Methods of Conditioning Shelled Corn

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DRYING methods which could be employed to condition the shelled corn stored at bin sites of the Commodity Credit Corporation were tested and demonstrated during the winter and spring, 1950, by engineers engaged in crop-drying investigations. The program, sponsored by the Production and Marketing Administration, U.S. Department of Agriculture, was carried out at the Chalmers bin site in White County, Indiana.

Moisture limits for storage of grain in farm-type bins for periods of one year or more have been established through research and experience. The median moisture limit* established for the storage of shelled corn without loss of grade is 13 per cent, wet basis, as reported in USDA Farmers' Bulletin No. 2009.

A large part of the 1948 corn crop produced in Ohio, Indiana, Illinois, and Missouri, and delivered to the Commodity Credit Corporation under the price support program in the fall of 1949, was at moisture levels above 13 per cent. This condition was a result of unusually high atmospheric humidity conditions in this area during the late summer and early fall while the corn was still stored in the ear in farm cribs.

The drying program described here was outlined to meet a possible emergency situation. The material presented in this paper describes the methods selected in view of the situation as it then existed, and does not necessarily imply that the methods employed are the best that are applicable where advance planning for conditioning can be accomplished. These tests demonstrated that drying can be successfully accomplished under such conditions by several methods. The best method or methods for this application will be determined through further research and experience.

At the Chalmers, Ind., bin site, CCC-owned corn was stored in structures of two general types. One was the farm-type metal or wood storage bin of from 2000-5000-bu capacity. The other type has been termed "flat storage" and has a storage capacity of about 25,000 bu. No provisions had been made to equip any of the bins for ventilation of the grain.

Consideration was given to a number of possible methods of conditioning grain. The criteria used for selection of methods to be investigated were (a) drying capacity, (b) drying cost, (c) handling cost, (d) equipment, and (e) control of the amount of moisture removed.

Drying Capacity. The capacity of a drying system is affected by both the amount of corn dried per hour and the number of hours of operation per day. There were several objections to 24-hr operation of driers that involved continual or intermittent handling of the grain, under the conditions of operation at the bin site. A drying system of only moderate capacity that could be operated 24 hr per day compared favorably with those of higher hourly capacity, but operated only during the daylight hours.

Drying and Handling Cost. It was readily apparent that the actual drying operation cost for reducing the moisture content 2 to 3 per cent was small as compared to the cost of moving the corn to a location where it could be dried. Any method which involved trucking to and from a drier required four handlings of the grain (loading and unloading), and the expense involved prompted selection of methods which held the amount of trucking to a minimum.

Equipment Investment. Consideration was given, first, to the original cost of the equipment, and, second, to its probable resale value. The government grain storage program is at present on a temporary basis. Moreover, an every year occurrence of wet grain was not expected in any one location. For these reasons, investment in permanent equipment involving a high initial cost was not considered desirable.

Control of Moisture Removal. It is necessary to control

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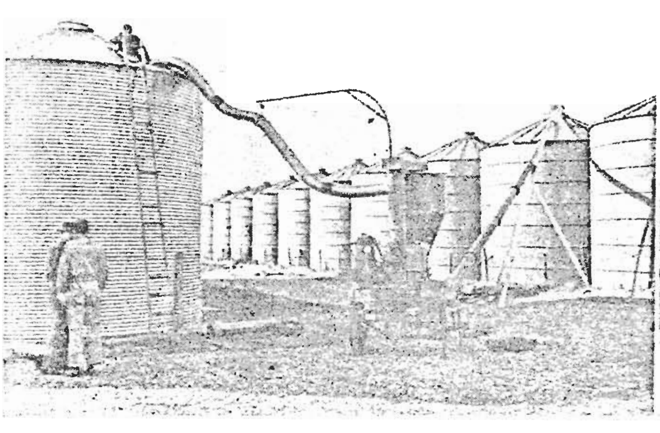
*Median moisture limit applies to storage under climatic conditions midway between the best and worst for the particular grain-producing area.



