried by the duct by the maximum air velocity that is to be permitted within the duct.

$$\frac{\text{Total air volume (cfm)}}{\text{air velocity (fpm)}} = \text{Cross-section (sq. ft.)}$$

For upright storages, an air velocity within the duct of 2,000 feet per minute (fpm) is permissible.

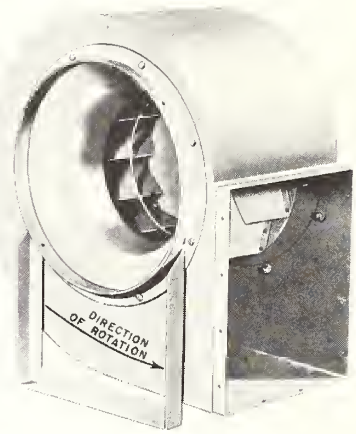
Maximum recommended air velocities in ducts for flat storages are given in table 3 for suction aeration systems. The kind of grain, grain depths,





A

Figure 4.—Centrifugal fan consisting of a fan rotor or wheel within a scroll type of housing. It is designed to move air over a wide range of volumes and pressures (up to 15 inches of water and above). The fan wheel may be equipped with radial tip blades or three other types.

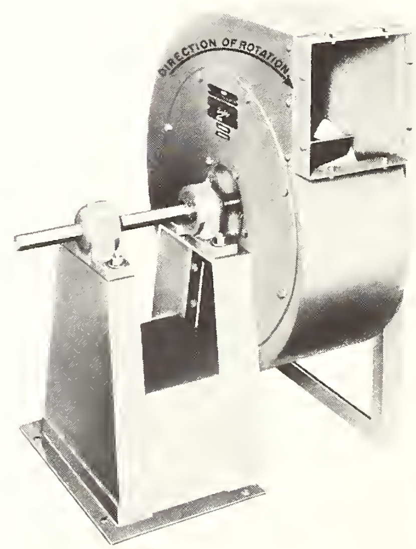


B

A. Fan wheel equipped with forward curve tip blade.

B. Fan wheel equipped with backward curve tip blade.

C. Fan wheel equipped with straight tip blade.



C

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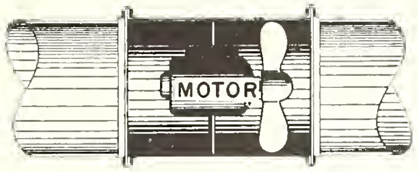
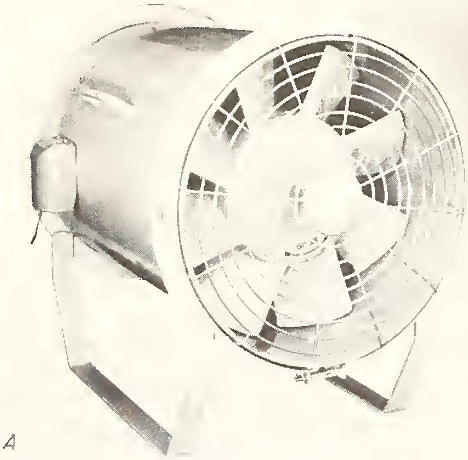
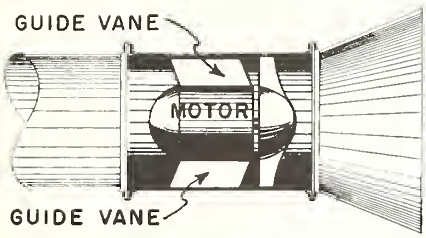


A. TUBEAXIAL FAN

A tubeaxial fan consists of an axial flow wheel within a cylinder. It is designed to move air through a wide range of volume at low to medium static pressures.

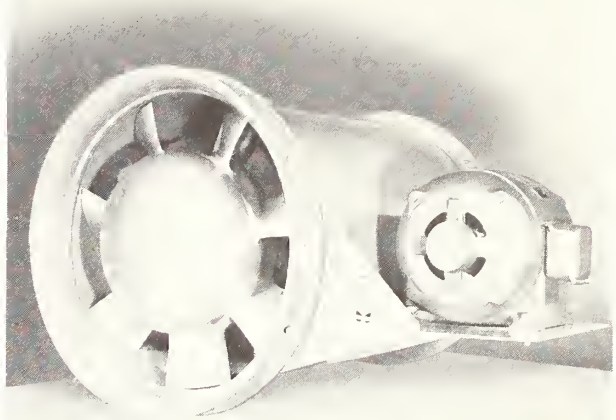


A

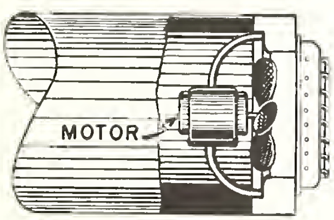


B. VANEAXIAL FAN

A vaneaxial fan consists of an axial flow wheel within a cylinder combined with a set of air guide vanes located either before or after the wheel. It is designed to move air over a wide range of volume and pressures.



B



C. PROPELLER FAN

A propeller fan consists of an axial flow fan within a mounting ring or plate. It is designed to move air over a wide range of volume at low static pressures.

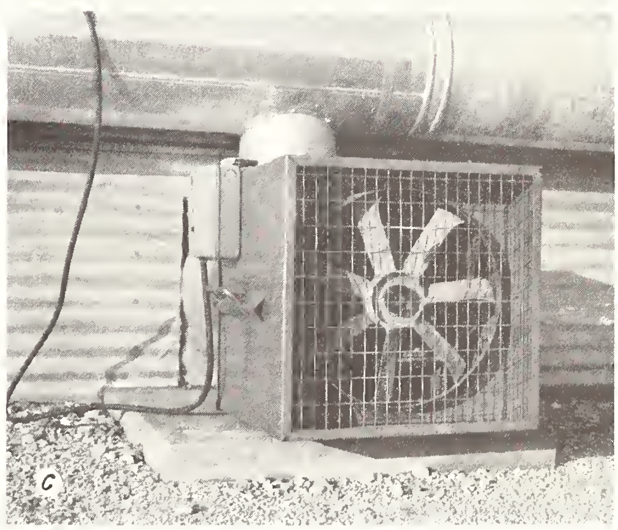


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Figure 5.—Axial flow fans.

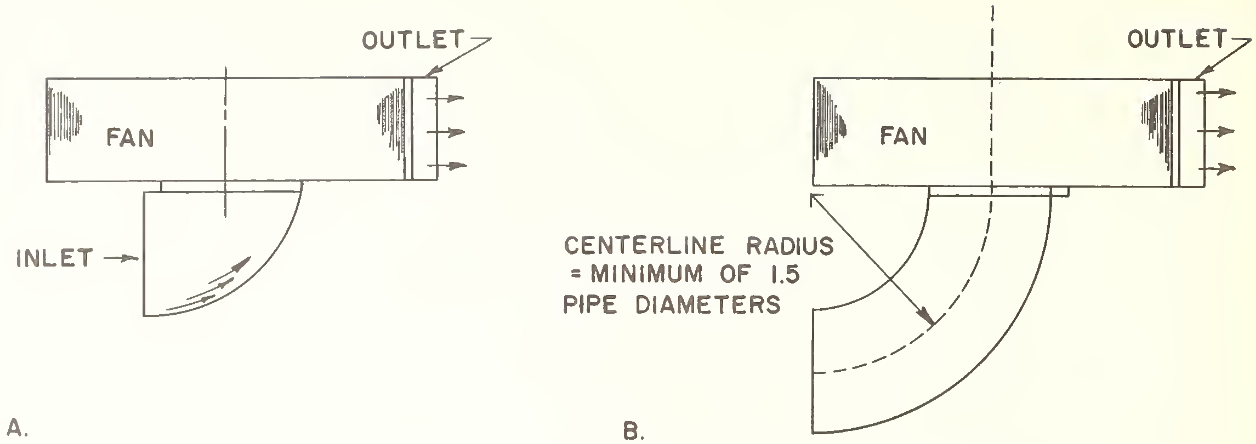


FIGURE 6.—Short inlet elbows (*A*) restrict fan output; long elbows (*B*) improve output.

and airflow rates were considered in developing this table.

With long ducts in flat storages it is beneficial to make the fan connection near the mid-point of the duct. This permits reducing the cross-sectional area of the duct by one-half.

TABLE 3.—*Recommended maximum allowable air velocities within ducts installed in flat storages* [1]

Airflow rate per bushel	Air velocity within ducts (feet per minute) — For grain depths of				
	10 feet	20 feet	30 feet	40 feet	50 feet
Corn, Soybeans, and Other Large Grains					
C.f.m.	*F.p.m.*	*F.p.m.*	*F.p.m.*	*F.p.m.*	*F.p.m.*
1/20	--------	750	1,000	1,250	1,250
1/10	750	1,000	1,250	1,500	1,750
1/5	1,000	1,250	--------	--------	--------
Wheat, Grain Sorghum and Other Small Grains					
1/20	--------	1,000	1,500	1,750	2,000
1/10	750	1,500	2,000	--------	--------
1/5	1,000	2,000	--------	--------	--------

[1] Calculated for suction systems with ducts up to 100 feet in length. Assumes duct with rough inner surface and corrugations or inside framing. Duct friction loss calculated using a roughness coefficient of 2.5; velocity head loss equal to 1.7 h_v. (Shove, Gene C., Air Flow Analysis of Grain Ventilation Ducts. Thesis PH.D, Iowa State University, Ames, Iowa.)

At least one manufacturer of duct systems for flat storages provides a paper cover with calibrated perforations for the duct. This cover is designed to equalize the flow of air passing from the grain into the duct, throughout the entire length of the duct. This permits the use of long ducts with smaller cross-sectional area than is normally required. Manufacturer's specifications should be followed closely.

Tight covers over certain portions of the duct in suction systems will also help to equalize the airflow throughout the length of a duct. Care must be exercised in fitting such a cover to obtain satisfactory airflow.

DUCT SURFACE AREA

Limiting the velocity of the air entering (or leaving) the grain surrounding the duct prevents excessive pressure losses in this region. This velocity is influenced by the amount of surface area provided in the perforated duct and the airflow rate used.

With a semi-circular perforated duct the air enters or leaves the grain over the entire surface area. Therefore the entire duct surface can be included in determining the amount of surface area needed to hold static pressures to a desirable minimum (fig. 8). However, some modification is needed where a circular perforated duct rests on the floor or against a wall. Then only 80 percent of the surface area should be considered.

For **upright storages,** the surface area of the ducts may be the controlling factor in determining their size. It is desirable that the ducts have sufficient surface area—circumference—to limit the air velocity through the grain near the duct to *30 fpm.* or less.

For **flat storages,** the ducts should have sufficient surface area to limit the air velocity through the grain near the duct to *20 fpm.* or less. Generally, for *level-loaded* storages the surface area of the longer ducts will be adequate if the cross-sectional area is adequate.

The total square feet of surface area required in a perforated duct can be determined as follows:

$$\frac{\text{Total air volume per duct (cfm.)}}{\text{Selected duct surface velocity (fpm.)}} = \text{Total duct surface area per duct (sq. ft.).}$$

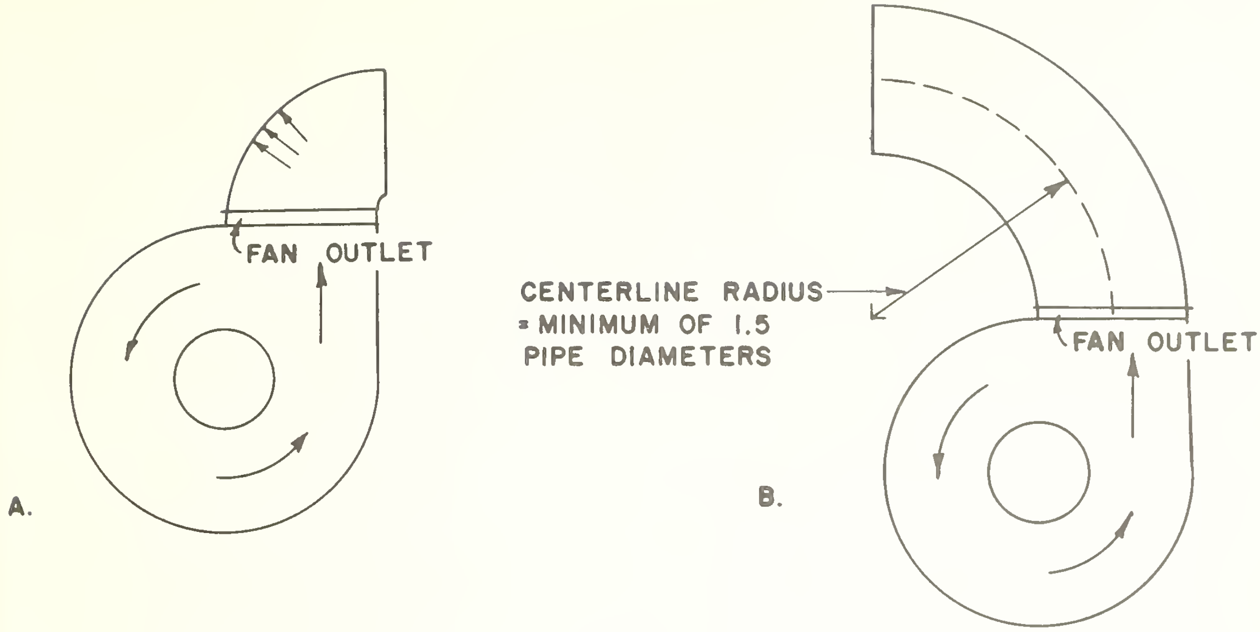


FIGURE 7.—A short elbow attached to a fan outlet as in (*A*) is bad practice. A longer elbow installed as in (*B*) is better.

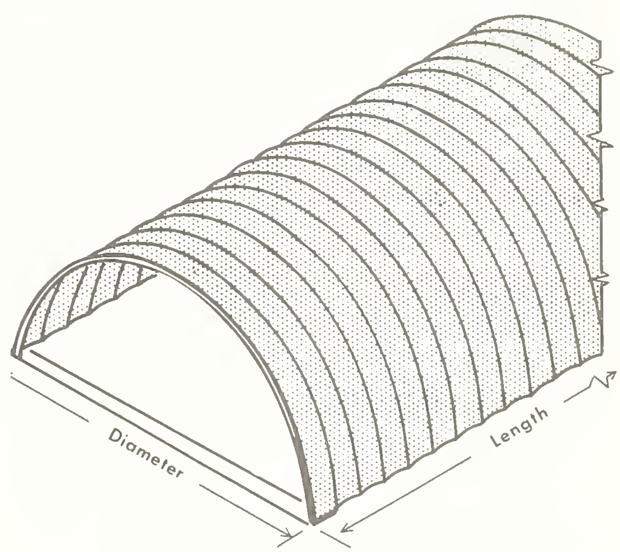
For example, for a duct in an upright storage handling 1,200 c.f.m. at a selected velocity of 30 feet per minute, the total square feet of surface area equals, $\frac{1{,}200 \text{ cfm.}}{30 \text{ fpm.}} = 40$ square feet of surface area. Thus a perforated semicircular duct 16 feet long requires 2½ square feet of surface area per foot length of duct $\left(\frac{40}{16} = 2\frac{1}{2}\text{ feet; } 2\frac{1}{2} \times 1 \text{ foot} = 2\frac{1}{2}\right.$ square feet per foot of length). A perforated semi-circular duct 20 inches across the base and 10 inches in radius would meet these requirements.

DUCTS FOR UPRIGHT STORAGES

The static grain load on ducts may reach 1,500 pounds per square foot in upright storages. The duct also must withstand an additional drawoff load when in the path of grain moving from storage. This drawoff load may be several times the static grain load and must be considered in selecting and installing ducts. Both duct strength and duct anchoring become major considerations.

A single duct of 14- to 18-gage, of the type shown in figures 9, 10, and 11, frequently is used in upright storages. These ducts are usually uniform in size along their entire length. Ducts extending across a large part of the bin diameter are desirable. A 2-foot clearance from the edge of the bin drawoff should be maintained.

A circular duct of galvanized or black iron sheet metal can be perforated and formed into grain tight smooth or corrugated sections. Many concrete storages have small service entrances which can be used for installing prefabricated ducts up to about 18 inches in diameter. Larger ducts can



Semi-circular perforated corrugated duct with air openings spaced uniformly over the surface.

Duct surface area equals:
Semicircular duct—½ diameter x length x 3.14
Circular duct—diameter x length x 3.14

Note: An additional 20 to 25 percent of duct surface area should be provided where a circular perforated duct rests against a bin wall or floor.

FIGURE 8.—Duct surface area.

