

Corn Drying

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TABLE OF CONTENTS

	Page
Introduction	3
Consumption and Production of Corn in Oregon.....	3
Effect of Temperature and Humidity in Retarding Oregon Corn Production	3
Dehydration as Related to Harvesting Problems.....	4
Fundamentals of Artificial Drying.....	5
Preparation of the Shelled Corn for the Drier.....	5
Construction of a Shelled-corn Drier.....	5
Drive for the Corrugated Rolls.....	6
Experimental Results	10
Differential in Moisture Percentage Across the Column.....	10
Output of Shelled-corn Drier.....	14
Recirculation of Air in the Drier.....	14
Principles of Air Recirculation.....	15
Distribution and Flow of Air in the Drier.....	16
Quantity of Air	16
Air Ducts	16
Fans	17
Air Flow in the Shelled-corn Drier.....	20
Relative Humidity	20
Cost of Drying Shelled Corn.....	23
Fuel Cost	23
Power Cost	23
Interest and Depreciation.....	23
Summary of Drying Costs.....	24
Operating the Shelled-corn Drier.....	25
Grade Standards for Shelled Corn.....	25
Drying Ear Corn	26
Natural-draft Driers	26
Forced-draft Drier	27
Plans for a Forced-draft, Ear-corn Drier.....	29
Characteristics of the Ear-corn Drier.....	29
Capacity	29
Drying Time	29
Moisture Content	30
Temperature	30
Fan Capacity	30
Furnace Capacity	30

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By

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INTRODUCTION

OREGON'S corn production is inadequate to supply the demands for livestock and poultry feed in the state, which necessitates the importation of approximately 1,000 carloads of corn or its equivalent annually. Good yields of corn have been grown in Oregon for many years, but Willamette Valley farmers have experienced considerable difficulty in preventing damage to corn when stored through the winter in cribs. This is caused by the relatively high moisture content of the corn at harvest time and also by the mild, humid climatic conditions during the winter storage period. In the middle western corn growing sections the corn is ordinarily only slightly lower in moisture content when harvested than is western Oregon corn at harvest time, but the climate is much colder and drier; a condition much more favorable for the storage of corn in cribs.

Consumption and production of corn in Oregon. During the ten-year period from 1925 to 1935 Oregon's average yearly imports of corn amounted to 38,976 tons,* or 1,582,400 bushels. Oregon's production of corn for grain for the year 1929† was reported as 788,450 bushels, which was only 26.4 per cent of the corn consumed in Oregon as grain during that year.

The fact that during the period (1930-1933) only .7 of one per cent of the corn inspected in Portland was from Oregon indicates that practically all the corn produced in Oregon is consumed either on the farm or at nearby markets.‡

The location of areas producing corn in Oregon is shown in Figure 1. Ninety-three per cent of Oregon's corn is produced in the region west of the Cascade Mountains, where there is high relative humidity. An average of the mean temperatures from November to April, the normal months for storage of ear corn, is 43.7° Fahrenheit, and the average maximum temperature is above 60° Fahrenheit for each of the months during the winter storage period.

Effects of temperature and humidity in retarding Oregon corn production. The moisture content of corn produced in an ordinary season in western Oregon will range from 25 to 30 per cent at harvest time, while occasionally it may reach 35 per cent. While corn is stored in cribs successfully in the Middle West when it contains as much as 30 per cent moisture,§

*From receipts of grain at Portland, Oregon, as reported by the Portland Merchant Exchange. "Northwestern Miller," April 17, 1935.

†Data from 1930 Agricultural Census.

‡Compiled by A. W. Oliver, Department of Animal Husbandry, from data from Portland Grain Inspector.

§Indiana Experiment Station Report for 1931.

temperatures are relatively low during the major portion of the storage period. The low temperatures reduce the probability of spoilage and low humidities facilitate the drying out of the corn in storage. Corn that is grown in western Oregon and successfully stored in cribs cannot be sold as dry corn until the following summer without artificial drying.

Dehydration as related to harvesting problems. Dehydration of Oregon corn enables the producer to avoid all of the losses from adverse weather conditions. It makes possible the production of corn that will conform to specifications set up for U. S. Standards grades, allowing the Oregon producer to compete in the open market with imported grain. Since Oregon is on a deficiency basis for corn the Oregon wholesale price is usually based on the Midwest price plus freight, or on the delivered price of Argentine corn. Therefore, if Oregon producers can dry their corn for less than the freight cost of importing they will have a price advantage over the Midwestern corn grower. In June, 1936, the freight rate on corn was 52 cents per hundredweight from Lincoln, Nebraska, to Portland, Oregon, which amounts to \$10.40 per ton. Oregon producers have dried corn at a total cost of \$4.00 per ton.

Dehydration enables a producer, if he desires, to make sales of his crop immediately after harvest. Oregon producers have made deliveries of corn to the buyers two days after the corn had been standing in the field. This is a practical illustration of the control that dehydration equipment gives the corn producer.

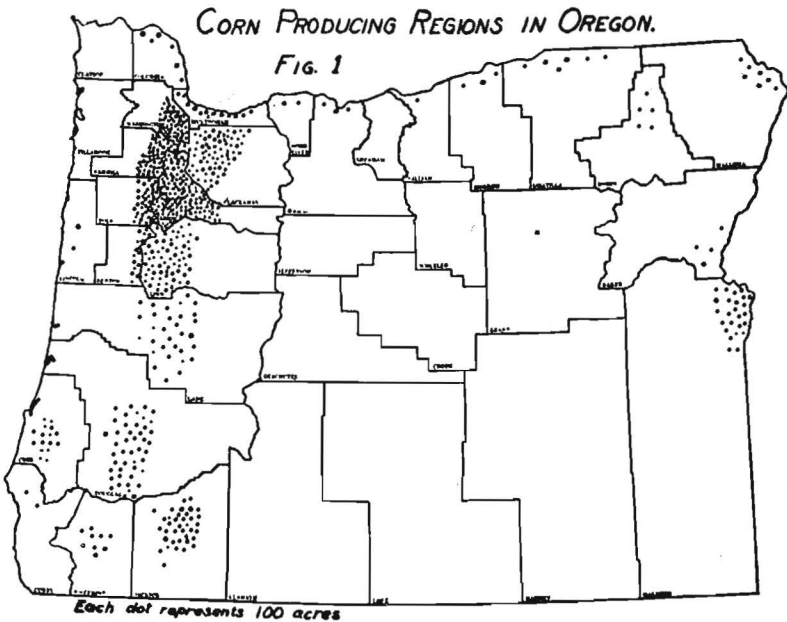


Figure 1. From "Relation of Moisture Content and Various Storage Methods to Grade and Quality of Mature Western Oregon Corn and a Comparison of Oregon and Midwestern corn," by Rex Warren—1933.

