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DRYING RICE

in Heated Air Dryers WITH AERATION as a Supplementary Treatment

Marketing Research Report No. 508

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Transportation and Facilities Research Division
in cooperation with
TEXAS AGRICULTURAL EXPERIMENT STATION

PREFACE

The research on which this report is based is part of a study of improved methods, equipment, and facilities for the off-farm conditioning, handling, and storage of rough (paddy) and milled rice.

This research was conducted in cooperation with the Texas Agricultural Experiment Station. Dr. L. D. Crane, Superintendent of the Rice-Pasture Experiment Station, Beaumont, Tex., and his staff contributed to the project by helpful suggestions, by obtaining rice, and by making facilities at the Station available to project personnel. Gene Payne, Manager of Eagle Lake Rice Dryer, made his drying facilities available for the study at a commercial rice dryer.

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Growth Through Agricultural Progress

Washington, D. C. November 1961

DRYING RICE IN HEATED AIR DRYERS WITH AERATION AS A SUPPLEMENTAL TREATMENT

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SUMMARY

Research was conducted at the Rice-Pasture Experiment Station near Beaumont, Tex., to explore the usefulness of aeration as a treatment supplemental to drying of rough rice in commercial heated-air dryers.

Green rice was aerated in steel bins, each having a capacity of approximately 250 barrels. Airflow rates varied from 0.2 cfm (cubic feet of air per minute) per barrel in some bins to 2 cfm per barrel in others. The moisture content of the rice varied between lots from less than 18 to more than 23 percent (wet basis).

Several lots of long-grain rice (Bluebonnet 50 and TP-49 varieties) with an initial moisture content below 20 percent, aerated at 0.7 cfm per barrel (or higher), showed no change in grade when held in aerated storage for as long as 10 days prior to a series of passes through a heated-air dryer.

One lot of medium-grain rice (Gulfrose) with an initial moisture content of 23 percent, aerated at the rate of 0.7 cfm per barrel, was not damaged when held in aerated storage for 3 days. Another lot at 22 percent, aerated at 2 cfm per barrel for 7 days prior to a series of passes through the dryer, was reduced in grade from No. 2 to No. 6.

Cooling rice to outdoor temperature by aeration during the tempering period (between passes through the dryer) resulted in savings of both fuel and dryer operation time. These savings were attributed to moisture reduction which accompanied such cooling.

Observations were made of the time required to cool binned, dryer-heated rice to near outside temperature. Cooling rates varied with different conditions of rice temperature, moisture content, and outdoor temperature, but in general varied directly with the airflow rate. The time required to move a cooling zone through a bin of rice initially at 114° F. was approximately 25 hours with an airflow rate of 1 cfm per barrel.

Drying studies were made at a commercial rice dryer where the cooling of rice between dryer passes had been practiced for 4 years. The percent of the total drying occurring during aeration periods varied from 31 to 54 percent for the drying operations studied.

BACKGROUND INFORMATION

Rice is harvested almost exclusively by combines in the rice-producing regions of the United States. It is common practice to combine rice when the moisture content of the kernels is in the range from 16 to 24 percent. The maximum moisture content for safe storage generally is considered to be around 12 to 13 percent. Therefore, it is urgent that the moisture content be reduced quickly.

Several methods of drying rice are available to farmers, but most of the combine-harvested rice is custom-dried in continuous-flow, heated-air dryers. Such a dryer usually consists of a tall, vertical column through which rice flows by gravity. Heated air is forced through 4- to 6-inch layers of rice as the rice moves slowly downward. Some dryers are designed so that rice is continually agitated as it flows downward, while in other makes, there is no attempt to divert the rice from a straight path. The temperature to which the air is heated and the speed at which rice flows through the dryer can be varied on most makes of dryers.

With continuous-flow, heated-air dryers, the drying process for rice ordinarily consists of a series of passes through the dryer. Dryer operator experience has shown that a faster drying rate and better market quality can be obtained by the multipass drying method than by other methods used. Tempering periods are interspersed between dryer passes in multipass drying. Rice is tempered by holding it in bins 6 to 24 hours between dryer passes and allowing the moisture to equalize within the rice kernel.

The procedure used in drying rough rice affects the head yield (percentage of rough rice which can be milled as unbroken kernels). The market value of head rice is higher than that of broken kernels; therefore, a drying procedure resulting in the highest possible yield of head rice is of great economic importance.

The harvest season is short for a particular variety of rice in any area. During this rush period, continuous dryer operation and a fast drying procedure generally are necessary to keep up with incoming rice. Unfortunately, most drying procedures which speed the rate of drying also are likely to cause stresses within kernels. These stresses may cause checking, which results in broken kernels when the rice is milled. Thus, the two major objectives of a dryer operator, fast drying and maintenance of market quality, are difficult to obtain simultaneously.

An experimental rice dryer, similar to commercial dryers except for its smaller size and lower drying capacity, was built by the U. S. Department of Agriculture at the Rice-Pasture Experiment Station, Beaumont, Tex. (fig. 1). Studies are being made with this dryer to establish better methods of drying and to explore the uses of aeration as a supplemental treatment for drying rice in heated-air, continuous-flow dryers. Figure 2 shows one of the small fans used on the experimental bins for aerating the green and dried rice.

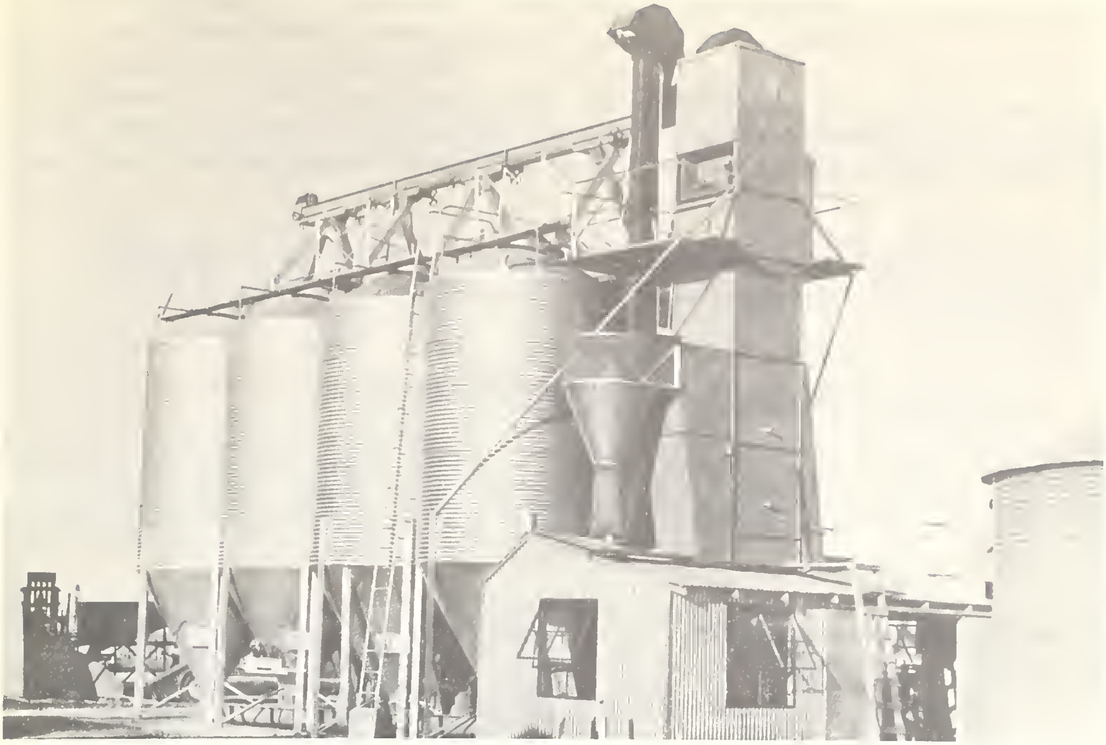

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Figure 1.--Experimental rice dryer at Rice-Pasture Experiment Station, Beaumont, Texas.

