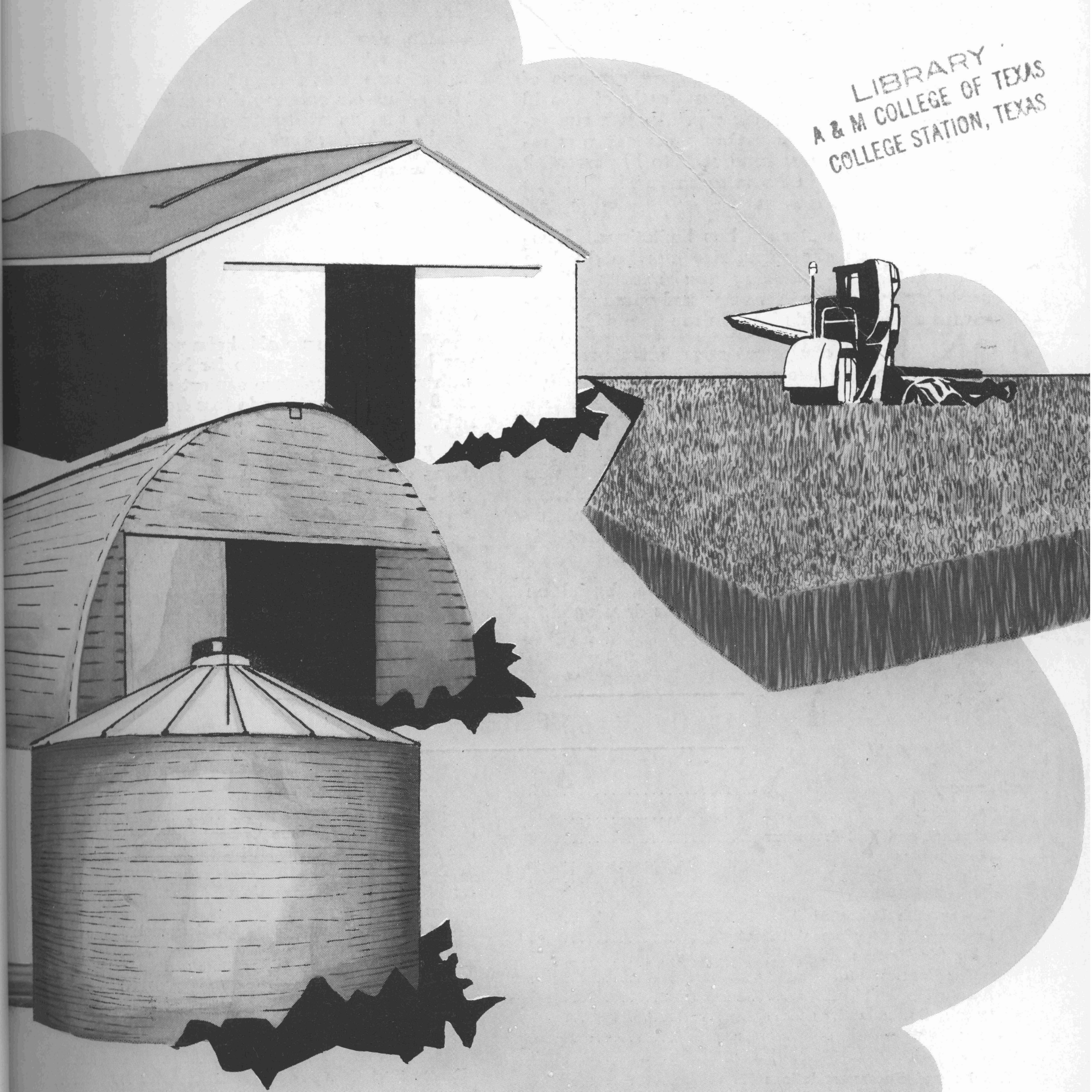
RCH 1960 B-952

Drying Rough Rice in Storage



TEXAS AGRICULTURAL EXPERIMENT STATIO
R. D. LEWIS, DIRECTOR, COLLEGE STATION, TEXAS

SUMMARY

Research was conducted at the Rice-Pasture Experiment Station near Beaumont during 7 crop years (1952-53 through 1958-59) to determine the engineering problems and the practicability of drying rough rice in storage in Texas. Drying rice in storage means drying rice in the same bin in which it is to be stored.

Rough rice, with initial moisture contents of 15.0 to 23.0 percent, was dried at depths of 4 to 10 feet with both unheated air and air with supplemental heat. After the moisture content was reduced to a safe storage level of 12 to 13 percent, it was held in storage in the same bin in which it was dried from 3 to 6.5 months.

Drying rice in storage has limitations. However, these tests show that rice can be dried in storage in the rice-producing area of Texas without quality loss, when air flow rates and operating procedures outlined in this bulletin are followed.

Building and equipment requirements for drying rice in storage also are given in this bulletin.

To prevent loss in grade, milling yields and germination with both unheated air and supplemental heat, an air flow rate of 9.0 cubic feet per minute (cfm) per barrel (2.5 cfm per bushel) was found necessary to dry rice with an initial moisture content of 20 percent. The maximum depth of rice for the most economical drying was 8 feet at this moisture level.

A simple fan operating schedule, based on pushing air up through the rice, was developed.

Loading storage bins to a depth of 2 to 3 feet in succession until all storage space was utilized, resulted in the maximum fan capacity on the wettest rice. This procedure also resulted in faster drying and reduced the possibility of damage from mold.

Supplemental heat was found to be practical during prolonged periods of high humidity or late in the season during cold weather. The temperature of the air entering the rice may be raised 1[?] above outside air temperature, but should not exceed 95° F. after heating.

In unheated air and supplemental heat drying applications under Texas conditions, the moisture in the wettest layer of rice had to be reduced below 16 percent in 15 days, or less, to prevent loss in grade from discolored kernels. Further reduction in moisture to a safe storage level of 12.5 percent was accomplished over a longer period of time without loss in grade.

An air flow rate of 0.4 cfm per barrel (1/10 cfm per bushel) was effective for holding undried rice with an initial moisture content of 18 to 19 percent for 9 days without grade loss from discolored kernels.

Aeration was effective in maintaining the condition of rice after it was dried to a safe storage level. Rice in each bin was aerated as often as necessary to reduce the temperatures in the rice to 60° F. or less. Fans were operated when the outside air temperature was 10° F., or more, below the average rice temperature, except during foggy or rainy periods. Fan and air distribution systems used for drying also were satisfactory for aeration.

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Drying Rough Rice in Storage

J. W. Sorenson, Jr. and L. E. Crane*

ALL OF THE RICE produced in Texas is harvested by combines at moisture contents too high for safe storage. The maximum moisture content for safe storage is 12 to 13 percent. For this reason, it is necessary to provide some method of drying to reduce the moisture content to a safe storage level.

The three rice-drying methods used today are (1) heated-air drying; (2) unheated-air drying; and (3) drying with low-temperature air, referred to in this bulletin as drying with supplement heat.

Heated-air drying is the use of forced ventilation with the addition of large amounts of heat for removing moisture. Unheated-air drying refers to the use of forced ventilation with normal atmospheric air. Drying with supplemental heat is the same as drying with unheated air except that a small amount of heat is added to the drying air to lower the relative humidity during periods when the atmospheric air has a high relative humidity. The temperature rise of the drying air usually is limited to 10 to 15°.

Heated air is not recommended for drying deep depths of rice, since it results in overdrying the bottom part and may cause spoilage in the upper layers of rice. Commercial rice drying usually is performed in continuous-flow dryers by forcing large volumes of heated air through thin layers of rice (4 to 10 inches thick).

Unheated air and supplemental heat are suitable for drying deep depths of grain. Drying grain at depths of 8 to 10 feet is known as bin drying, or drying in storage, since the grain is dried in the same bin in which it is to be stored. This method of drying is suited particularly for on-farm installations since the amount of handling is reduced to a minimum. However, there are certain limitations. The most important of these is weather, since the rate of drying with unheated air depends considerably on suitable weather conditions. Drying with unheated air and supplemental heat is a slow process, but if grain is stored for a period longer than is required for drying, the time element is not important.

During the past few years, there has been considerable interest in the possibility of drying rice in storage in the Gulf Coast area. The humid weather conditions exisiting in this area and the differences in varieties and handling practices made it necessary to develop facilities and operating procedures applicable to the rice-producing area of Texas, Figure 1. To fill this need, the Texas Agricultural Experiment Station began research in 1952 to determine the solutions to some of the engineering problems and the practicability of drying rice in storage under Texas conditions.

This bulletin provides information on equipment needs, air flow requirements and operating schedules for drying and storing rice. It includes information on the relationship of drying time to the drying air temperature, moisture content and depth of rice. Information on the effects of drying and storage treatments on the germination, milling yield and other related factors also are provided.

EQUIPMENT AND TEST PROCEDURE

Rough rice, at different moisture levels, was dried at depths of 4 to 10 feet with unheated air and with supplemental heat at Substation No. 4 near Beaumont, Texas. After the moisture content of the rice was reduced to a safe storage level (12 to 13 percent), it was stored 3 to 6.5 months in the same bin in which it was dried. Results were obtained for 7 crop years, 1952-53 through 1958-59.

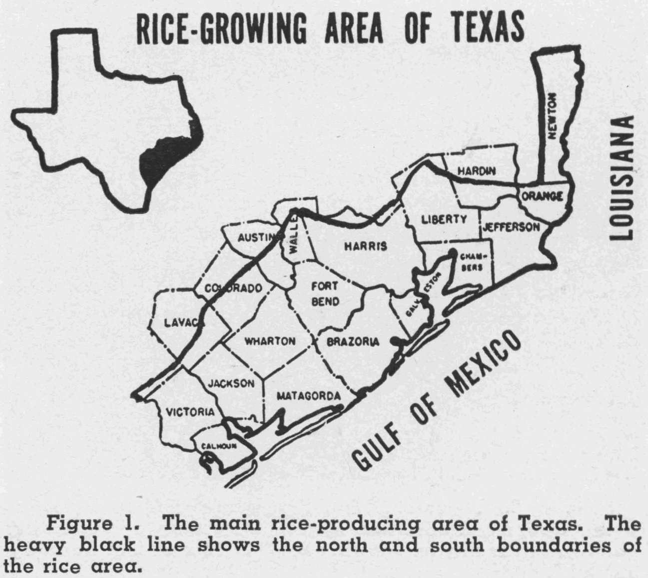

Figure 1. The main rice-producing area of Texas. The heavy black line shows the north and south boundaries of the rice area.

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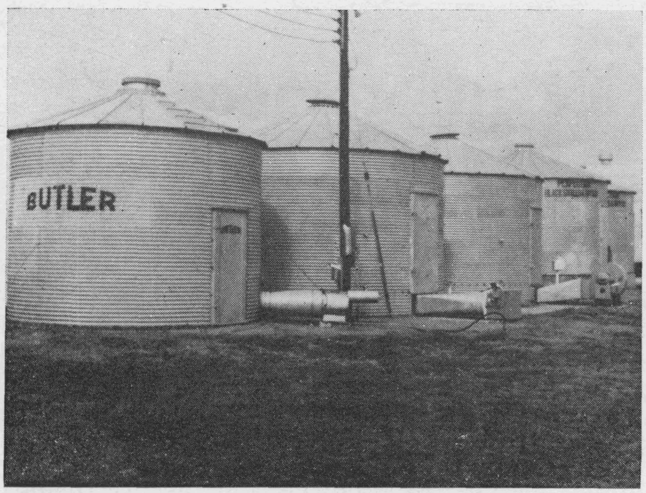


Figure 2. These round, steel bins were used in rice drying and storage tests. A supplemental heater is shown on the bin in the foreground.