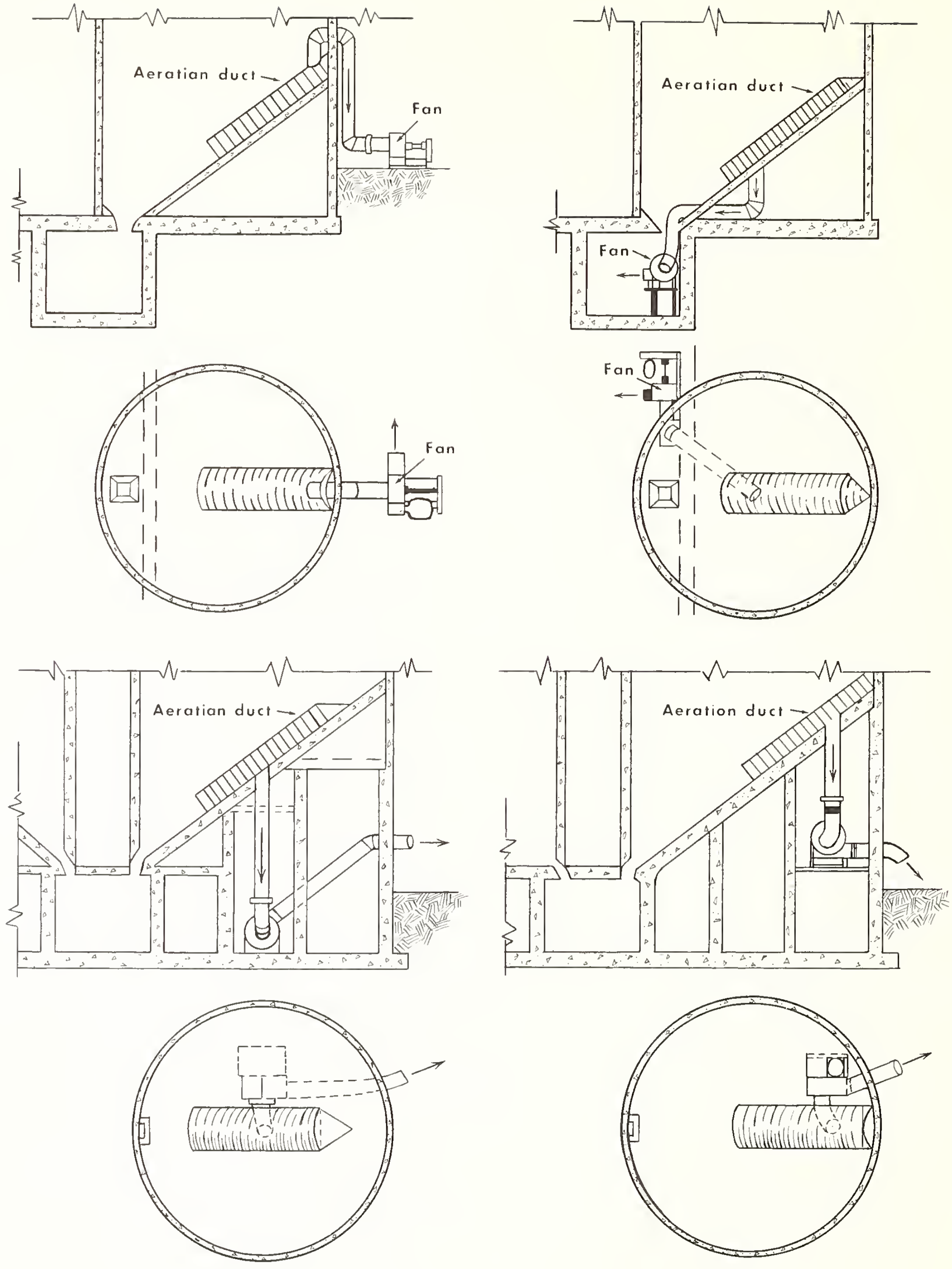


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FIGURE 9.—Typical aeration system layout for upright storages with hopper bottoms.

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Figure 10.—Circular metal ducts (*A*) perforated and corrugated and (*B*) prefabricated well casing.

be fabricated in parts and assembled inside the bin. Metal fittings and brackets are used to fasten the ducts to the bin floor and walls with rivets, power driven fasteners, expansion bolts, steel bolts, or a combination of other fasteners.

Semi-circular and arch-shaped ducts, with one flat side, have a larger base area for anchoring. Perforated sheet metal is used by corrugating or supporting on frames and then by welding the duct to a base of strap iron or angle iron (fig. 11).

Other types of floor ducts include those installed laterally from a solid main duct and those installed radially from a central plenum chamber.

The **vertical-type perforated duct** (fig. 12) is installed against the inside bin wall with the lower end connected to a supply pipe. The supply pipe extends through the hopper fill, bin floor, or foundation to a manifold or fan connection. The duct can be completely fabricated prior to installation in the storage. Excellent results have been obtained by locating this duct almost directly below the fill spout in the bin roof; this location is generally at the maximum depth of grain.

In a **"crossflow" system** for upright storages, the ducts are installed vertically against the inside walls as shown in figure 13. The air is moved across the bin from one duct to the other. The shorter air path permits higher airflow rates

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Figure 11.—Semi-circular perforated and corrugated steel aeration duct. Steel base plates on each side of the duct anchor the duct to the storage. The end plate provides support for each end of the duct.

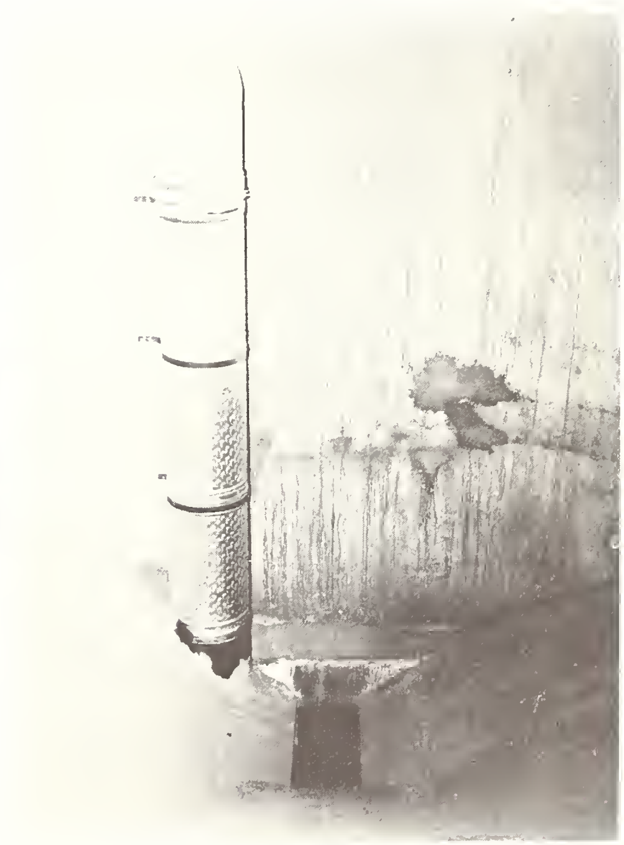

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Figure 12.—Vertical type duct for upright storage with hopper bottom.

CROSSFLOW AERATION SYSTEM

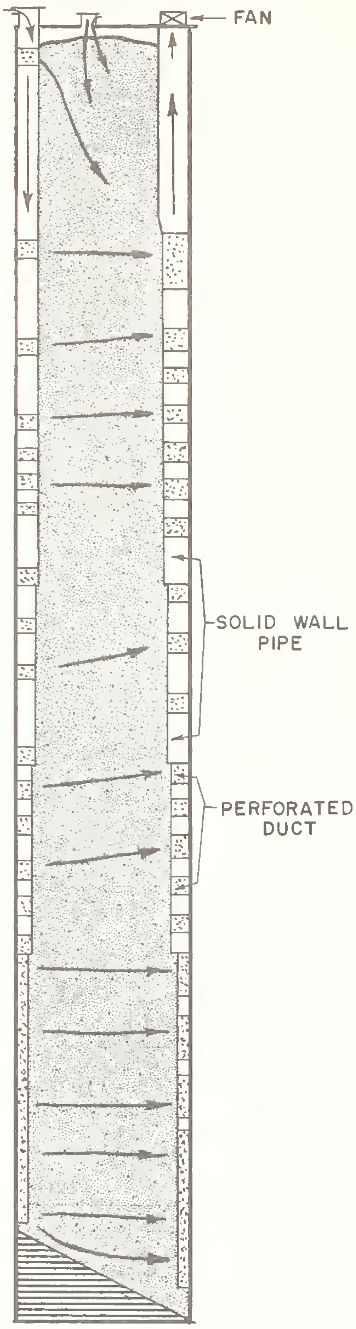

FIGURE 13.—Crossflow aeration system in upright storage.

with the same power required for a floor-duct system. The main advantages are lower operating costs, faster cooling rates, and a higher airflow through the center of the bin where natural cooling is the slowest. The main disdavantages are the higher initial cost and the more complex design; probably the main reasons why more crossflow systems have not been installed. Also, it is difficult to obtain uniform airflow throughout the entire depth of grain and provision must be made to aerate partially filled bins. In terminal elevators, where most of the "crossflow" systems are installed, the operators turn the grain into aerated bins for cooling and then move the grain to another bin after cooling has been completed. With this method only 10 to 20 percent of the storage bins need to be equipped for aeration. Additional research is needed to develop improved designs which will provide better distribution of air at lower equipment costs.

The **partial hopper** (fig. 14) is used extensively in rice storages and has proven satisfactory. It has the advantage of being relatively inexpensive to install, and, if properly installed, has adequate structural strength. In some upright storages, adequate area for the air to leave (or enter) the grain cannot be provided, although this can sometimes be rectified by perforating the partial hopper.

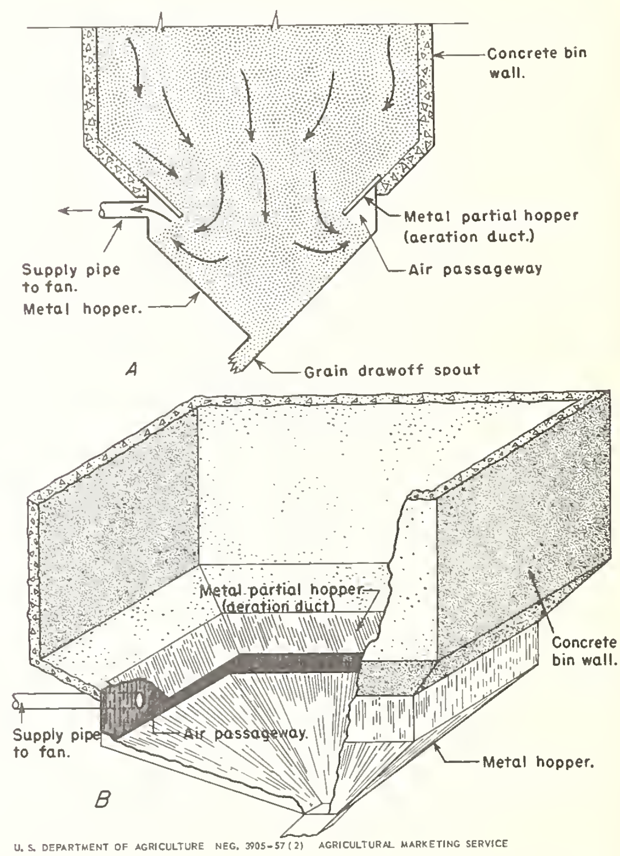

FIGURE 14.—Metal partial hopper installed in a rectangular upright storage to serve as a duct. (A) Section through lower part of storage showing grain in place around partial hopper and air passageway. (B) Cutaway view of lower part of storage showing arrangement of partial hopper.

DUCTS FOR FLAT STORAGES

The design of adequate duct systems for flat storages becomes more complicated, particularly for the larger ones with "peaked" loading. Half-round or round metal ducts, corrugated or smooth, with perforations uniformly spaced over the duct surface are available commercially and are commonly used. Ducts for flat storage generally are constructed of 16- to 20-gage sheet metal.

Ducts may be installed either lengthwise or crosswise of the storage according to the operator's preference. In peak-loaded storages it is difficult to obtain uniform airflow through the grain because of the variations in grain depth. It is always advisable to have an engineering analysis of the proposed duct system. Duct systems designed for level-loaded storages are seldom adequate if the surface of the grain is sloped more than 10 percent.

For **level-loaded** storages and **peak-loaded storages with lengthwise ducts** the duct size is determined by the maximum air velocity to be permitted (table 3). The duct size calculation can be made as shown on page 7. For **peak-loaded storages with crosswise ducts,** the air velocities listed in table 3 can be used as a general guide. In this type of system the duct size may be varied over the length of the duct. In the engineering analysis of the system the pressure losses occurring within the duct should be calculated.

Although it may not be the controlling design factor, the surface area also should be checked against the maximum requirements for the duct design. (See page 10).

Duct spacing and layout. In flat storages the duct spacing and layout is determined by building dimensions, grain depth, and the methods of loading (level or peaked grain surface). Variations in spacings are required to accommodate doorways, framing member spacing, and location of the storage in relation to other buildings, roads, railroads, and other facilities. Prefabricated flat storages are available in standard widths of from 40 to 150 feet. The lengths can be varied by adding sections and storages 600 feet long are not uncommon. The most common roof pitches range from ⅙ up to ⅓; therefore, the stored grain may be 20 feet, and more, deeper at the peak than at the sidewalls.

Studies in aerated commercial storages showed that the air moves radially in a semicircular area around the duct and mainly at right angles to the grain surface through the rest of the grain. Other studies substantiate these findings. For example, Ives, Hukill, and Saul[6] report that: "In non-linear or duct type (two dimensional airflow) systems all airflow streamlines are straight and parallel above a level equal to approximately ½ of the center to center duct spacing, but that there is a stagnation point midway between the ducts where there is practically no air movement." Because of radial airflow there are varying lengths of airflow paths from the grain surface to the duct and the grain halfway between the ducts cools the slowest. Careful attention must be paid to duct spacing as the amount of poorly aerated grain becomes greater as the distance between ducts increases.

For **level-loaded** flat storages over 40-feet wide and with grain up to 30-feet deep, the duct spacing should not exceed the grain depth. Performance has been satisfactory with one lengthwise duct in storages up to 40-feet wide and with grain 12-to-15-feet deep. Duct spacing should not exceed 30 feet when the grain depth exceeds 30 feet.

For **peak-loaded** flat storages special consideration must be given to the spacing of the ducts because of the uneven depths of grain.

Lengthwise ducts in peak-loaded storages 40 feet wide and over should be spaced so that the longest air path served by any duct is no more than 1½ times the shortest air path served by that duct (fig. 15). The shortest path to be served is considered the grain depth to be used in designing that duct. Several trial sketches, with plotted length of air paths, may be needed to arrive at the most satisfactory duct spacing and layout. Where the grain slopes towards the ends of a storage, ducts are placed crosswise under the shallower grain or the lengthwise ducts are modified to restrict the airflow (fig. 16).

Several layouts with ducts installed lengthwise are shown in figures 16 and 17.

Crosswise ducts in peak-loaded storages generally should not be spaced wider than the least depth of grain. When there is a big difference between the grain depth at the wall and at the

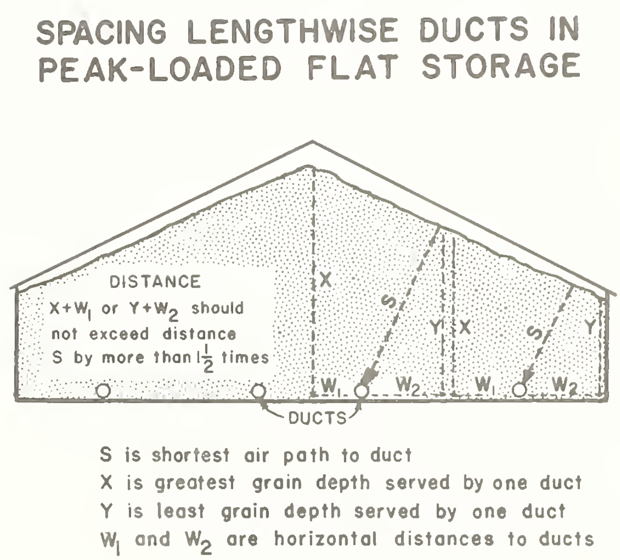

FIGURE 15.—Lengthwise ducts spaced with longest air path not more than 1½ times the shortest path.

[6] Ives, Norton C., Hukill, W. V., Saul, R. A. Grain Ventilation and Drying Patterns. Amer. Soc. Agr. Engin. Meeting, Chicago, Ill., Dec. 17, 1958.

peak some deviation from this recommendation may be warranted to hold the cost of the duct system to a practical limit. Too much deviation, however, can result in considerable additional hours of fan operation to completely aerate the grain receiving the lowest airflow.

Duct systems may be designed so that the resistance in the grain surrounding the ducts *plus* the resistance in the remaining grain is about the same throughout the length of the ducts, regardless of differences in the grain depth. One way of doing this is to reduce the amount of perforated surface area of the ducts under the shallower

LENGTHWISE DUCTS FOR LARGE FLAT STORAGE

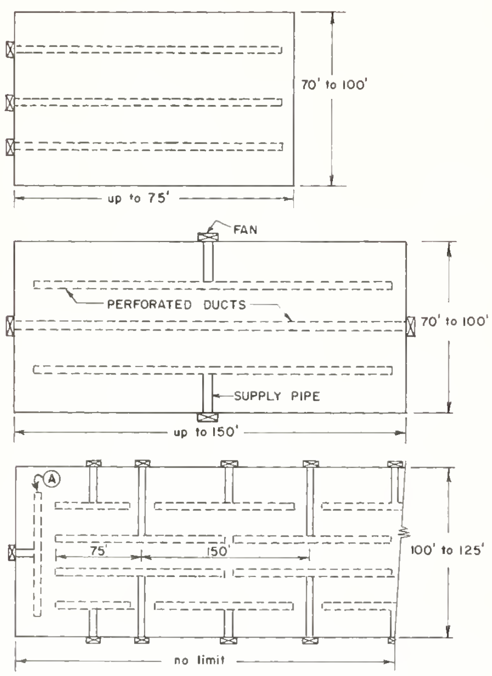

FIGURE 16.—Typical layouts of lengthwise duct systems for large flat storages. The duct (A) shown in the bottom layout is suggested for storages where the grain slopes downward to the end wall.

grain in order to increase the resistance (static pressure) in the grain adjacent to the duct. This can be done by reducing the duct diameter—keeping in mind permissible air velocities within the duct (table 3)—or by inserting sections of solid duct where the diameter cannot be safely reduced (fig. 18). If necessary the duct size can be increased under the deeper grain to reduce the static pressure in the grain adjacent to the duct. An engineering analysis of the duct system design is recommended to insure a reasonably uniform flow of air through the grain. A separate report is being prepared that will discuss the design of a crosswise duct system for peak-loaded flat storages.

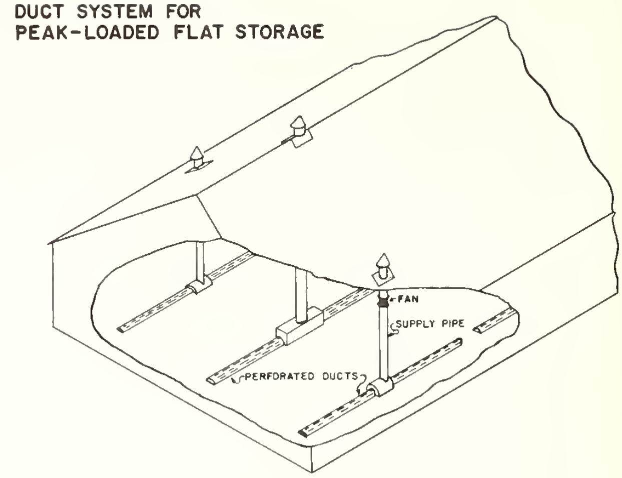

FIGURE 17.—Lengthwise ducts with fans located in vertical supply pipes.

SUPPLY PIPES

Supply pipes provide for passage of air between the duct and the fan. They are usually round, smooth sheet metal pipes. They should be well supported and anchored. A maximum air velocity of 2,500 fpm is permissible for supply pipes, but 1,500 to 2,000 fpm is preferred.