Aeration, the moving of air through stored grain at low airflow rates for purposes other than drying to maintain or improve its value 1/, was used to maintain the quality of green rice for limited periods of time before the start of a series of dryer passes. Used in this manner, aeration alleviates the rush period and eliminates the need for fast drying.

Research in Arkansas 2/ indicated that rice containing from 18 to 24 percent moisture may be kept for a week or possibly 10 days with an airflow rate of 1 cfm per bushel (3.6 cfm per barrel). In tests using small bins in Texas 3/, an airflow rate of 0.4 cfm per barrel was adequate to maintain the quality of Bluebonnet rice harvested at 18 to 19 percent moisture and stored for 9 days. Further tests on holding green rice of different varieties with different initial moisture contents and airflow rates (0.2 to 2 cfm per barrel) would be useful in adding to previous findings.

1/ Aeration of Grain in Commercial Storages. U. S. Dept. Agr., Mktg. Res. Rpt. No. 178, revised November 1960.

2/ McNeal, Xzin: Aeration, Storage, and Conditioning of Rice, an unpublished paper presented to the Southwest Section of the American Society of Agricultural Engineers, April 1952.

3/ Sorenson, J. W. Jr., and Crane, L. E.: Drying Rough Rice in Storage. Texas Agr. Expt. Sta., B-952, March 1960.

Aeration also may be used for cooling rice between dryer passes. Such cooling generally is accompanied by removal of moisture. Tests were run to compare drying costs for lots of rice cooled to atmospheric temperature during the tempering period with costs for other lots which were tempered at high temperature. These tests were run to determine if moisture removed by cooling during the tempering period saved fuel and reduced dryer operation time.

Aeration may be used also for cooling rice to outdoor air temperature following the final pass through the dryer, which eliminates the use of the dryer for cooling.

AERATION FOR MAINTAINING QUALITY OF UNDRIED RICE

Green rice was held in aerated storage for varying periods up to 22 days, before going to the dryer for the first time. Between dryer passes, some lots of rice were cooled by aeration and stored for several days. Others were tempered without cooling and rerun through the dryer within 24 hours.

The aerated storages referred to in this report are corrugated steel, hopper-bottomed bins, 9 feet in diameter, and with a capacity of approximately 250 barrels of dry rough rice (fig. 1). Air was supplied by fans of different sizes, installed one to each bin. Aeration ducts were installed in the hoppers of the bins, except for one bin where ducts were installed on opposite walls for crossflow. Airflow rates varied within a range from 0.13 cfm per barrel in some bins to 2 cfm per barrel in others. These rates were determined by measuring air static pressures at various locations in the bins of rice, and computing an average pressure drop per foot depth of rice. The airflow rate in cfm per square foot of bin area was obtained by referring to published data 4/. Calibrated nozzles installed on the intake side of the fans also were used for determining the airflow.

BN-14656

Figure 2.--A small centrifugal fan and fractional horsepower electric motor used for aerating rice in the experimental bins.

4/ Shedd, C. K., Resistance of Grains and Seeds to Airflow, Agricultural Engineering: 616-619 - 1953.

The moisture content of rice was determined with moisture meters before and after each storage period.

Data for 24 lots of green rice of 3 varieties in aerated storage are summarized in table 1. Milling yield data were not included because there was no indication that the milling yield was affected during these storage periods.

A change in grade was the consideration used in judging whether or not the quality of green rice was maintained. On this basis, holding green rice with aeration was successful for 16 of 24 lots of rice. An excessively long storage period or high initial moisture content appears to have caused the reduction in grade for most of the other lots. Exceptions include lot E-58 of the TP-49 variety, which was downgraded because of the presence of chalky kernels, and Gulfrose lot D-59, which was downgraded because of the presence of red rice and damaged kernels. It is unlikely that these defects were due to the storage treatment, and, except for sampling error, they would have been detected in the initial samples.

The longest storage period before dryer treatments for any lot was 22 days. This storage period proved to be too long for Bluebonnet 50 rice at 20.5 percent moisture content, aerated with an airflow rate of 2.0 cfm per barrel. The final grade was No. 3, whereas the initial sample was graded No. 1.

The quality of some lots of rice stored for 10 days or longer was maintained, while other lots showed a drop in grade. It appeared that the high moisture content of 3 lots was responsible for deterioration that caused these lots to be downgraded. The initial moisture contents of the 3 lots were 21.3, 20.7, and 20.0 percent. The initial moisture contents for 4 lots stored without quality loss were 18.5, 19.3, 19.6, and 20.4 percent. The airflow rates ranged from 0.7 cfm per barrel for one lot to 2.0 cfm per barrel for others, but airflow rates did not appear to be an important influence on the final grades. One of the lots aerated at 2.0 cfm per barrel was downgraded, and the lot aerated at 0.7 cfm per barrel was not. No drop in grade (for anything other than chalky kernels) was noted for lots of Bluebonnet 50 and TP-49 that were held in aerated bins for periods less than 10 days.

Storage tests with Gulfrose indicated a shorter safe storage time. This may have been due to high moisture content of the rice, warm outdoor temperatures (harvest season was late July and August), or a characteristic of this variety. Lot C-59, with an initial moisture content of 22.0 percent and aerated for 7 days at 2.0 cfm per barrel, was reduced in grade from No. 1 to No. 6. Better results were obtained with the 3 lots held for only 3 days with aeration rates in the range of 0.85 to 0.70 cfm per barrel. Lot F-59, initially at 23 percent moisture, was maintained at No. 2. Lot E dropped from No. 2 to No. 4, but the damage probably occurred during an 8-day storage period following the first pass through the dryer. Lot D dropped from No. 1 to No. 2 due to red rice and damaged kernels that were not detected in the initial sample.