Storage Bins

Full-scale Bins

Seven conventional farm-type bins and two steel buildings were used in these tests.

The conventional bins were constructed of steel, Figure 2. One of the bins was 14 feet in diameter with a capacity of 275 barrels (45,000 pounds). The other six bins were 18 feet in diameter with a capacity of 600 barrels (100,000 pounds) each. The 14-foot diameter bin was equipped with metal air ducts to distribute the forced air. The remainder of the bins were equipped with perforated floor drying systems.

One of the steel buildings used in the drying tests was 16 x 28 feet long, with a capacity of 600 barrels, Figure 3A. This building was equipped with a center duct. The other building, in which four bins were constructed, was 32 x feet long, Figure 3B. Capacities of these bi ranged from 500 barrels (81,000 pounds) 1,100 barrels (178,000 pounds). All of the bi were equipped with half-round ducts made expanded metal and covered with screen wire.

Small-scale Bins

Eight plywood bins of 12.5-barrel (45 bushe capacity each were used in these tests. Each b was 2½ feet square and 10½ feet deep. A fa floor covered with screen wire was installed inches above the bottom of each bin, which pr vided a rice depth of 9 feet. All of the bins we placed in one end of a 32 x 60-foot building wi the fans located to draw air from the outsi Orifice plates were used to control the air fl rate to each bin. Each bin had thermocoupl spaced along the vertical centerline at 6 inches feet and 8 feet from the bottom, Figure 4. Sa pling ports were installede in each bin near t thermocouple locations, Figure 4.

Drying with Unheated Air

Tests were conducted with small-scale a full-scale bins. Initial moisture content of t rice was 15.0 to 23.2 percent, wet basis. T small-scale bins were used to determine minimu air flow requirements for drying with unheat air.

Centrifugal and propeller fans were used supply air for drying the rice. All of the fa were driven by electric motors.

Drying with Supplemental Heat

Supplemental heat was used to bin dry ri with initial moisture contents ranging from 1 to 23.0 percent, wet basis. Electric and gas he

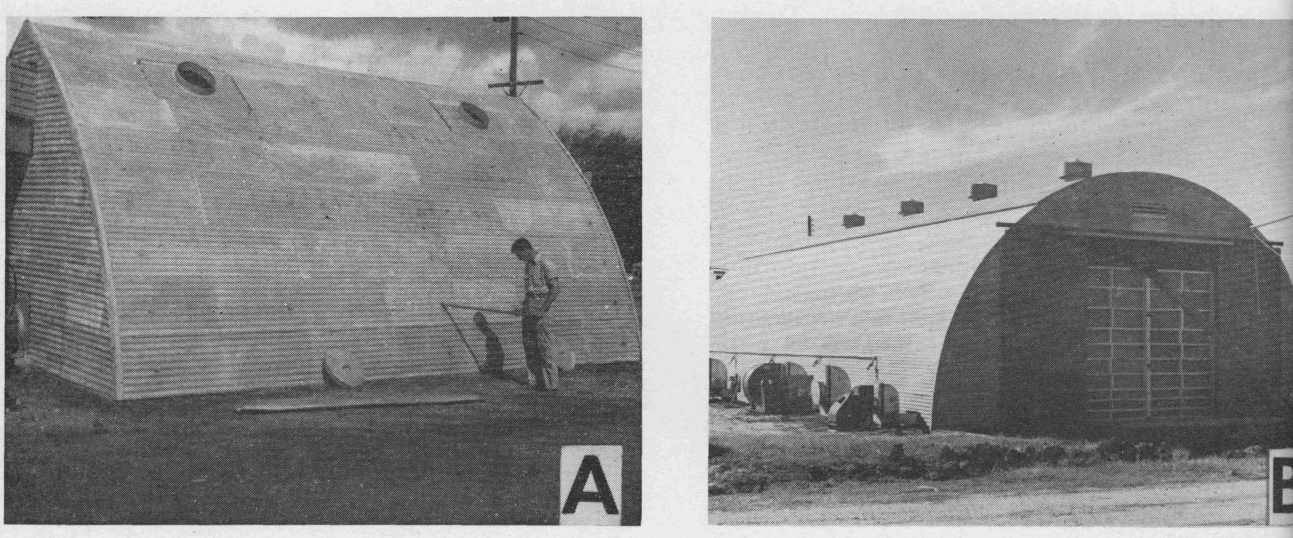


Figure 3. These steel buildings were used in drying and storage tests. A. This 16 x 28-foot building was equipped w a fan and air distribution system for drying and aerating rice. Samples for moisture content were taken through sampl ports in bin walls, as shown. B. This 32 x 60-foot building was used for bin drying tests with unheated air and with supp mental heat.

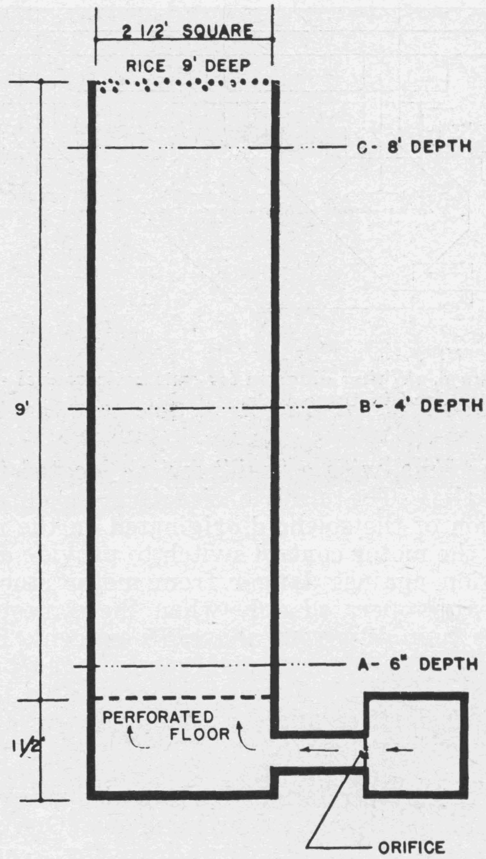


Figure 4. Samples of rice were drawn through ports in walls of small-scale bins (left). Cross-section of small-scale bin showing three levels at which samples were taken (right).

ers were used to heat the air to the desired temperature.

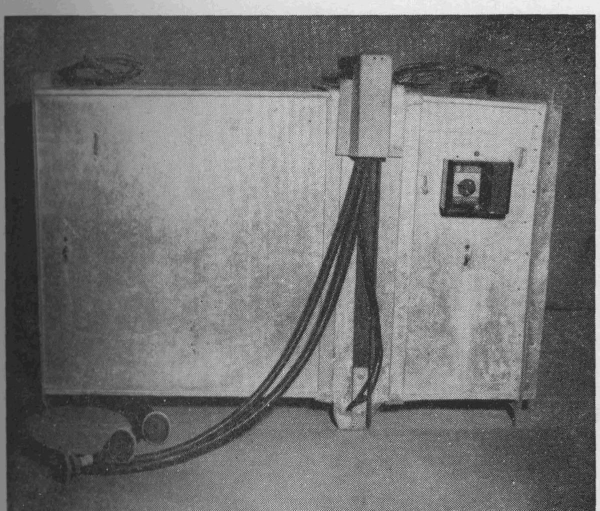
Electric Heaters

The electric heater consisted of six 2,000-watt fin calrod heaters installed in a sheet metal duct, Figure 5. The duct, with heaters, was connected to the fan outlet and the air was heated as it was forced around the heaters before it passed through the rice. A temperature rise of 10° was obtained when air was supplied at a rate of 3,200 cfm.

A three-step thermostat, set for a maximum temperature of 92° F., was used to control the temperature of the air entering the rice, Figure 6. The operation of each heater was controlled by a plunger-type mercury relay. A humidistat was used to operate the heater when the atmospheric relative humidity was above 75 percent.

Gas Heaters

An experimental gas heater was constructed, Figure 7. It consisted of a low-pressure, injector-type industrial burner installed directly in the air stream to the intake of the fan. The unit was designed to burn natural or LP gas at a pressure of 8 to 11 inches of water gauge. Safety controls were used to reduce the danger from fan stoppage and flame failure. These controls consisted of a solenoid valve in the gas supply line connected to a thermal element located in the



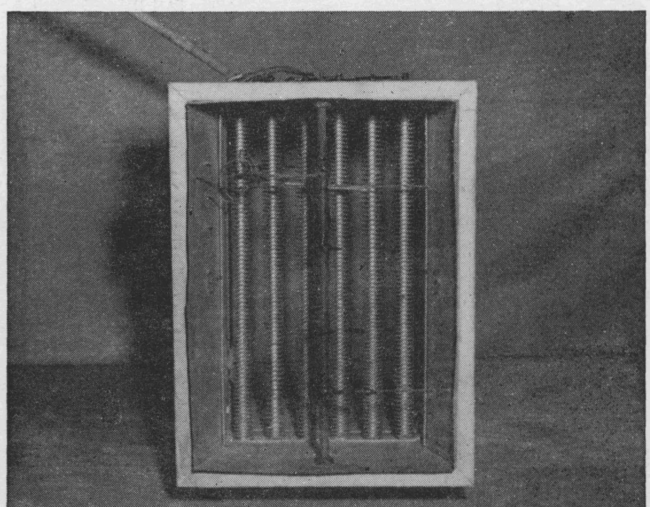


Figure 5. Side view (left) and end view (right) of electric heater used to provide supplemental heat during tests.

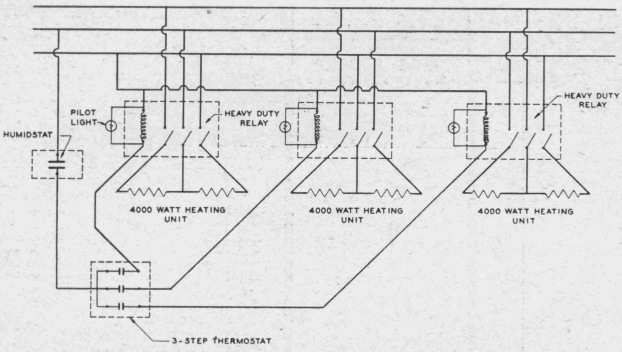


Figure 6. Wiring diagram for automatic control of electric heater used in these tests.

burner flame, with a "sail" switch located in the fan intake. The electric circuit controlling the operation of the solenoid originated on the motor side of the motor control switch to provide double protection against danger from motor stoppage. The heater operated only when the atmospheric relative humidity was above 75 percent, but it was necessary to light and turn off the burner manually. The BTU input was controlled by the size of the orifice and/or by opening or closing the gas cock valve.

Three commercial gas heaters also were used, Figure 8. All three used propane gas. One of the heaters was operated automatically by a humidity controller placed on the floor of the air chamber underneath a perforated floor in the drying bin. The controller was set to maintain a relative humidity of 65 percent or less in the air chamber. The heater cycled "on and off" to make needed corrections for humidities higher than 65 percent. The other two heaters were semiautomatic in that they were adjusted to provide a fixed quantity of gas and did not cycle "on and off" as the automatically operated heater did. A humidity controller was used to opera these two heaters only when the atmospheric r ative humidity was above 75 percent. All of t heaters were equipped with safety controls to c off the gas supply in the event of power or fla failure.