Often it is necessary to use elbows to make turns in supply pipes. Elbows range in shape from the simple square (miter) elbow to the multiple-piece elbow (fig. 19). The square elbow should be avoided because of the relatively high pressure losses due to friction in such an elbow. On the other hand, there is probably little gain in using multiple-piece elbows with more than 5 pieces for small pipes and more than 7 for large pipes. Elbows with a centerline radius equal to at least 1.5 pipe diameters (fig. 19) are considered acceptable and desirable with respect to both installation and operation.

The loss of air pressure in an elbow is often expressed by stating the length of straight pipe (having the same cross-section as the elbow) which would give an equivalent loss of pressure. To illustrate the comparative losses in the square elbow and the 3-piece elbow shown in figure 19, assume that the diameter of the two elbows is the same and that each elbow carries an equal volume of air. Under these conditions the losses in the square elbow would be about 4 times greater than in the 3-piece elbow.

Branch takeoffs in supply pipes should be arranged to cut or slice into the air stream in order to reduce as far as possible the losses in such connections. Abrupt changes in pipe sizes also cause losses in air delivery and should be avoided.

With a manifold system, a slide gate or damper should be provided in the pipe from each bin. These gates can be adjusted to control the aeration of each bin and can be closed after aeration is completed.

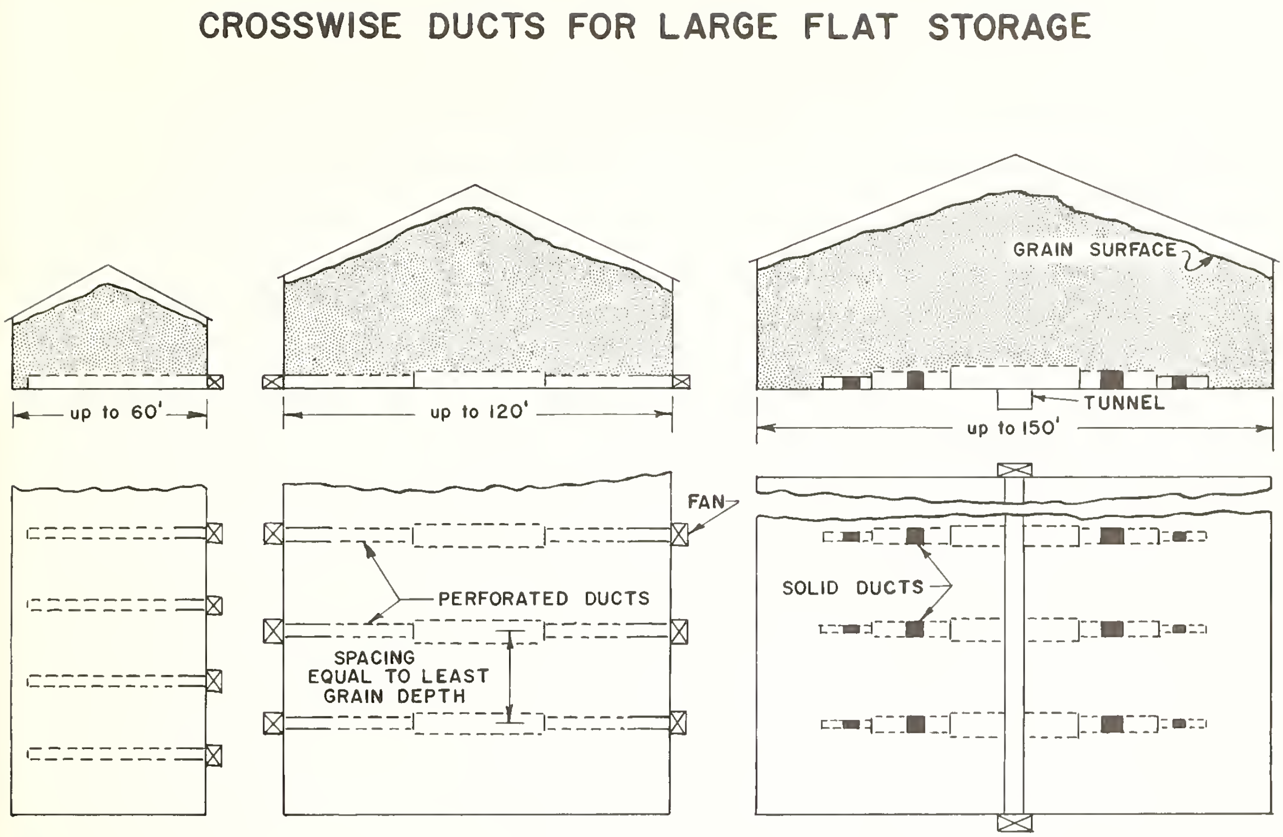

FIGURE 18.—Typical layouts of crosswise duct systems for large peak-loaded flat storages. Tunnel shown at right serves as the main air supply chamber and provides space for a grain conveyor. Storages can be of any length desired.

ESTIMATING FAN HORSEPOWER AND STATIC PRESSURE REQUIREMENTS

Figures 20 to 25 inclusive provide information for estimating the fan horsepower and static pressure requirements for aerating grain of various kinds, at different rates of airflow (cfm per bushel, hundredweight, or barrel) and at depths ranging from 10 to 150 feet. Basic static pressures were calculated from those reported by Shedd for loose grain.[7] To make allowances for packed fill the basic values given for loose grain have been increased as follows: Wheat and shelled corn, 30 percent; grain sorghum, rice, soybeans, 40 percent; and oats 50 percent. In cases where grain is stored for long periods or where excessive fine material is present in the grain these allowances may not be adequate and static pressures and power requirements may exceed those given in the charts for specified airflow rates.

Basic static pressures were further increased to compensate for pressure losses inside the duct, in the grain surrounding the duct, and in the supply pipes. For each grain, the minimum loss allowed was based on an air velocity of 15 fpm through the grain near the duct; the maximum loss allowed was based on an air velocity of 30 fpm; otherwise the basic values were increased by 20 percent.

Fan horsepower requirements were calculated as follows:

$$\text{Fan horsepower} = \frac{\text{cfm x static pressure (inches of water)}}{3{,}000}$$

A static efficiency of 47 percent was assumed in calculating the fan horsepower. Suppliers may furnish fans having a higher or a lower efficiency than 47 percent; then, the horsepower requirements given in figures 20 to 25 should be adjusted accordingly. For example, assume that an aeration system requires 0.2 horsepower per 1,000 bushels of grain sorghum as read from figure 23. With a fan having a static efficiency of 55 percent, the system would require the following horsepower:

$$\frac{0.2\text{ (HP per 1,000 bu) x 0.47 (chart static efficiency)}}{0.55\text{ (static efficiency of selected fan)}} = 0.17\text{ HP per 1,000 bu}$$

[7] Shedd, C. K. Resistance of Grains and Seeds to Airflow. Agr. Engin. 34: 616–619. 1953.

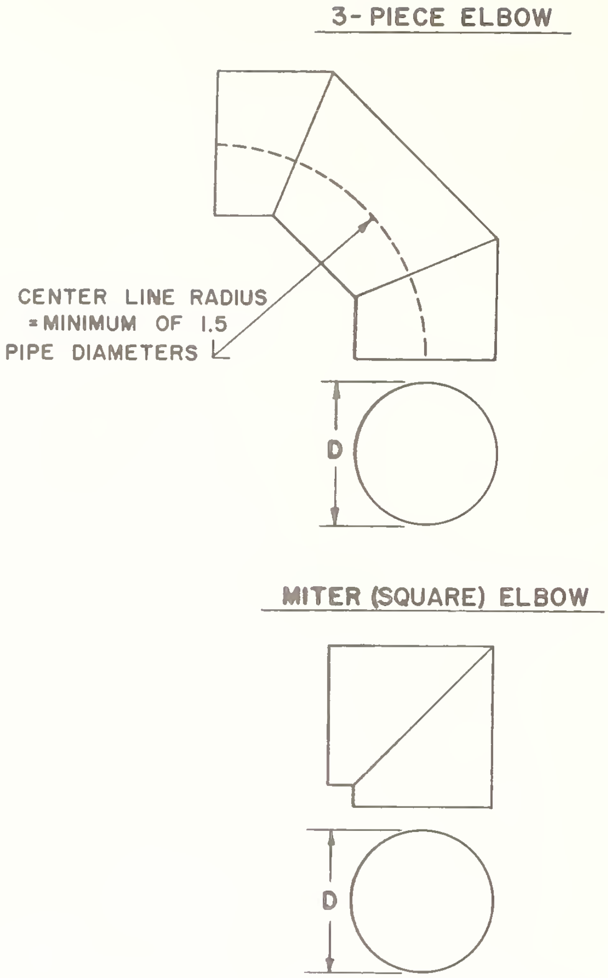

FIGURE 19.—Two types of elbows for making turns in supply pipes.

In using the charts for selecting a fan and motor, keep in mind:

1. Kinds of grain to be aerated. An aeration system may be designed for only one kind of grain, or for two or more kinds. Plan the system to insure having adequate fans and motors for the job. (See the examples given below.)
2. Volume of grain in bushels, barrels, or hundredweight (cwt).
3. Maximum depth of grain to be aerated (in peak-loaded flat storages the depth selected for design purposes may be somewhat less than the greatest depth at the peak).
4. Airflow rate in cfm per bushel, barrel, or cwt.
5. Total volume of air needed (total volume of grain x airflow rate in cfm per unit volume).

Examples of how to use the charts to determine an and motor requirements:

A. An aeration system to be designed for aerating wheat in a storage 80 feet deep (capacity 28,800 bushels) using a fixed fan:
   1. Wheat to be aerated at $\frac{1}{20}$ cfm per bushel; use the chart in figure 21.
      a. Find 80 feet at bottom of chart.
      b. Follow vertical line to $\frac{1}{20}$ cfm curve.
      c. Read static pressure by following horizontal line from point on cfm curve (b. above) to left column of chart, in this case 7.4 inches of water.
      d. Total air volume=28,800 x $\frac{1}{20}$= 1,440 cfm.
      e. Repeat a. and b. above, then estimate where this point falls between dashed lines indicating horsepower per 1,000 bushels; in this case approximately 0.13 horsepower per 1,000 bushels.
      f. Total horsepower required for

$$\text{wheat}=\frac{28{,}800 \times 0.13}{1{,}000}=3.7 \text{ HP}$$

   Note: A 5-horsepower motor would be selected unless the fan manufacturer can supply a more efficient fan requiring less horsepower.

B. An aeration system to be designed for aerating either wheat *or* shelled corn in a storage 80 feet deep (capacity 28,800 bushels) using a fixed fan:

Where an aeration system is used to aerate two or more kinds of grain, the fan usually is selected to supply the desired airflow for the grain with the highest resistance; in this example, wheat. The static pressure and horsepower can be determined from the charts. However, additional horsepower will be needed for aerating the grain with the lowest resistance (in this example, shelled corn) if a nonoverloading fan or some other satisfactory method for preventing motor overload is not used. One method is to slow the fan speed by changing the pulley size on the fan or motor. Another method is to place a damper or slide gate in the supply pipe. Both methods require considerable adjustments.

When an overloading fan is to be used without altering the system, a rule-of-thumb is to provide twice as much horsepower for aerating shelled corn as for wheat. Closer estimates can be made from fan performance data and by fan and aeration engineers. The additional initial cost of a larger motor should not be more than the cost of other methods of preventing overloading. And the larger motor should use electric current only in proportion to the operating load.

1. Wheat to be aerated at $\frac{1}{20}$ cfm per bushel: use the chart in figure 21. Follow 1. a, 1. b, 1. c, and 1. d as in A, above.

Note: Motor to be selected under one of the methods outlined in 2, below.

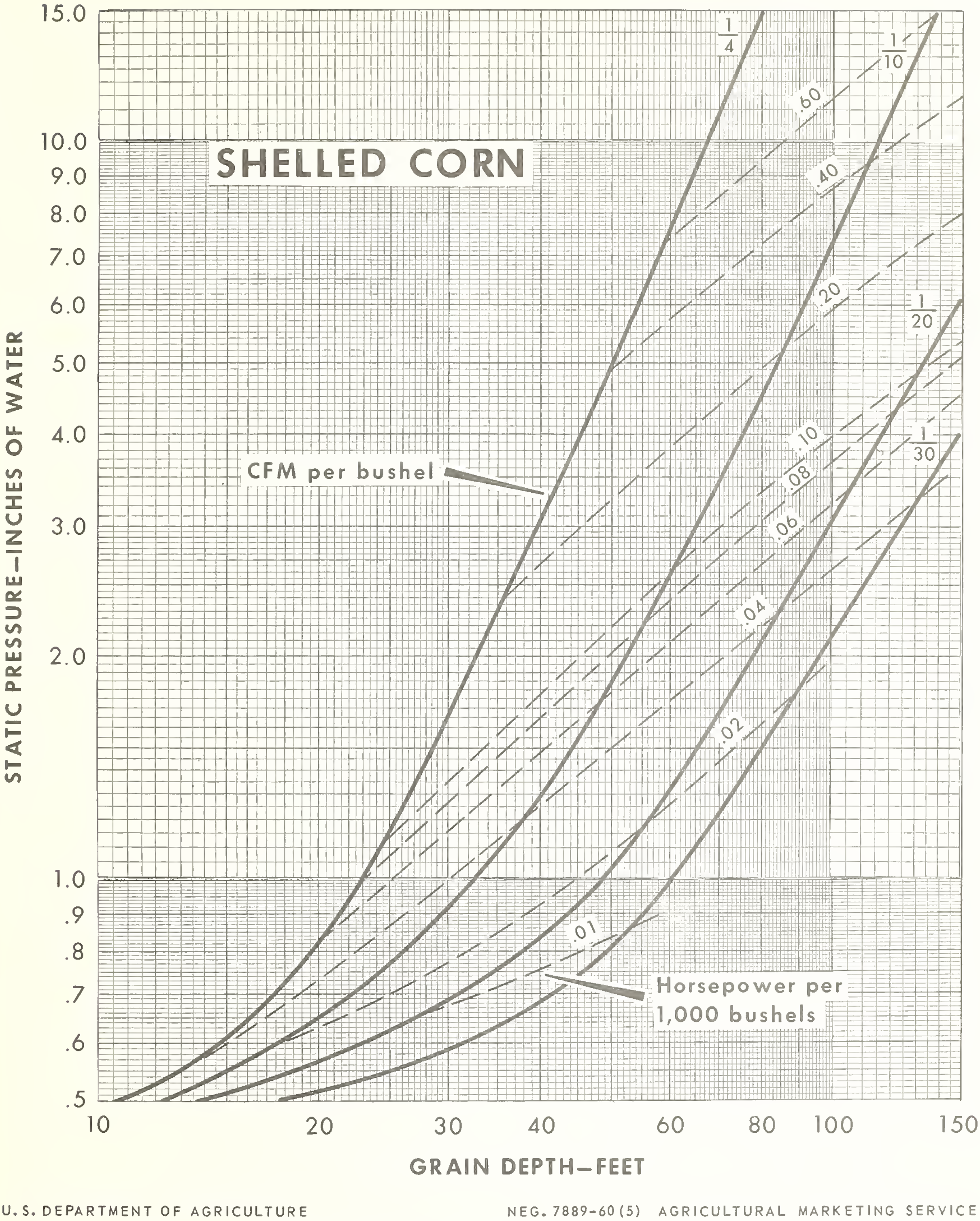

FIGURE 20.—Fan horsepower and static pressure (inches of water) requirements for aerating shelled corn at different rates of airflow (cfm per bushel) and at grain depths ranging from 10 to 150 feet.

2. Shelled corn to be aerated with the same motor and overloading type fan that is to be used for aerating wheat:
   a. Method 1.—Damper not used and no change in fan speed—use a 7½-horsepower motor, twice the horsepower required for wheat. Airflow rate will be approximately 1/10 cfm per bushel, twice that selected for wheat.
   b. Method 2.—Speed of fan not changed but damper to be used—use same horsepower

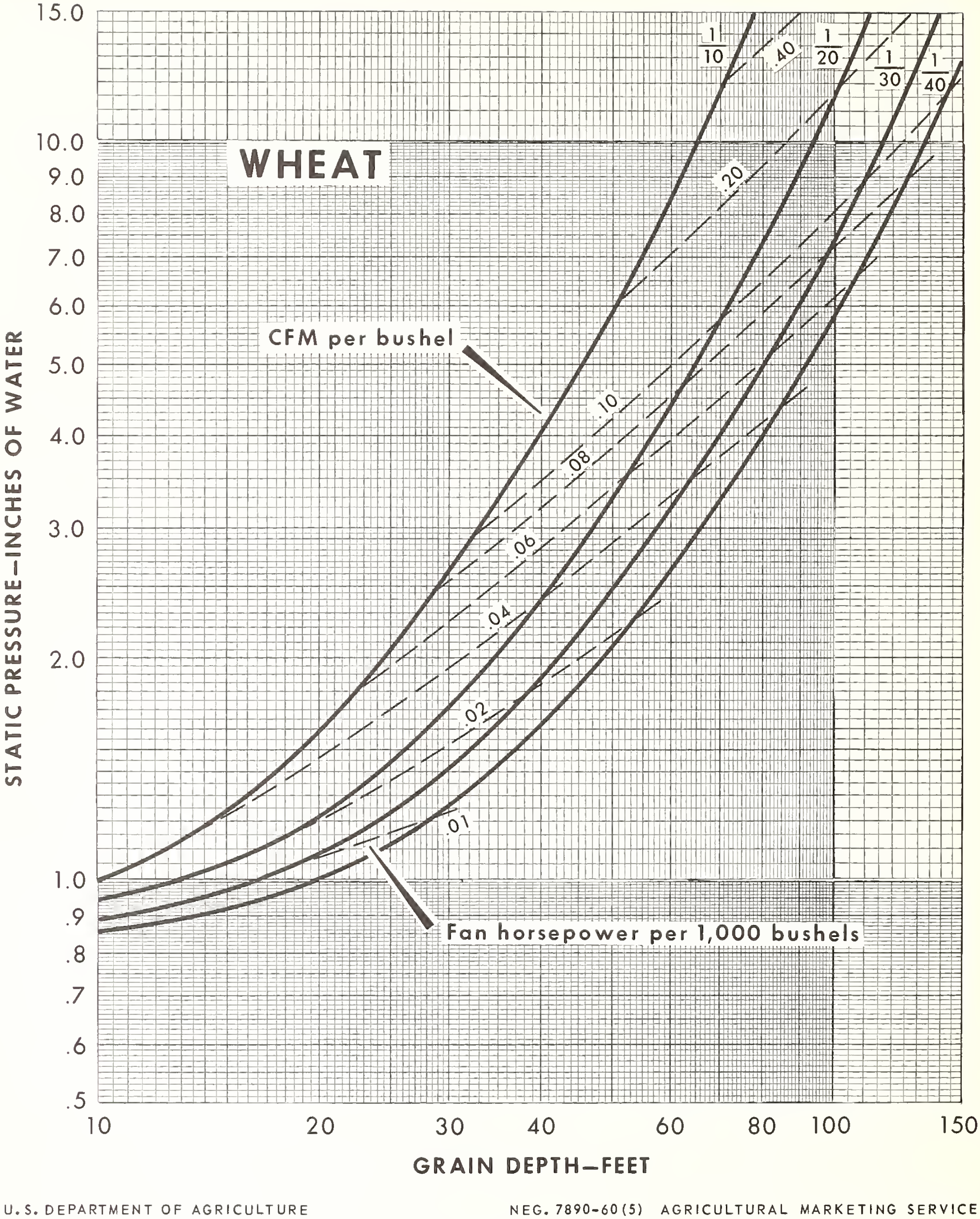

FIGURE 21.—Fan horsepower and static pressure (inches of water) requirements for aerating wheat at different rates of airflow (cfm per bushel) and at grain depths ranging from 10 to 150 feet.