Table 1.--Grades of green rice of different varieties, held in aerated storage at specified moisture contents, airflow rates, and periods before drying

Variety and lot designation	Storage before drying: Period	Moisture Content (wet basis): Initial	Moisture Content (wet basis): Final	Aeration rate	Initial quality	Quality after drying
	Days	Percent	Percent	cfm per barrel	Grade	Grade
Bluebonnet 50:						
A-58	22	20.5	16.9	2.00	No. 1	No. 3 1/
B-58	14	18.5	16.3	.85	No. 1	No. 1
D-58	5	19.1	16.9	.75	No. 1	No. 1
A-59	2	21.1	19.8	.85	No. 1	No. 1
B-59	2	22.6	21.3	.85	No. 1	No. 1
C-59	13	20.7	17.1	.75	No. 1	No. 3 1/
D-59	11	20.4	15.8	2.00	No. 1	No. 1
E-59	2	18.4	18.0	0.25	No. 1	No. 1
F-59	4	18.2	17.1	.13	No. 1	No. 1
G-59	13	19.3	15.8	.70	No. 2 2/	No. 1
TP-49						
A-58	14	21.3	19.2	2.00	No. 1	No. 3 1/
B-58	9	19.3	18.6	.85	No. 1	No. 1
C-58	3	19.7	18.9	.13	No. 1	No. 1
D-58	10	19.6	17.4	.85	No. 1	No. 1
E-58	6	20.3	19.3	.75	No. 1	No. 2 3/
A-59	10	20.0	18.6	.85	No. 1	No. 5 1/
B-59	4	19.9	18.4	.85	No. 1	No. 1
C-59	4	19.0	17.3	.70	No. 1	No. 1
D-59	2	17.9	17.4	.25	No. 1	No. 1
G-59	8	17.5	16.6	.75	No. 1	No. 1
Gulfrose:						
C-59	7	22.0	19.1	2.00	No. 1	No. 6 1/
D-59	3	21.7	20.5	.85	No. 1	No. 2 2/
E-59	3	21.4	20.2	.75	No. 2 2/	No. 4 1&2/
F-59	3	23.0	22.6	.70	No. 2 2/	No. 2 1&2/

1/ Heat-damaged kernels.

2/ Red rice or damaged kernels.

3/ Chalky kernels.

Sufficient data were not available to establish that the higher rates of airflow used were effective in bettering storage conditions. All of the long storage periods were associated with high airflow rates and, consequently, failures to maintain quality also were associated with high airflow rates. The longest storage period attempted for the airflow rate of 0.13 cfm per barrel was 4 days. This was done with no loss in grade, but this lot of rice (Bluebonnet 50, F-59) had an initial moisture content of only 18.2 percent.

A drop in moisture content was noted for all 24 lots during the preliminary storage period. The average moisture reduction for all lots was 1.8 percent (wet basis), but for 9 lots aerated for 10 or more days, the average moisture reduction was 2.8 percent.

These tests indicated that Bluebonnet 50 and TP-49, with a moisture content below 20 percent, aerated at 0.7 cfm per barrel or more, can be stored for as long as 10 days with no reduction in grade. It is not yet clear that the same is true for Gulfrose and other medium-grain varieties with similar characteristics; however, it does appear feasible to store rice of this type for as long as 3 days when the moisture content does not exceed 22 percent and the aeration rate is 0.7 cfm per barrel or more.

Further studies with replicated treatments are needed to establish more exactly the effects of the storage period, airflow rate, moisture content of rice, temperature and humidity conditions of the air, and variety of rice upon market quality of rice stored in aerated bins for prolonged periods while still at high moisture contents.

AERATION DURING TEMPERING PERIODS

Two methods of tempering were used for lots of rice dried with the experimental dryer in 1959 and 1960. Of the 36 lots involved, half were tempered between dryer passes at high temperatures for periods of 6 to 24 hours. This is the usual practice at commercial rice dryers. The other lots were cooled to outdoor air temperature by aeration during tempering periods. Samples of rice from all lots were taken before and after drying and graded by the U. S. Department of Agriculture grading office at Beaumont, Tex.

Tempering and drying treatments, with information about moisture content and size of lots, are listed in table 2. Half of the 6 lots of Gulfrose were aerated during tempering periods, while the other 3 lots were tempered at high temperature. In other respects, all lots of Gulfrose received similar drying treatments. Lots of Bluebonnet 50, TP-49, and NATO were paired so that 2 lots, one aerated and one not aerated during the tempering periods, had similar drying treatments. The time in the dryer and the temperature of rice leaving the dryer were varied for other pairs of lots.

Figures 3 and 4 show diagrammatically the drying operations for lots of rice dried in 1959 and 1960, respectively. Shown are the relative amounts of moisture removed during individual passes through the dryer and during aeration periods. Also shown for each lot is the percent of the total drying which took place during aeration periods between drying passes.

Table 2.--Tempering and drying treatments, moisture contents, weight, and quantity of moisture removed from 36 lots of rice

Variety and lot designation	Tempering treatment 1/	Time in dryer 2/	Temperature of rice leaving dryer 3/	Moisture content (Wet basis) 4/ Initial	Moisture content (Wet basis) 4/ Final	Volume of rice at final M. C.	Moisture removed
		Minutes	Degrees, F.	Percent	Percent	Barrels	Cwt.
GULFROSE							
A-59	Aerated	15	112	20.2	11.1	179	33.1
B-59	Aerated	15	108	20.4	11.5	215	38.7
E-59	Aerated	15	110	20.2	11.3	185	33.4
C-59	Not aerated	15	112	19.1	11.1	218	34.9
D-59	Not aerated	15	111	20.5	11.4	205	38.1
F-59	Not aerated	15	112	22.6	11.5	183	42.4
BLUEBONNET 50							
A-59	Not aerated	15	117	19.8	12.6	217	31.0
B-59	Aerated	15	113	21.3	12.5	185	33.3
C-59	Aerated	15	108	17.1	12.7	208	17.6
D-59	Not aerated	15	106	15.8	12.2	202	14.0
E-59	Not aerated	25	117	18.0	11.4	220	16.0
F-59	Aerated	25	115	17.1	11.9	206	21.2
TP-49							
A-59	Not aerated	15	108	18.6	12.4	233	28.1
B-59	Aerated	15	107	18.4	12.9	230	24.8
C-59	Aerated	25	120	17.3	11.7	230	25.1
D-59	Not aerated	25	122	17.4	11.6	210	24.9
E-59	Not aerated	15	119	19.2	12.4	208	27.9
F-59	Aerated	15	114	19.9	12.5	226	33.7
NATO							
A-60	Not aerated	15	131	21.6	11.9	213	42.7
B-60	Aerated	15	123	22.3	12.0	223	48.0
C-60	Aerated	25	127	21.1	11.9	226	42.7
D-60	Not aerated	25	132	20.0	11.4	239	41.7
E-60	Aerated	15	112	21.5	12.5	217	40.5
F-60	Not aerated	15	110	20.7	12.8	216	34.9
BLUEBONNET 50							
A-60	Aerated	15	122	20.6	12.3	218	36.8
B-60	Not aerated	15	125	21.5	12.2	209	36.1
C-60	Aerated	25	125	20.5	11.5	222	40.6
D-60	Not aerated	25	130	21.2	11.8	220	42.5
E-60	Aerated	15	112	20.0	12.8	234	34.0
F-60	Not aerated	15	116	19.7	12.2	217	32.7
TP-49							
A-60	Aerated	25	130	22.3	13.1	219	41.9
C-60	Not aerated	25	124	22.8	12.7	220	46.6
B-60	Not aerated	15	125	21.2	12.4	203	36.6
D-60	Aerated	15	118	19.4	12.1	202	29.7
E-60	Not aerated	15	110	18.6	12.6	215	25.2
G-60	Aerated	15	110	17.8	12.4	204	21.4

1/ The sequence of dryer passes for some lots of rice designated as "Not aerated" had to be interrupted. If these interruptions were for more than 24 hours, the rice was aerated until the sequence of dryer passes was resumed.