Aeration

Aeration is the moving of small amounts outside air through stored rice, for purposes oth than drying, to maintain or improve its qualit

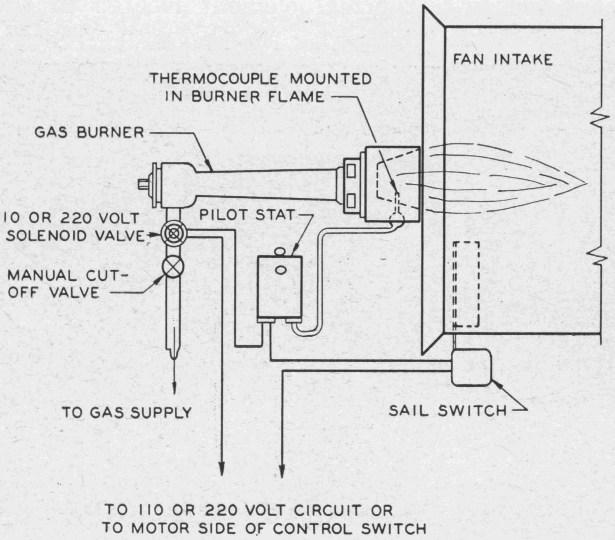
Studies of the effect of temperature a moisture content on the quality of undried ri held for various lengths of time in aerated sto age were made with the small-scale bins. Bi of rice with initial moisture contents of 16 to percent were aerated with air flow rates of and 0.4 cfm per barrel (1/20 and 1/10 cfm p bushel).

Quality Determinations

Temperature observations were made at re ular intervals during the drying and storage pe iod. Samples for moisture content, milling yiel and germination were taken at three levels each bin at the start of drying. These sampl were air dried in thin layers and used as check Similar samples were taken after drying and the end of the storage period and comparati analyses were made.

Instruments

A portable potontiometer and copper-consta tan thermocouples were used to determine te peratures at various locations in the rice. Brown-Duvel moisture tester was used for moi ture determinations. A deep bin probe was us to obtain samples of rice from the bins. An i clined manometer, with scale graduations of .



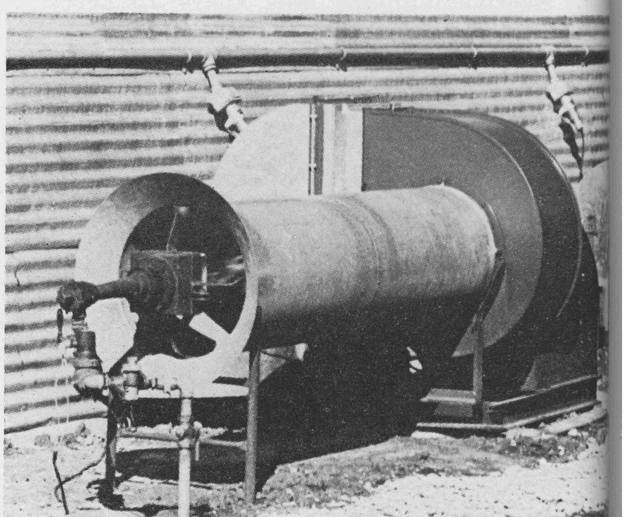


Figure 7. Schematic of experimental gas heater, with safety controls, used to dry rice with supplemental heat (lef Actual view of installation is shown at right. When a fan with bearings on the opposite side from the inlet is used, the e tended intake (right) can be eliminated and the flame pointed directly into the fan intake.

inch of water, was used to measure static pressures at various depths of rice in each bin.

Rice

Bluebonnet 50, Century Patna 231, Zenith, T.P. 49 and Rexoro rice varieties were used during the 7-year test period. Rice used in these tests either was loaned by farmers in the Beaumont area or produced on Substation No. 4.

RESULTS AND RECOMMENDATIONS

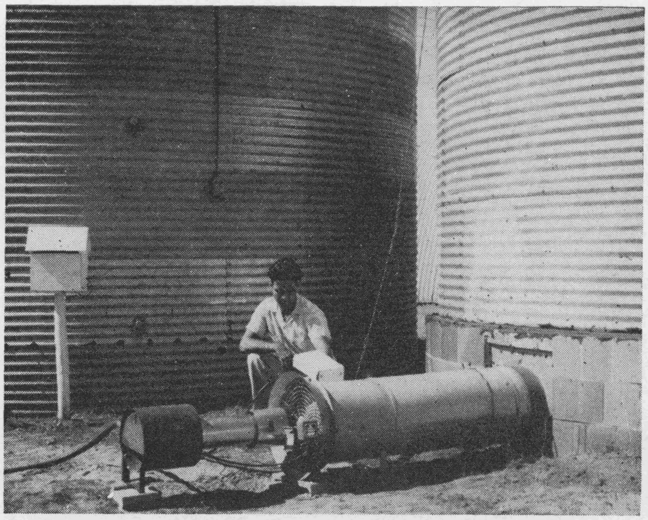
Drying with Unheated Air

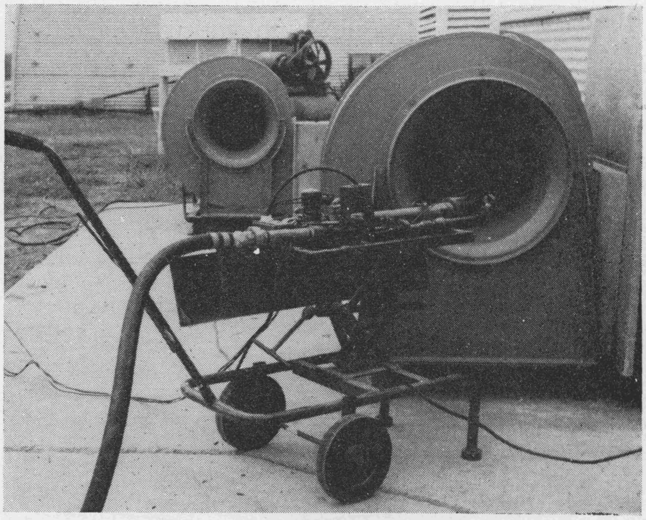
Bin drying rice with unheated air has advantages over drying with supplemental heat. Unheated air drying requires less investment in equipment and less attention by the operator, reduces fire hazards and usually results in more uniform rice drying. However, there are certain limitations. The most important is uncontrollable weather, since the rate of drying with unheated air is dependent on weather conditions. If rice is to be sold soon after harvest, the comparatively long period required for drying with unheated air is a disadvantage. In this case, another drying method is advisable. If rice is stored for a period longer than is required for drying with unheated air, the time element is not important. Supervision over a longer period of time is required when unheated air is used as the drying agent. Other important factors determining the effectiveness of unheated air drying are the moisture content and temperature of the rice, depth of rice in the bin and rate and uniformity of air flow through the rice.

Drying Equipment

The equipment required for bin drying with unheated air consists of a structure for holding the rice, an air distribution system and a fan driven by an electric motor or gasoline engine. Wood, concrete or steel bins are satisfactory for storing rice (1). A tight structure should be provided to prevent air and moisture leakage through the bin floors and walls. Bins should be located on well-drained areas to prevent moisture leakage around the floor-wall joints.

An air distribution system which provides adequate distribution of air throughout the bin should be used. Types of air distribution systems used in these tests were perforated floor, main duct and lateral, lateral and center duct, Figure 9. Lateral systems are satisfactory for buildings and for round and rectangular bins. Perforated floors are better suited for small diameter round bins than for larger storage structures. A center duct is limited to use in a narrow building (a width of 16 feet was used in tests) and requires a building with wall openings to permit uniform distribution of the air through the rice. A lateral system or a perforated floor is recommended for drying rice in storage.





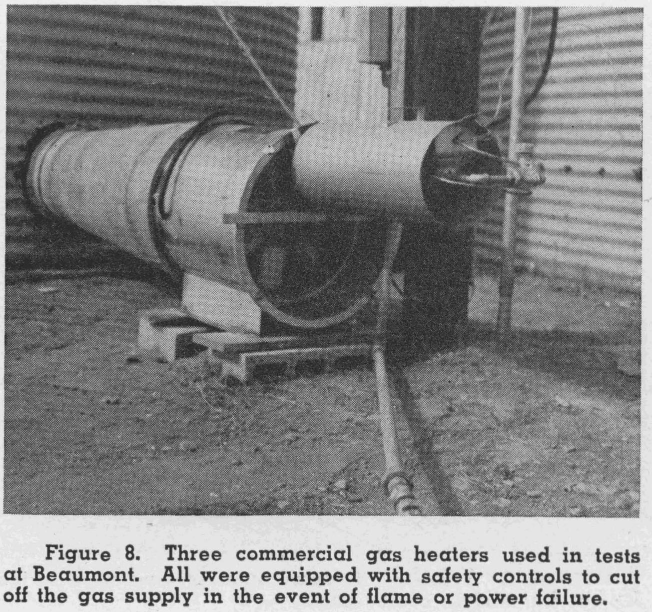


Figure 8. Three commercial gas heaters used in tests at Beaumont. All were equipped with safety controls to cut off the gas supply in the event of flame or power failure.

Centrifugal and propeller fans were suitable for bin drying rice. Centrifugal fans ordinarily used for this method of drying either have "forward-curved" blades or "backward-curved" blades, Figure 10. "Forward-curved" fans are lighter and less expensive than "backward-curved" fans. However, with the "forward-curved" fan there is a possibility of overloading the motor if the fan operates against static pressures lower than those used in the design of the system. This is undesirable for bin drying since rice depths vary during the time bins are being filled. A "backward-curved" blade fan has a self-limiting horsepower characteristic, which means that overloading does not occur in the usual operating range so that it is not necessary to provide motor capacity beyond that required to carry the normal load.

The two types of propeller fans used for bin drying are vaneaxial and tubeaxial, Figure 11. A vaneaxial fan consists of a fan wheel within a cylinder with a set of air guide vanes either ahead or behind the fan wheel. It is designed to mo air over a wide range of volumes and pressur A tubeaxial fan consists of a fan wheel wit a cylinder without air guide vanes. Its constru tion is similar to a vaneaxial fan. The tubeax fan is designed to move air over a wide range volumes at medium pressures.

Propeller fans designed to operate again static pressures of 3 inches or more usually a suitable for drying rice in storage. The init cost of these fans usually is lower than the co of centrifugal fans. Low initial cost, togeth with the small space required and the ease of i stallation, are advantages. However, in locatio where fan noise is a factor, centrifugal fa should be considered.

Air Flow Requirements

The use of the proper air flow rate to d rice with unheated air is of primary concer Figure 12. Interrelated with the air flow requi ment is the initial moisture content of the ri