requirement (3.7 HP) and airflow rate (1/20 cfm) as for wheat. The proper setting of the damper can be determined by attaching an ammeter to the electric motor to indicate when the maximum allowable motor load is reached. Another method is to use a manometer when setting the damper to indicate when the static pressure (in the pipe between the fan and the damper) is equal to that determined for

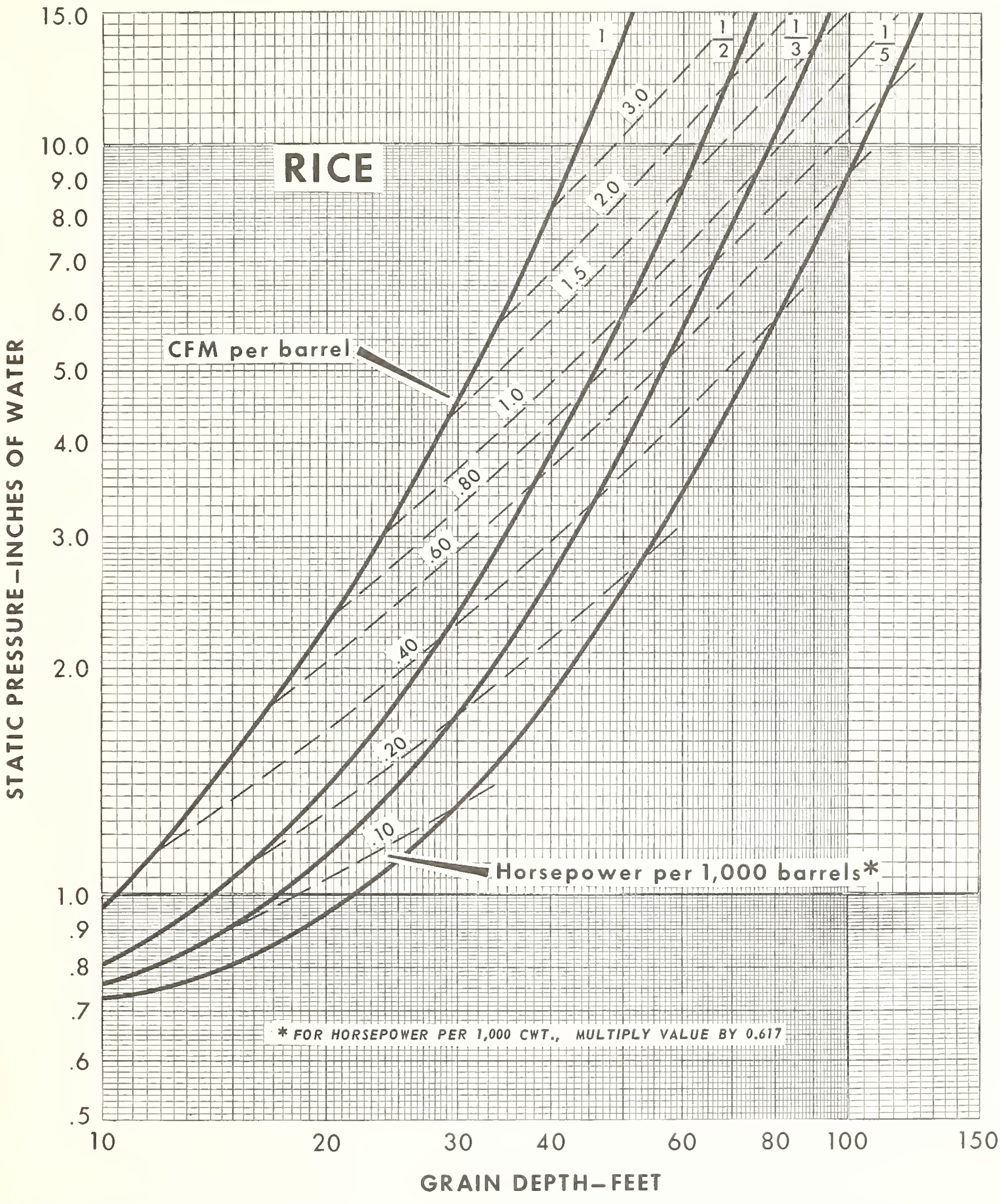

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FIGURE 22.—Fan horsepower and static pressure (inches of water) requirements for aerating rice at different rates of airflow (cfm per barrel) and at grain depths ranging from 10 to 150 feet.

wheat which was 7.4 inches of water. Then the airflow through the corn should be the same as through the wheat.

c. Method 3.—Speed of fan reduced but no damper used—use same horsepower requirement (3.7 HP) as for wheat. The fan manufacturer's capacity rating tables should be used to obtain an estimate of the airflow rate at the reduced fan speed.

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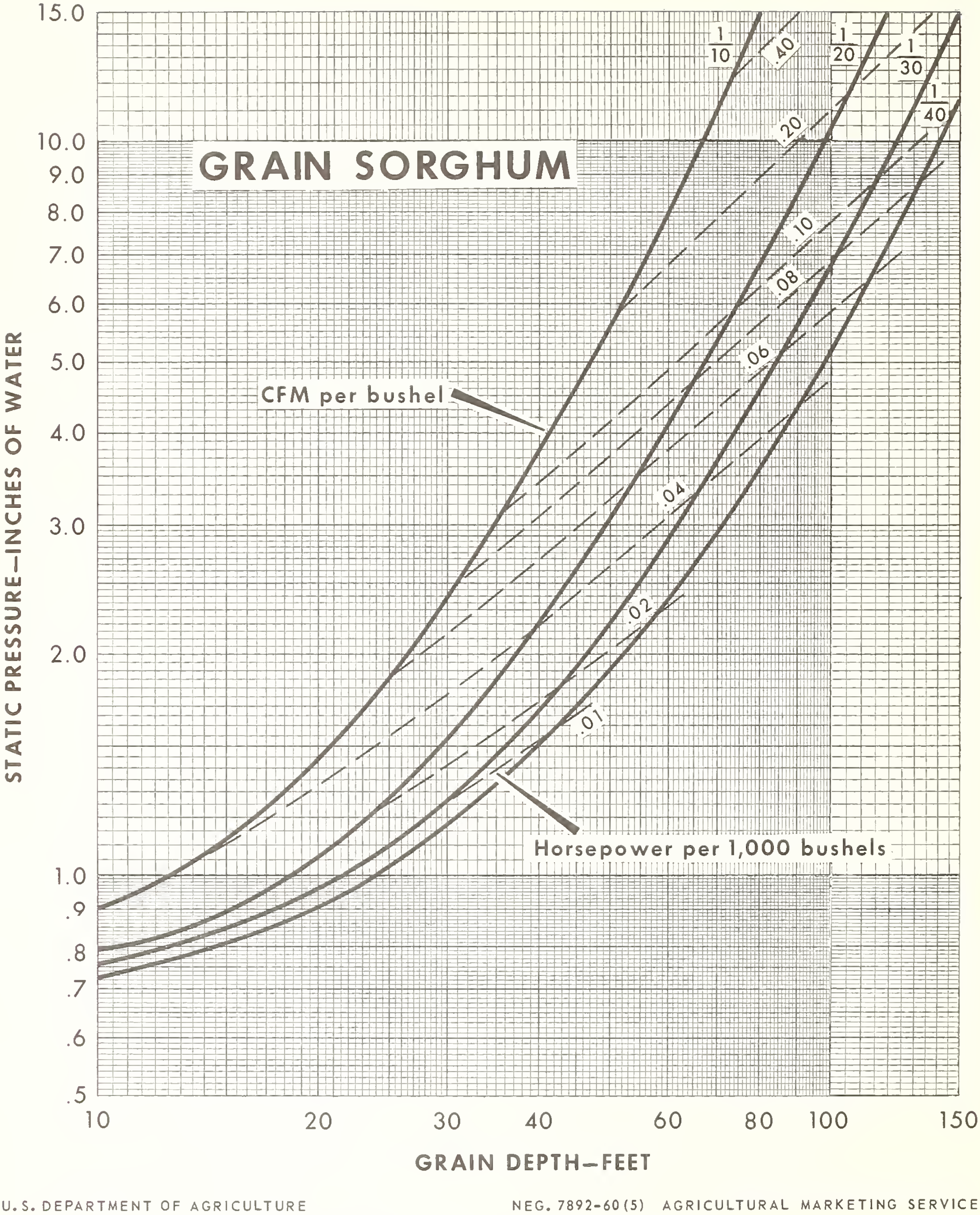

FIGURE 23.—Fan horsepower and static pressure (inches of water) requirements for aerating grain sorghum at different rates of airflow (cfm per bushel) and at depths ranging from 10 to 150 feet.

A manifold system with one fixed fan can also be used to aerate two or more kinds of grain. Select a fan and motor that will supply air at the desired rate for the grain with the greatest static pressure and in the volume required for the number of storages to be aerated at one time. Damper or slide gates should be supplied for regulating the airflow to each storage.

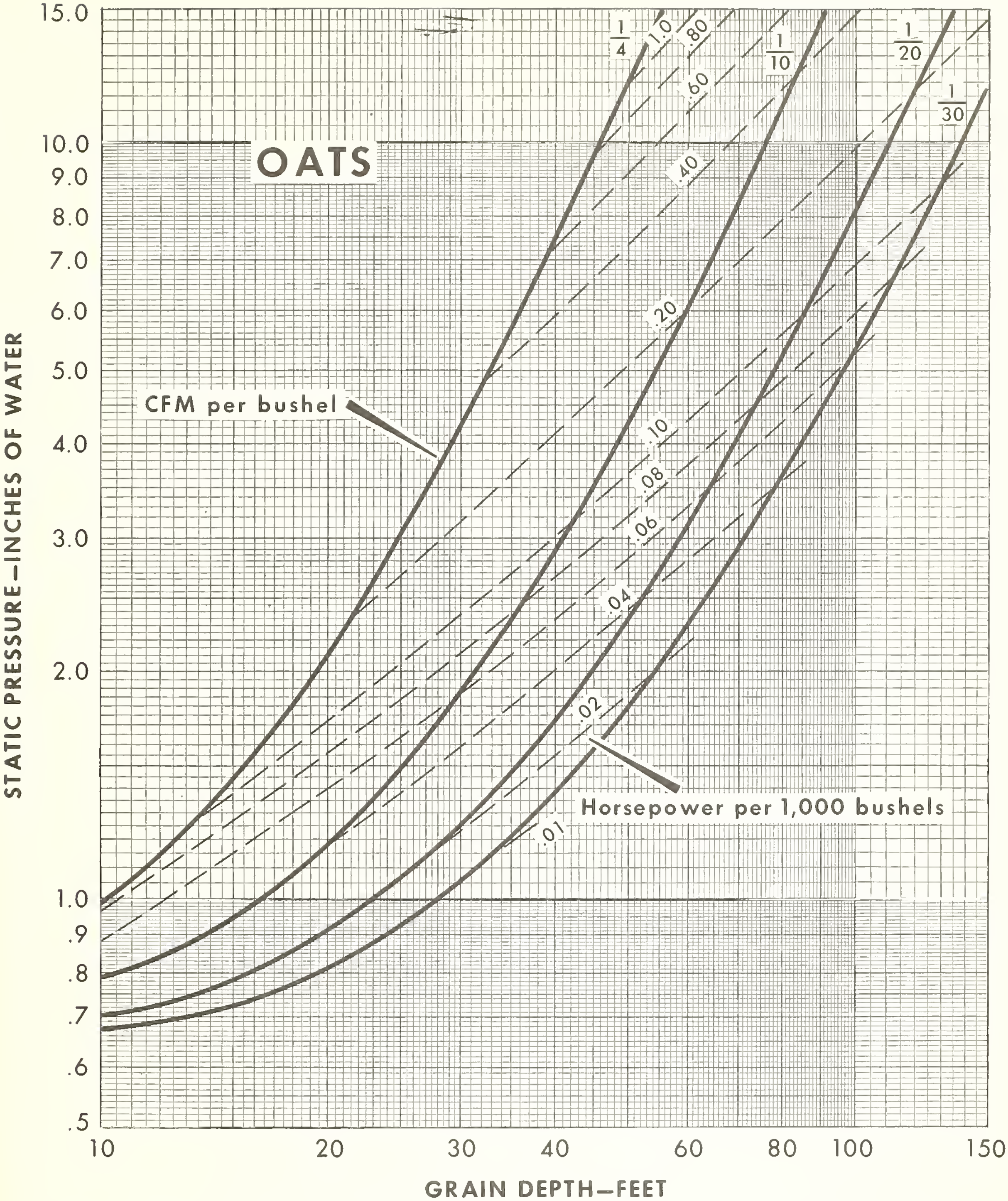

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Figure 24.—Fan horsepower and static pressure (inches of water) requirements for aerating oats at different rates of airflow (cfm per bushel) and at grain depths ranging from 10 to 150 feet.

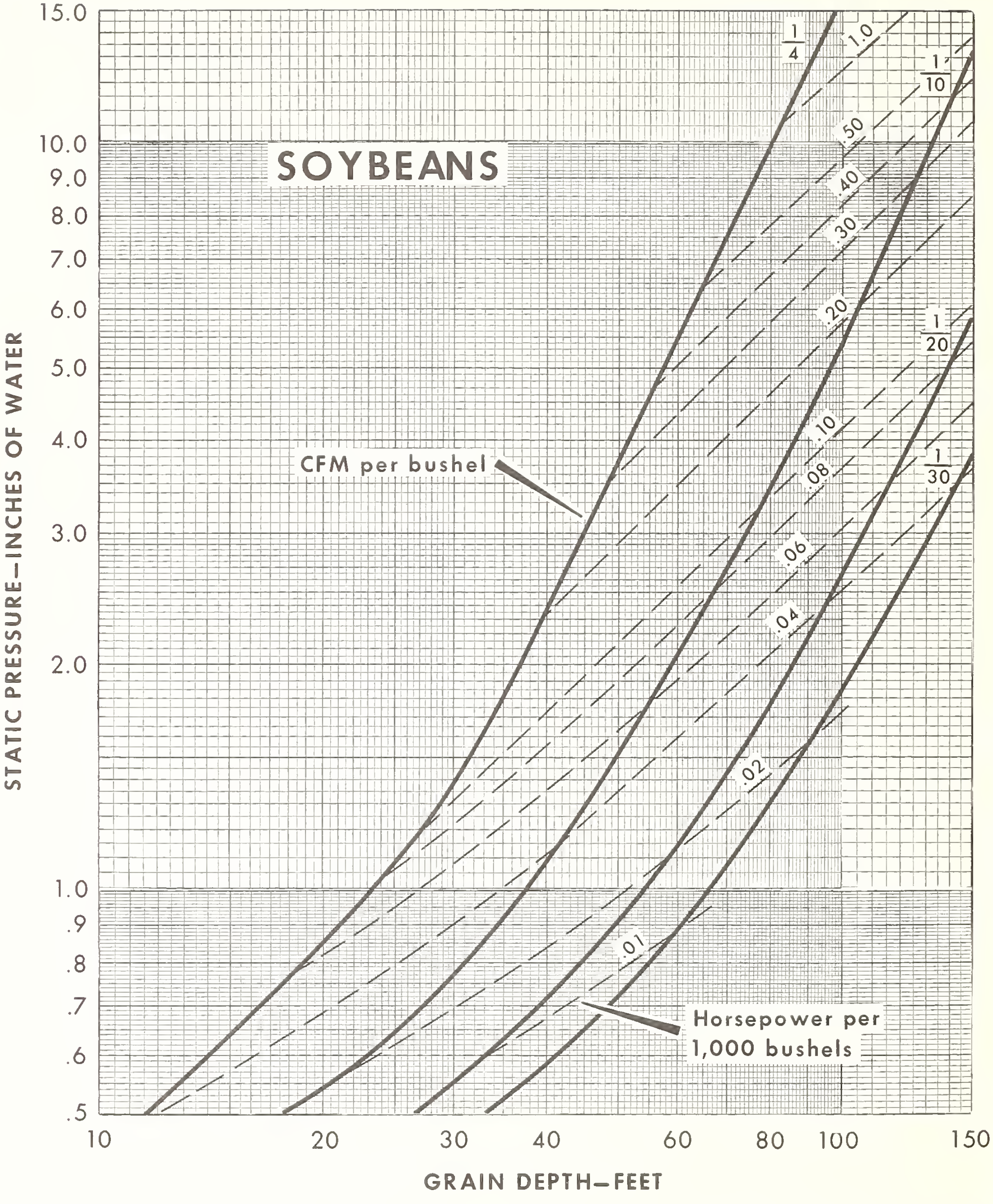

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Figure 25.—Fan horsepower and static pressure (inches of water) requirements for aerating soybeans at different rates of airflow (cfm per bushel) and at grain depths ranging from 10 to 150 feet.

ELECTRIC MOTORS

Electric motors, available in many different types and sizes, are generally used to drive aeration fans. Most fans require only low to medium starting torque. Most installations are designed for constant speed operation.