2/ The time in the dryer was computed by dividing dryer capacity (barrels) by the rate of flow of rice through the dryer (barrels per minute).

3/ Maximum average temperature of rice samples leaving the dryer for any one of several passes.

4/ Average initial moisture content of rice entering the dryer during the first pass, which generally was less than the moisture content of the rice when received. Average final moisture content for rice samples taken after rice had been cooled by aeration in storage following last dryer pass.

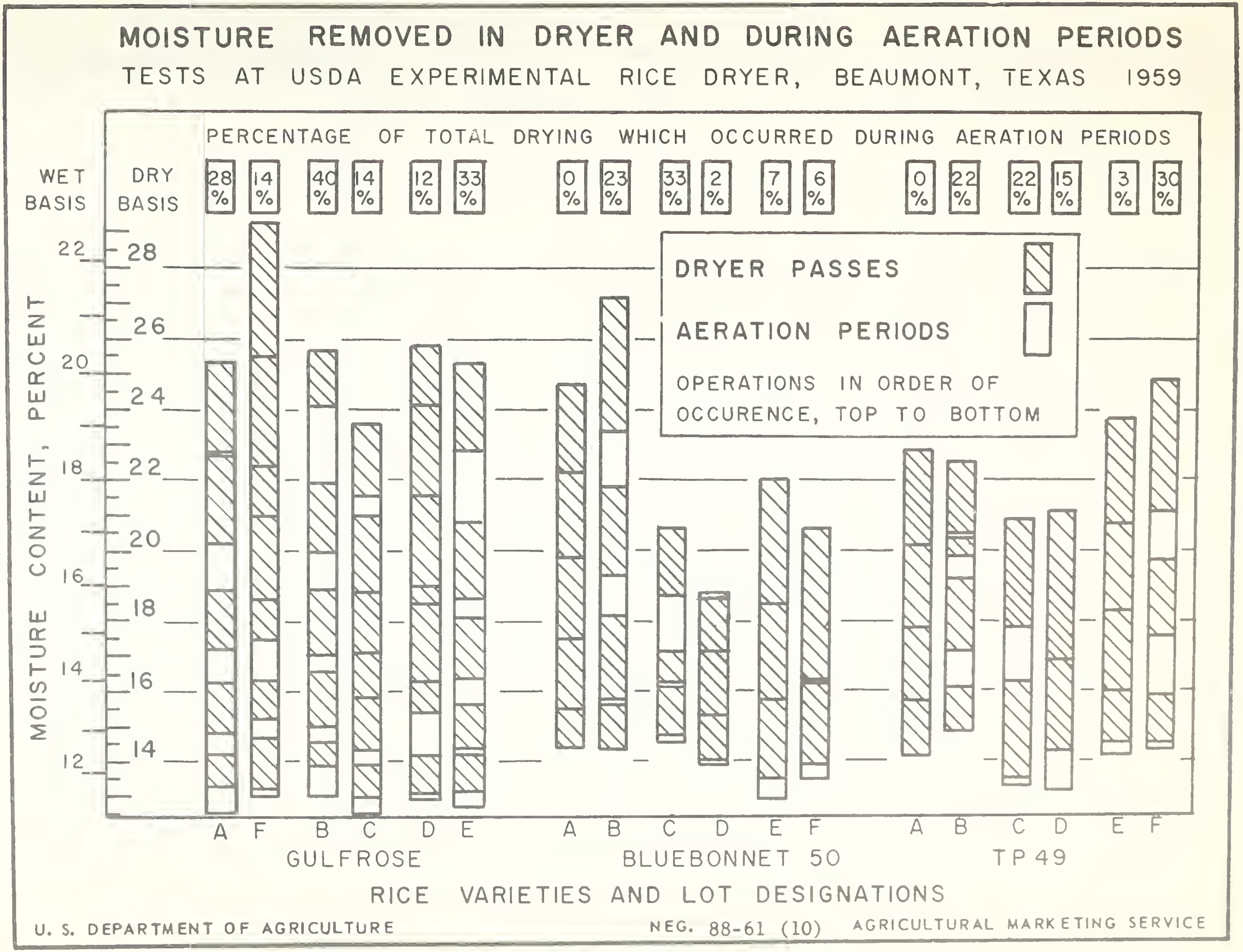

Figure 3.--Drying diagram for rice dried at the experimental dryer in 1959.