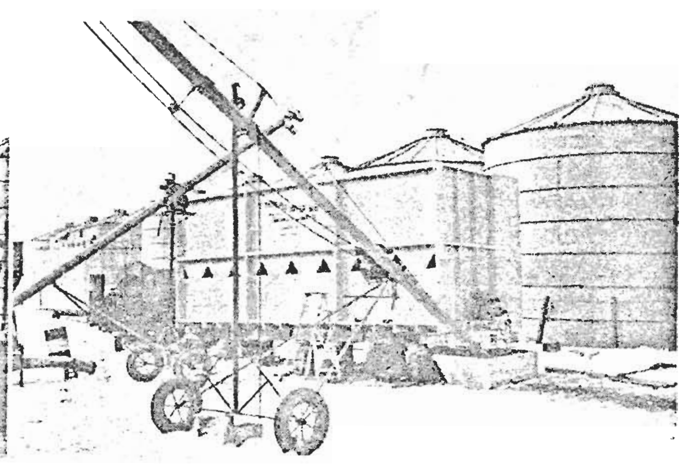


Fig. 1 *(Left)* The pneumatic grain-handling equipment used to transfer grain from the top of one bin to a nearby bin equipped for drying • Fig. 2 *(Right)* The 600-bu portable batch-type drying bin with the elevating equipment used for filling and emptying

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closely the final moisture content to which the grain is dried in order to provide safe moisture levels for storage without overdrying. The loss from overdrying becomes important in grain to be marketed. For example, for each per cent the moisture level is lowered beyond the safe storage limit, the loss in weight is nearly equal to 1 bu for every 100 bu dried.

DRYING METHODS AND EQUIPMENT

In view of the above, the application of portable farm-sized crop driers (forced-air heaters) to the drying of shelled corn in the CCC storages was undertaken. Driers of the type used are illustrated in Figs. 3, 5, and 6.

The methods selected for applying portable driers to the drying of shelled corn in each of the two types of storage buildings were as follows:

1 Farm-type bins (2200-3300 bu circular metal): (a) drying in storage bins equipped with perforated floors, and (b) drying in specially constructed movable batch-type drying bins.

2 Flat-type storages (25,000-bu quonset buildings), drying in the storage building equipped with duct system.

A perforated floor was used in the circular steel bins. The type of drier illustrated in Fig. 3 was attached to these bins. One of the methods used to transfer the corn from the nearby storage to an empty bin equipped with a perforated floor is shown in Fig. 1. Lots of shelled corn ranging from 600 to 2200 bu were dried at a time. The effectiveness of alternating periods of heated and natural air ventilation was tested.

Two types of portable batch-type drying bins were used with the portable driers. One type (Fig. 2) was developed and built by a commercial concern located in Indiana. The unit held approximately 600 bu. The drying air was distributed through the corn by a system of inverted troughs. A second type developed for these tests is illustrated in Fig. 3. Two columns of grain each 2 ft thick were separated about 3 ft to form a plenum chamber. The capacity per batch was 330 bu. A bin was provided on top to hold an additional 300 bu and was equipped with slides to drop the grain into the drying columns. In this way the only drying time lost was that required to empty the bin.

Both portable batch-type drying bins were equipped with augers for unloading. Portable auger elevators were used as shown in Fig. 2 to transfer the grain from the storage bin to the drying bin and then back to an adjacent empty storage bin. Thus with one empty bin at the end of a row of bins, drying could proceed, without trucking, by moving the portable bin along the bin row.

Drying of shelled corn in the flat storages was accomplished by the installation of duct systems. Two types of ducts were tried. One required an empty storage for installation, Fig. 4. The corn was then transferred directly from an adjacent building with auger elevators. A second type consisted of perforated tubes which were forced into the corn through the sides of the building. This method eliminated moving the corn.

A portable drier was attached at each end of the central duct system and Fig. 5 shows a drier attached at the front end. One half of the corn in the storage bin equipped with the perforated pipes was dried at a time. The drying fan was connected to the perforated pipes by a manifold-type canvas duct, Fig. 6.