Fundamentals of artificial drying. Artificial drying consists of evaporating excess moisture from a material into the surrounding air, which must be replaced with dry air in order that the process may continue. Heat increases the rate of evaporation. In ordinary cases air is used both as a medium to carry the heat to the material to be dried and to carry away the moisture that is evaporated. The rate of drying is accelerated by increasing the temperature and the velocity of the air surrounding the commodity to be dried.



Figure 2. Elevating corn into an ear-corn drier. Cylinder type corn sheller shown at right.

Preparation of the shelled corn for the drier. Previous to 1932 only a limited amount of corn was dried in Oregon and all driers were ear-corn driers. When the experimental work on corn drying was started in 1932, the shelling of the corn as it came from the field was considered a difficult problem. An inexpensive, drum-type rotary sheller was used and found to give satisfactory results (see Figure 2). Corn with a moisture content as high as 35 per cent was shelled with very little crushing of kernels. It is recommended that corn shelled as it comes from the field be cleaned before drying, as this will increase the output of corn from the drier. The cleaning unit available with most corn shellers is adequate for this purpose. If the sheller-cleaner and drier are located on the same elevation, conveyor elevators are recommended to reduce labor in carrying corn from the sheller-cleaner to the drier. After the corn is dried it should be recleaned before it goes to the consumer.

Construction of a shelled-corn drier. The drier designed for the tests was a vertical-column continuous-process corn drier (see Figure 3). The two corn columns are 18 inches wide, 4 feet high, and constructed so that

the thickness could be varied from 2 to 6 inches for various performance tests. Each column is formed by two upright members with $\frac{1}{4}$ -inch-mesh hardware cloth on both sides. The hardware cloth was supported by using $\frac{1}{2}$ -inch by $\frac{3}{4}$ -inch iron stiffeners to keep the column at uniform thickness.

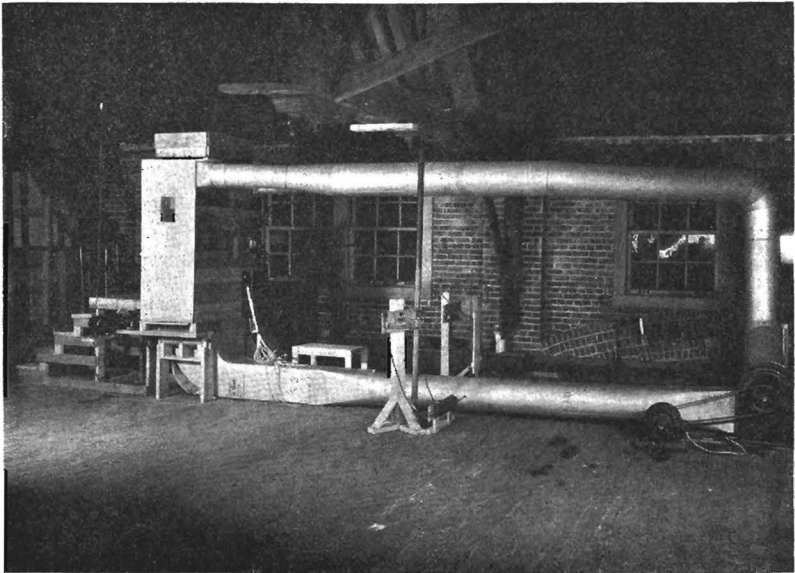


Figure 3. The experimental shelled-corn drier.

The space between the two columns is enclosed by boarding up between the upright members of the columns, and by ceiling over at the top of the column. This forms a dead-end air duct between the columns. When the heated air is forced into this vertical duct it escapes by passing through the corn column.

Undried corn is delivered into the hopper above the columns and flows down by gravity as the dry corn is removed from the bottom of the column by the mechanical draw-off unit. A draw-off unit (see Figure 4) was designed, with adjustable speed controls, for removing corn as it was dried (see Figures 5 and 6). This made a continuous-process drier from which it is possible to remove corn at any desired moisture content.

Drive for the corrugated rolls. Figure 8 shows the arrangement used to turn the draw-off rolls at one to ten revolutions per minute as required. A quarter horsepower motor drives the draw-off mechanism through two speed reduction units in series in order to get the speed desired on the face plate shown in Figure 7. The wing nut shown in Figure 7 makes it possible to change the length of the stroke to the drive rod. The ratchets shown in Figure 8 rotate the gear wheels and corrugated roll which are mounted on the same shaft.

A fractional horsepower electric motor with built-in reduction gears to produce about 30 r. p. m. would be more satisfactory than the belt driven speed reducers shown in Figure 4.