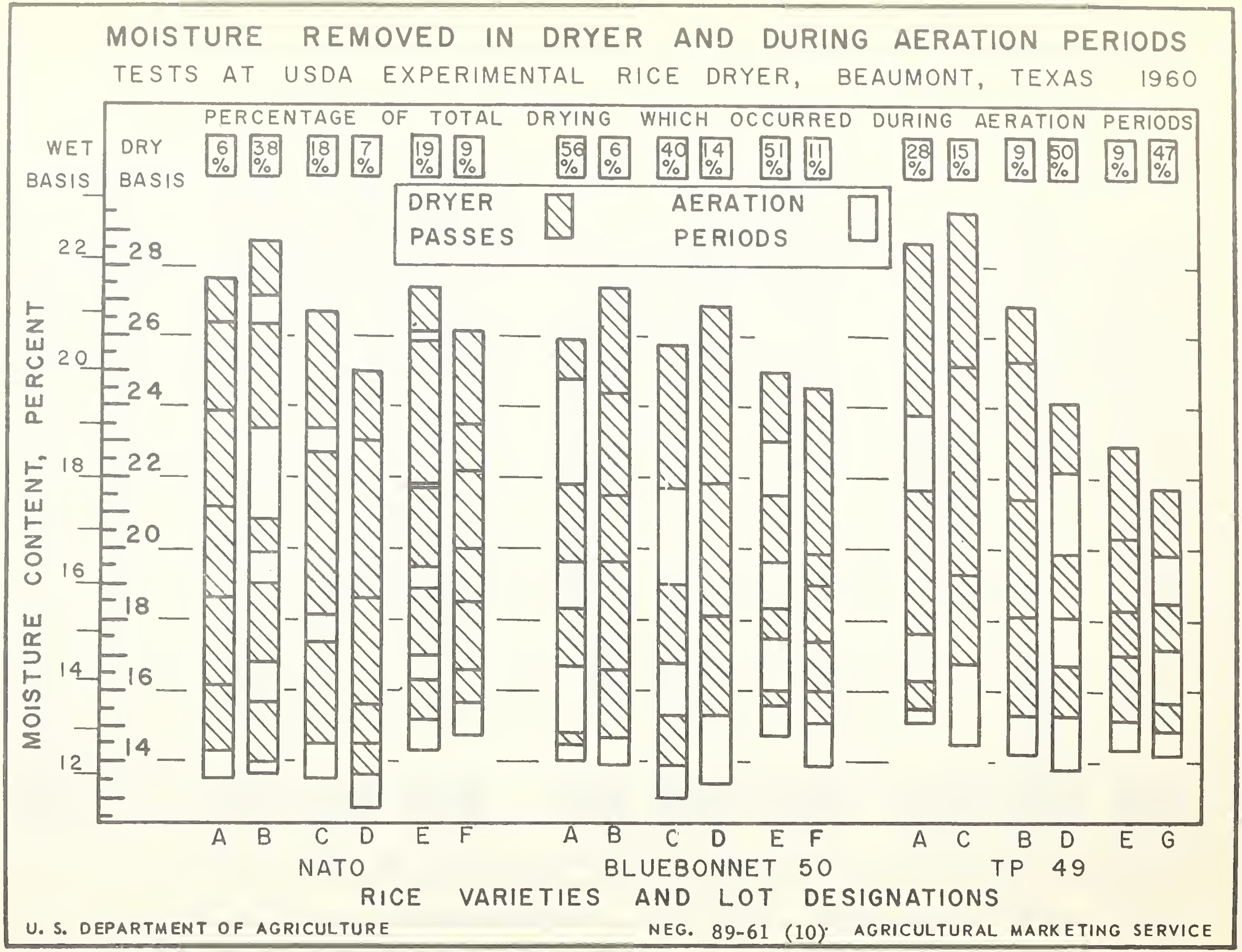

Figure 4.--Drying diagram for rice dried at the experimental rice dryer in 1960.

This percent does not include any drying that may have occurred before the drying passes were started. Aeration used to maintain the quality of the green rice generally removed some moisture.

In a few instances, the sequence of drying passes from some lots designated as "not aerated" had to be interrupted. If this interruption was for an extended time, the rice was aerated until the sequence of drying passes could be started again. However, each lot designated as "not aerated" received a number of consecutive passes through the dryer with no aeration between passes.

An examination of rice inspection certificates for all rice samples indicated that neither grades nor milling yields were affected by the treatments received during the tempering periods.

The amount of moisture removed during aeration periods was not predictable but, in general, was progressively less for a particular lot following each dryer pass. The amount of moisture removed during aeration periods was influenced by the difference in temperature of the rice as it left the dryer and the temperature of the outside air. The larger temperature differentials generally resulted in an increased amount of drying. With only a few exceptions, at least half as much moisture was removed during an aeration period following a pass through the dryer as was removed during the dryer pass. There were several instances in which the amount of moisture removed during the aeration period actually exceeded the amount removed during the preceding dryer pass.

The hours of operation and the amount of fuel used in drying 36 lots of rice (table 2) are listed in table 3. To compare these cost items for lots of different sizes, the costs were prorated per barrel of rice dried; and to compare costs for lots with different initial moisture contents, they were prorated per hundredweight of water removed.

Comparisons of average number of dryer passes, gas consumption, and dryer operation time for lots of rice receiving different treatments during tempering periods are shown in table 4. Lots of rice aerated between passes required 20 percent fewer passes than lots tempered at high temperatures. In general, this amounted to one less pass through the dryer. Gas consumption was less for lots cooled to air temperature by aeration. Savings of butane were 14 percent when prorated per barrel of rice dried, and 18 percent when prorated per hundredweight of moisture removed. Savings in dryer operation time for lots receiving the aeration tempering treatment were more than 18 percent when prorated per barrel of rice dried and more than 22 percent when prorated per hundredweight of moisture removed.

Watt-hour meters were used to measure the amount of electrical energy used by the dryer and conveying equipment during each pass. The amount of electricity used varied directly with dryer operation time, and savings of the same magnitude were realized for the aerated lots, as far as energy used by the dryer and conveying equipment was concerned. However, these savings were nullified by electrical energy required for operating fans on aeration systems during tempering periods.

Table 3.--Cost factors for fuel and operation hours for 36 lots of rice receiving different treatments during tempering periods between dryer passes

Variety and lot designation	Tempering treatment	Cost factors: Total for drying operation: Gas 1/	Cost factors: Total for drying operation: Operation	Cost factors: Prorated per barrel of rice dried: Gas	Cost factors: Prorated per barrel of rice dried: Operation	Cost factors: Prorated per cwt of moisture removal: Gas	Cost factors: Prorated per cwt of moisture removal: Operation
		Gallons	Hours	Gallons	Hours	Gallons	Hours
GULFROSE							
A-59	Aerated	54.6	9.3	0.302	0.051	1.65	0.281
B-59	Aerated	59.7	10.4	0.276	0.053	1.54	0.268
E-59	Aerated	54.8	10.0	0.295	0.054	1.64	0.299
C-59	Not aerated	82.5	12.4	0.375	0.056	2.36	0.356
D-59	Not aerated	69.5	12.9	0.336	0.062	1.83	0.338
F-59	Not aerated	70.8	12.5	0.385	0.068	1.67	0.294
BLUEBONNET 50							
A-59	Not aerated	76.5	9.9	0.356	0.046	2.47	0.319
B-59	Aerated	64.9	7.7	0.352	0.042	1.95	0.231
C-59	Aerated	41.4	6.0	0.201	0.029	2.35	0.341
D-59	Not aerated	47.4	8.0	0.235	0.040	3.40	0.571
E-59	Not aerated	65.1	10.5	0.293	0.047	4.07	0.656
F-59	Aerated	44.1	6.8	0.214	0.033	2.08	0.321
TP-49							
A-59	Not aerated	67.3	8.0	0.290	0.034	2.40	0.284
B-59	Aerated	50.8	6.2	0.224	0.027	2.05	0.250
C-59	Aerated	55.9	6.8	0.241	0.029	2.23	0.271
D-59	Not aerated	53.6	6.6	0.246	0.030	2.15	0.265
E-59	Not aerated	61.1	7.0	0.295	0.034	2.19	0.250
F-59	Aerated	61.1	6.2	0.272	0.028	1.81	0.184
NATO							
A-60	Not aerated	102.0	11.8	0.480	0.055	2.39	0.276
B-60	Aerated	98.0	10.3	0.440	0.046	2.04	0.215
C-60	Aerated	88.5	10.5	0.390	0.047	2.07	0.246
D-60	Not aerated	102.0	14.3	0.430	0.060	2.45	0.343
E-60	Aerated	68.0	9.9	0.310	0.045	1.68	0.244
F-60	Not aerated	69.0	12.5	0.320	0.058	1.97	0.358
BLUEBONNET 50							
A-60	Aerated	69.0	7.5	0.317	0.034	1.88	0.204
B-60	Not aerated	83.3	9.4	0.399	0.045	2.31	0.260
C-60	Aerated	83.1	10.7	0.375	0.048	2.05	0.264
D-60	Not aerated	91.0	10.5	0.413	0.048	2.14	0.247
E-60	Aerated	62.0	7.7	0.265	0.033	1.82	0.226
F-60	Not aerated	64.0	9.2	0.295	0.042	1.96	0.281
TP-49							
A-60	Aerated	88.1	9.2	0.420	0.042	2.11	0.220
C-60	Not aerated	113.5	11.5	0.516	0.052	2.43	0.247
B-60	Not aerated	91.8	8.6	0.450	0.042	2.51	0.235
D-60	Aerated	71.8	6.7	0.354	0.033	2.42	0.226
E-60	Not aerated	78.5	8.2	0.367	0.038	3.12	0.325
G-60	Aerated	51.7	6.1	0.252	0.030	2.42	0.285

1/ Butane.