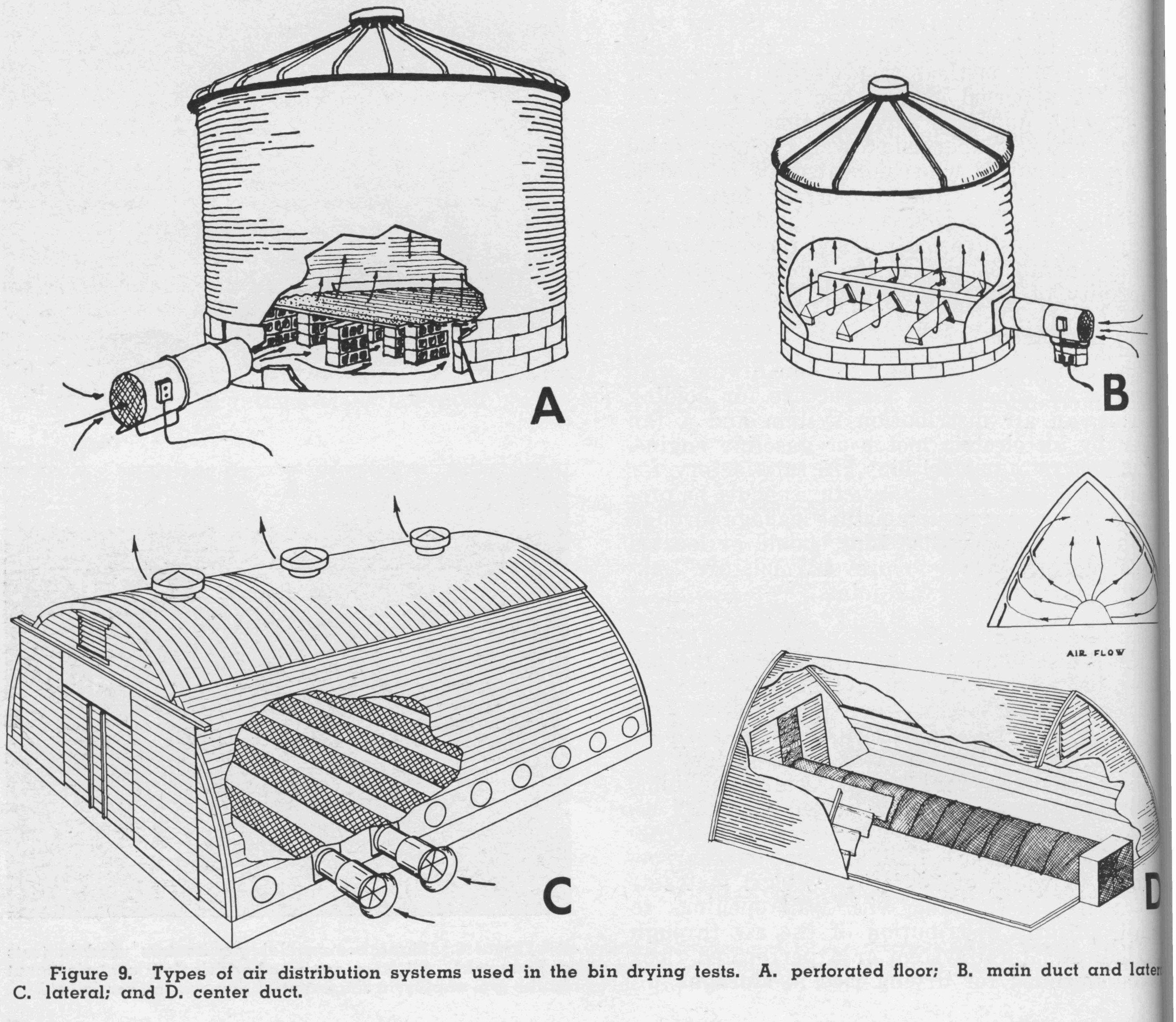


Figure 9. Types of air distribution systems used in the bin drying tests. A. perforated floor; B. main duct and later C. lateral; and D. center duct.

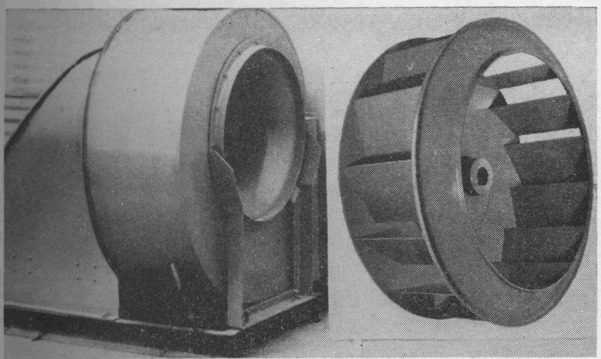


Figure 10. One of the "backward-curved" centrifugal fans used in these tests.

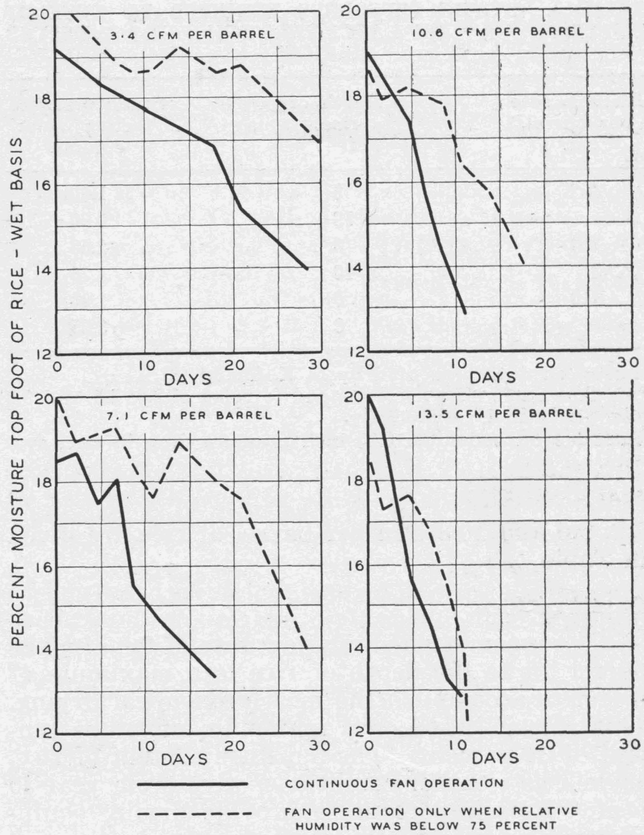
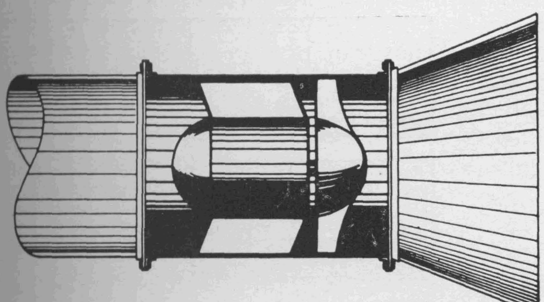


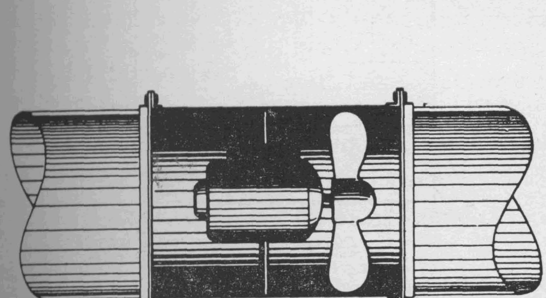
Figure 12. Time required to dry an 8-foot depth of 18- to 20-percent moisture rice with unheated air in October 1953. Air was supplied at rates of 3.4, 7.1, 10.6 and 13.5 cfm per barrel.

and the basic drying rate of the rice. Air must be supplied at a rate to complete drying before the rice is damaged by mold growth or other causes. For this reason, the drying rate in the wettest layer of rice provides the basis for selecting the required air flow rate rather than the average moisture observed during the drying operation.

A minimum air flow rate of 7.2 cfm per barrel (2.0 cfm per bushel) was indicated by these tests. This rate was based on favorable weather for drying and on rice with a maximum moisture content of 20 percent. However, this rate should be higher to take into consideration more severe weather conditions and rice with higher initial moisture content. To insure drying without loss in grade, milling yields and germination under the different weather and moisture conditions occurring within a season or from year to year, an air flow of 9.0 cfm per barrel (2.5 cfm per bushel) is recommended for drying rice in Texas.

Drying equipment dealers and others who select fans for drying rice require information on the total air volume and the static pressure requirements. Static pressure is a measure of the resistance that the air distribution system and rice offer to the air flow. It is designated in inches of water. Static pressures against which fans must operate to develop air flow rates of





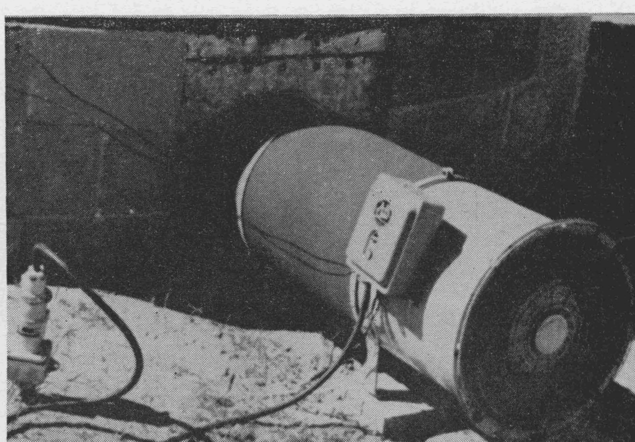


Figure 11. Two types of propeller fans. The vaneaxial fan (top left) is designed to move air over a wide range of volumes and static pressures. The tubeaxial fan (bottom left) is designed to move air over a wide range of volumes at medium static pressures. A tubeaxial fan installation is shown at right.

TABLE 1. STATIC PRESSURES REQUIRED TO DEVELOP DIFFERENT AIR FLOW RATES THROUGH VARIOUS DEPTHS OF RICE[1]

Air flow rate per barrel, cfm[2]	Depth of rice, feet	Static pressure, inches water column[3]
7.2	8	1.80
	10	3.00
9.0	8	2.50
	10	4.25
10.8	6	1.80
	8	3.25

[1]Based on data presented by C. K. Shedd (2).
[2]Air flow rates shown correspond to rates of 2.0, 2.5 and 3.0 cfm per bushel, respectively.
[3]Includes an estimated 0.25 inch pressure drop in duct system.

7.2, 9.0 and 10.8 cfm per barrel of rice are given in Table 1.

Depth of Rice

The recommended air flow rate of 9.0 cfm per barrel limits the depth of rice to a maximum of 8 feet to accomplish the most economical drying. This rate is based on a maximum moisture content of 20 percent. The moisture content of rice, as well as weather conditions, vary from year to year. It is important to provide drying equipment of sufficient capacity to insure drying rice without quality loss under the different conditions encountered, Figure 13. When the initial moisture content of the rice is above the 20-percent level or when the rice is harvested late in the season, the depth of rice should be reduced to obtain higher air flow rates needed for the more severe drying conditions. Recommended depths for drying rice at different initial moisture ranges are shown in Table 2. This is based on the selection of equipment to provide the recommended air flow rate of 9.0 cfm per barrel at 8-foot depth.

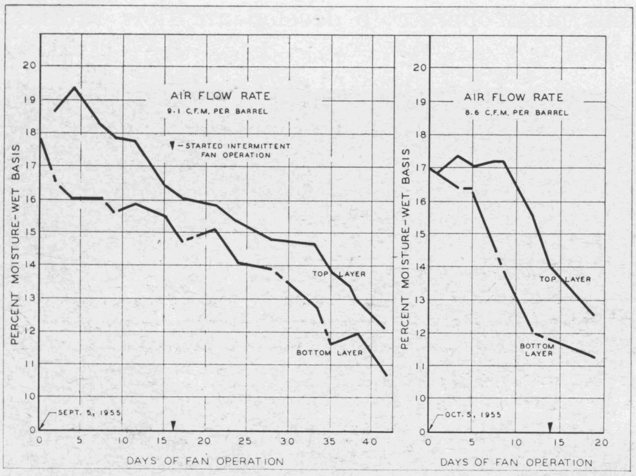
Fan Operating Schedule

A primary factor in the selection of a fan o erating schedule is drying at a rate fast enou to prevent mold development. Another importa consideration is simplicity of operating instru tions requiring a minimum of supervision of t drying operation. Other desirable features in fan operating schedule are maximum drying eff ciency and use of minimum air flow rates.

The direction of air movement through ri has little effect on the dryer performance. How ever, it is recommended that air be pushed through the rice for the following reasons: (the wettest layer of rice is at the top whe sampling is easily accomplished; (2) heat fro the motor and fan can be utilized in drying; a (3) under farm conditions the wettest rice fr quently is the first loaded into the bin and t first to be dried.