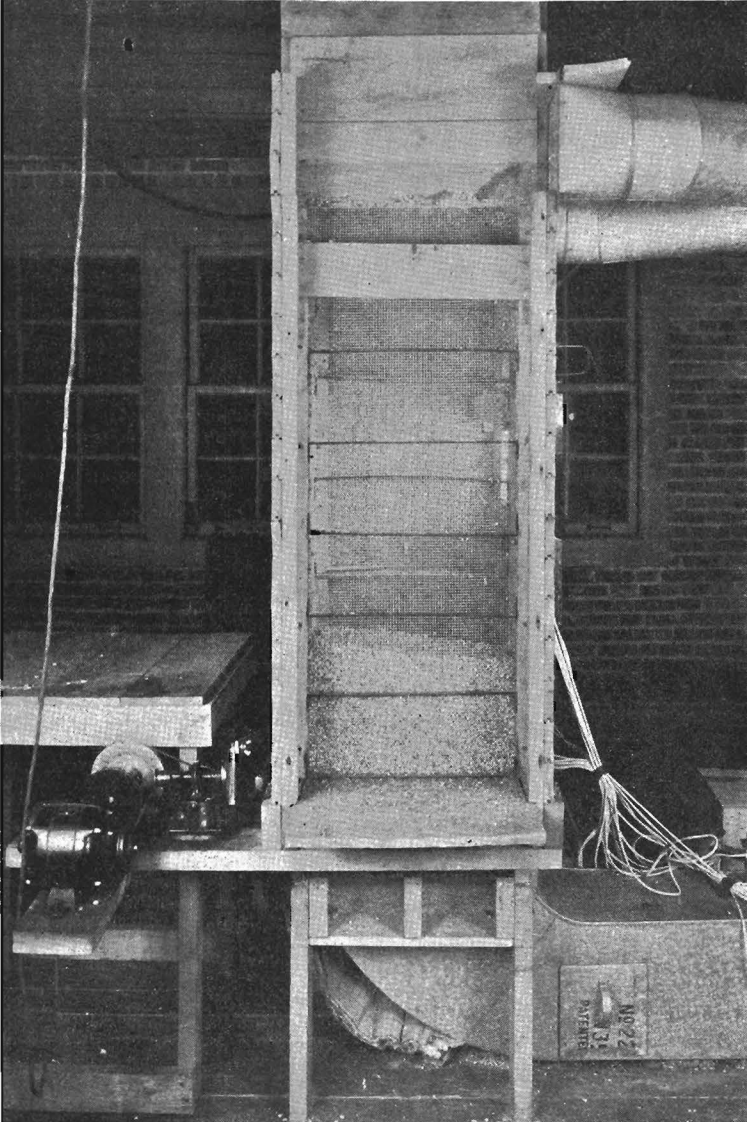


Figure 4. Shelled-corn drier with partly filled column.

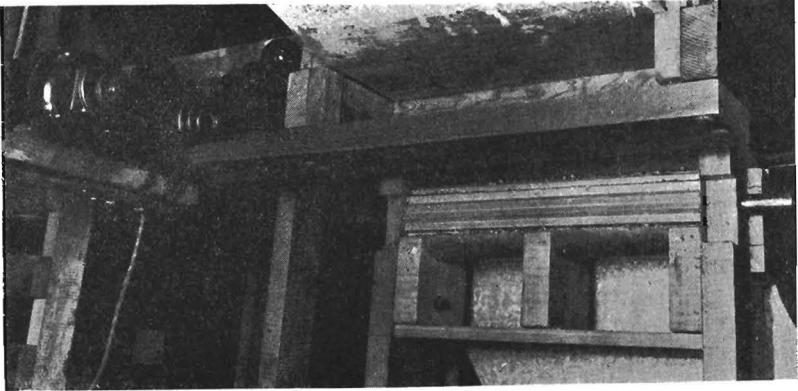


Figure 5. Draw-off mechanism for shelled-corn drier.

DRAW-OFF ROLL ASSEMBLY

Scale - HALF SIZE

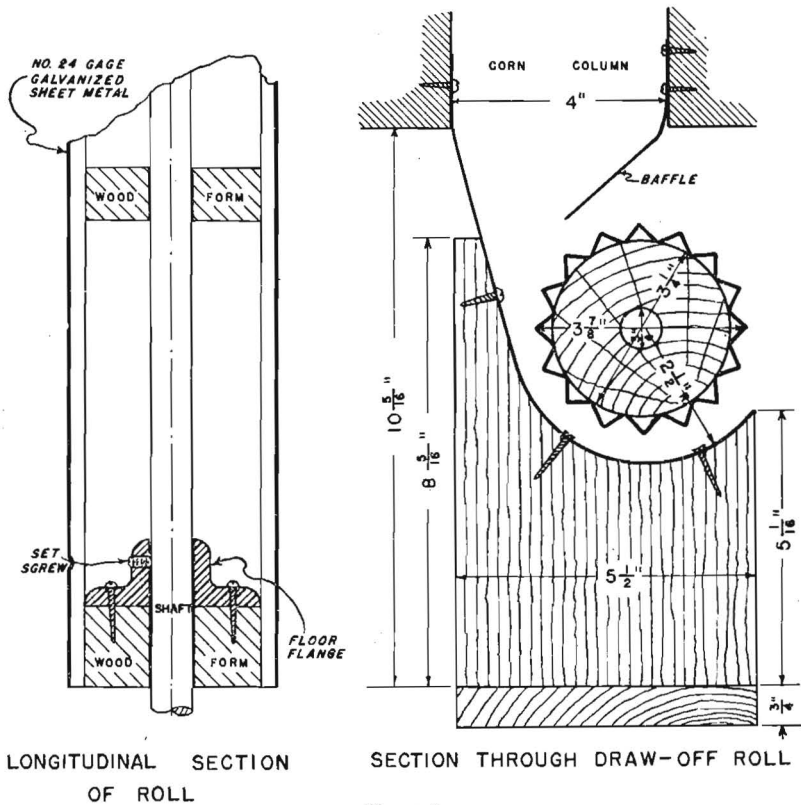


Figure 6.