Table 4.--Comparison of dryer passes, gas consumption, and dryer operation time for lots of rice receiving different treatments during tempering periods between dryer passes

Item	Tempering treatment: Not aerated	Tempering treatment: Aerated	Reduction by aeration
			Percent
Average number of dryer passes per lot.	4.61	3.67	20.4
Average gas consumption:			
Gallons per barrel of rice dried.	0.36	0.31	14.0
Gallons per hundredweight of moisture removed.	2.43	1.99	18.3
Average dryer operation time (labor):			
Hours per barrel of rice dried.	0.048	0.039	18.6
Hours per hundredweight of moisture removed	0.328	0.254	22.5

To make a rough estimate of relative costs of labor, gas, and electricity for drying one barrel of rice with the experimental dryer, it was assumed that only one laborer at $1.50 per hour was needed. The cost of butane gas was assumed to be 10 cents per gallon and electricity to be 2 cents per kilowatt hour. Using figures in table 4, for lots aerated between passes, labor costs were 5.8 cents (.039 hours x 150 cents per hour), fuel costs were 3.1 cents (0.31 gallons x 10 cents per gallon), and electricity (not listed in table) costs were 0.7 cents (0.35 kwh per barrel x 2 cents per kwh), for each barrel of rice dried.

The saving of dryer operation time was of more importance than any other saving resulting from using aeration during tempering periods. Labor costs as well as depreciation of the dryer and conveying equipment are related to operation time. Less operation time makes it possible for a commercial dryer to dry a larger volume of rice during the harvest season.

These tests were planned to compare two methods of drying rice and not necessarily for efficiency in consumption of fuel, electricity, or labor. Thus the estimated costs of each should not be considered typical for commercial rice dryers. In fact, the efficiency of drying larger lots at commercial dryers should exceed that for experimental-size lots discussed in this report. However, a saving of fuel and operation time should be realized at any dryer when rice is cooled by aeration to near outside air temperature during the tempering period between dryer passes.

Cooling Time

Aeration should be continued until all the rice has been cooled to near outside air temperature. A cooling zone travels through a depth of rice starting at the point where air enters and proceeds in the direction of airflow to the point where air is exhausted. The cooling zone has a temperature gradient varying from the initial temperature of the rice to the temperature of the air. With a shallow depth of rice and high airflow rate, the entire depth is apt to be included in the cooling zone. But with bins and airflow rates commonly used, the depth of the cooling zone is much less than the depth of rice. When that is the case, rice near the air exhaust will remain at its initial temperature for several hours after rice in other parts of the bin is cooled to near outdoor air temperature.

Cooling rates were obtained in several bins of rice by making continuous records of temperatures at 1-foot intervals in a vertical plane within the rice. Rice temperatures were recorded with a potentiometer. Airflow rates were obtained by using calibrated nozzles on the fans. The time required to cool a bin of undried rice from well over 100° F. to outdoor air temperature was much less than the time computed using a heat balance equation. Heat given up by the rice for evaporating moisture accounts for the faster cooling time.

Outdoor temperatures vary during cooling periods. For this reason, it was arbitrarily assumed that cooling was complete when all rice within the bin was cooled to, or below, the maximum outside air temperature during the cooling period. On this basis, a bin of rice initially at 114° F., aerated at 1 cfm per barrel, was cooled to 84° F. in 25 hours. This time appeared to be in agreement with cooling times in other bins of rice when the initial rice temperature ranged from 110° F. to 120° F. Rice at lower temperatures cooled slower. For instance, a bin of rice initially at 74° F. was cooled to 50° F. in 34 hours when aerated at 1 cfm per barrel. Curves based on case studies made at 1 cfm per barrel are plotted in figure 5. In plotting the curves at the various airflow rates, it was assumed that the cooling time in hours is inversely proportional to the airflow rate in cfm per barrel. These curves can be interpolated for initial temperatures between 74° and 114° F., and cooling times may be estimated for a wide range of airflow and rice temperature conditions.

AERATION DURING TEMPERING PERIODS AT A COMMERCIAL RICE DRYER

The drying procedure at a commercial rice dryer in Texas was studied, and data are presented here to amplify the results obtained at the experimental rice dryer on the use of aeration during tempering periods. The management of the commercial dryer had used aeration for cooling rice between dryer passes for all rice dried during 4 years.

Four dryer units were used. These were identical, and sized so that 100 barrels of rice were needed to fill each. During the continuous flow operations, the rate of flow was 6.67 barrels per minute, allowing approximately 15 minutes for the rice to be exposed to heat during each pass. The plan of