The type of motor selected will be dependent upon the electric service available, the power supplier's regulations, and insurance ratings. Existing local codes and ordinances must be complied with in installing motors. A totally enclosed, fan-cooled motor usually is required for aeration duty where grain dust is present and where complete weather protection is needed. In selecting the size of motor for operating a fan, it is advisable to select at least the size next larger than the fan requirements. Motors may be connected either directly to the fan shaft or by V-belt drives.

Where *three-phase* current is available a squirrel cage induction motor is recommended. These motors are available in all sizes likely to be needed for aeration work, from ⅛ horsepower and upwards. Standard voltages are 110, 220, and 440. Full voltage starting is the rule for these motors up to 30 horsepower. However, some power companies may require low voltage starting on motors in this range.

Single-phase induction motors are suitable for fan operation, but are more expensive than 3-phase motors. Many power companies object to use of single-phase motors over 7½ horsepower.

MOTOR CONTROLS

Control equipment for aeration fan motors should be installed in accordance with the National Electric Code and the requirements of local authorities. The control equipment should include: (1) Means of starting and stopping the motor; (2) means of disconnecting the motor from the power supply; (3) overload and low voltage protection for the motor; and (4) short-circuit protection for the motor and motor-branch circuit.

A motor starting switch, either magnetic or manual, with built-in overload protection is recommended for motors of one horsepower, and larger. Smaller motors should have either overload protection built into the motor or time-delay fuses or circuit breakers rated according to the motor amperage. Fuses or automatic circuit breakers should be included in motor circuits to protect against short circuits in the wiring.

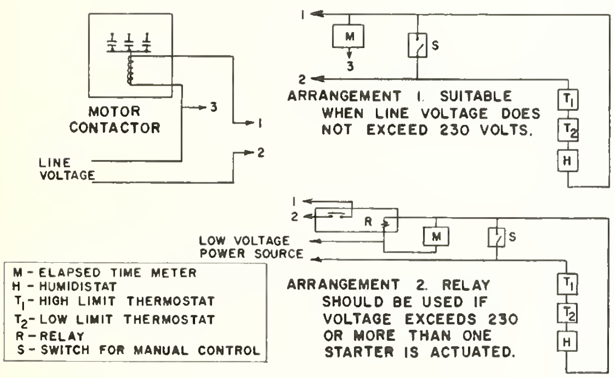


FIGURE 26.—Magnetic starter, circuits, and actuators for automatic control of aeration fans.

Automatic motor controls are used to limit aeration to periods of favorable weather and to reduce the attendant labor required. They allow fan operation to be continued through the night, on week-ends and on holidays, when in many plants there is no one on duty. Also, with automatic controls one can take advantage of weather favorable for aerating, while with manual controls much of the good aeration weather may not be used.

Automatic motor controls for fans generally are made up of standard thermostats and humidistats used in heating and air-conditioning applications. Time clocks, interval timers, selector switches, pilot lights, and elapsed time meters are sometimes added to the system to further control fan operation and to provide the operator with information on how long the fan runs. Except for small fractional horsepower motors, magnetic motor starters are required where automatic controls are used.

A control system circuit employing a high-limit thermostat, a low-limit thermostat, a humidistat—all three connected in series—and an elapsed time meter is shown in figure 26. The high-limit thermostat prevents fan operation when the air temperature is above the set point, and the low-limit thermostat prevents operation when the air temperature is below the set point. The humidistat prevents operation when the relative humidity of the air is above the set point.

The design of the enclosure for, and the location of the control panel are important to the proper operation of control systems for aeration fans. The control elements should be surrounded by air at the same condition as that being moved through the grain, but they should not be located in excessively dusty or windy locations. A well-ventilated enclosure in a shady location is best.

Automatic controls must be kept in good working order and set properly or their effectiveness in selecting proper weather conditions is lost. Therefore, they require occasional inspection and servicing. Time clocks must be reset each time electrical service to the control is interrupted. The moisture sensing elements in humidistats are particularly sensitive to dust, and must be kept clean. Sensing elements made of hair may need to be replaced every year or two.

GENERAL OPERATING CONDITIONS FOR AERATION SYSTEMS

Maintaining the market quality of stored grain by aeration involves the movement of atmospheric air of acceptable temperature and relative humidity through the grain. The quality and moisture content of the grain to be aerated are important. Obviously, aeration can not be expected to substantially improve grain of low market quality.

General operating conditions are discussed in this section. A detailed report on methods and procedures for operating aeration systems in the

Corn Belt has been published.[8] Similar reports for the Southeast, the Southwest, and the Central Plains are being prepared for publication.

GRAIN MOISTURE CONTENT

Grain can absorb moisture from or give up moisture to the air surrounding it. Sometimes the grain neither loses nor gains moisture. It is then considered to be at its "equilibrium moisture content" for the temperature and relative humidity of the air surrounding the grain. Some information on equilibrium moisture contents is available for most grains (table 4).

Research results and the experience of commercial operators showing the maximum moisture content and the accompanying relative humidity for the safe storage of grains are presented in table 4.

ATMOSPHERIC CONDITIONS

The temperature and the relative humidity of outside air change frequently with variations occurring each day. However, by proper setting of temperature and humidity controllers, or by determining atmospheric conditions before and during aeration, proper aeration conditions can be assured.

TABLE 4.—*Maximum moisture content for safe storage and corresponding relative humidities for specified kinds of grains and seeds*

Kinds of grains and seeds	Maximum moisture content for safe storage (wet basis)	Relative humidity of air at which grain is in equilibrium with air (77° F.)
	Percent	*Percent*
Shelled corn, oats	[1] 13. 0	61
Wheat (hard red winter)	[1] 13. 0–13. 5	64–68
Wheat (soft red winter)	[1] 13. 0–13. 5	67–73
Wheat (hard red spring)	[2] 14. 0–14. 5	73–74
Soybeans	11. 0	68
Rice	13. 0	71
Pea beans	16. 0–18. 0	76–84
Grain sorghum	[1] 13. 0	65

[1] Southern areas 12 percent.
[2] Higher moisture limits applicable because of lower average air temperatures in producing area.

Air temperatures.—Table 5 lists for several areas the suggested maximum monthly operating air temperatures for cooling grain. These temperatures were selected on the basis of past weather records and results of grain aeration tests. They are suitable for either manual or automatic fan control. Good results have been obtained when fans were operated while the air was at, or below, these temperatures but fans were not operated when temperatures were higher than those listed. Grain was cooled to temperatures equal to or slightly lower than these maximum operating air temperatures and then the fans were stopped.

Air relative humidity.—It is usually advisable to aerate grain with air having average humidities approximating those listed in table 4. Continuous aeration of storable grain using air with higher humidities will increase the grain moisture. However, aeration with air having a relative humidity as high as 80 percent has been satisfactory where the air temperature is *at least 10 degrees lower* than the temperature of the grain. Grain aerated under these conditions should be checked frequently to make sure no deterioration is taking place. Daily air humidities normally fluctuate over a wide range, from near 100 percent at night and early morning down well below 60 to 70 percent on clear days. Therefore, fans need to be stopped only when the average daily humidity exceeds the limits outlined above. However, if grain having temperatures of 95° to 100° F., or higher, and having some excess moisture, goes into storage, it may be desirable to run the fan when air humidities are above 80 percent. Some cooling will be accomplished and aeration airflow rates usually are so low that any moisture change in the grain will be extremely slow. A humidistat may be used to stop the operation of the fan when humidities are high and during periods of rain and fog. This also may be done manually.

GRAIN MOISTURE CHANGE DURING AERATION

Drying.—Some drying occurs when grain is cooled by air. In passing through the grain the cooling air is warmed and is able to hold more moisture as its temperature is increased. Any increased moisture in the cooling air must come from the grain. In cooling tests in the Central Plains the moisture content of the grain was reduced as follows: Summer—0.3 percent; fall—0.2 percent; and winter—0.1 percent. The temperature of the grain was reduced approximately 15° F. for each cooling stage. This drying also influences the cooling rate and the amount of cooling resulting from evaporation of moisture is considerable.

Wetting.—Grain near the air entrance may be cooled to air temperature long before grain temperatures are reduced in other parts of the storage. Some moisture may be added to this cooled grain before aeration is completed. However, there is little danger of excessive wetting of the grain if: (1) The grain is not cooler than the air being moved through it; and (2) aeration is not continued in high humidity weather *after* the grain has cooled to near air temperature.

[8] Foster, G. H., and Stahl, B. M. Operating Grain Aeration Systems in the Corn Belt. Mktg. Res. Rpt. No. 337, U.S. Dept. Agr., Sept. 1959.

TABLE 5.—*Suggested maximum monthly operating air temperatures for cooling grain in specified areas*

Month	Central Plains [1]	North Central [1]	South East [2]	South West [1]
	Degrees F.	*Degrees F.*	*Degrees F.*	*Degrees F.*
July	85	75	85	90
August	85	75	85	90
September	70	65	85	80
October	60	55	70	70
November	50	45	60	60
December	50	45	45	60
January	50	45	45	50
February	50	45	50	50
March	50	45	55	50
April	60	55	60	60
May	70	65	75	70
June	85	75	80	85

[1] Allows about 12 or more hours of operation each day under normal conditions.

[2] Allows approximately 6 hours of operation each day at relative humidities below 80 percent.

SATISFACTORY GRAIN TEMPERATURES

General storage practice indicates that a grain temperature of about 50° F. is satisfactory, particularly if there is a chance of the grain being moved during hot weather. Apparently grain at 50° F. can be moved during the summer with little danger of moisture condensation and subsequent spoilage. Grain temperatures of 35° and 40° F. have proven satisfactory where the grain was not moved during warm weather.

The higher the grain temperature the more the air will be warmed while it passes through the grain, and each pound of air will carry away additional heat. Therefore, about the same length of time is required to cool all grain to air temperature, regardless of the initial grain temperature (fig. 27). However, when the grain moisture content is reduced during aeration, the additional cooling resulting from the evaporation of water will shorten the cooling time.

COOLING ZONE

As aeration progresses a cooling zone is established which moves through the grain in the direction of airflow (fig. 28). All the grain behind the zone will be near the entering air temperature; all ahead of it will be near the initial grain temperature. The depth and shape of the zone will depend on the airflow rate, the amount of cooling or heating occurring near the bin walls, and the amount and concentration of cracked grain and foreign material in the stored grain.

As grain cools by zones (fig. 28), the airflow must be adequate to move the cooling zone through all the grain within an allowable time limit. There is danger of grain deterioration in that part of the bin cooled last, particularly in warmer climates. This factor is the most important

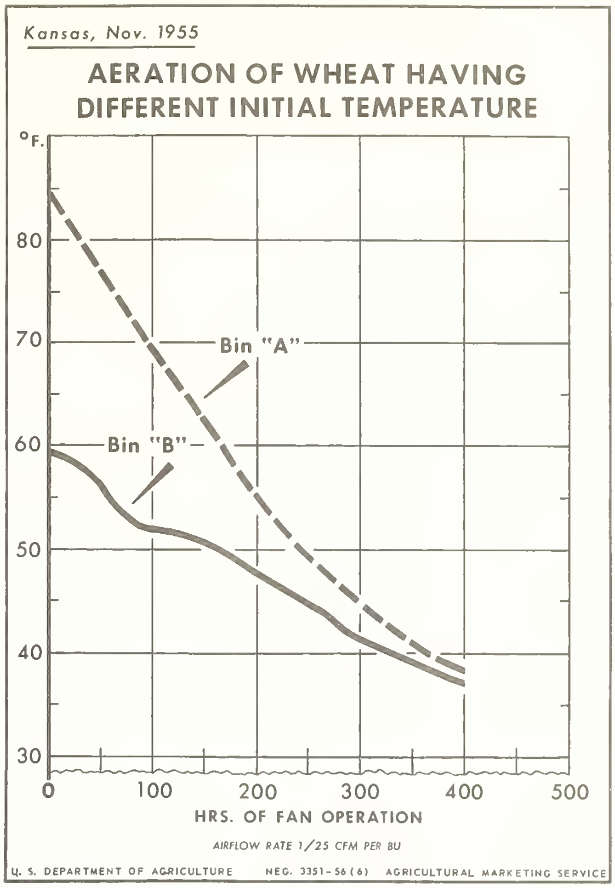


FIGURE 27.—Grain cools to near air temperature in about the same number of hours of fan operation regardless of initial grain temperature. The average air temperature ranged between 25° to 43° F. during the cooling period.

consideration in establishing time limits for completing a cooling stage. Reasonable power requirements and favorable aeration weather also must be considered in selecting airflow rates.

TIME REQUIRED FOR COOLING GRAIN

The time required to cool the grain will vary with the airflow rate used, the amount of cooling resulting from evaporation of moisture from the grain during aeration, and the uniformity of airflow through the grain (fig. 29).

As a general guide, in the central part of the United States a fan must operate the following number of hours at an airflow rate of 1/10 cfm per 60-pound bushel, to cool grain: Summer aeration—80 hours; fall aeration—120 hours; winter aeration—160 hours.

The range in cooling time is attributed to the difference in amount of evaporative cooling occurring during each season. Generally, the grain is cooled as much as 15 to 20 degrees F. during each season or cooling stage. The grain temperature after each season's cooling should

COOLING ZONE DURING AERATION

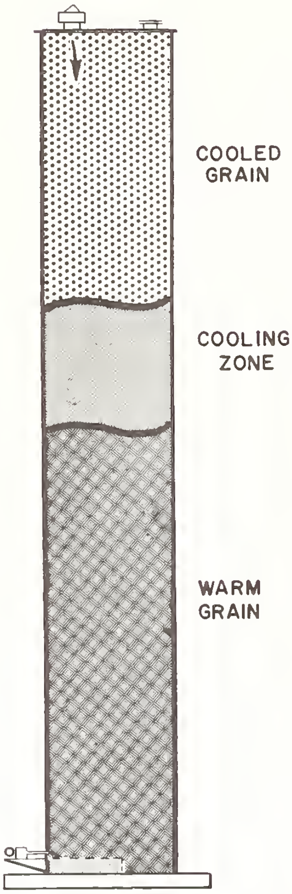


Figure 28.—Cooling zone in stored grain during aeration.

be equal to or slightly lower than the maximum air temperatures shown in table 5, page 27.

The time required for cooling with airflow rates other than $\frac{1}{10}$ cfm per bushel is inversely proportional to the airflow rate used. That is, if the airflow rate is reduced to $\frac{1}{20}$ cfm the estimated hours of fan operation are double those given above.

PREVENTING MOLD GROWTH AND INSECT ACTIVITY

Fans should be started as soon as the storage is filled with warm, summer-harvested grain if atmospheric conditions are suitable. Grain temperatures should be lowered as soon as possible to minimize the mold growth and insect activity.

Ordinarily grain is cooled by aerating it by successive stages during the summer, fall, and winter seasons (fig. 30). Each cooling stage begins when substantial cooling becomes possible with seasonal changes. Reduction of grain temperature soon after the grain is stored helps to retard insect activity and mold development.

Some study has been given to cooling grain in *upright storages* by a single stage. With this method aeration is postponed until later in the season when the air temperature is low enough to cool the grain to the desired temperature. One objection to this method is that aeration may be started so late that some grain has deteriorated or moisture has migrated. Costs for single-stage cooling are less than for cooling by successive stages.

PROGRESS OF COOLING IN AERATED STORAGE

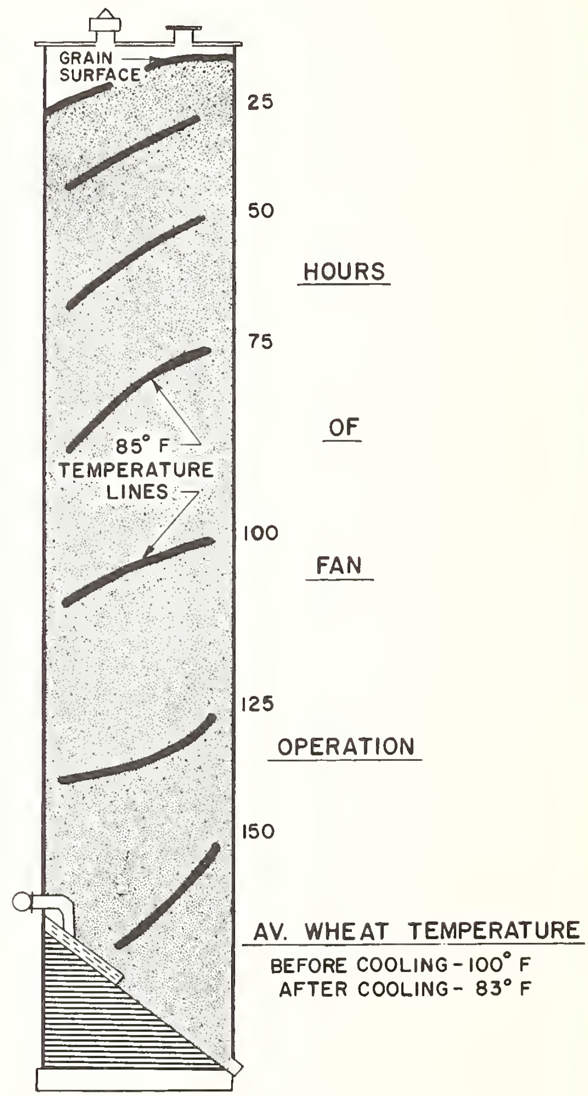


Figure 29.—Aerated wheat in storage 18 feet in diameter and 101 feet high; airflow rate—$\frac{1}{20}$ cfm per bushel; Kansas, July 1955.