RESULTS

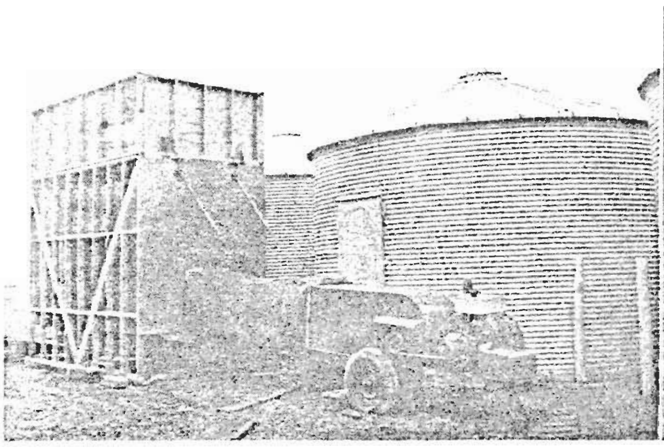
Considerable demonstration activity in connection with drying 70,000 bu of shelled corn was included along with the investigations reported herein. The time schedule required to meet the demonstration dates often precluded the collection of

TABLE 1 SUMMARY OF SERIES B DRYING TESTS IN 18-FT-DIAMETER STORAGE BINS EQUIPPED WITH PERFORATED FLOORS

1 Test No.	B1	B2	B3	B4	B5	B6
2 Date started	2-1-50	2-3-50	2-20-50	2-24-50	2-23-50	2-7-50
Date completed	2-20-50	2-20-50	2-21-50	2-25-50	3-15-50	2-7-50
3 Number bushels	1,700	1,600	1,000	1,200	2,000	600
4 Depth of grain, ft	8½	8	5	6	10	3
5 Initial moisture, % w.b.	14.8	14.4	14.5	15.0	14.4	15.3
6 Final moisture, avg % w.b.	13.7	12.9	13.0	13.5	13.2	13.5
Bottom ⅓	13.5	11.3	12.3	12.9	11.8	——
Middle ⅓	13.5	13.6	13.0	13.5	13.5	——
Top ⅓	14.2	13.8	13.7	14.0	14.3	——
Top surface	14.7	14.6	13.9	14.7	14.4	——
7 Water removed, lb.	1,000	1,550	970	1,150	1,600	700
8 Estimated air flow, cfm						
Total	6,250	7,000	8,700	9,000	5,700	11,000
Per bushel	3.7	4.4	8.7	7.5	2.8	18.4
9 Drier operation, hr						
With heat	61	16	10	10½	20	2
Without heat	12	17	10	9	68	1+
10 Fuel used, gal						
Heater—No. 1 fuel oil	48	50	40	42	81	18
Engine—gasoline	75	42	20	21	95	4+
11 Avg temperatures, deg F						
Atmosphere	36	37	36	8	25	34
Heated air*	54	94	96	74	100	140
Dew point	30	30	29	2	20	——
12 Drying cost, cents†						
Per bushel	1.3	1.0	1.0	0.9	1.6	0.6
Per pound water removed	2.2	1.0	1.0	0.9	2.0	0.5

†Cost for fuel oil (14c per gallon) and gasoline (21c per gallon) only.

*From 3 to 5 F temperature rise was obtained from the waste heat of the fan engine in all tests except B6.