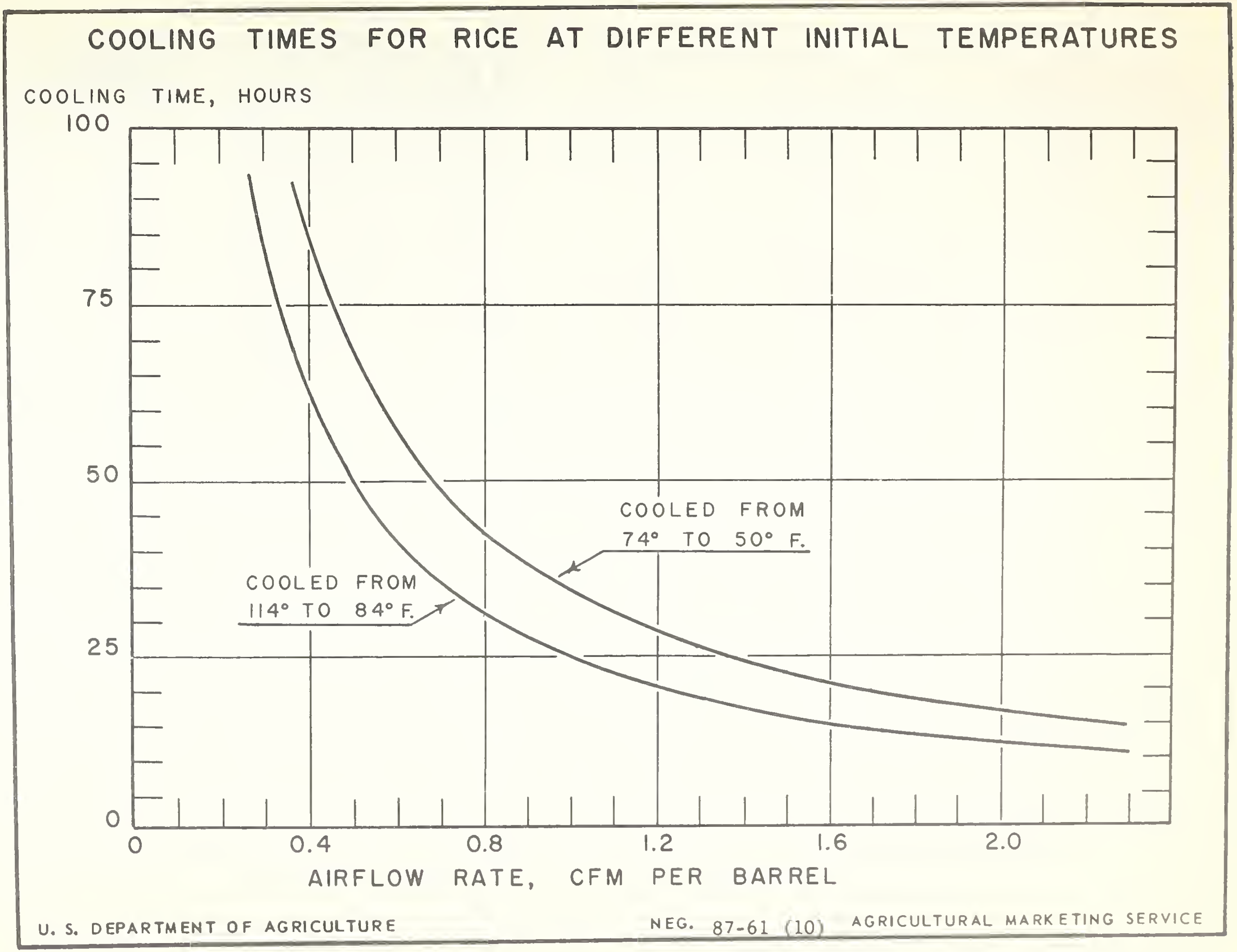

Figure 5.--More time was required to cool rice from 74° to 50° F. than from 114° to 84° F.

operation was to use one dryer unit for the first pass, the next unit for the second pass, a third unit for the third pass, and the fourth unit for the fourth and additional passes for each lot being dried. Sixty bins, each of 500-barrel capacity, were used for holding rice as it was being dried. These bins were arranged in 4 rows with 15 bins in a row. The first row of bins was used as receiving bins for green rice. Following the first dryer pass, the rice was stored in one of the bins in the second row. It was cooled in this bin and then moved through dryer unit 2. After the second dryer pass, the rice was stored in one of the bins in the third row. Again it was cooled, and then conveyed to dryer unit 3.

Following the third dryer pass, the moisture content was determined, and if the rice was dry enough to meet market requirements it was moved directly to storage and cooled by aeration. (Most of the more common long-grain varieties at moistures up to about 22 percent required only three passes through the dryer, but medium-grain varieties usually required 4 or 5 passes.) If the rice needed additional drying, it was stored in one of the bins in the fourth row, cooled, and then moved through dryer unit 4. Following the fourth pass, dry rice was moved to other bins for long-term storage or until it was sold.

Rice not dry enough following the fourth pass was returned to a bin in the fourth row and passed through dryer unit 4 again.

Two multiple aeration systems were used, with 30 bins included in each system. Gate valves were installed so that each of the bins could be disconnected from the aeration system. Airflow rates varied with the number of bins being aerated, but with all bins filled and connected to the system, the average airflow rate exceeded 1 cfm per barrel.

The moisture content and temperature of the rice entering and leaving the dryers, as well as the length of time that rice was in aerated storage following each drying pass, are listed in table 5 for three or more passes for each of the six lots of rice, each approximately 500 barrels. Samples were taken at 15-minute intervals as rice entered the dryer and at the same intervals as it left the dryer. Moisture content and temperature determinations were made for each sample. The data in table 5 are averages for five samples of rice entering the dryer and for five leaving it. The aeration periods between passes varied from 12 to 26 hours. The policy of the dryer operator was to temper rice between passes for at least 12 hours, and for longer periods when necessary. It appears from the data in table 5 that 12 hours of aeration were adequate for cooling the rice with the aeration rates used.

The relative amounts of moisture removed in the dryer and during the aeration periods between passes are shown in figure 6. Also shown are the percents of the total drying occurring during aeration periods, which varied from a low of 31 percent to a high of 54 percent for the six lots. These amounts do not include moisture removed while aerating the rice before moving it through the dryer or while cooling the rice after the last pass through the dryer. This information was not obtainable because lots of the same variety were mixed when moved to larger bins for long-term storage.

Table 5.--Moisture content and temperature for samples of rice entering and leaving dryers and time in aerated storage preceding dryer passes

	Dryer passes			
	No. 1	No. 2	No. 3	No. 4
NATO - lot 16				
Moisture content 1/, entering dryer, percent	20.3	18.9	17.7	15.5
Moisture content 1/, leaving dryer, percent	19.5	18.1	16.5	14.5
Temperature, entering dryer, °F.	83	84	88	88
Temperature, leaving dryer, °F.	106	113	115	123
Aeration period before pass, hours	-	15	12	15
NATO - lot 21				
Moisture content, entering dryer, percent	22.4	21.3	20.0	18.0
Moisture content, leaving dryer, percent	22.3	20.8	18.8	16.8
Temperature, entering dryer, °F.	89	88	92	93
Temperature, leaving dryer, °F.	106	111	113	116
Aeration period before pass, hours	-	15	14	13
CENTURY PATNA - lot 32-1				
Moisture content, entering dryer, percent	21.5	17.2	14.6	
Moisture content, leaving dryer, percent	19.4	15.8	12.6	
Temperature, entering dryer, °F.	88	82	78	
Temperature, leaving dryer, °F.	111	113	122	
Aeration period before pass, hours	-	18	23	
CENTURY PATNA - lot 32-2				
Moisture content, entering dryer, percent	19.6	15.9	13.4	
Moisture content, leaving dryer, percent	17.6	14.0	12.2	
Temperature, entering dryer, °F.	95	77	78	
Temperature, leaving dryer, °F.	111	115	120	
Aeration period before pass, hours	-	24	24	
BLUEBONNET - lot 33-1				
Moisture content, entering dryer, percent	21.0	17.5	15.0	12.4
Moisture content, leaving dryer, percent	20.4	15.7	13.8	11.7
Temperature, entering dryer, °F.	87	79	77	86
Temperature, leaving dryer, °F.	106	110	111	111
Aeration period before pass, hours	-	17.5	24	22
BLUEBONNET - lot 33-2				
Moisture content, entering dryer, percent	20.3	16.8	13.8	12.1
Moisture content, leaving dryer, percent	19.1	15.4	13.0	11.3
Temperature, entering dryer, °F.	95	78	77	85
Temperature, leaving dryer, °F.	104	112	114	114
Aeration period before pass, hours	-	17	20	26

1/ Moisture content, wet basis.