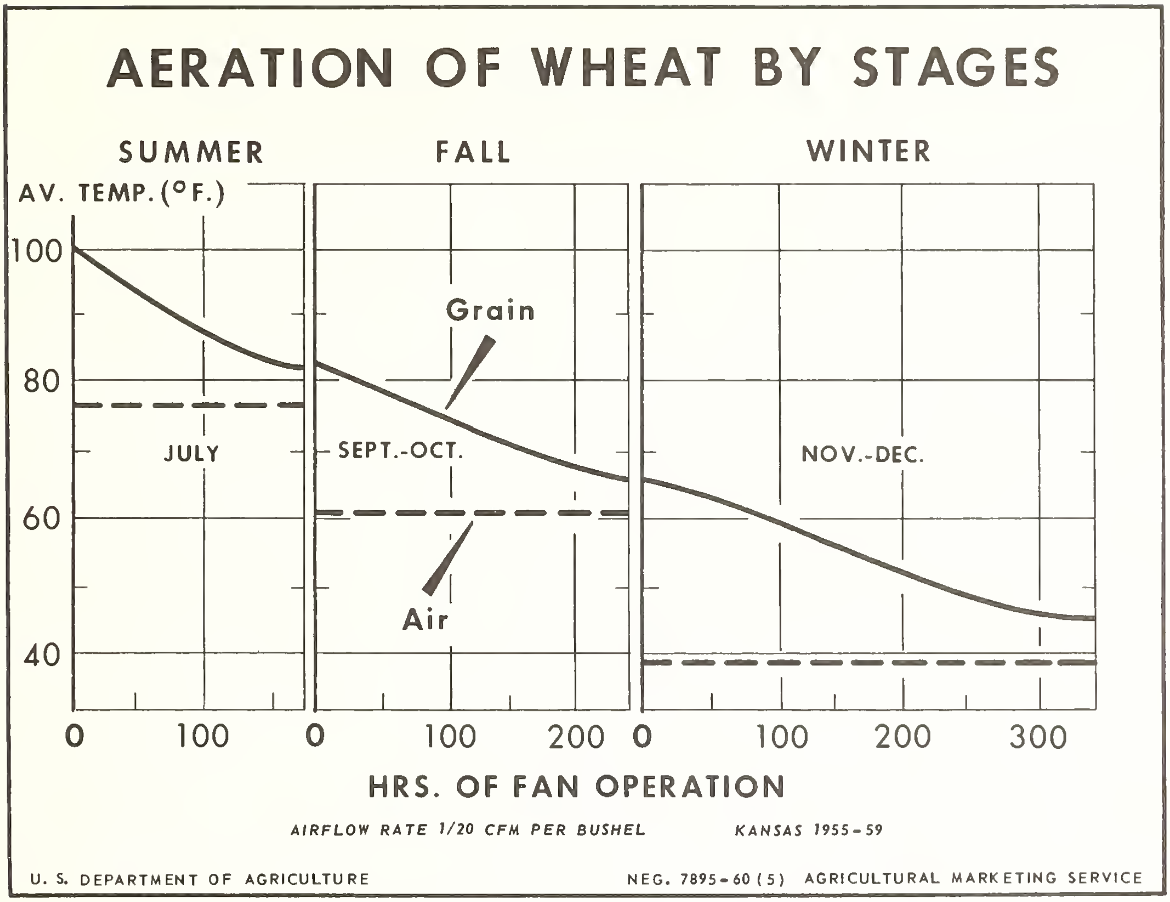


Figure 30.—Aeration of wheat by stages.

By either plan, once a cooling zone has been started through stored grain it should be moved on through. Otherwise there may be areas in the bin (the cooling zone) where grain temperatures vary enough to cause spoilage (fig. 31).

EQUALIZING STORED GRAIN TEMPERATURES

Aeration to equalize stored grain temperatures may be started whenever the air temperature is 10° to 15° F. below that of the warmest portion of the stored grain.

In both *flat* and *upright* storages fan operation usually is intermittent. At the higher airflow rates practical in flat storages, the fan is operated about one week each month, from September through December or January. Or, it is operated until grain temperatures are fairly uniform throughout the storage.

In large upright storages fans usually are operated daily during the fall and winter months when air conditions are suitable. Automatic control is recommended so as to take full advantage of favorable weather. (See section on Motor Controls.)

MOISTURE CONDENSATION IN SURFACE GRAIN

It has been repeatedly demonstrated that aeration during the fall and winter is *beneficial;* it will prevent excessive migration of moisture from the warm area in a bin to the top layer of grain. A similar, but less obvious, migration and accumulation of moisture may occur in the cold subsurface layers of grain during the spring season.

Additional aeration during the spring when the air becomes warm and dry may be desirable to remove or distribute this moisture. Some precautions are needed when aerating stored grain in the spring and local recommendations should be followed.

MOVING COLD GRAIN DURING WARM WEATHER

In the northern grain producing areas it is possible to cool grain below freezing temperatures. These temperatures will kill stored grain insects, and also may stop or retard various deterioration processes. However, warehousemen have found

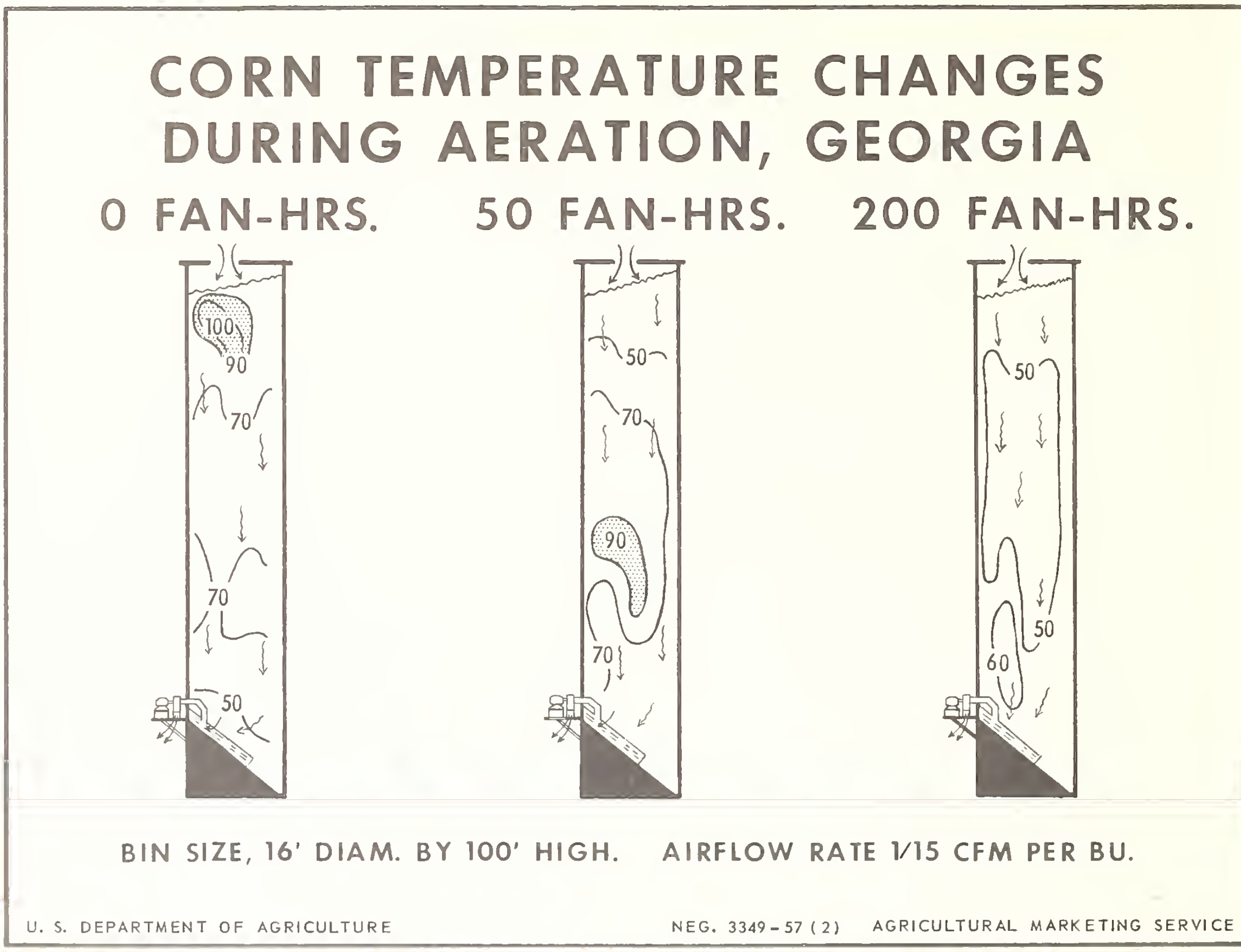


FIGURE 31.—Corn temperature patterns in this Georgia storage illustrate how "hot spots" may not cool down but move on out of the grain during aeration.

that low temperatures also may have disadvantages. The risk of moisture accumulation beneath the grain surface is increased. Moreover, if cold grain must be moved or shipped during warm weather some condensation of moisture on the grain may occur and there is danger of spoilage. Grain at 45° to 50° F. can be moved during hot weather with little danger of spoilage.

USE OF GRAIN TEMPERATURE INDICATORS

Most grain storage operators closely follow temperature changes of the grain they have in storage. These changes, together with other quality indexes, influence their schedules for aeration or for turning grain from unaerated bins. Where the grain is aerated, and little or no turning is done, it is important that dependable temperature indicating equipment be used.

The most common grain temperature indicators are mercury thermometers and thermocouples. Bimetallic and recording thermometers or thermistors and electrical resistance elements could be used but have limitations which will probably prevent extensive application in grain storages.

Most modern upright storages make use of insulated thermocouple wires wound on steel cables which are encased in an abrasion- and fumigant-resistant covering. These cables are permanently suspended from the bin roof and connected to a centrally located potentiometer where temperatures can be observed. For upright storages of from 15 to 20 feet in diameter, a single cable, having thermocouple junctions at 5- to 7-foot intervals along the cable, can be used to detect dangerous temperature conditions. Additional cables should be used when the storage diameter exceeds 20 feet.

In some flat storages probe thermometers are inserted at various locations and depths to determine grain temperatures. However, making a complete record of bulk temperature conditions in this manner is time-consuming. An indication of sudden increase in temperature may be missed unless thermometers are re-inserted at definite positions in the bulk. Also thermocouple cables having junctions at 3- or 4-foot intervals along the cable can be suspended from the roof framing, or inserted into the grain after the bin is filled. Detection of localized heating between the thermocouple cables may depend upon additional periodic inspection of the grain bulk.

High grain temperatures serve as a warning of possible damage from insects, microorganisms, or faulty aeration. Therefore temperature indicating equipment must be used regularly and the results recorded. When any abnormal rise in temperature is found, records should be made daily until corrective treatment has proved effective. If the grain is being aerated, temperatures should be recorded at least once a week until all of the bulk has reached the desired temperature.

COSTS OF AND POSSIBLE SAVINGS FROM AERATION SYSTEMS

COSTS OF OWNERSHIP AND OPERATION

Examples of actual equipment and installation costs of aeration systems in some of the typical off-farm grain storages in Texas and Kansas are shown in tables 6 to 9 respectively.

An example of the electric power costs incurred in the operation of an aeration system under specified conditions is shown in table 10.

Equipment and installation costs per bin of an aeration system for an upright storage for corn at 1/15 cfm per bushel is shown below. The sloping bottom bin is 16 feet in diameter and 94 feet high, and has a capacity of 15,000 bushels. These figures are based on cost information gathered in 1955 from an experimental installation in Georgia.

Type of aeration system	Duct and supply pipe	Fan and motor	Electric wiring and starter	Automatic controls	Total cost per bin	Cost per bushel
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Individual—1 fan for each bin	60	385	215	35	795	4. 6

TABLE 6.—*Equipment and installation costs of aeration systems for flat storages, Midville, Ga., 1959*

Type of aeration system	Duct and supply pipe	Fan and motor	Electric wiring and starter	Automatic controls	Total cost	Cost per bushel
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Flat storage, 50′ x 60′, 24,000 bushels wheat, one fixed fan with manifold connection to all ducts	755. 00	[1] 125. 00	[2] 40. 00	50. 00	905. 00	4. 04
Flat storage, 80′ x 100′, 90,000 bushels oats, one fixed fan with manifold connection to all ducts	1, 670. 00	[3] 375. 00	105. 00	50. 00	2, 185. 00	2. 44

[1] One-third horsepower motor and fan. [2] No starter used. [3] Two horsepower motor and fan.

TABLE 7.—*Equipment and installation costs of aeration systems for a 6-bin, upright storage for grain sorghum at an airflow rate of 1/10 cfm per bushel* [1]

[*Bin 22 feet diameter by 42 feet high; capacity 12,700 bushels; flat bottom*]

Type of aeration system	Equipment and installation costs							
	Duct and supply pipe	Fan and motor	Electric wiring and magnetic starter	Automatic controls	Fumigation facilities	Total cost	Cost per bin	Cost per bushel
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Fixed fans—permanent connection for each bin. 1 fan for each of 6 bins	294	[2] 2, 340	750	42	480	3, 906	651	5. 1
Manifold—permanent connection for 6 bins. 1 fan for 6 bins	1, 670	[3] 815	256	42	271	3, 054	509	4. 0
Portable—portable connection for each bin. 1 fan for each 2 bins	294	[4] 1, 170	525	42	180	2, 211	368. 50	2. 9

[1] Based on cost information available from a commercial installation in Texas, 1955.
[2] 6–1 HP motors and fans. [3] 1–15 HP motor and fan. [4] 3–1 HP motors and fan.

TABLE 8.—*Equipment and installation costs of aeration systems for upright storages (wheat)*[1]

[*Bin 26 feet diameter by 100 feet high; 45,000 bushel capacity; flat bottom*]

Type of aeration system	Basic unit	Airflow rate	Equipment and installation costs					
			Duct and supply pipe	Fan and motor	Electric wiring and controls	Total cost	Cost per bin	Cost per bushel
		cfm per bu.	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Fixed fan for each bin	1 bin	1/20 for 1 bin	390	475	175	1, 040	1, 040	2. 3
Manifold for 4 bins. 1 fan per 4 bins	4 bins	1/40 for 4 bins or 1/20 for 1 bin	1, 675	535	325	2, 535	636	1. 4
Manifold for 8 bins. 1 fan per 8 bins	8 bins	1/40 for 4 bins or 1/20 for 1 bin	3, 300	575	450	4, 325	541	1. 2
Portable connection for each bin. 1 fan per 4 bins	4 bins	1/20 for 1 bin	1, 520	575	350	2, 445	610	1. 4
Portable connection for each 2 bins. 1 fan per 8 bins	8 bins	1/20 for 2 bins	2, 975	625	450	4, 050	506	1. 1

[1] Based on cost information available from a limited number of commercial installations in Kansas, 1956.

TABLE 9.—*Equipment and installation costs of aeration systems for upright storages (wheat)*[1]

[*Bin 18 feet diameter by 100 feet high; 20,000 bushel storage capacity; hopper bottom*]

Type of aeration system	Basic unit	Airflow rate	Equipment and installation costs					
			Duct and supply pipe	Fan and motor	Electric wiring and controls	Total cost	Cost per bin	Cost per bushel
		Cfm per bu.	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
Fixed fan for each bin	1 bin	1/20 for 1 bin	380	395	175	950	950	4. 7
Manifold for 4 bins. 1 fan per 4 bins	4 bins	1/40 for 4 bins or 1/20 for 1 bin	1, 560	395	270	2, 225	556	2. 7
Manifold for 8 bins. 1 fan per 8 bins	8 bins	1/40 for 4 bins or 1/20 for 1 bin	3, 120	425	400	3, 945	493	2. 4
Portable connection for each bin. 1 fan per 4 bins	4 bins	1/20 for 1 bin	1, 440	425	300	2, 165	541	2. 7
Portable connection for 2 bins. 1 fan per 8 bins	8 bins	1/20 for 2 bins	2, 760	475	400	3, 635	457	2. 2

[1] Based on cost information available from a limited number of commercial installations in Kansas, 1956.

TABLE 10.—*Electric power costs incurred in the operation of aeration systems in upright wheat storages having a 100-foot grain depth, by specified cooling methods and airflow rates* [1]

Cooling method	Airflow rate	Electric power costs per bushel per year [2]
	cfm per bushel	*Cents*
Single stage	1/20	1/10
Three stages	1/20	1/4
Single stage	1/40	1/20
Three stages	1/40	1/10

[1] Data from experimental installations in Kansas.
[2] Based on power costs of 2 cents per kilowatt-hour.

Further examples of equipment and installation costs of aeration systems for flat and tank storages and for a "crossflow" system for upright storages are shown below.

Equipment and Installation Costs of Aeration Systems for Flat Storages, Texas 1959

1. Storage 80 feet wide and 216 feet long with 16-foot side walls and 8-in-12 roof slope. Capacity 356,000 bushels. Airflow rate 1/10 cfm per bushel.

Tunnel system—Tunnel, concrete 2½ ft. x 4 ft. lengthwise under center of building:

Cost of digging tunnel	$180.00	
Steel	100.00	
Labor and forming	500.00	
Concrete	600.00	
Miscellaneous and overhead	138.00	
		$1,518.00
Duct, including channels and gate valves		1,979.40
Fans, two (2), 20-horsepower, 36-inch vaneaxial, complete with starters		2,057.46
Wiring		900.00
Total		6,454.86

$\frac{\$6,454.86}{356,000 \text{ bu.}} = 1.81$ cents per bushel.

2. Storage 80 feet wide and 200 feet long with 20-foot side walls and a 6-in-12 roof slope. Capacity 360,000 bushels. Airflow rate 1/10 cfm per bushel.

Manifold system with 2 fans on each side of the building.

Manifolds, connecting pipes, transitions, and return duct for fumigation	$3,090.00
Duct, 600 feet of 23-inch diameter, half-round, corrugated, and perforated	750.00
4 fans, each to deliver 8,300 cfm at 2.5 inches static pressure	1,000.00
Wiring	900.00
Total	5,800.00

$\frac{\$5,800.00}{360,000 \text{ bu.}} = 1.61$ cents per bushel.

3. Storage 80 feet wide and 200 feet long with 20-foot side walls and a 6-in-12 roof slope. Capacity 360,000 bushels. Airflow rate 0.15 cfm per bushel.

Manifold system with 5 fans on each side of the building.

Manifolds, connecting pipes, and return duct for fumigation	$2,251.00
Duct, 600 feet of 30-inch diameter, half-round, corrugated, perforated, with channels	1,800.00
10 fans, each to deliver 5,600 cfm at 3.5 inches static pressure	2,500.00
Wiring	2,000.00
Total	8,551.00

$\frac{\$8,551.00}{360,000 \text{ bu.}} = 2.38$ cents per bushel.

4. Storage building 80 feet wide and 360 feet long with 22-foot side walls and a 4-in-12 roof slope. **Capacity** 600,000 bushels. Airflow rate 1/10 cfm per bushel.

Manifold system with 5 fans on each side of the building.