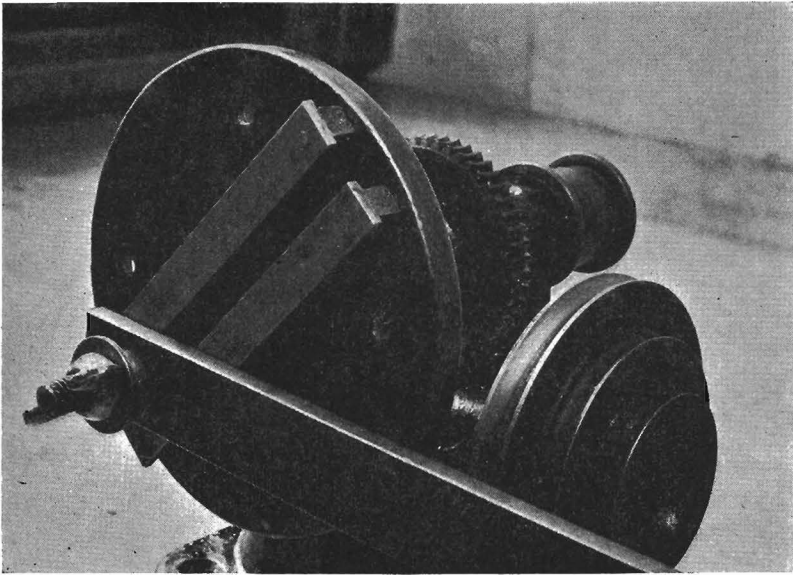


Figure 7. Face plate and thumbscrew used to adjust the length of stroke on the draw-off rolls.

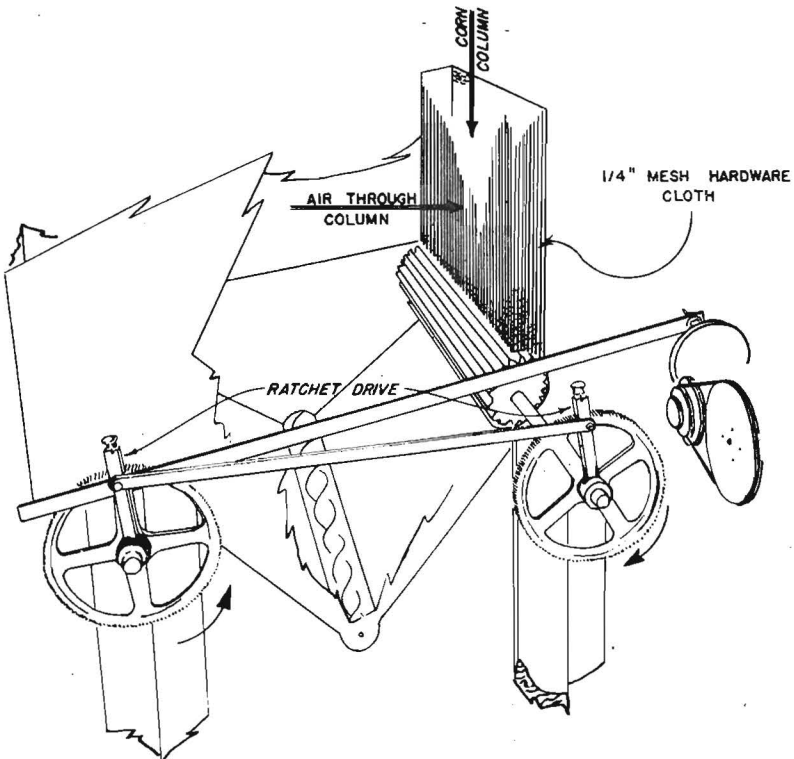


Figure 8. Sketch showing method of removing shelled corn from the drier and arrangement for speed adjustment.

EXPERIMENTAL RESULTS

Differential in moisture percentage across the column. The height and the width of the corn column do not affect the efficiency of the drier. The thickness of the column of corn, however, was found to be very important. A maximum width of 36 inches is recommended, as it would be difficult to support the hardware cloth sides of a wider column. The difference in moisture content of the corn from the extreme inside and extreme outside of the column was determined by making moisture determinations on samples of corn taken in grain sampling tubes. This difference in per cent of moisture across the column will be referred to in the following discussion as "moisture differential."

VARIATION IN MOISTURE PERCENTAGE OF CORN FROM THE INSIDE AND OUTSIDE OF COLUMN

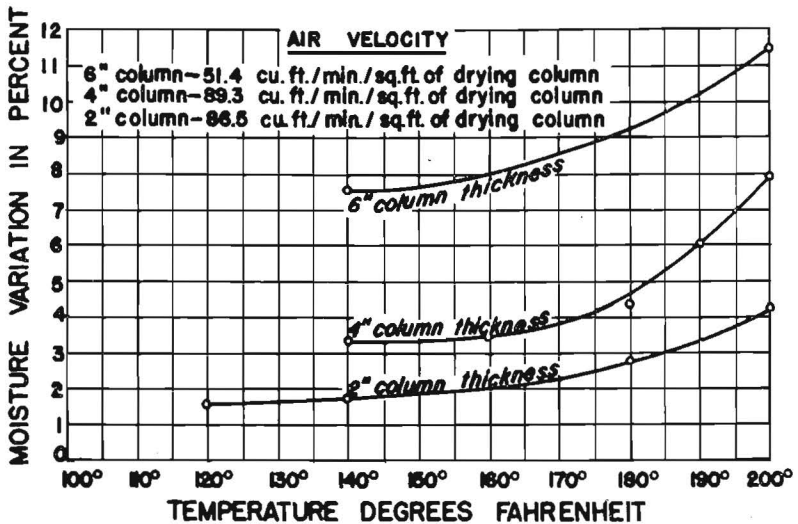


Figure 9.

The heated air is cooled as it passes through the column of corn, giving up heat to the corn and absorbing the moisture. For that reason the corn that moves down the inside of the column is exposed to a higher temperature and lower relative humidity than the corn that moves down the outside of the column. This condition tends to dry the inside of the corn column faster than the outside. This results in a moisture differential across the column of corn. By overdrying the corn on the inside of a column the moisture content of a composite sample from the entire output of the drier could be made to conform to any desired per cent of moisture; but a large moisture differential across the column is undesirable.

An analysis of data from thirty-six tests with the continuous-process, shelled-corn drier indicates that three variables materially affect the moisture differential across the column. These variables are: (1) The thickness of the corn column; (2) the temperature of the air entering the drier; and (3) the air velocity through the corn column.