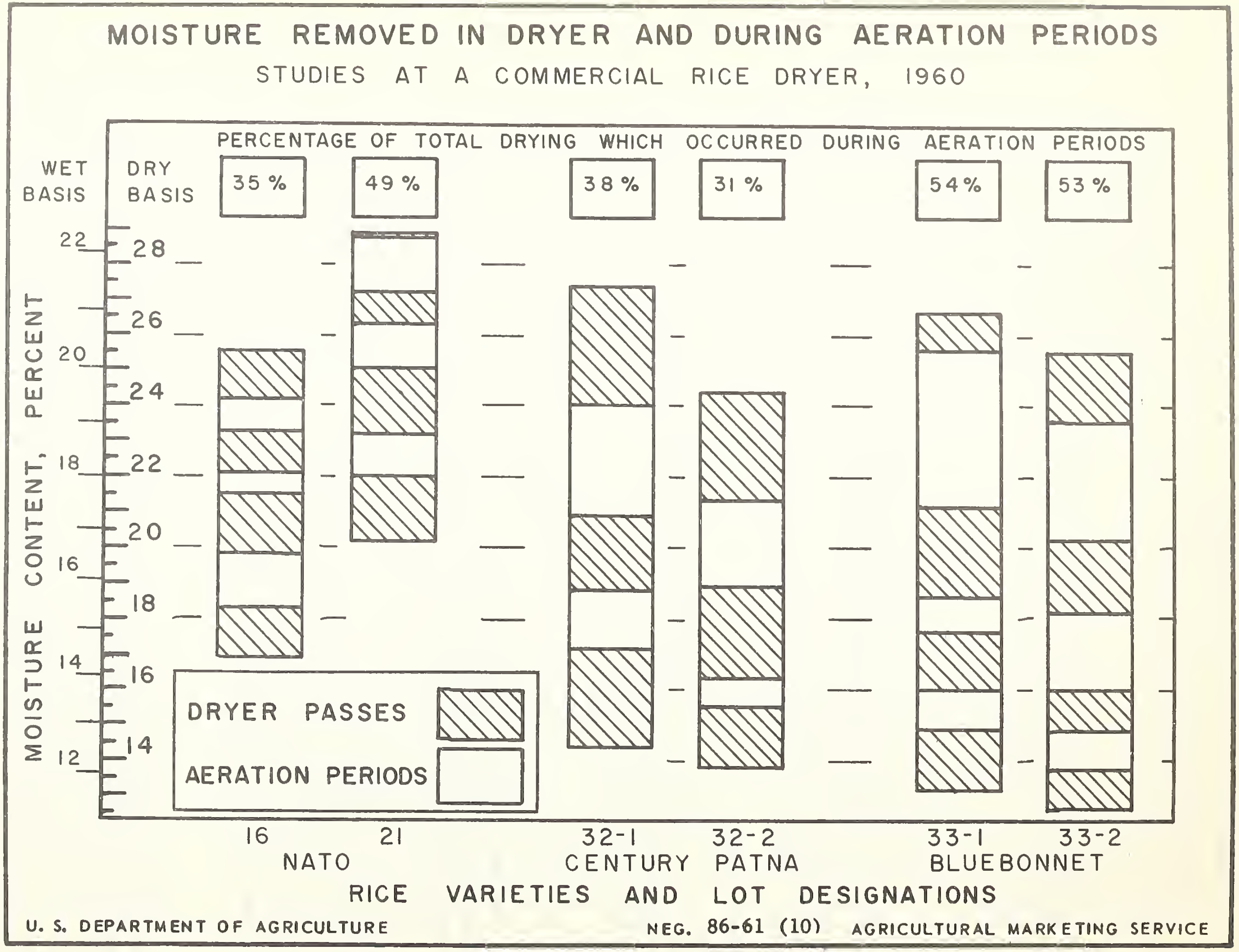

Figure 6.--Drying diagram for rice dried at a commercial dryer.

Table 6 compares the ownership and operating costs of two methods of drying 200,000 barrels (324,000 cwt.) of rice annually. With the first method, an average of five passes per lot of rice are used with no aeration between passes. Because the handling equipment is used for receiving, weighing, and shipping as well as for drying, the uses are prorated as shown in table 6.

With the improved method, an average of three passes per lot of rice are used, with aeration following each pass. Because of reduced usage with this improved procedure, the handling equipment is used only 60 to 67 percent of the total annual usage during drying operations, and ownership and operating costs charged to drying are prorated accordingly. Depreciation on all equipment is based on an increase in the expected life as shown.

Because the aeration system is used for holding undried rice until it can be dried, and for maintaining the quality of the dried rice during storage, the ownership and operating costs are prorated for the different uses, 30 percent being charged to drying.

Computed costs in table 6 show an annual saving of about $5,000 when the improved method is used in drying 200,000 barrels of rice annually. Because these savings are computed for a specific drying installation, they may not be representative of savings with an improved method at rice dryers where a different number of dryers, or pieces of handling equipment, are used.

Costs for both methods do not include the cost of receiving or shipping rice, or the cost of the structure housing the drying facility and other fixed costs. These costs are assumed to be the same for both methods. Also, no monetary value is included for the increased efficiency of receiving rice nor for the ability to receive rice as fast as it is harvested with the improved method. According to the dryer operators, these advantages are very valuable and may mean the difference in getting or not getting several thousand barrels of rice at a particular dryer. Many dryer operators feel that this advantage alone is worth as much as the saving in drying costs.

Table 6.--Ownership and operating costs of equipment used in drying 200,000 barrels (324,000 cwt) of rice with two specified operating methods

Equipment and operating method	Initial cost	Percentage of operation time for drying 1/	Expected life	Depreciation	Interest at 5½ percent	Insurance and taxes at 4 percent	Total	Power and maintenance	Labor	Annual cost: Total	Annual cost: Per barrel	Annual cost: Per cwt
	Dollars	Percent	Years	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Cents	Cents
Five passes through dryer with no aeration between passes:												
4 tunnel conveyors	12,800	71.4	15	466.48	251.33	365.57	1,083.38	112.41				
4 dryer units	68,000	100.0	10	6,800.00	1,870.00	2,720.00	11,390.00	4,095.52				
8 bucket elevators	29,376	80.0	20	1,175.04	646.27	940.03	2,761.34	445.25				
4 gallery conveyors	16,000	85.5	15	912.00	376.20	547.20	1,835.40	168.34				
							17,070.12	4,821.52	2,904	24,795.64	12.4	7.7
Three passes through dryer with aeration following each pass:												
4 tunnel conveyors	12,800	60.0	21	2/ 365.71	211.20	307.20	884.11	89.41				
4 dryer units	68,000	100.0	20	2/ 3,400.00	1,870.00	2,720.00	7,990.00	3,913.31				
8 bucket elevators	29,376	63.7	26	2/ 719.71	514.59	748.50	1,982.80	313.27				
4 gallery conveyors	16,000	66.7	19	2/ 561.68	293.48	426.88	1,282.04	125.64				
2 aeration systems	3,800		20	2/ 57.00	31.35	45.60	133.95	116.52				
							12,272.90	4,558.15	2,904	19,735.05	9.9	6.1

1/ Percentage of total annual operating time for drying.
2/ Based on useful life as shown.

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