System complete, including wiring	$12, 633. 00

$$\frac{\$12,633.00}{60{,}000 \text{ bu.}} = 2.1 \text{ cents per bushel.}$$

Equipment and Installation Costs of Aeration System for Oil Tank Storages. Texas 1959

1. Tank, 119 feet in diameter and 40 feet high. Capacity 360,000 bushels. Airflow rate 1/10 cfm per bushel.

Duct, 244 feet of 30-inch diameter, half-round, corrugated, and perforated	$850. 00
Transitions	432. 00
6 fans—7½ horsepower, vaneaxial (Marine surplus)	1, 200. 00
Controls	195. 00
Automatic louvers	306. 00
Installation (labor cost and miscellaneous)	250. 00
Wiring	400. 00
Total	3, 633. 00

$$\frac{\$3,633.00}{360,000 \text{ bu.}} = 1.0 \text{ cent per bushel.}$$

2. Tank, 96 feet in diameter and 30 feet high. Capacity 180,000 bushels. Airflow rate 1/10 cfm per bushel.

Duct, transitions and six 3-horsepower tube-axial fans	$2, 600. 00
Wiring	400. 00
Installation costs	125. 00
Total	3, 125. 00

$$\frac{\$3,125.00}{180,000 \text{ bu.}} = 1.74 \text{ cents per bushel.}$$

3. Tanks, 8, each 21 feet in diameter and 65 feet high. Capacity 167,000 bushels. Airflow rate 1/10 cfm per bushel.

Manifold system using one fan for 8 bins.

Duct, 320 feet of 15-inch diameter half-round, corrugated, and perforated	$960. 00
Fan and motor	825. 00
Manifold, connecting pipes, and gate valves	400. 00
Motor starter and controls	290. 00
Installation cost	325. 00
Total	2, 800. 00

$$\frac{\$2,800.00}{167,000 \text{ bu.}} = 1.68 \text{ cents per bushel.}$$

Equipment and Installation Costs of a "Crossflow" Aeration System

1. *Crossflow system* in hexagon-shaped bin 150 feet high. Capacity 21,000 bushels. Airflow rate 1/10 cfm per bushel.

One fixed fan

Duct, fan, and transitions	$800. 00
Wiring	50. 00
Installation cost	150. 00
Total	1, 000. 00

$$\frac{\$1,000.00}{21,000 \text{ bu.}} = 4.77 \text{ cents per bushel.}$$

AERATION AND TURNING COSTS

The total annual costs for the entire storage should be considered in making cost comparisons between aerating and turning grain. A proportionate share of the ownership costs—depreciation, interest, insurance, and taxes—should be allocated in either case. Operating costs include those for power, labor, maintenance, and repair required for each method. Any weight loss due to loss of moisture from the grain or from grain breakage should also be considered. The cost of empty space needed for turning should be included.

One large grain firm estimates that operating costs average 1/10 cent per bushel each time grain is turned. Other operators of flat and upright storages estimate these costs to range from 1/10 to 1/2 cent per bushel for each turn. In some areas grain usually is turned an average of four times a year. On this basis operating costs would range from 4/10 to 2 cents per bushel per year for the four turns.

Available data indicate that power costs for operating aeration systems range from 1/10 to 1/2 cent per bushel per year. Operating costs will vary with the kind of grain, type of storage—upright or flat, airflow rate, type of system, and the number of times grain is cooled annually.

The storage owner must consider several points in making a decision as to whether to install an aeration system. In general, if he now turns his grain he should consider aeration. However, if the grain is stored for only 1 to 3 months, and not turned, aeration may not pay. Or, if the grain temperatures are not above 70° F. when the grain is stored, and where moisture migration and accumulation is not a factor during the winter months, aeration may not be needed. Aeration does not permit visual inspection of grain. However, with available reliable grain-temperature-indicating equipment, it usually is possible to detect heating before serious deterioration occurs. Aeration also provides a practical and economical means of fumigating stored grain without moving it.

COMPARATIVE COSTS FOR AERATING AND TURNING RICE AND GRAIN SORGHUM

Some comparative annual costs for aerating and for turning rice are shown in table 11. No costs are included for the equipment used for filling and emptying the storage, for shrinkage, or for market quality changes in the grain during storage.

In comparing the costs of turning and aerating grain, one item that should be taken into consideration is the practice of leaving at least one empty bin for turning grain. One installation in Southern Texas consisting of 5 steel upright storages, each having 25,700 bushel storage capacity, stored grain sorghum in 4 storages before aeration systems were installed. One empty storage received the turned grain. Aeration systems were installed in each of the 5 storages. Following the installation of the aeration systems, grain was stored in all 5 storages. This increased the total capacity by 27,500 bushels. At a storage rate of 1½ cents per bushel per month, the "additional" storage capacity increased the monthly revenue $385.50.

TABLE 11.—*Comparative annual ownership and operation costs for cooling rice in upright storages by turning and by aeration, Texas 1959* [1]

Method and equipment	Initial cost	Expected life	Ownership costs [2]				Operating costs		Annual cost	Cost [3]	
			Depreciation	Interest at 5½%	Insurance and taxes at 4%	Total	Power and maintenance	Labor		Per barrel	Per cwt.
	Dollars	Years	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Cents	Cents
Turning: [4]											
2-tunnel augers	4, 800	15	128. 00	52. 80	76. 80	257. 60	115. 20				
2-galley augers	4, 800	15	128. 00	52. 80	76. 80	257. 60	115. 20				
2-bucket elevators	6, 000	20	120. 00	66. 00	96. 00	282. 00	84. 00				
						797. 20	314. 40	[5] 1, 620	2, 731. 60	3. 64	2. 25
2-tunnel conveyors	8, 000	15	213. 33	88. 00	128. 00	429. 33	62. 00				
2-gallery augers	4, 800	15	128. 00	52. 80	76. 80	257. 60	115. 20				
2-bucket elevators	6, 000	20	120. 00	66. 00	96. 00	282. 00	84. 00				
						968. 93	261. 20	[5] 1, 620	2, 850. 13	3. 80	2. 35
2-tunnel conveyors	8, 000	15	213. 33	88. 00	128. 00	429. 33	62. 00				
2-gallery conveyors	9, 600	15	256. 00	105. 60	153. 60	515. 20	69. 60				
2-bucket elevators	6, 000	20	120. 00	66. 00	96. 00	282. 00	84. 00				
						1, 226. 53	215. 60	[5] 1, 620	3, 062. 13	4. 08	2. 5
Aeration:											
2—40 HP motor and fan units	9, 500	20	475. 00	261. 25	380. 00	926. 25	700. 00	[6] 72	1, 988. 25	1. 99	1. 25

[1] 75,000 barrels (121,500 cwt.) turned 4 times annually; 100,000 barrels (162,000 cwt.) aerated annually in 4 stages.
[2] Interest based on average value of equipment; insurance and taxes based on initial value of equipment.
[3] No burden costs applied.
[4] Equipment used 40 percent of total annual operating time in turning rice 4 times.
[5] 450 hours at $3.60 per hour (1 man at $2.60 per hour, and 1 man at $1 per hour).
[6] 20 hours at $3.60 per hour (1 man at $2.60 per hour, one man at $1 per hour).

APPENDIX

INFORMATION AND CALCULATIONS FOR DESIGNING AN AERATION SYSTEM

Example—Wheat aeration system for an upright storage:

Design Steps	*Example*
I. Establish storage dimensions and capacity	One fan and one storage
A. Bin size—diameter and depth	18′ diameter—100′ depth
B. Bin capacity—Bushels:	
1. Floor area	0.7854 x $(18)^2$=254 sq. ft.
2. Volume (cu. ft.)=floor area x depth	254 x 100=25,400 cu. ft.
3. Capacity (bu.)=volume (cu. ft.) x 0.8 (1 cubic foot equals 0.8 bushel).	25,400 x 0.8=20,000 bu.
II. Establish airflow rate and volume	
A. Select airflow rate (cfm/bu.) (table 1, p. 6)	$\frac{1}{20}$ cfm per bushel
B. Total volume (cfm)=total bu. x cfm per bu.	20,000 x $\frac{1}{20}$=1,000 cfm
III. Determine duct requirements (page 7)	
A. Total duct surface area (sq. ft.)=$\frac{\text{Air volume (cfm)}}{\text{30 fpm}}$=$33\frac{1}{3}$ sq. ft.	
B. Select duct dimension:	
1. Select shape of duct	Round, perforated duct
2. Cross section size—diameter or dimension	Try 12-inch diameter (table 12, app.)
a. Surface area per foot of length (circumference).	3.14 sq. ft. per foot of length
NOTE. Effective surface area of round pipe in contact with floor, use 80 percent.	3.14 x 0.8=2.5 sq. ft. per foot of length
3. Length required=total duct surface area ÷surface area required per ft. of length. NOTE. Check bin size and clearance at drawoff.	$\frac{33.3}{2.5}$=13.3 ft. minimum length needed for surface area
4. Select duct dimensions	Use 12-inch diameter and 14-foot length in 18-foot diameter bin
C. Check velocity within duct	Maximum 2,000 fpm (page 16)
Velocity (fpm)=$\frac{\text{air volume (cfm)}}{\text{Cross sect. area (sq. ft.)}}$	$\frac{1,000}{0.78}$=1,280 fpm
D. Duct openings (page 7)	Recommendations for grain to be aerated
E. Strength of duct (page 7)	14-gage corrugated and perforated
IV. Determine supply pipe requirements (page 16)	
A. Cross section area based on maximum velocity of 2,500 fpm=$\frac{\text{air volume (cfm)}}{2,500}$	$\frac{1,000}{2,500}$ =0.4 square feet
9-inch minimum	Use 12-inch to match aeration duct
V. Additional design factors for connection of several bins to a single fan (see IV)	Does not apply this example
VI. Opening for air entrance to bin	
A. Select opening with cross-sectional area twice that of supply pipe	Fill hole, window, etc.
B. Provide for continuous opening and protection from weather	
VII. Assemble fan requirements	
A. Airflow rate (II–A)	$\frac{1}{20}$ cfm per bushel
B. Total air volume (II–B)	1,000 cfm

Example—Wheat aeration system for an upright storage—Continued

Design Steps	*Example*
VIII. Determine power and static pressure requirements	Use chart in figure 21
A. Static pressure	12.3 inches of water
B. Estimated power needed based on 0.21 HP per 1,000 bu. from chart in figure 21.	0.21 x 20=4.2 HP
C. Select motor	Use 5 HP electric motor

(Check with fan and motor supplier to determine if estimated power requirement is correct for the fan to be supplied.)

IX. Select controls
A. Automatic—temperature and humidity
B. Magnetic motor starter
C. Manual switch

Example—Rice aeration system designed for a flat storage:

I. Description of bin. A flat storage bin built inside an existing warehouse. Bin 15 feet by 31½ feet, of frame construction with corrugated sheet metal walls. Rice depth 12 feet. The capacity at a depth of 12 feet is approximately 1,267 barrels (4,560 bushels).

II. Desired features of aeration system. As indicated in table 1, recommended airflow rates in flat storages in southern areas are from 1/20 to 1/5 cfm per bushel. The airflow rate for this storage was selected as ¾ cfm per barrel (1/5 cfm per bushel). The total air requirement then is about *950 cfm*. Other desired features are:

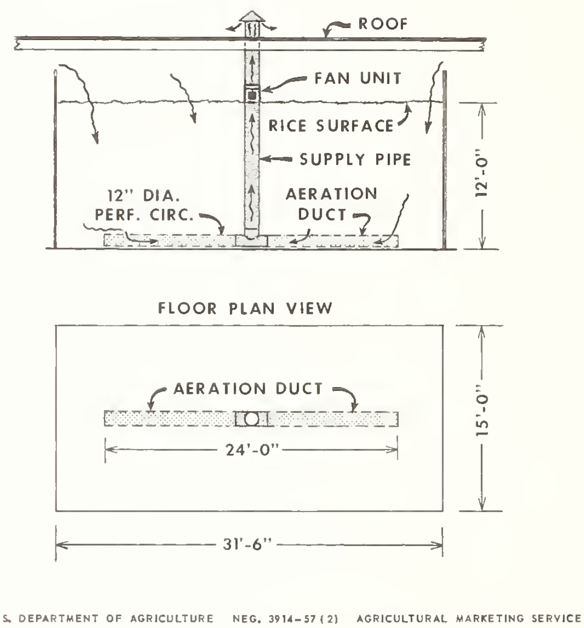


Figure 32.—Rice aeration system for flat storage. Rice bins were built inside an existing rice warehouse.

A. That the exhaust air from the rice be discharged outside the warehouse.
B. That the system be simple in construction and be portable so that when rice is not being stored the bin can be used for storing other materials.
C. That the system be easily converted to a closed system for fumigation.
D. That the system provide for the changing of direction of airflow through the rice.

The system was planned as shown in figure 32. By placing the fan as shown in the drawing the air is discharged out of the warehouse just above the roof. The construction and equipment are of such a nature that the parts are easily disconnected and moved. The system can be easily converted to a closed system by disconnecting the duct from the exhaust of the fan, raising the duct up and spreading an airtight sheet over the top of the fan and the grain. The direction of air through the rice may be changed by disconnecting the fan and turning it over.

Example—Rice aeration system designed for a flat storage—Continued

III. Aeration duct requirements

A. Duct spacing (page 15):

Following the general recommendations for duct spacing in flat storages the length of aeration duct needed was 24 feet

B. Duct surface area:

1. Required total surface area $\frac{950 \text{ cfm (I)}}{20 \text{ fpm (page 10)}} = \frac{47.5}{0.8}$ square feet $= 59.5$ sq. ft.
2. Surface area per foot length of duct

   Total surface area ÷ total length of duct $\frac{59.5 \text{ sq. ft.}}{24} = 2.5$ sq. ft.
3. A 12-inch diameter perforated circular duct was chosen. As the duct was relatively short the added cost for the larger size was slight.

IV. Assemble fan requirements

A. Airflow rate (II) ---------- $\frac{3}{4}$ cfm per barrel

B. Total air volume ---------- 950 cfm

V. Power and static pressure requirements

Use chart in figure 22

A. Static pressure ---------- 0.95 to 1.00 inch water

B. Estimated power needed ---------- $\frac{1}{2}$ horsepower

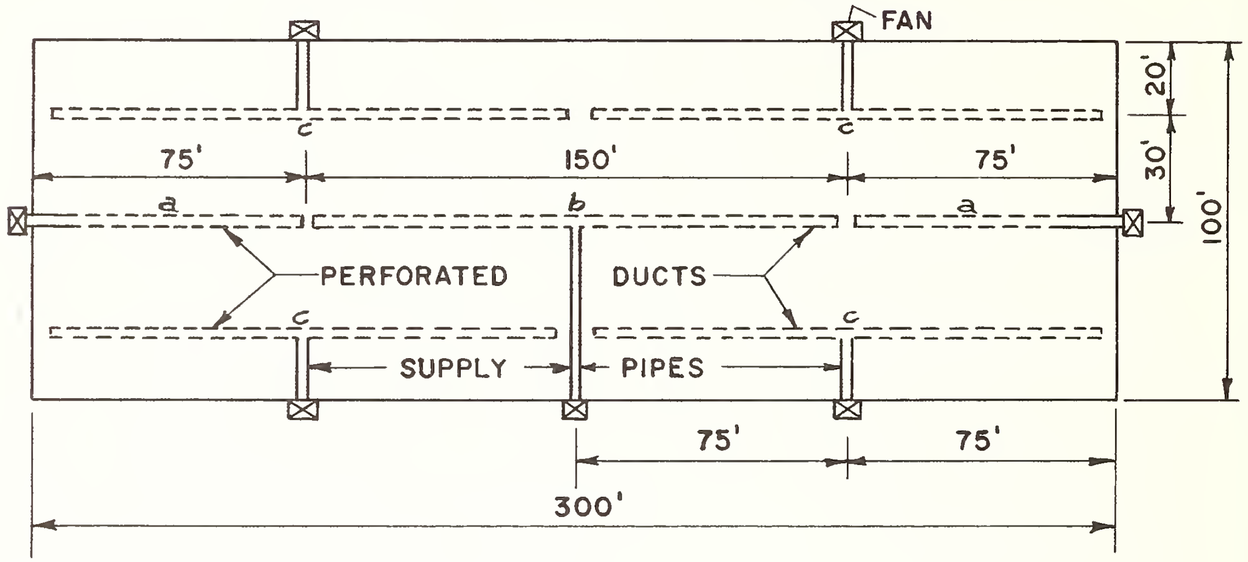
C. Select fan and motor. Axial flow fans are available that will deliver 950 cfm at 1 inch static pressure at $\frac{1}{2}$ horsepower.

Example—Wheat aeration system for a flat storage

Design Steps	*Example*
I. Establish storage dimensions and capacity	
A. Bin size—width, length, wall height	100′ wide, 300′ long, 24′ wall height
B. Type of loading—level or peak	Peak loading—34′ grain depth at peak-full length, 20′ at side walls (Fig. 33)
C. Bin capacity—bushels	
1. Floor area	100 x 300=30,000 sq. ft.
2. Volume (cu. ft.)	$30{,}000 \times 20 + \frac{14 \times 30{,}000}{2} = 810{,}000$ cu. ft.
3. Capacity (bu.)=volume (cu. ft.) x 0.8	810,000 x 0.8=650,000 bu.
II. Select type of system and airflow rate	
A. Type of system	Fixed fan for each duct
B. Select design airflow rate (cfm per bu.)	$\frac{1}{15}$ cfm/bu.
III. Layout of ducts by sketch	Sketch (Fig. 33)
IV. Estimate quantity of grain aerated by each duct (Cross section of grain served by duct x grain depth x duct length x 0.8=bu. served per duct)	Center ducts at end wall—(2)—75′ long $40 \times 28 \times 75 \times 0.8 + \frac{40 \times 6 \times 75 \times 0.8}{2}$ =75,000 bu. each duct (*a*, fig. 33) Center duct with T-supply pipe—(1)—150′ long $40 \times 28 \times 150 \times 0.8 + \frac{40 \times 6 \times 150 \times 0.8}{2}$ =150,000 bu. (*b*, fig. 33) Side ducts—(4)—Each 150′ long $30 \times 20 \times 150 \times 0.8 + \frac{30 \times 8 \times 150 \times 0.8}{2}$ =87,000 bu. (*c*, fig. 33)

LENGTHWISE DUCTS FOR LARGE FLAT STORAGE

FLOOR PLAN - DUCT LAYOUT



AIR PATHS AND DUCT SPACING

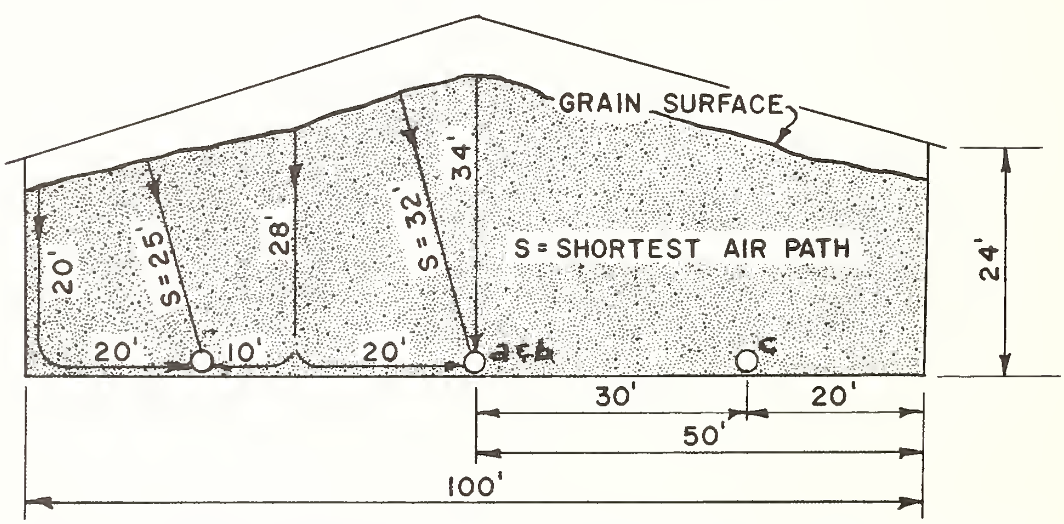


FIGURE 33.—Layout and spacing of lengthwise ducts in a flat storage 100 feet wide. Ducts located so that the longest air path is not more than 1½ times the shortest path for any duct.