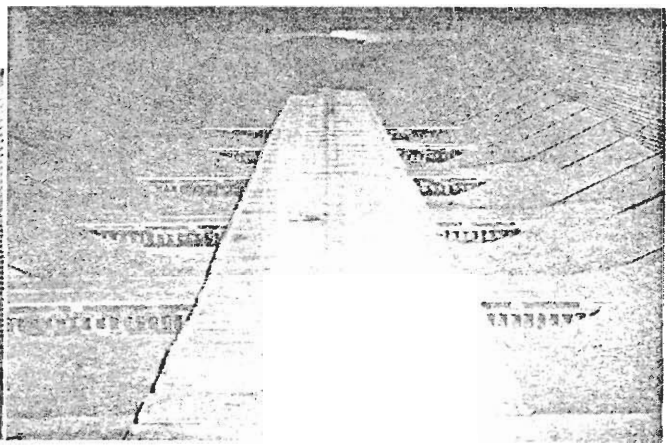


Fig. 3 *(Left)* The column-type batch-drying bin with portable drier in operation • Fig. 4 *(Right)* Duct system with concrete block laterals used in test F3

complete research data with the limited personnel available. This, together with the variable weather conditions encountered during the winter and early spring, accounts for some of the apparent discrepancies of the data from similar tests. However, the relatively large amount of corn dried by each of the three methods lends reliability to the comparisons between methods if not between individual tests.

Drying in Storage Bins with Perforated Floors. The general summary of the drying data collected in tests utilizing perforated floors in storage bins appears in Table 1. Different temperatures of the heated air together with various amounts of corn are represented in the tests. Also, alternate periods of ventilation with heated and natural air were used in an effort to reduce the moisture differential between the bottom and top of the grain. The schedule was as follows:

Test B1—continuous heated-air drying with a limited temperature rise

Test B2—4 hr heat, 4 hr natural air, alternately

Test B3—5 hr heat, 5 hr natural air, alternately

Test B4—10 hr heat, followed by 10 hr natural air

Test B5—10 hr heat, 10 hr natural air, alternately

Test B6—high heat input with limited depth of grain.

In test B1, an effort was made to operate a drier rated at 4 gal of oil per hour at a reduced rate of one gallon per hour. The burner did not operate satisfactorily at a fuel rate of one-fourth its rated capacity. The length of time required to reduce the moisture by only one per cent was considered excessive. With the reduced temperature rise, the cost for fuel for the engine-driven fan was greater than the oil used to heat the air.

The use of alternate periods of heated and natural-air ventilation provided improved operating conditions during the heating period since the driers were run at rated oil capacity while the burner was on. However, the moisture differential between the grain in the top and bottom of the bin was not reduced sufficiently by this method when more than 1200 bu were dried at one time.

When the amount of corn dried at one time was limited to about 1000 bu, satisfactory drying was accomplished. This amount could be dried in one day by supplying heat during daylight hours only, and cooling with natural-air ventilation at night. The drying capacity per 24-hr day per drier compared favorably with that of the drier used with the specially constructed drying bin which was operated only during daylight hours. However, drying the smaller batches required either extra handling of the grain or filling the bins to less than the full capacity.

Drying in Specially Constructed Portable Drying Bins. The portable drying bins overcome two of the difficulties encountered in connection with drying in storage bins. First, full capacity of the heating units could be utilized since the depth of corn through which the air passed was reduced. Secondly, the grain was mixed after drying as the grain was returned to the storage bin. This effectively eliminated the moisture differential problem encountered in the storage bin drying tests.

The results of fourteen tests in two types of portable drying bins are given in Table 2. Four of the tests were made in the larger bin and ten in the smaller one.

The drier used with the larger bin had an oil capacity of 8 to 10 gal per hour. This larger drier was also used with the smaller bin in tests P10 and 11. For the other tests in the smaller bin, a drier rated at 4 gal of oil per hour was used.

The moisture content of the corn was reduced about 1.4 per cent average for all tests. This was accomplished by supplying 3.1 gal of fuel for each 100 bu dried. Slightly less drying was accomplished than planned since the final average moisture was about 13.3 per cent, wet basis, in place of the desired 13 per cent. Most of the tests were conducted at an ambient temperature under 40 F and some during rainy and snowy weather. In general, more moisture was removed per gallon of fuel supplied when the outdoor temperature was higher.