Table 1. INCREASE IN MOISTURE DIFFERENTIAL ACROSS A 4-INCH CORN COLUMN WITH INCREASED DRYING TEMPERATURES, AND AN AIR FLOW OF APPROXIMATELY 90 CUBIC FEET PER SQUARE FOOT OF CORN COLUMN

Temperature ° F.	Differential across the column	Temperature difference of air entering and leaving column in ° F.
140°	3.3	21
160°	3.5	32
180°	4.7	46
200°	8.0	56

The thickness of the drier's corn column: When drying at 180°F., the "moisture differential" was 2.8, 4.7, and 9.2 per cent when using 2-, 4- and 6-inch column thickness (see Figure 9). With a given air temperature and velocity the smallest moisture differential was obtained when using a two-inch corn column. This column thickness was impractical as the corn would not flow evenly through the column; but it would flow through the 4-inch column satisfactorily. The moisture differential across the column when operating at 160° Fahrenheit and an air flow of 90 cubic feet per minute per square foot of corn column, was found to be only 3.5 per cent, using the 4-inch column. This column thickness was found satisfactory. While no test data are available, a shelled-corn drier with a 3½-inch column thickness has been built and operated on a nearby farm and has been found satisfactory.

The temperature of the air entering the drier: The effect of temperature variations on the moisture differential across the column is shown in Figure 9. As the drying temperature is increased the moisture differential across the column is increased also.

The increase in the moisture differential across the column with increasing drying temperature as shown in Table 1 is accounted for by the greater temperature drop of the air as it passes through the column of corn (see third column, Table 1), thus exposing the corn on two sides of the column to greater variations in temperature.

Table 2. DATA SHOWING VARIOUS PERFORMANCE FACTORS WHICH ARE INFLUENCED BY VARYING THE TEMPERATURE OF THE AIR OF THE DRIER WITH 4-INCH COLUMN.

Temperature of the drier air in ° F.	Flow of air through 1 sq. ft. of corn column cu. ft. per min.	Output of corn at 12 per cent moisture from undried corn at 30 per cent lbs. per hour	Movement of corn in the column in inches per hr.	Minutes corn was exposed to heat
TEMPERATURE	AIR VELOCITY	OUTPUT	SPEED	HEATING TIME
120	97.9	27.0	14.5	198
140	96.0	34.3	18.5	155
160	106.7	81.2	22.0	131
200	105.1	125.3	40.0	72

The air velocity through the corn column. The slower the air velocity through the column at any given drying temperature and column thickness, the greater will be the moisture differential across the column. The air movement in the drier might also be expressed as the velocity in feet per minute through an area equivalent to the corn column. The velocity past

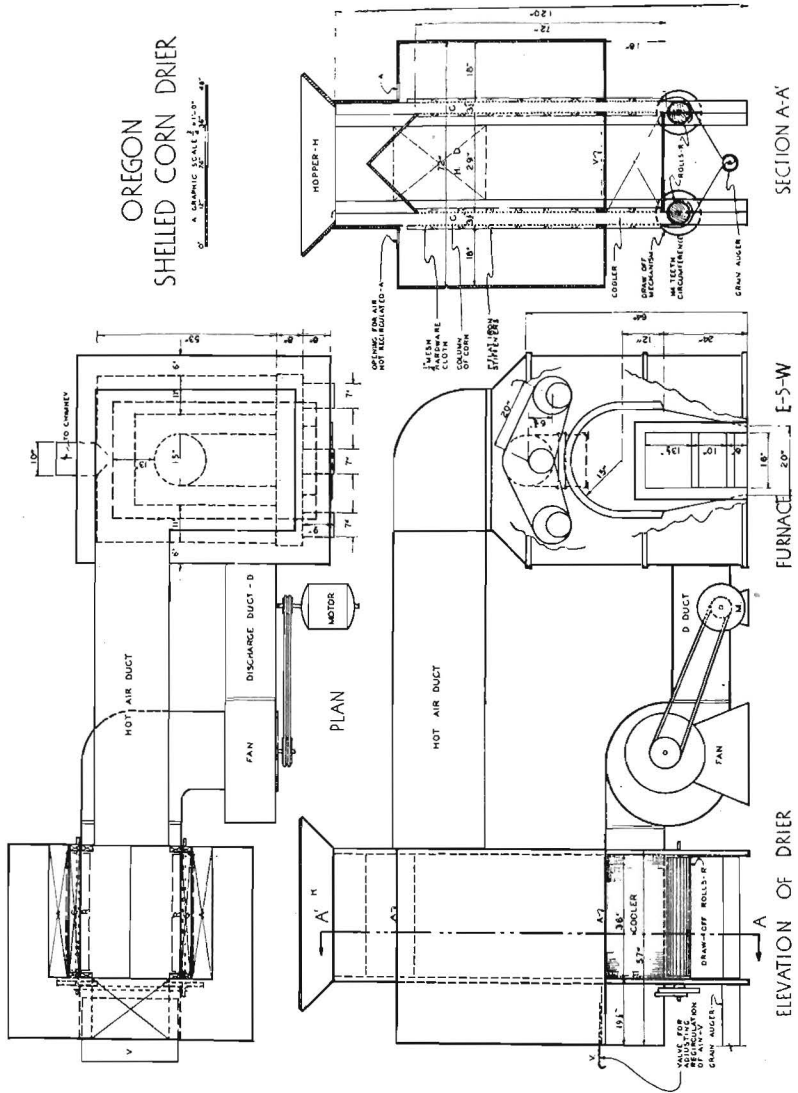


Figure 10.

each corn kernel is much greater than the velocity expressed on this basis. From the tests that were made, the open space between the corn kernels represents approximately 41.4 per cent of the total volume of the corn column. The velocity past the corn kernels of a full column would be approximately 2.4 times the velocity in an empty column, using the same quantity of air.