The following fan operating schedule is re ommended in Texas:

Start the fan as soon as the air distributi system is uniformly covered with rice. Push a through the rice continuously until the moistu content of the top foot of rice is reduced to abo 15 percent. After the moisture is reduced this level, operate the fans only when the relati humidity is less than 75 percent (usually duri daylight hours on clear, bright days). Contin this procedure until the moisture content of t top foot of rice is reduced to 12.5 percent. Tu the fan off if heavy rains occur during the p riod of continuous fan operation. When rai



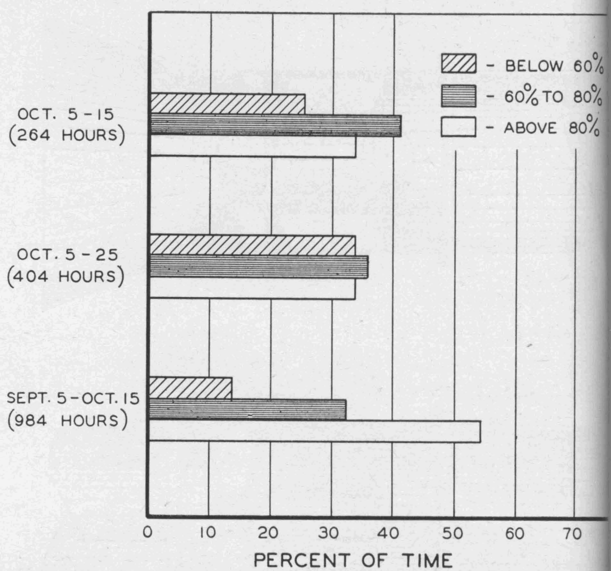


Figure 13. These graphs show the effect of weather conditions on the time required to dry 8-foot depths of Century Pat rice with unheated air. Rice harvested in October dried in about one-half the time required to dry rice harvested in Septem ber. This was accounted for by the more favorable weather conditions occurring in October than in September, shown by t percent of time the relative humidity was within indicated limits in the graphs on the right. The rainfall was 4.92 inches duri September and 0.18 inches during the first half of October. There was no loss in grade, milling yields or germination in eith lot.

periods last longer than 24 hours, keep the rice cool by operating the fan 2 to 3 hours each day until the weather clears.

Loading Bins

Faster drying can be accomplished by loading storage bins in layers. This is accomplished by loading each bin to a depth of 2 to 3 feet in succession. Then, starting with the first bin, 2 or 3 feet are added to each bin progressively until all of the storage space is utilized. Equipment used for loading the bins is shown in Figure 14.

With this procedure, the maximum fan capacity can be used on the wettest rice. This will result in faster drying and reduce the possibility of damage from molds.

Sampling for Moisture Content

The moisture content should be checked at least twice a week during the drying operation. The rice should be probed at 8- to 10-feet intervals over the surface of the rice and samples drawn from the bottom, mid-depth and top foot. Rice from each level should be mixed thoroughly and a moisture check made for each level.

Since low temperatures during drying do not always indicate that rice is in good condition, the samples pulled for moisture content also should be checked for mold growth.

Drying with Supplemental Heat

Supplemental heat is used to improve the effectiveness of unheated air drying systems during prolonged periods of high humidity or during cold weather. Drying rice in storage with supplemental heat has the following advantages and disadvantages over drying with unheated air. The chief advantage is that drying can be accomplished regardless of weather conditions and a comparatively shorter drying time is needed. Disadvantages include the possibility of overheating the rice which may result in overdrying and quality loss, higher initial equipment costs, closer supervision and greater danger of fire.

Drying Equipment

A structure for holding the rice, a fan and an air distribution system as described for bin drying with unheated air are satisfactory for bin drying with supplemental heat. In addition, a heating unit is required to heat the air to the desired temperature.

Supplemental Heat Units. Electric and gas heaters were used in these tests.

The advantages in using an electric heater are that electricity provides a clean source of heat and controls are readily available and easy to install for automatic operation. However, an electric heater has the following disadvantages: it may be more expensive to operate; it necessitates increased wire and equipment sizes to take care of increased electrical loads when the heaters are used; and it creates high-peak, short-duration loads which may be undesirable in some areas.

TABLE 2. RECOMMENDED DEPTHS FOR DRYING RICE WITH DIFFERENT INITIAL MOISTURE CONTENTS

Initial moisture content of rice, percent[1]	Maximum depth of rice at start, feet	Operating procedures
20 to 22	6	When the top foot of rice is reduced to 16 percent moisture, more rice may be added to fill to the recommended depths shown below.
16 to 20	8	When the top foot of rice is reduced to 15 percent moisture, rice with a moisture content of 16 percent or less may be added to fill the bin to a depth of 10 feet.

[1]A moisture content of 22 percent is the maximum recommended for drying rice with unheated air.

Natural or LP gas generally is a satisfactory source of heat in most areas. One or the other of these gases is readily available; the burners are inexpensive; the operating cost is reasonable; and simple, inexpensive controls can be installed to cut off the gas supply automatically in case of flame, fan or power failure.

A semiautomatic gas heater adjusted to provide a fixed quantity of heat was found satisfactory for drying rice in storage. The variation in output by the burner was controlled by the size of orifice used and/or by opening or closing a gas cock valve. Semiautomatic refers to a burner that must be lighted and turned on manually, but is equipped with safety controls to automatically cut off the gas supply in the event of flame or power failure.

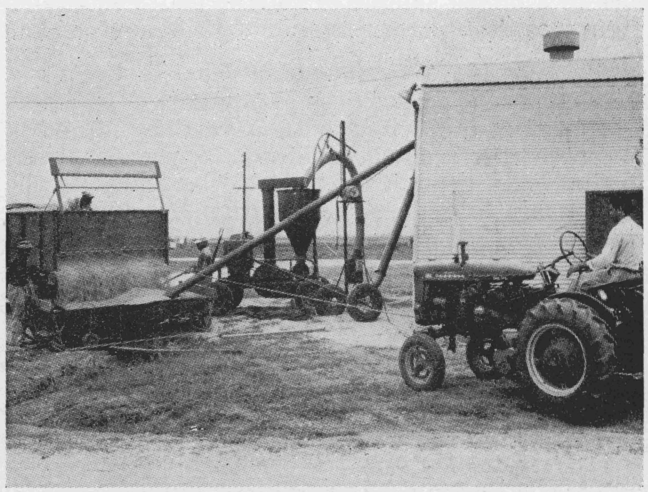


Figure 14. Typical scene of unloading rice from trucks into storage bins with an auger loader and grain tow board. The pneumatic conveyor, shown in background, also was used for unloading trucks and storage bins.

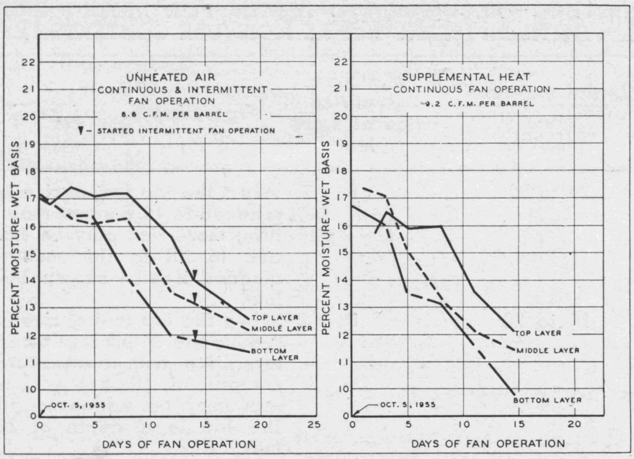


Figure 15. Results of drying 8-foot depths of Century Patna rice with unheated air and with supplemental heat are shown in these graphs. Figure 13 shows that weather conditions during these tests were favorable for drying with unheated air. As a result, not much was gained by using supplemental heat.

A semiautomatic heater, as described, could be made to operate automatically by using a pilot burner and a humidistat set to control the operation at the desired humidity range. With a burner adjusted to provide a fixed quantity of heat, the atmospheric humidity, rather than the humidity of the drying air, could be used as a basis for operating the heater.

Air Temperature

Too high an air temperature will cause overdrying of rice near the bottom of the bin, resulting in unnecessary loss in weight and in quality of the rice, Figures 15 and 16. For example, rice dried at a 10-foot depth with an air temperature of 112° F. (outside air temperature averaged 55° F.) resulted in a reduction of milling yields from 51 to 72 percent at the start of drying to 24 to 71 percent after drying, Table 3. The first figure represents the percentage whole grains or head rice in a milled sample of rough rice. The second figure is the percentage of whole and broken milled grains.

Rough rice at a moisture content of 12.5 percent is in equilibrium with a relative humidity of 65 percent (1). Therefore, to prevent overdrying, only enough heat should be added to the drying air to reduce the relative humidity to a minimum of 65 percent. A study of the weather records in the Beaumont area shows that when the atmospheric relative humidity is 75 percent or above, the air temperature usually is 80° F., or less, Figure 17. Late in the season, the outside temperature may be as low as 40° F. Supplemental heat is recommended during these periods of adverse weather. The initial temperature of the air has little effect on the temperature rise necessary to reduce the relative humidity to 65 percent, when the outside air temperature ranges from 40 to 80° F. When the relative humidity of the outside air is 75, 85 or 95 percent, a temperature rise of 5, 9 and 12°, respectively, is r quired to reduce the relative humidity of the dr ing air to 65 percent. Based on this informati a maximum temperature rise of 12° is reco mended for drying rice with supplemental he in Texas.

Recommendations for Using Supplemental Heat

Recommendations for using supplemen heat are as follows:

Supplemental heat is not recommended as standard practice for bin drying. However, is desirable to have equipment available for u during adverse weather conditions. This nor ally will be during prolonged periods of high h midity (above 75 percent). The temperature the air entering the rice may be raised 12° abo

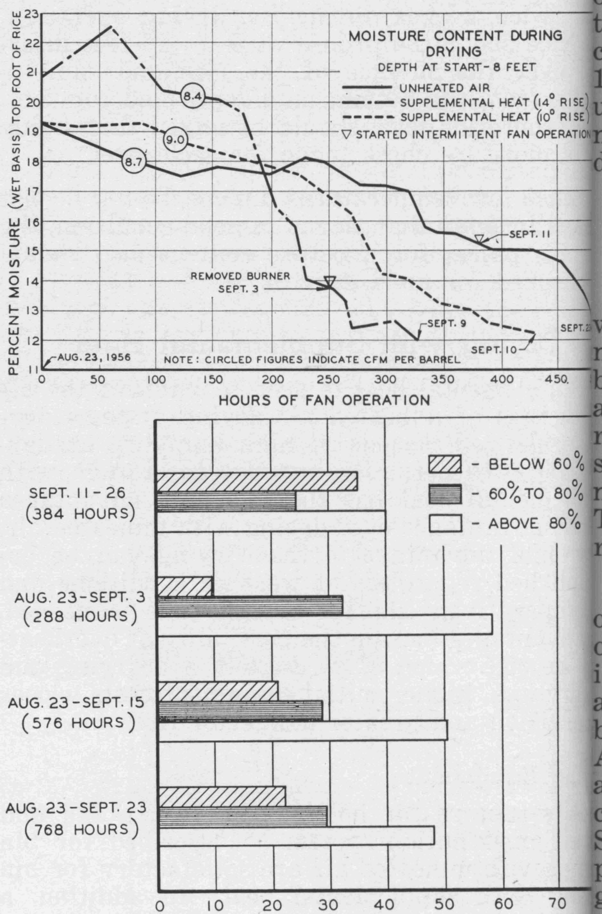


Figure 16. The top graph shows the results of tests w unheated air and with supplemental heat. The bottom gr shows the percent of time the relative humidity was wit indicated limits. Weather conditions during the first par the drying period were extremely unfavorable for dry with unheated air. For example, the rainfall was 3.19 inc from August 23 to September 10, compared to no rai from September 11 to September 23. As a result, the dry time was considerably reduced by using supplemental he There was no loss in grade, milling yield or germinatio any of these lots of Bluebonnet 50 rice.