The effect of using a higher temperature rise can be noted in the results of these tests. For example, in tests P10 and 11 a temperature rise of nearly 100 F was maintained in the drying air with the higher capacity drying unit. The moisture content of 330 bu of corn was lowered from 1.5 to 2.0 per cent with 11 gal of fuel. In tests P6, 7, 8, and 9, and using the drier at 3½ gal of fuel per hour to maintain a temperature rise of about 45 F, the moisture content was lowered from 1 to 1.5 per cent with the same amount of fuel.

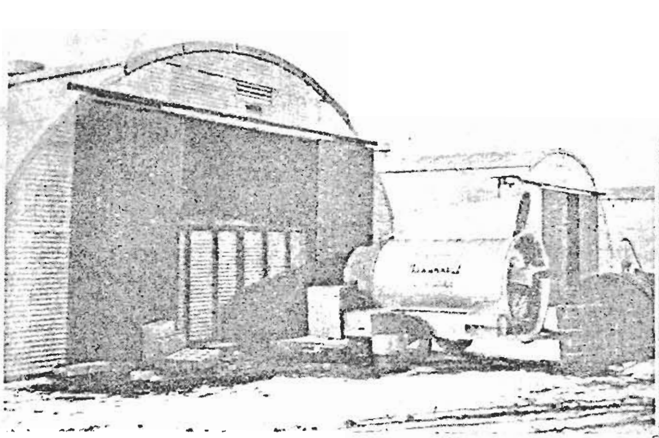
Drying in Flat Storage Buildings Equipped with Duct System. The corn in three quonset storage buildings of 25,000-bu capacity was dried. Either two portable driers were connected to each building and operated simultaneously, or one drier was used to dry one-half of the building and then later attached to the other half. Tests F1 and 2 in Table 3 were made on the corn in the same building. Different duct systems were used in each end. Also, the schedule of drier operation was different for each end. Test F4 includes the drying in only one-half of the building and the building was divided length-

TABLE 2 SUMMARY OF SERIES P DRYING TESTS IN PORTABLE DRYING BINS

1	Test no.	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
2	Date	2-3	2-6	2-23	2-24	2-7	2-9	2-10	2-15	2-16	2-17	2-22	2-24	4-13	4-19
3	Number bushels	600	600	600	600	330	330	330	330	330	330	330	330	330	330
4	Initial avg moisture, % w.b.	15.0	14.8	14.6	14.6	14.9	14.5	14.6	14.4	14.4	14.4	14.8	15.2	14.7	14.8
5	Final avg moisture, % w.b.	13.3	13.5	13.5	13.3	13.8	13.8	12.9	13.4	13.4	12.4	13.3	14.2	13.1	12.5
6	Water removed, lb	700	500	450	520	260	180	390	230	230	440	340	240	370	490
7	Estimated airflow, cfm														
	Total (in thousands)	11	11	11	11	10.5	10.5	10.5	10.5	10.5	10.2	10.0	10.5	10.5	10.5
	Per bushel	18.3	18.3	18.3	18.3	31.8	31.8	31.8	31.8	31.8	31.8	31.0	31.0	31.8	31.8
8	Drier operation, hr														
	With heat	2	2	2½	2	2	3	3	3	3	1½	1½	3	3¾	3¼
	Without heat	1½	1⅔	1	1	1½	1	1	1	1	1	1	2	1¾	1
9	Drier fuel rate, gph	8	8	8	10	3½	3½	3½	3½	3½	8	8	3	4	4
10	Fuel Used, gal														
	Heater, No. 1 fuel oil	16	16	20	20	7	11	11	11	11	11	11	9	14	12
	Engine, gasoline	4+	4+	5	4	7	8	8	8	8	4	4	8	7	5+
11	Avg temperature, deg F														
	Atmosphere	36	41	32	10	36	38	46	30	29	36	20	14	34	54
	Heated air*	128	130	120	133	82	80	90	74	73	125	115	58	85	108
12	Drying cost, cents†														
	Per bushel	0.5	0.5	0.6	0.6	0.7	0.9	0.9	0.9	0.9	0.7	0.7	0.9	1.0	0.8
	Per pound water removed	0.4	0.6	0.9	0.7	0.9	1.8	0.8	1.4	1.4	0.5	0.7	1.2	0.9	0.6

*Approximately 3 F temperature rise was obtained from the waste heat of the fan engine in tests P5, 6, 7, 8, 9, 12, 13, and 14.