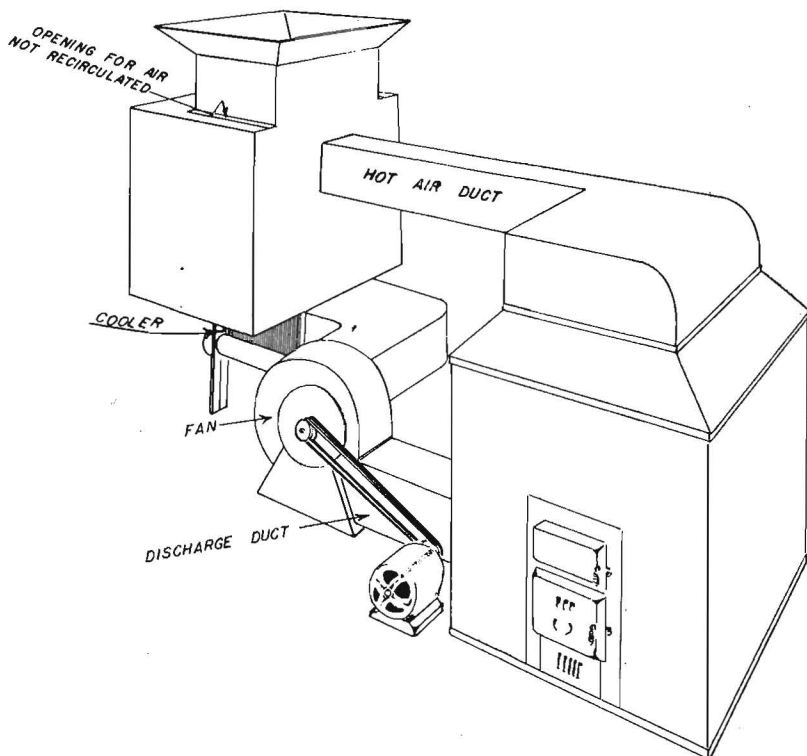


Figure 11. Suggested arrangement for connecting shelled-corn drier fan and furnace.

A comparison of two groups of tests made when using a 4-inch column of corn demonstrates the effect of air velocity. The average temperature of the series of tests was 170° Fahrenheit. An increase of the air velocity from 88.4 to 106.5 feet per minute per square foot of column area, which amounted to a 20 per cent increase, decreased the moisture differential across the column by .41 per cent, which was 12 per cent less than the previous moisture differential. A static pressure of .7 of an inch of water is required to produce an air flow of 90 cubic feet of air per minute through a square foot of corn column. The total static pressure which the fan must operate against will be approximately one inch of water, as a pressure of .2 to .3

of an inch of water will be required to force the air around the furnace and through the duct system.

Output of shelled-corn drier. The two most important factors affecting the quantity of corn which can be dried in a shelled-corn drier are first, the temperature of the drying air; and second, the velocity of the drying air in the column. The air temperature should be kept as high as practicable in order to get the maximum output from any given size of drier. A temperature of 170 to 180° Fahrenheit is recommended. The output per square foot of column area increases from 5.5 pounds per hour at 140° Fahrenheit to 9.0 pounds per hour at 180° Fahrenheit (see Figure 12). While a change in the operating temperature materially affects the output of the drier in pounds of corn per hour, it does not change the over-all efficiency of the drier unit. The amount of heat required per ton of corn dried is practically constant regardless of the drying temperatures when effectively utilizing recirculation.

Recirculation of air in the drier. Recirculating the air consists of directing the flow so that a portion of the air is returned to the furnace. Recirculation is feasible in this type of drier because the air that passes through the corn column once only is quite warm and has considerable drying capacity. In the operation of the experimental shelled-corn drier, from 60 to 80 per cent of the air was returned to the fan and heating plant.

EFFECT OF DRYING TEMPERATURE ON THE RATE OF OUTPUT OF DRY CORN

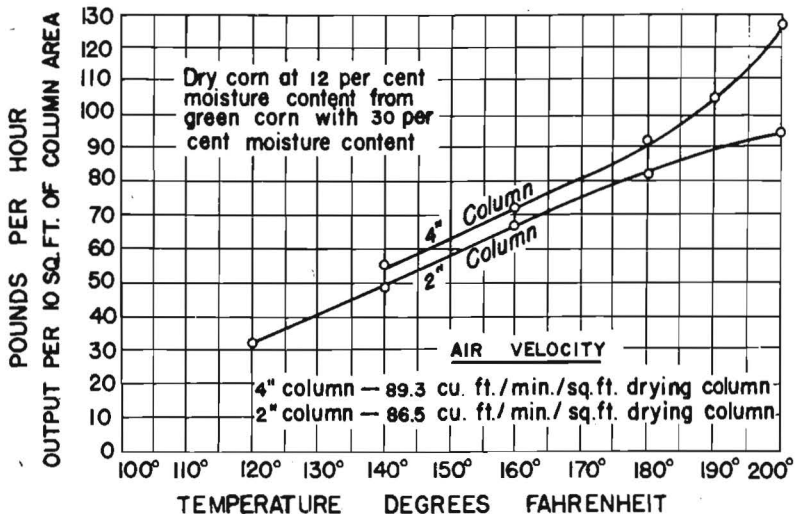


Figure 12.

The air is returned at relatively high temperature and requires considerably less heat from the furnace than fresh air. From 20 to 30 per cent of the air is replaced continuously with fresh air.