Example—Wheat aeration system for a flat storage—Continued

Design Steps	*Example*
V. Determine air volume per duct (bu. per duct x cfm per bu.).	Center duct at end wall $\frac{75{,}000}{15}=5{,}000$ cfm Center duct with T-supply pipe $\frac{150{,}000}{15}=10{,}000$ cfm 5,000 cfm each side of supply pipe Side duct $\frac{87{,}000}{15}=5{,}800$ cfm 2,900 cfm each side of supply pipe
VI. Determine fan and motor requirements	Center duct at end wall—fan and motor—(2)
A. Air volume per duct	5,000 cfm
B. Static pressure (SP) for shortest air path (Fig. 21).	2.15″ SP
C. Estimate power requirement—obtain HP per 1,000 bu. from Fig. 21.	.05 x 75=3.75 HP (32′, fig. 33)
D. Select motor	Use 5 HP
	Center duct with T-supply pipe—fan and motor—(1) A. 10,000 cfm B. 2.15″ SP C. .05 x 150=7.5 HP D. Use 7½ HP or 10 HP Side duct—fan and motor—(4) A. 5,800 cfm B. 1.45″ SP C. .032 x 87=2.8 HP D. Use 3 HP
VII. Determine duct requirements	
A. Select shape and type of duct	Round duct, slotted openings
B. Air velocity allowable, table 3, page 10	1,800 fpm Center ducts at end wall (2)—75′ long Center duct with T-supply pipe—(2 sections)—75′ long
C. Cross section area $\frac{\text{air volume (cfm)}}{\text{air velocity (fpm)}}$	Cross section area$=\frac{5{,}000}{1{,}800}=2.78$ sq. ft. Use 24″ dia. (table 12, App.) Side duct—(8 sections)—75′ long Air velocity from table—1,500 fpm Cross section area$=\frac{2{,}900}{1{,}500}=1.93$ sq. ft. Use 20″ dia.

Design Steps	*Example*
VII. Determine duct requirements—Continued	
D. Check surface area	Center duct—24″ dia.
1. Surface area per foot of length	6.3 sq. ft. per foot of length
Note: Effective surface area of round pipe in contact with floor, use 80 percent	6.3 x 0.8=5.05 sq. ft. per ft. of length, effective
2. Total surface area—(surface area per ft. of length x duct length).	5.05 x 75=380 sq. ft.
3. Air velocity for surface area= $\frac{\text{air volume (cfm)}}{\text{surface area (sq. ft.)}}$	$\frac{5{,}000}{380}=13.2$ fpm
	Side duct—20″ dia.
	1. 5.25 sq. ft. per foot of length
	2. 5.25 x 0.8=4.2 sq. ft. per ft. of length, effective
	3. 4.2 x 75=315 sq. ft.
	$\frac{2{,}900}{315}=9.2$ fpm
E. Aeration duct openings (page 15)	Slotted openings—1/16″ wide 10% of duct area open
F. Strength of duct (page 15) 16 to 20 gage for flat storage	Use 16 gage
VIII. Determine supply pipe requirements	
A. Cross section area based on velocity of 2,500 fpm $\frac{\text{air volume (cfm)}}{\text{air velocity (fpm)}}$	Center duct at end wall $\frac{5{,}000}{2{,}500}=2.0$ sq. ft. 20″ dia. or larger
	Center duct—T-supply pipe $\frac{10{,}000}{2{,}500}=4.0$ sq. ft. 27″ dia. or larger
	Side duct $\frac{5{,}800}{2{,}500}=2.3$ sq. ft. 20″ dia. or larger
IX. Opening for air entrance to bin	Roof ventilators and end wall ventilators
Provide opening with cross-sectional area twice that of supply pipes.	Supply pipe for center ducts 2 x 2.0+1 x 4.0 =8 sq. ft.
Provide opening when fans operate and protect from weather.	Supply pipe for side ducts 4 x 2.3=9.2 sq. ft.
	Total supply pipe cross section area=17.2 sq. ft.
	Provide openings—35 sq. ft.
X. Select controls.	
A. Automatic—temperature and humidity.	
B. Magnetic motor starters.	
C. Manual cut-off switches.	

Example—Manifold system for wheat aeration in upright storage

Design Steps	*Example*
I. Establish storage dimensions and capacity	24 large bins
A. Bin size—shape and depth	Round 18″ dia. 102′ average depth—Hopper bottom
1. Cross section area	$0.7854 \times (18)^2 = 254$ sq. ft.
2. Volume (cu. ft.) = area x depth	$254 \times 102 = 25{,}908$ cu. ft. (fig. 34)
3. Capacity (bu.) = volume x bushels per cu. ft. (0.8)	$25{,}908 \times 0.8 = 20{,}727$ bu.
II. Establish airflow and type of system:	
A. Select airflow rate (cfm/bu) table 1, page[2]	$\frac{1}{30}$ cfm per bushel
B. Volume of air (cfm) per bin = (bu. per bin) x (cfm per bu.)	$20{,}727 \times \frac{1}{30} = 691$ cfm
C. Select type of system (fig. 34)	Manifold system with one fan and motor unit per 8 bins. Aerate ½ of bins at one time
D. Volume of air per fan	691 cfm $\times$ 4 bins $= 2{,}674$ cfm
III. Determine aeration duct requirements (p. 7):	
A. Bin duct surface area (p. 10) $\frac{\text{air volume per bin}}{\text{air velocity per effective area}}$	$\frac{691 \text{ cfm}}{30 \text{ fpm}} = 23$ sq. ft. (minimum)
B. Select duct type and dimension:	
1. Select type design to satisfy over-all storage site	New bins—use vertical ducts Old bins, use ducts on bin bottoms
2. Cross-section size—select round perforated pipe	Plan 12-inch dia. area = 0.78 sq. ft. (table 12, app.)
a. Surface area per foot of length diameter x 3.14 = sq. ft.	3.14 sq. ft.
b. Effective surface area of round pipe use 80%	$3.14 \times 80\% = 2.5$ sq. ft. per foot of length
3. Length required $\frac{\text{bin duct surface area}}{\text{area per ft. of length}}$	$\frac{23}{2.5} = 9.2$ ft. minimum needed
4. Design factor—for distribution, floor ducts should extend through the major portion of the bin diameter. Assume bin bottom will allow duct length	Check bin size and clearance at drawoff. Plan use of 12 in. dia., 14 ft. of aeration duct
C. Check velocity within duct	Design velocity 2,000 fpm or less
Velocity (fpm) $= \frac{\text{air volume per bin (cfm)}}{\text{cross-section area (sq. ft.)}}$	$\frac{691}{0.78} = 890$ fpm meets requirements
D. Aeration duct openings (p. 7)	Must keep grain from filling duct
E. Strength of duct (p. 11)	14 gage perforated—wall pipe casing
IV. Determine supply pipe requirements (p. 16):	
A. Individual bin, pipe through wall—cross-section area.	Plan 10 in. dia., 0.54 sq. ft. area
1. Check linear velocity $= \frac{\text{air volume}}{\text{area}}$	$\frac{691}{0.54} = 1{,}280$ fpm meets requirement
B. Manifold from 8 bins to fan unit—dimension	2,764 cfm per fan-motor unit Plan round, 20-gage manifold pipe to fan
1. Volume to aerate 4 bins (step II, D)	$\frac{2{,}764}{2{,}500} = 1.11$ sq. ft. minimum
2. Cross-section area based on design linear velocity, 2,500 fpm Area $= \frac{\text{volume (cfm)}}{\text{2,500 (fpm)}}$	Use 14½-in. diam. pipe = 1.14 sq. ft.

MANIFOLD AERATION SYSTEM LAYOUT FOR UPRIGHT GRAIN STORAGE

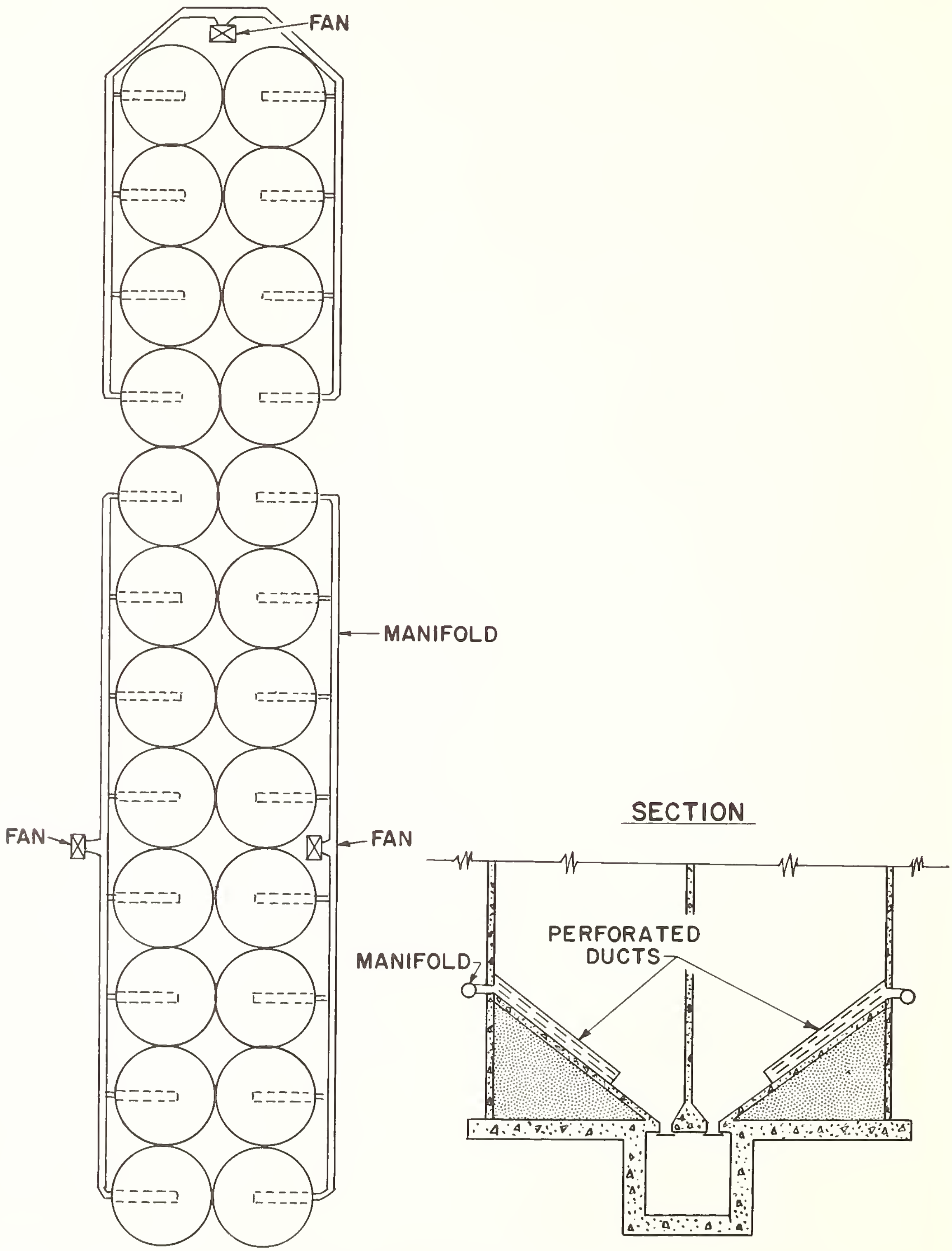


FIGURE 34.—Aeration system for 24 bins, each 18 feet in diameter, 102 feet deep and holding 20,700 bushels; three manifolds, each connected to eight bins; three centrifugal fans; and, three 7½ horsepower electric motors.

Example—Manifold system for wheat aeration in upright storage—Continued

Design Steps	*Example*
V. Additional design factors:	
A. Individual bin—air gate valves	Gate valves installed at 10 in. pipes through bin wall
B. Air friction loss in supply pipe considered	Transitions and elbows by standard sheet metal construction
VI. Opening for air entrance to bin:	
A. Provide opening with cross-sectional area twice that of supply pipe	Bin fill hole or ventilator in roof of bin. 2 x 0.54=1.1 sq. ft.
B. Continuous opening and protection from weather	Check before and during aeration operation
VII. Assemble fan and motor requirements:	
A. Total air volume required per fan	2,674 cfm
B. Static pressure, use chart in figure 21	102 ft. of grain, consider 8.0 in. water
C. Estimated power needed based on same chart	4 bins—20,727 x 4=82,908 bu. $\frac{0.09 \times 82,908}{1,000}=7.46$ HP
D. Select motor size	7.5 HP, 1,750 rpm electric motor for each 8-bin manifold
VIII. Select motor controls and accessories:	
A. Magnetic motor starters	7.5 HP, line voltage
B. Manual switches	3-pole, line voltage, industrial circuit breaker
C. Automatic control system	Temperature and humidity switches Elapsed time recorder

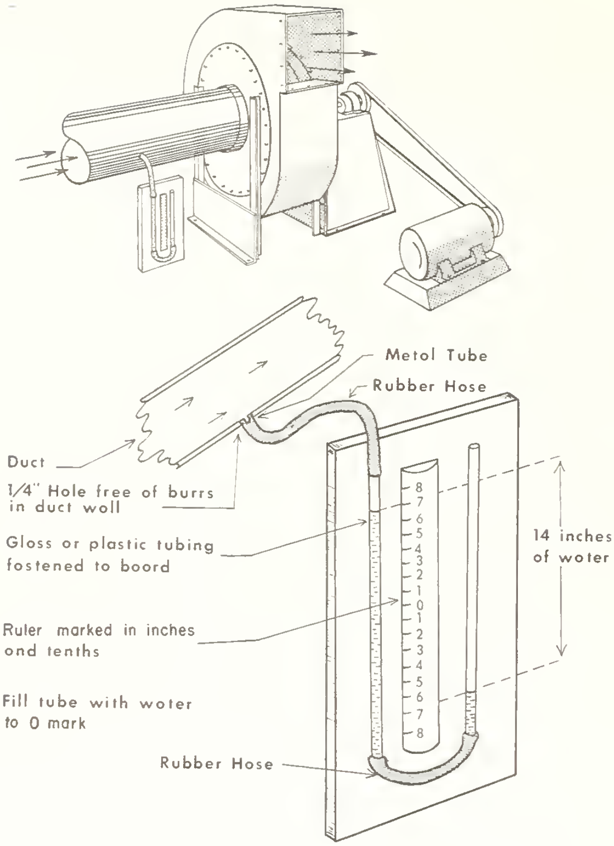


FIGURE 35.—A U-tube pressure gage in use measuring the static pressure being exerted by a fan in pulling air from an aeration duct. The gage shows fan operating at a static pressure (suction) of 14 inches of water.

TABLE 12.—*Areas and circumferences of circular ducts.*

Diameter of duct	Duct	
	Area	Circumference
Inches	*Square feet*	*Feet*
6	.1964	1.571
7	.2673	1.833
8	.3491	2.094
9	.4418	2.356
10	.5454	2.618
11	.6600	2.880
12	.7854	3.142
13	.9218	3.403
14	1.069	3.665
15	1.227	3.927
16	1.396	4.189
17	1.576	4.451
18	1.767	4.712
19	1.969	4.974
20	2.182	5.236
21	2.405	5.498
22	2.640	5.760
23	2.885	6.021
24	3.142	6.283
25	3.409	6.545
26	3.687	6.807
27	3.976	7.069
28	4.276	7.330
29	4.587	7.592
30	4.909	7.854
31	5.231	8.116
32	5.585	8.378
33	5.940	8.639
34	6.305	8.901
35	6.681	9.163
36	7.069	9.425
37	7.467	9.686
38	7.876	9.948
39	8.296	10.21
40	8.727	10.47
41	9.168	10.73
42	9.621	10.99
43	10.08	11.26
44	10.56	11.52
45	11.04	11.78

STATIC PRESSURE MEASUREMENTS

Various instruments are employed for measuring static pressures. The U-tube is probably the simplest and most common of the self-indicating pressure gages or manometers (fig. 35). The U-tube is a glass or plastic tube partially filled with water. The static pressure is read directly in inches of water by reading the difference in the levels of water of the two sides. The bore of the tube should be 3/16 to 1/4 inch in diameter and the walls perfectly clean. In general, the U-tube should be located level with the desired point of pressure observation. Otherwise, a significant error may result from the weight of the column of fluid in the connecting tube.

The "pressure tap" or connection may be a small hole, from 1/16 to 1/4 inch in diameter, drilled in the side of the supply pipe. A tube is used to make a connection between the pressure tap and the U-tube.

The U-tube (fig. 35) is simple to build and is satisfactory for making static pressure readings for checking the performance of a fan on an aeration system. Similar pressure gages also can be purchased.

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