†Cost for fuel oil (14c per gal) and gasoline (21c per gal) only.



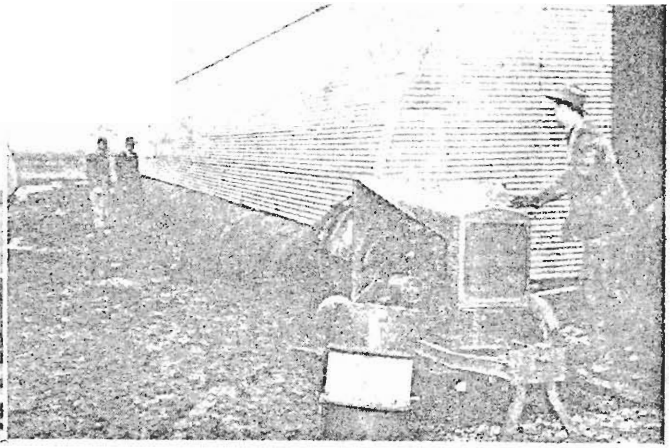


Fig. 5 *(Left)* The portable drier as used in test F1 • Fig 6 *(Right)* The engine-driven fan in operation in test F4

wise instead of across the short dimension. The drier used in tests F1, 2, and 3 was of the heat exchanger type and had a maximum fuel rate of 6 gal of oil per hour. In test F4, an engine-driven 36-in propeller fan was used. The engine was shrouded in such a way that the waste engine heat was drawn into the drying air stream.

The schedule of drier operation in each of the tests was as follows:

Test F1. Twenty-four hours with heat followed by an equal period of ventilation with natural air

Test F2. Continuous operation with heat at a low-temperature rise followed by a cooling period with natural air

TABLE 3 SUMMARY OF SERIES F DRYING TESTS IN FLAT TYPE STORAGE BUILDINGS EQUIPPED WITH DUCT SYSTEMS

1	Test No.	F1	F2	F3	F4
2	Date started	2-15-50	2-16-50	5-1-50	5-1-50
	Date completed	3-11-50	3-14-50	5-6-50	5-11-50
3	Number bushels*	11,000	11,000	22,000	12,000
4	Type of duct systems†	A	B	C	D
5	Initial moisture, % w.b.	14.7	14.4	14.7	14.3
6	Final avg moisture, % w.b.	13.0	13.0	13.2	13.2
7	Water removed, lb	12,000	10,000	21,000	9,000
8	Estimated airflow, cfm			(two driers)	
	Total	12,000	12,000	25,000	9,200
	Per bushel	1.1	1.1	1.2	0.8
9	Drier operation, hr				Engine
	With heat	164	235	60	Heat Only
	Without heat	162	67	43	178
10	Fuel used, gal‡				
	Heater, No. 1 fuel oil	654	586	600	——
	Engine, gasoline	336	298	232	305
11	Temperature, deg avg				
	Atmosphere	31	31	64	65
	Heated air	65	50	103	79
	Dew point	24	24	51	52
12	Drying cost—cents‡				
	Per bushel	1.5	1.3	0.6	0.5
	Per pound water removed	1.4	1.4	0.6	0.7

*Only one-half of the corn stored in a 32x96 ft quonset building was included in tests F1, 2, and 4.

†Dimensions and spacing of duct systems used: Type A. Central duct 2 ft high x 4 ft wide inside, length of building with laterals 6 ft long spaced 8 ft o.c.; area under inverted trough laterals 50 sq in. Type B. Central duct same as Type A, with same laterals except 9 ft long and spaced 4 ft o.c. Type C. Central duct same as Type A, with concrete block laterals 8 ft long and spaced 8 ft o.c.; area under laterals, 110 sq in. Type D. Perforated tubes 10 in in diameter spaced 8 ft o.c. and extending 12 ft in toward center from side of building.