Principles of air recirculation. The purpose of air recirculation is to reduce the heat loss in the air as exhausted from the drier, and at the same time maintain a relatively high velocity through the corn column. To keep the moisture differential across the column of corn at 4 per cent or below

HEAT SAVED AT VARIOUS DRYING TEMPERATURES BY RECIRCULATION OF AIR

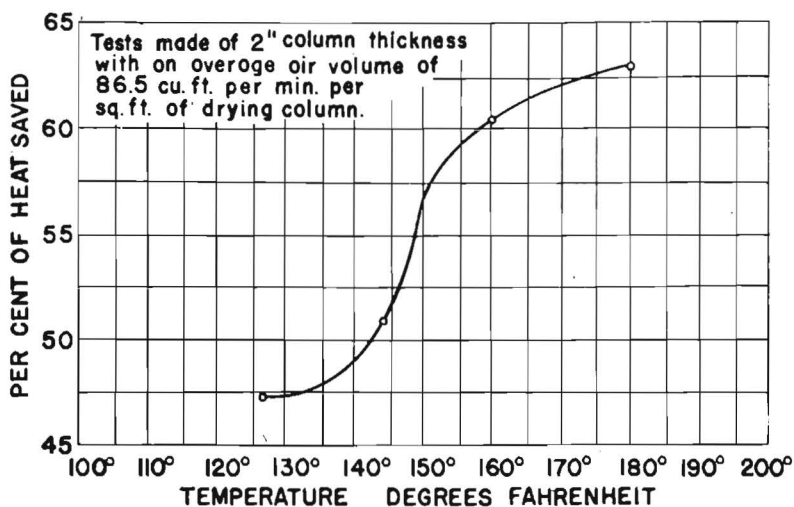


Figure 13.

requires that an air volume of approximately 90 cubic feet per minute be maintained through each square foot of corn column. At this velocity through the corn column the exhaust air retains considerable drying capacity and requires a relatively small amount of heat to bring it up to the operating temperature of the drier. A given size of heating plant could heat the air required for a recirculating corn drier of approximately twice the capacity of a drier without recirculation (see Figure 13). Figure 14 shows the amount of water vapor which air at 50 per cent relative humidity carries at various temperatures. Note that the curve shows that a given quantity of air at 157° Fahrenheit carries twice the weight of water vapor that is carried by air at 130° Fahrenheit. This demonstrates a particular advantage of using a temperature of 170° to 180° Fahrenheit on the hot side of the drier. Recirculation aids in removing the maximum amount of water from the corn with each cubic foot of air discharged from the drier, as the

relative humidity of the air leaving the drier can be kept as high as desired. A relative humidity of 70 per cent on the exhaust side of the drier is recommended.

Distribution and flow of air in the drier. Dehydraters must be constructed so that air can be effectively distributed to remove heat from the furnace and to utilize the heat in evaporating water from the material to be dried. In designing an effective air distributing system the following points should be given consideration:

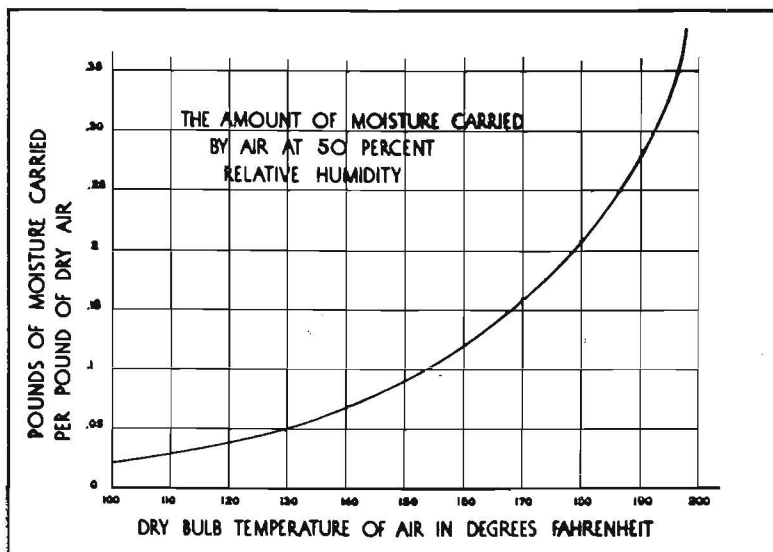


Figure 14.

1. The quantity and temperature of the air required.
2. Air ducts of proper size and shape in order to reduce friction to a minimum.
3. A fan having such characteristics that it will efficiently deliver the required quantity of air against the total pressure encountered.
4. A control valve for the air system.

Quantity of air. In operating shelled-corn driers it has been found desirable to use 100 cubic feet per minute per square foot of drier column area. Example—in a drier having two columns, each 3 x 6 feet the total column area is 36 square feet. To operate a drier of this size, 3,600 cubic feet of air per minute would be required.

Air ducts. Air ducts may be either cylindrical or rectangular depending on the convenience and cost of installation. Where rectangular ducts are used, the height and width should be as near equal as possible and in no case should their ratio exceed 1 to 10.

Unnecessary turns in air ducts should be avoided. When turns are necessary the radius of the center line of the duct should not be less than one and one-half times the duct diameter!* Smaller losses result if the radius to the center line of the duct is two diameters. There is very slight advantage, however, in making the radius of the curve greater than this.

Ducts should be of adequate size to maintain relatively low friction losses. It is suggested that air friction losses in the ducts and around the furnace not exceed .2 of an inch of water when a .7 of an inch of water is required to force air through the columns of corn in the drier.

Friction losses for air flowing in pipes of various sizes are given in Figure 15.

Example problem—use of air friction chart (Figure 15): Assume that a drying unit requires 4,000 cubic feet of air per minute, that fifty feet of piping will be required, and that it is advisable to keep the friction loss at .1 of an inch of water or less.

Question: Determine the size of pipe to use.

Explanation: Refer to the chart of Figure 15. At the bottom of the chart friction losses are given in inches of water per 100 feet of pipe. On the right side of the chart are given quantities of air in cubic feet per minute. One set of diagonal lines indicates the diameter of the pipe and the other indicates the velocity of the air. This problem requires that the allowable static pressure loss for fifty feet of pipe not exceed .1 of an inch, which is equivalent to a loss of .2 of an inch of water per 100 feet of pipe. Beginning at the point of .2 at the bottom of the chart follow the .2 friction loss line vertically to the point where it intersects a horizontal line opposite 4,000 cubic feet of air per minute. This point is approximately half way between the diagonal lines representing 20-inch pipe and 22-inch pipe. Therefore, a pipe 21 inches in diameter would be required.

If a rectangular duct is to be used it should have approximately 10 per cent greater cross section area than a round duct.

Fans. Two-blade propeller fans and multiblade windmill types are adaptable where operating against a low static pressure. Measurements have been made on a satisfactory multiblade fan installation which was operating against a total pressure head of .5 of an inch of water. Any fan should be purchased with a guarantee to deliver a definite amount of air against a specified pressure.