TABLE 3. EFFECT OF DRYING WITH SUPPLEMENTAL HEAT ON HEAD RICE YIELDS AND GERMINATION

Year	Maximum temperature in rice during drying, degrees F.	Average moisture content, percent		Head rice, percent[1]		Germination, percent	
		Start of drying	End of drying	Start of drying	End of drying	Start of drying	End of drying
1952	112	22.3	16.7	51.0	24.0	86.8	82.5
1955	86	17.0	12.1	63.0	64.0	91.3	93.5
1956	95	18.0	10.6	57.6	61.6	88.6	96.8
1956	90	20.3	11.5	51.3	54.6	84.0	88.2
1956	98	20.5	11.6	52.3	55.6	87.5	85.2
1957	93	21.0	11.1	55.3	60.0	87.0	92.6
1957	90	20.6	11.8	60.0	61.0	89.7	92.3
1958	85	21.6	12.6	60.0	62.3	45.0	66.0

[1]The percentage of whole grains that a sample of rough rice yields when milled.

outside air temperature, but should not exceed 95° F. after heating. Supplemental heat should be used until the moisture content of the top foot of rice is reduced to 15 percent. After the moisture is reduced to this level, use unheated air to complete the drying to a safe storage level of 12.5 percent. During the time unheated air is used, operate the fan only when the relative humidity is less than 75 percent (usually during daylight hours on clear, bright days).

Relationship of Time, Temperature and Moisture Content in Drying

An important consideration in drying rice with unheated air or supplemental heat is the maximum time permissible to complete drying before damage from molds or other micro-organic action occurs. This is particularly important with rice because damage from molds usually is associated with a discoloration of kernels, commonly termed "heat damage" or "stack burn." The effect of "heat damage" on the grade of rough rice is shown in Table 4.

The lower limit of temperature for the growth of most storage molds is about 40° F. and the optimum temperature for growth of most of them is 80° to 90° F. (3). Semeniuk (4) found that a minimum relative humidity of 80 percent in bulk bins is required for continued mold growths. A relative humidity of 80 percent corresponds to an equilibrium moisture content of about 15 percent, wet basis, for rough rice at 70° F. (5). Studies made by Del Prado (6) with rice at temperatures between 63° and 75° F. show that mold growth increases with increasing moisture content above 15 percent.

Full-scale Tests

Unheated air drying tests conducted at Beaumont with full-scale bins, from 1952-57, showed the relationship between the length of the drying period and quality loss as determined by U. S. Grade. For example, excessive "heat damage" occurred when the moisture content in the wettest layer of rice at temperatures of 80° to 86° F. remained above 15 percent for 8 to 10 days. On the other hand, rice at 65° to 78° F. was dried during September and October without grade loss when it remained above 15 percent moisture for as long as 15 days. Rice dried during November and December was held above 15 percent moisture from 30 to 40 days without quality loss. Rice temperatures during these months ranged from 45° to 55° F. After the rice was reduced to 15 percent moisture, further reduction in moisture to a safe storage level of 12.5 percent was accomplished over a longer period of time, without loss in grade and milling yields. The results of these tests support the results obtained by several researchers (7, 8, 9) and demonstrate the importance of providing adequate drying equipment and proper operating procedures to insure drying rice without quality loss under the different moisture and weather conditions encountered from year to year.

Small-scale Tests

In 1957 and 1958, studies were conducted with small-scale bins to obtain additional data on the effect of different air flow rates through stored rice at different initial moisture contents on the quality of rice as measured by U. S. Grade.

Samples were pulled periodically at three depths, Figure 4, for moisture determination, milling and germination tests and mold studies.

1957 Tests. Four bins were filled to a depth of 9 feet on September 29 with 16- to 17-percent moisture Bluebonnet 50 rice. Aeration was started immediately after the bins were filled. Air

TABLE 4. ALLOWABLE NUMBER OF "HEAT-DAMAGED" KERNELS IN 500 GRAMS FOR DIFFERENT GRADES OF ROUGH RICE[1]

Grade	Maximum number of heat-damaged kernels
U. S. No. 1	1
U. S. No. 2	2
U. S. No. 3	5
U. S. No. 4	10
U. S. No. 5	30
U. S. No. 6	75
U. S. sample grade	Above 75

[1]From official U. S. Standards for rough rice.

was supplied at a rate of 0.2 cfm per barrel (1/20 cfm per bushel) through two of the bins and at a rate of 0.4 cfm per barrel (1/10 cfm per bushel) through the other two bins. Rice in these bins was aerated continuously until January 31, 1958 (4 months' storage). After that time, the bins were aerated only during the day. The bins were aerated in that manner until the test was terminated on March 1, 1958. Air was pushed through the rice in all of the bins.

At the end of the 5-month storage period, moisture content of rice aerated with air supplied at a rate of 0.2 cfm per barrel had decreased 1.0 percent (16.2 to 15.2 percent) in the bottom of the bin compared to 0.5 percent (16.5 to 16.0 percent) 8 feet from the bottom. In the bins aerated with air supplied at a rate of 0.4 cfm per barrel, moisture had decreased 2.3 percent (16.1 to 13.8 percent) at the bottom and 1.1 (16.4 to 15.3 percent) at the 8-foot level. Temperatures at the 4- and 8-foot depths were about the same for all bins during the test period, ranging from a high of 77° to 81° F. at the start to a low 50° to 62° F. at the end of the storage peri Temperatures in the bottom of the bins follow about the same pattern as the atmospheric te peratures.

There was no loss in germination, grade milling yields in any of the bins during the st age period, Table 5. The moisture content of r for the two air flow rates are shown graphic in Figure 18.

1958 Tests. Four bins were filled to a 9-f depth with Bluebonnet 50 rice on September The initial moisture content of the rice ran from 18.4 to 19.3 percent. Unheated air w supplied at rates of 0.2 and 0.4 cfm per bar through the bins. There were two replicati for each bin. Air was pushed through the r continuously for 42 days in all of the bins.

The moisture content at different depths, wi corresponding temperatures in the rice, are sho in Figure 19. Moisture content and temperatu

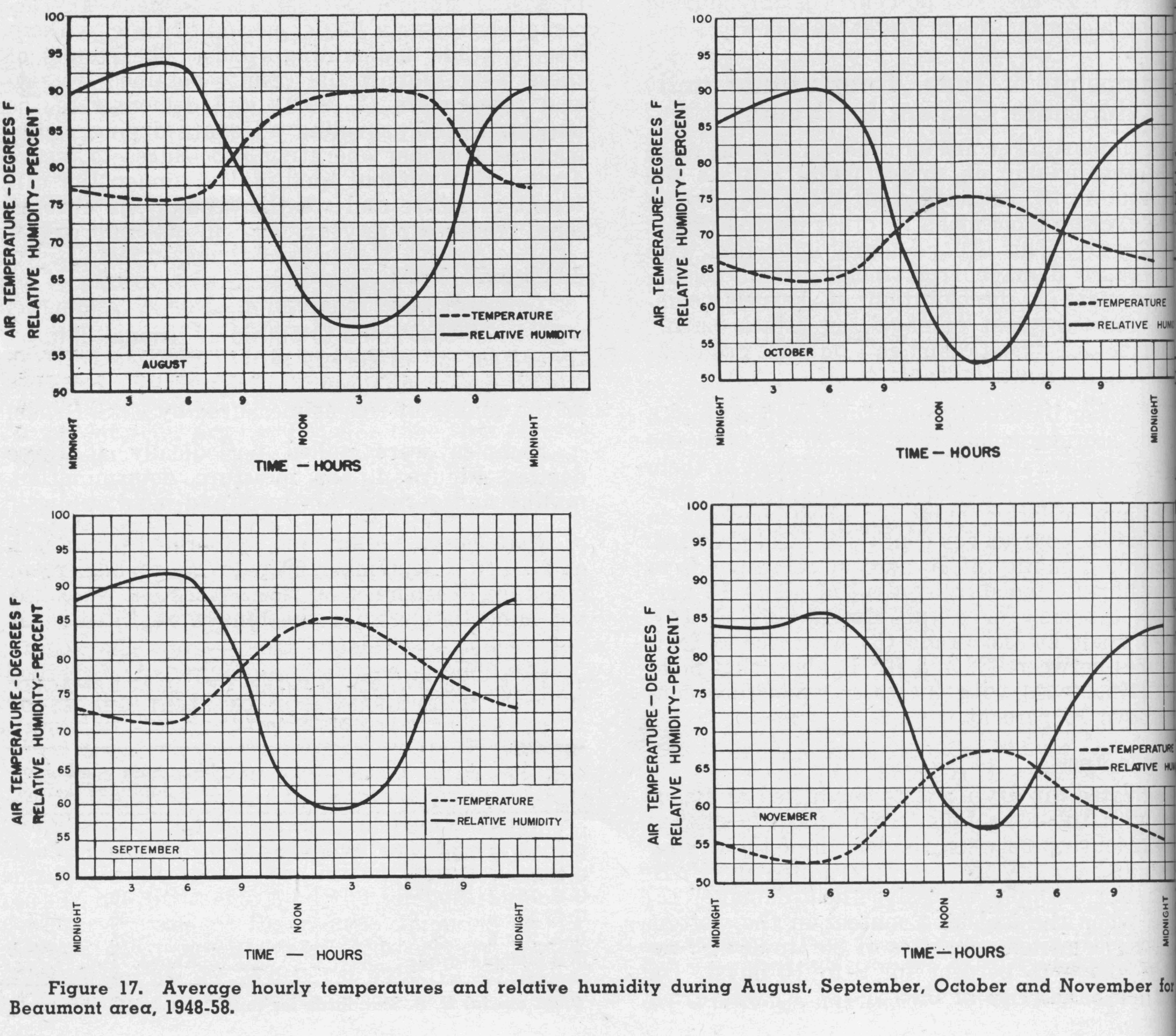


Figure 17. Average hourly temperatures and relative humidity during August, September, October and November for Beaumont area, 1948-58.

of rice dried at the same time with air flow rates of 7.2 and 9.5 cfm per barrel, respectively, are shown in Figure 20.

The moisture content of the rice at the 4- and 8-foot depths in the low air flow rate bins remained above 17 percent for most of the test period. Moisture at the 6-inch depth was reduced from 18.9 to 16 percent in 18 days (425 hours of fan operation) in the bins supplied with air at a rate of 0.2 cfm per barrel and from 18.4 to 16 percent in 7 days (170 hours of fan operation) in bins supplied with air at a rate of 0.4 cfm per barrel. Temperatures at the 6-inch depth were reduced from 96.5° to 77° F. in 2 days (50 hours of fan operation) with both air flow rates. At the 8-foot level, 9 days (210 hours of fan operation) were required to reduce temperatures from 98° to 77° F. in bins aerated with 0.2 cfm per barrel compared to 5 days (125 hours of fan operation) with an air flow of 0.4 cfm per barrel.

Samples from all three depths in each bin were plated on malt-salt agar after surface sterilization to determine the number of seeds containing molds and the changes in prevalence of the various species normally present in rice after harvest (3). All species are classified as field molds with the exception of those belonging to

TABLE 5. THE EFFECT OF AERATION WITH AIR FLOW RATES OF 0.2 AND 0.4 CFM PER BARREL ON MAINTAINING THE QUALITY OF BLUEBONNET 50 RICE WITH AN INITIAL MOISTURE CONTENT OF 16.1 TO 16.6 PERCENT, 1957-58

Item	0.2 cfm per barrel		0.4 cfm per barrel	
	At start	After 153 days	At start	After 153 days
Moisture content, percent				
6 inches from bottom	16.2	15.2	16.1	13.8
4 feet from bottom	16.6	16.0	16.2	14.7
8 feet from bottom	16.5	16.0	16.4	15.3
Average	16.4	15.7	16.2	14.6
Milling yields, percent[1]				
6 inches from bottom	61-70	63-73	62-70	65-72
4 feet from bottom	62-70	63-72	61-70	63-72
8 feet from bottom	62-69	62-72	60-69	62-71
Average	62-70	63-72	61-70	63-72
U. S. Grade				
6 inches from bottom	No. 2	No. 2	No. 1	No. 2[2]
4 feet from bottom	No. 2	No. 2	No. 2	No. 3[2]
8 feet from bottom	No. 2	No. 2	No. 2	No. 2
Average	No. 2	No. 2	No. 2	No. 2
Germination, percent				
6 inches from bottom	87.5	96.0	86.5	94.0
4 feet from bottom	89.5	93.2	83.5	96.5
8 feet from bottom	87.5	91.7	85.5	92.5
Average	88.2	93.7	85.0	94.3

[1]The first figure shown for milling yield is the percentage of whole grains or head rice that a sample of rough rice yields when milled. The second figure is the percentage of whole and broken grains.