‡Heat-exchanger-type drier used with calculated exchange efficiency of 75 per cent. For comparison with tests in Tables 1, and 2, the oil consumption and costs should be reduced by one-fourth. Costs are for fuel oil (14c per gallon) and gasoline (21c per gallon) only.

Test F3. Continuous operation with heat at an increased-temperature rise followed by cooling.

Test F4. Continuous operation with heat from fan engine only.

Moisture determinations made at the halfway point in the drying period in tests F1 and 2 indicated the moisture differential within the corn was not as great as expected. Also the results indicated that drying was not progressing as rapidly as desired. The rate of oil input to the driers was then increased from 3½ to 6 gal per hour in test F1, and 2 to 3½ gal in test F2.

The results of tests F1 and 2 were nearly identical, with the same power and fuel cost per pound of water removed. Apparently there is little difference whether the heat is supplied to the corn at a high rate, but intermittently, or at a lower continuous rate, providing the total heat supplied is the same.

Test F3 was conducted later in the year when the outdoor weather conditions were more nearly ideal for drying. The maximum temperature rise available from the driers was used. The drying cost per pound of water removed was less than one-half that of the two previous tests. The moisture content of 22,000 bu of corn was lowered 1.5 per cent in 4⅓ days. Thus the drying progressed at a rate of 5100 bu per day or a little over 100 bu per hr per drier. However, the final moisture differential within the bin was greater than was desired. This is discussed more fully below.

The drying fan using the waste heat from the gasoline engine was used successfully in test F4. However, it should be noted that the outdoor temperature was relatively high and that the engine supplied only one-half of the total temperature rise above the dew point temperature. This equipment appears practical for this type of application especially during periods of reasonably good drying weather.

Efficiencies of Drying Tests. No attempt was made to report individual test efficiencies. The data collected was insufficient to make comparable efficiency calculations on all tests. The efficiencies, figured as the ratio of the heat utilized in drying to the total sensible heat input, were low. This was expected since the initial moisture of the corn dried was too low to utilize fully the heat available for drying. The low outdoor temperatures prevailing during the time most of the tests were made also adversely affected the efficiencies.

PERFORMANCE OF DUCT SYSTEMS

It was not considered practical to install perforated floors in the flat-type storages where the floor area is large in comparison to the total volume. Duct systems are much less expensive and easier to install.

A first consideration in the design of duct systems is the size and spacing of the ducts for distributing the amount of drying air required. There are, however, additional considerations that must be taken into account in duct system design which are not apparent from tests and experience with false perforated floors. False floors usually have the same area as that of the cross section of grain through which the drying air passes. Under these conditions, from 7 to 10 per cent of free opening is sufficient for the passage of the volume of air ordinarily used in drying. In applying these data to duct systems the following must be considered if high pressure losses due to concentration of airflow at the duct outlets are to be avoided:

(a) Total area of duct surface

(b) Total area of air openings in duct surface

(c) The distribution of openings over the duct surface.

A full analysis of this problem cannot be included in this paper. However, observations on pressure and moisture gradients through the corn have been observed on the duct systems used in these tests.

Figs. 7 and 8 illustrate the difference in final moisture distribution when the temperature rise of the drying air is increased. Fig. 8 represents the final moisture observed in "flat-storage" test F3. The corn next to the duct was reduced to a moisture content below 9 per cent. A much higher percentage of the corn near the surface is at a higher moisture level in test F3 than that dried with a lower temperature in test F1 and which is illustrated in Fig. 7. Reasonable consistency was experienced between the pressure measurements taken during drying and the final moisture distribution within the corn.

Perforated metal tubes 10 in in diameter and 12 ft long were inserted through the side of the quonset storage every 8 ft in test F4. Considerable work was involved in developing methods to insert the tubes. Measurements taken indicate that a force of 3000 lb plus 550 lb per ft of length in contact with the corn was required to force the tubes into the corn 8 to 10 ft below the surface. This method has one chief advantage in that the duct system can be installed after the storage is filled. Several disadvantages were apparent in this installation such as damage to the building and heat loss from the long exposed canvas connection from the drier to the tubes. The test results indicated that more tubes or larger size tubes were needed for drying at more rapid rates with heated air.

SUMMARY

1 Grain stored with a moisture level from 1 to 3 per cent above the safe storage limit can be dried satisfactorily at CCC-storage sites with farm-size portable crop driers.

2 Drying in portable drying bins provided the most practical method of using present crop driers to condition the corn stored in the farm-type storage bins. Drying in the storage buildings with duct systems for distributing the drying air appeared to be the most practical method of using portable driers to condition the corn stored in the flat-type storages.

3 The capacity of the farm-type driers under the conditions of these tests was about 1000 bu per day.

4 Approximately 2 gal of oil were required to reduce the moisture content of 100 bu of corn by one per cent under the test conditions described. Slightly more oil was required during cold, damp weather and less during warm, dry weather.

5 A temperature rise above the dew point of 40 F or more increased the speed of drying, but a means of mixing the corn after drying was required when high temperatures were used with normal rates of airflow.

6 Farm drier equipment is not yet developed sufficiently to give adequate service under continuous operating conditions, according to experiences in these tests. For continuous operation, the driers should be powered with electricity. If gasoline engines are used, provisions should be made to reduce the vibration to the point that controls will operate properly and fatigue failure of parts will be eliminated.

7 The cost of handling the grain in connection with the drying operation often exceeded the cost of drying. Handling equipment of the light-weight auger type appeared to be the most desirable for loading trucks from the bins and for transferring corn from one bin to the other. Six-inch augers, light enough in weight for one man to move, were capable of handling up to 25 bu of corn per minute. Pneumatic grain-moving equipment of the suction-intake pressure-discharge type was found most suitable for special jobs such as removal of corn from the top of a bin.

8 The installation of ventilating equipment in the storage prior to filling would eliminate most of the handling expense involved in these tests. Attention should be given to developing equipment suitable for use in conditioning corn stored at greater depths in the farm sized bins. This would eliminate the handling cost in connection with the use of portable drying bins.

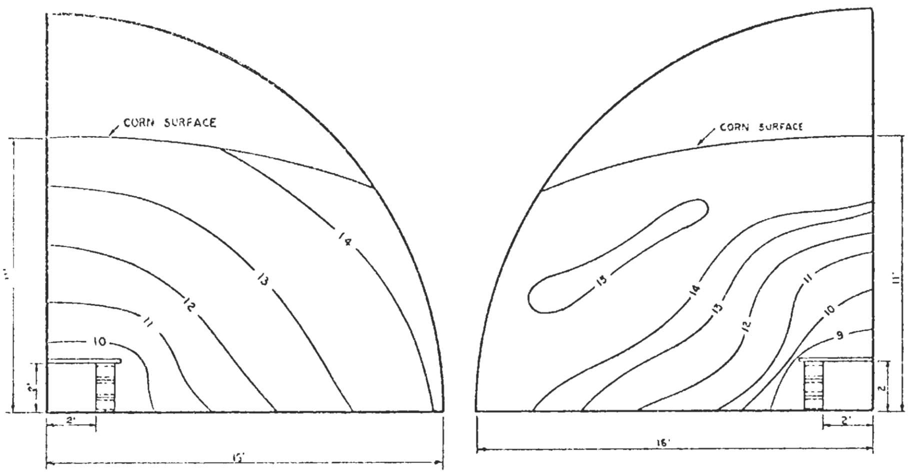


Fig. 7 *(Left)* Moisture contours (per cent, wet basis) over central air duct and between lateral ducts in test F1 • Fig. 8 *(Right)* Moisture contours (per cent, wet basis) over central air duct and between lateral ducts in test F3