[2]Loss in grade caused by chalky kernels.

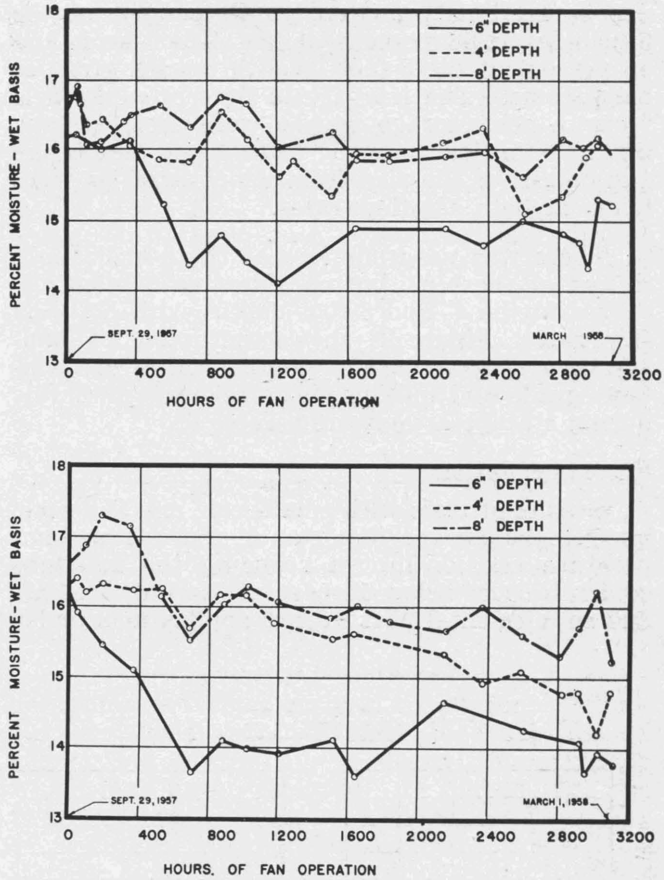


Figure 18. Moisture content of rice with an initial moisture content of 16.0 to 16.7 percent during 5-months' aeration with air supplied at rates of 0.2 cfm per barrel (top) and 0.4 cfm per barrel (bottom). There was no loss in grade or germination during the 5-month storage period.

the genera Aspergillus and Penicillium. Species of the latter genera have been found to invade cereal grains of all types and have caused deterioration during storage while infestation by most of the other species found in grain occurs in the field prior to harvest.

Field molds were isolated from 99 to 100 percent and storage molds were isolated from 0 to 2 percent of the kernels in the initial samples from all four of the low air flow rate bins taken at the time the bins were filled. After 9 days of fan operation with air supplied at the rate of 0.4 cfm per barrel, storage molds were isolated from 24 percent of the kernels from the 6-inch level; 38 percent of the kernels at the 4-foot level; and 58 percent of the kernels at the 8-foot level. This compares to 25 percent at the 6-inch level, 33 percent at the 4-foot level and 82 percent at the 8-foot level in the samples pulled on the same day from the bins receiving air at the rate of 0.2 cfm per barrel.

Storage mold invasion of the rice during the storage period reached a maximum of 64 percent at the 6-inch level, 89 percent at the 4-foot level and 81 percent at the 8-foot level in the 0.4 cfm per barrel bins compared to 73 percent at the 6-inch level, 86 percent at the 4-foot level and 96 percent at the 8-foot level in the 0.2 cfm per barrel bins. The increase in percent of kernels from which storage molds were isolated was highly significant among both days in storage and depths of the rice from which samples were taken at both air flow rates.

There was no grade loss at the 6-inch depth in any of the bins, but considerable damage occurred at the 4- and 8-foot depths with both air flow rates. Figure 21 shows the extent of damage occurring at various depths. Moisture content, grade and milling yields taken at intervals during storage are given in Table 6.

Recommendations

Results of tests with small-scale and full-scale bins emphasize the importance of the time-temperature relationship in reducing the moisture content of rice below 16 percent. In unheated air and supplemental heat drying applications under Texas conditions, the moisture in the wett layer of rice at temperatures of 70° to 75° must be reduced below 16 percent in 15 days, less, to prevent grade loss from discolored k nels. Further reduction in moisture to a sa storage level of 12.5 percent was accomplish over a period of several weeks in the Beaum area without grade loss. Tests conducted i the past 7 years indicate a minimum air fl rate of 9.0 cfm per barrel (2.5 cfm per bush to insure drying without loss in grade and mi ing yields under the different weather and mo ture conditions occurring within a season from year to year.

An air flow rate of 0.4 cfm per barrel w effective during September and October for ho ing undried rice with an initial moisture cont of 18 percent for 9 days without grade loss fr discolored kernels.

The quality of rice with initial moisture c tent ranging from 16.2 to 16.7 percent was ma

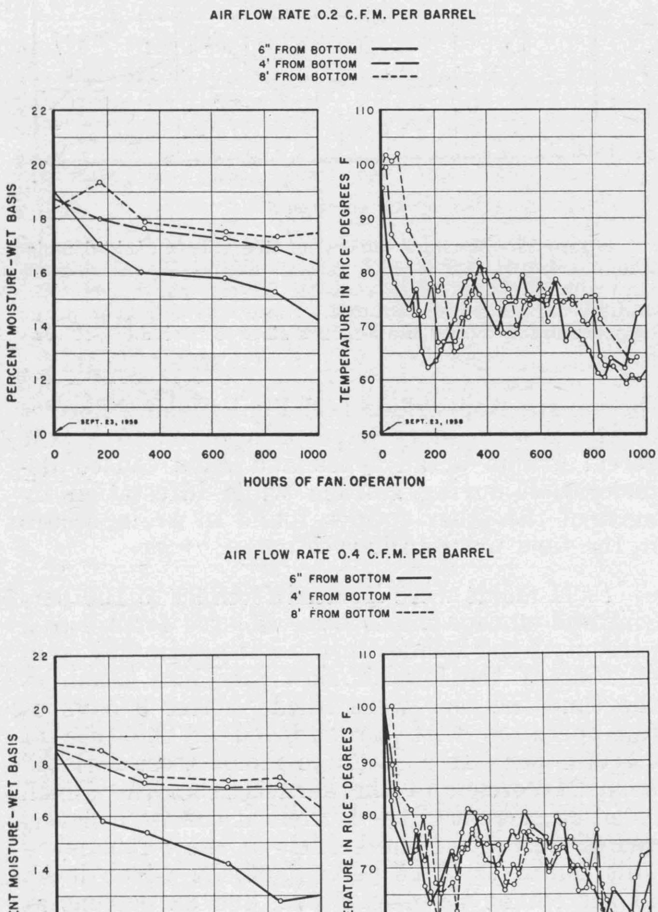


Figure 19. Moisture content at three depths with corresponding temperatures for 18- to 19-percent moisture rice aerated 42 days with air supplied at rates of 0.2 cfm per barrel (top) and 0.4 cfm per barrel (bottom).

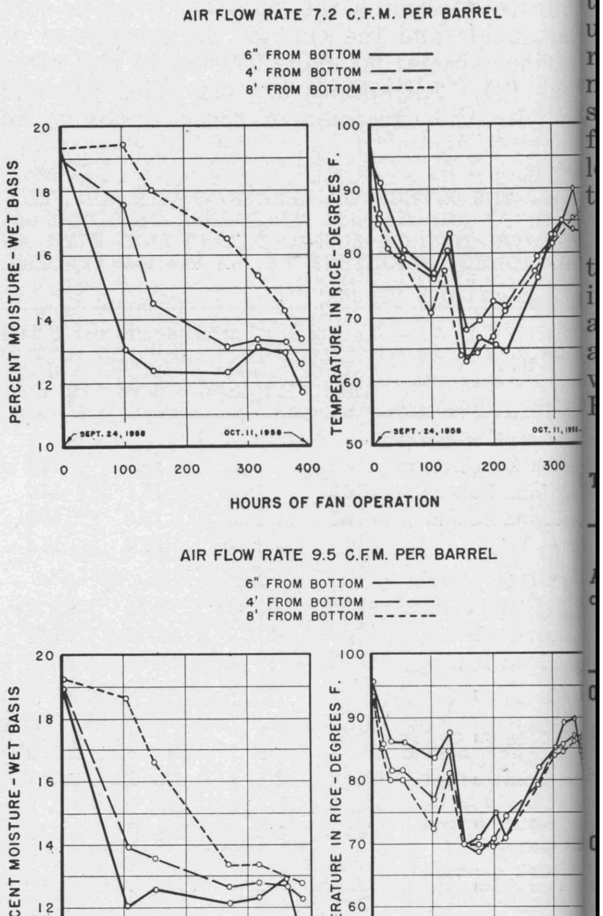


Figure 20. Moisture content at three depths with responding temperatures for rice dried with unheated supplied at rates of 7.2 cfm per barrel (top) and 9.5 cfm barrel (bottom).

tained for 5 months (September 29, 1957 to March 1, 1958) with aeration at air flow rates of 0.2 and 0.4 cfm per barrel.

AERATION

Rice dried in these tests was held in storage in the same bin in which it was dried from 3 to 6.5 months.

Rice in each bin was aerated as often as necessary to reduce the temperatures in the rice to 60° F. or less. Fans were operated when the outside air temperature was 10° F. or more below the average rice temperature. Fans were not operated during foggy or rainy periods. Controls for automatic operation of fans are shown in Figure 22.

A minimum air flow rate of 0.2 cfm per barrel is recommended for aerating rice in commercial storages (10). Fan and air distribution systems used for drying the rice in these tests supplied air at a higher rate, but also were satisfactory for aeration. With the high air flow rates used for drying, rice was cooled much faster than rice aerated with the low air flow rates recommended for commercial storages. For this reason, close supervision is required when high air flow rates are used to prevent large weight losses caused by excessive reduction in the moisture content of the rice.

Air was pushed up and pulled down through the rice. Both methods were effective in reducing temperatures in the rice. Pulling air down avoids condensation in the winter. The humid air leaving the rice does not come in contact with the cool surface rice or the cool bin roof. However, condensation was not a problem when

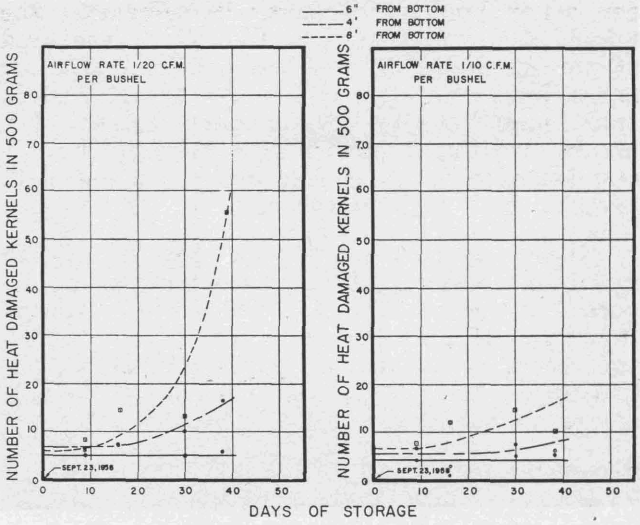


Figure 21. Number of heat-damaged kernels in samples of rice taken at different levels from bins aerated with air supplied at rates of 0.2 cfm per barrel (left) and 0.4 cfm per barrel (right). Initial moisture content at different levels with corresponding temperatures are shown in Figure 19.

aeration was started early in the season. Pulling air also gives an opportunity to smell the air coming out of the bin to detect any off odor which may have developed. In bin drying, rice is dried by pushing air up. Therefore, when bins are equipped with drying systems, it is advantageous to push air for aeration since it would be unnecessary to reverse the fan to change the direction of air flow.

QUALITY OF RICE DRIED IN STORAGE

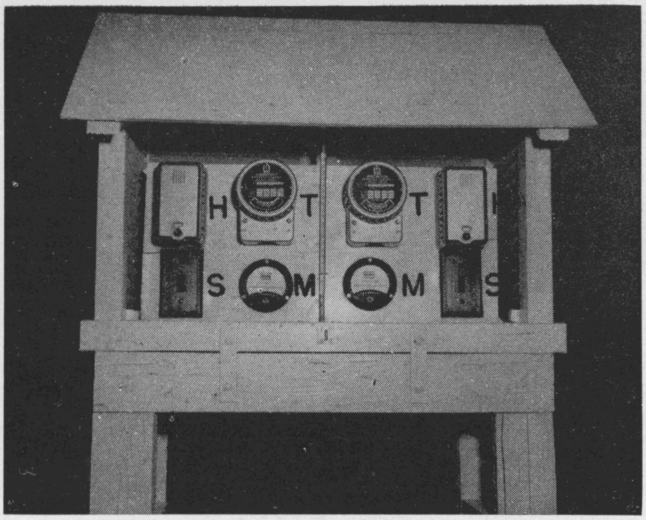
The effect of drying and storage conditions on germination, milling yields and U. S. Grade

TABLE 6. MOISTURE CONTENT, GRADE AND MILLING YIELDS OF SAMPLES OF HIGH-MOISTURE BLUEBONNET RICE TAKEN AT THREE LEVELS FROM BINS AERATED WITH AIR SUPPLIED AT RATES OF 0.2 AND 0.4 CFM PER BARREL, 1958[1]

Air flow rate and location in bin	Moisture content, percent						Grade and percent milling yields[2]					
	At start	Length of storage, days					At start	Length of storage, days				
		9	16	30	38	42		9	16	30	38	42
0.2 cfm per barrel												
6 inches from bottom	18.9	17.1	16.1	15.8	15.3	14.3	No. 3 66 - 73	No. 3 66 - 73	No. 4 64 - 71	No. 3 62 - 71	No. 4 67 - 74	No. 3 59 - 70
4 feet from bottom	18.7	18.0	17.8	17.4	17.0	16.4	No. 4 65 - 73	No. 4 66 - 73	No. 4 62 - 72	No. 4 62 - 71	No. 5 66 - 74	Sample 59 - 71
8 feet from bottom	18.4	19.4	17.9	17.4	17.5	17.4	No. 3 65 - 72	No. 4 65 - 73	Sample 63 - 71	Sample 61 - 71	Sample 65 - 73	Sample 59 - 71
0.4 cfm per barrel												
6 inches from bottom	18.6	15.9	15.5	14.4	13.0	13.1	No. 3 64 - 71	No. 3 66 - 73	No. 2 61 - 71	No. 3 63 - 72	No. 3 67 - 73	No. 3 59 - 70
4 feet from bottom	18.7	18.0	17.5	17.3	17.3	15.7	No. 3 65 - 73	No. 4 66 - 73	No. 2 61 - 71	No. 4 62 - 72	No. 3 67 - 74	Sample 65 - 73
8 feet from bottom	18.8	18.5	17.5	17.4	17.6	16.4	No. 4 65 - 73	No. 4 62 - 69	No. 5 62 - 71	Sample 64 - 71	Sample 65 - 73	Sample 60 - 71

[1]This rice was harvested from a field of down rice caused by a hurricane about a week before it was harvested. Some water was standing in the field during the harvesting operation. As a result, samples taken as the rice was received from the field showed "heat damage" and caused reduction in grade as shown above at the start of drying. "Heat damage" and/or musty odor were the grade factors causing a further grade reduction.

[2]The first figure shown for milling yield is the percentage of whole grains or head rice that a sample of rough rice yields when milled. The second figure is the percentage of whole and broken grains.



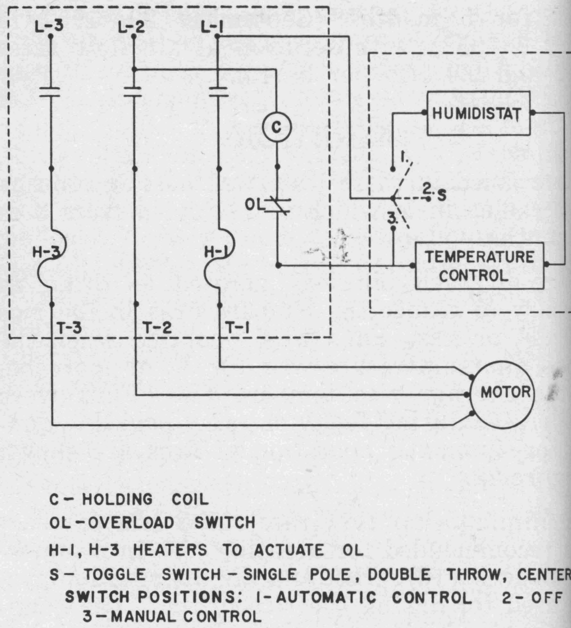


Figure 22. Two sets of controls for automatic operation of fans during aeration. Humidistat (H) and temperature control (T) permitted the fan motor to operate only when the temperature and relative humidity were below the desired level. A time meter (M) was used to register the hours of fan operation. The toggle switch (S) was used for manual control. Wiring diagram for automatic control of fan motors equipped with magnetic starters is shown at right.

are shown in Tables 7, 8 and 9. The losses in germination and milling yields during the first 3 years of the tests were attributed to the lack of established operating procedures and the low air flow rates used for drying. With the establishment of minimum air flow rates and improved operating procedures, rice was dried and held in storage for 4 to 6.5 months, from 1955-58, without loss in germination or head rice yields. Therefore, rice can be dried in storage in the Texas rice-producing area without quality loss when air flow rates and operating procedures outlined in this bulletin are followed.

Frequent inspection of the rice during drying and storage is required to insure maintenance of quality. In these tests, the moisture content and condition of the rice was checked at least twice a week during the drying operation. The rice was probed at 8- to 10-foot intervals over the surface of the rice and samples drawn from the b tom, at mid-depth and the top foot. Rice fr each level was mixed thoroughly and a moist check made for each level. Similar samples w taken once a month during the period the r remained in storage after it was dried to a m ture content considered safe for storage.

ACKNOWLEDGMENTS

The following cooperators contributed mat ials and equipment for these tests: Aerovent F and Equipment Company, Lansing, Michig Agri-Tec Steel Corporation, Johnstown, Oh Division of Agricultural Engineering, Agric tural Research Service, U. S. Department of A riculture; Black, Sivalls and Bryson, Kansas C Missouri; Butler Manufacturing Company, K sas City, Missouri; Lewis S. Doherty Ventilat Company, Baton Rouge, Louisiana; Farm Fa Inc., Indianapolis, Indiana; The McRan Compa Houston, Texas; and Stran-Steel Corporati Detroit, Michigan.

TABLE 7. AVERAGE CHANGE IN GERMINATION OF RICE DRIED WITH UNHEATED AIR AND STORED 3 TO 6.5 MONT
1952-1958

Year	Number of bins checked[1]	Length of storage, months	Average moisture content, percent		Average germination, percent		Average cha during dryi and storag
			Start of drying	End of storage	Start of drying	End of storage	
1952	2	3.0	19.3	13.5	89.1	87.9	—1.2
1953	3	3.0	19.1	12.0	91.3	90.6	—0.7
1954	6	4.0	18.5	11.4	81.2	80.3	—0.9
1955	5	5.0	17.5	11.2	84.2	85.7	+1.5
1956	6	6.5	18.0	11.2	84.0	93.5	+9.5
1957	10	4.5	17.0	11.9	86.6	94.9	+8.3
1958	9	4.0	18.2	12.5	71.2	73.5	+2.3

[1]Samples for moisture and germination tests were taken at three levels from each bin at the start of drying. These samp were air dried in thin layers and used as checks. Similar samples were taken after drying and at the end of the stor period and comparative analyses were made.

TABLE 8. AVERAGE CHANGE IN MILLING YIELDS OF RICE DRIED WITH UNHEATED AIR AND STORED 3 TO 6.5 MONTHS, 1952-1958

Year	Number of bins checked[1]	Length of storage, months	Average moisture content, percent		Head rice, percent[2]		Total rice percent[3]		Average change during drying and storage	
			Start of drying	End of storage	Start of drying	End of storage	Start of drying	End of storage	Head rice	Total rice
1952	2	3.0	19.3	13.5	46.5	45.5	72.0	72.0	−1.0	0
1953	11	3.0	19.0	12.2	57.0	58.3	68.4	69.8	+1.3	+1.4
1954	6	4.0	18.5	11.4	55.8	55.5	63.5	63.8	−0.3	+0.3
1955	5	5.0	17.5	11.3	57.6	59.1	67.8	66.9	+1.5	−0.9
1956	6	6.5	18.0	11.2	51.5	54.0	69.8	69.7	+2.5	−0.1
1957	10	4.5	17.0	11.9	61.5	61.2	70.0	70.5	+0.6	+.05
1958	5	4.0	18.2	12.5	56.8	57.8	69.6	69.4	+1.0	−0.2

[1]Samples for moisture content and milling tests were taken at three levels from each bin at the start of drying. These samples were air dried in thin layers and used as checks. Similar samples were taken after drying and at the end of the storage period and comparative analyses were made.
[2]The percentage of whole grains that a sample of rough rice yields when milled.
[3]The percentage of whole and broken grains.

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These tests were conducted at the Rice-Pasture Experiment Station, Beaumont, which is jointly operated by the Texas Agricultural Experiment Station, Texas Rice Improvement Association and U. S. Department of Agriculture.

TABLE 9. NUMBER OF SAMPLES OF RICE REDUCED IN GRADE DURING DRYING OPERATION DUE TO OCCURRENCE OF "HEAT-DAMAGED" KERNELS, 1953-1958

Year	Number of locations checked[1]	Number of samples reduced in grade due to heat damaged kernels
1953	20	1[2]
1954	18	1[3]
1955	38	3[4]
1956	32	0
1957	40	0
1958	36	2[5]

[1]Samples for U. S. Grade were taken at the start of drying from the bottom foot; at mid-depth and from the top foot in each bin when the depth of rice was 6 feet or more. At depths below 6 feet, samples were taken at the bottom and top only. These samples were air dried in thin layers and used as checks. Similar samples were taken after drying and comparative analyses were made.
[2]Caused by inadequate air flow.
[3]Check sample graded U. S. No. 2 due to "heat-damaged" kernels. Sample after drying graded U. S. No. 3.
[4]Reduction in grade caused by low rate of air flow and poor air distribution.
[5]Check samples graded U. S. No. 2 and U. S. No. 3, respectively, due to "heat-damaged" kernels. Both samples graded U. S. No. 5 after drying.

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Location of field research units of the Texas Agricultural Experiment Station and cooperating agencies

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