Drying shelled corn with the drier developed by the Oregon Experiment Station requires a fan which will deliver air efficiently against a total pressure of 1 inch of water. A pressure of .7 of an inch of water is required to force the air through the 4-inch column of corn and .2 to .3 of an inch of water may be required to overcome friction loss. A multivane fan was used with very satisfactory results and is recommended for the operation of shelled-corn driers.

The horsepower required for a fan depends upon the type of fan, the quantity of air it is necessary to move, and the static pressure against which the fan is working. In selecting a fan for a particular drier it is important that competent engineering assistance be obtained. A fan not

*American Society of Heating and Ventilating Engineers Guide—1937.

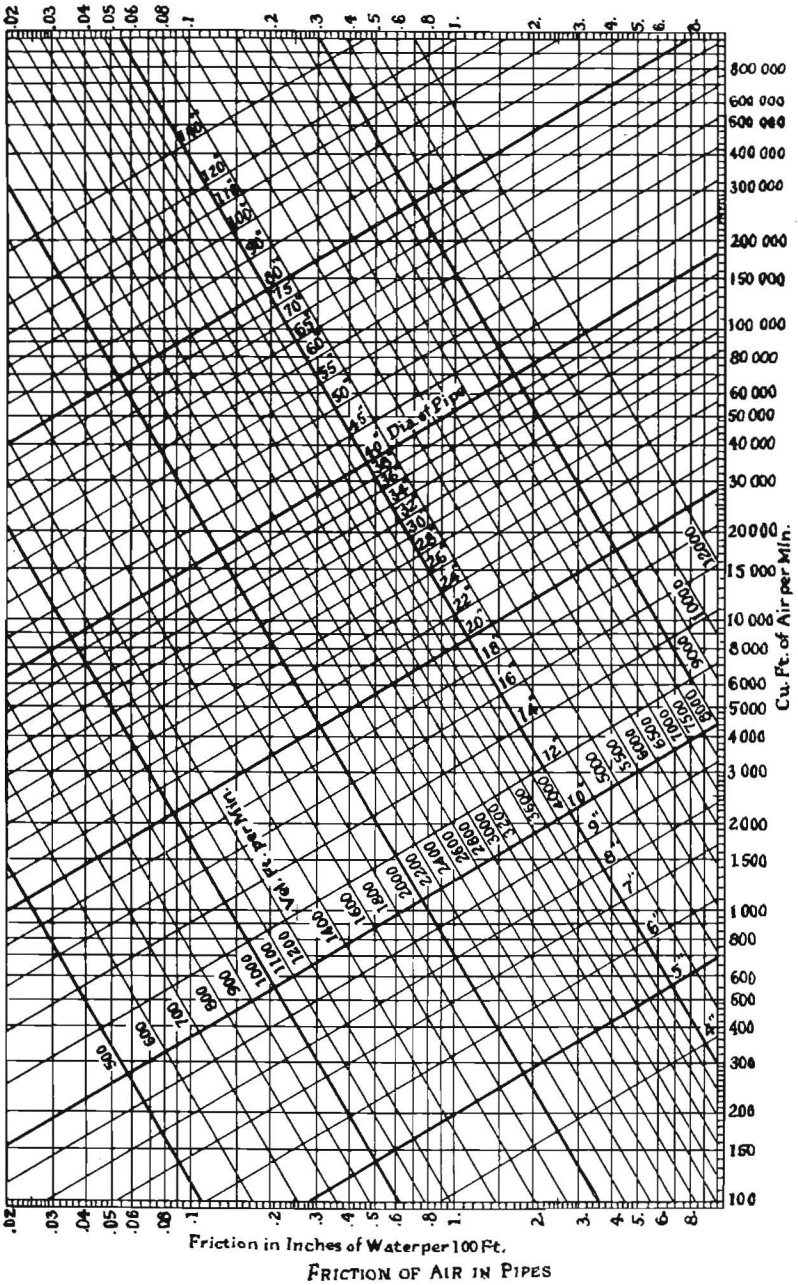


Figure 15. Reprinted with permission of the American Society of Heating and Ventilating Engineers—from page 366—Guide 1937.

Table 3. CAPACITIES AND STATIC PRESSURES OF SINGLE WIDTH LOAD LIMIT CONOIDAL TYPE FANS OPERATING AT 70° F. AND 29.92 INCHES BAROMETER—OUTLET VELOCITY 2,000 FEET PER MINUTE.*

Fan number	Diameter of blast wheel	Width of blast wheel	Capacity in cu. ft. per minute	¼" Static Pr.		½" Static Pr.		¾" Static Pr.		1" Static Pr.		1¼" Static Pr.	
				R.P.M.	H.P.	R.P.M.	H.P.	R.P.M.	H.P.	R.P.M.	H.P.	R.P.M.	H.P.
2	12"	5¾"	1,616	1,545	.242	1,665	.310	1,776	.375	1,881	.444	1,980	.514
2½	15"	7½"	2,526	1,236	.378	1,332	.484	1,420	.585	1,504	.693	1,583	.802
3	18"	8¾"	3,638	1,030	.544	1,110	.697	1,184	.843	1,254	.998	1,320	1.16
3½	21"	10"	4,950	883	.741	951	.949	1,015	1.15	1,075	1.36	1,131	1.57
4	24"	11¾"	6,469	773	.968	833	1.24	888	1.50	940	1.77	989	2.05
4½	27"	12¾"	8,184	687	1.22	739	1.57	788	1.90	836	2.25	879	2.60
5	30"	13¾"	10,100	618	1.51	666	1.94	710	2.34	752	2.77	792	3.21
6	36"	16¾"	14,550	515	2.18	555	2.79	592	3.37	627	3.99	660	4.62
7	42"	19¾"	19,804	441	2.96	476	3.80	507	4.59	537	5.43	565	6.29
8	48"	21¾"	25,867	386	3.87	416	4.96	444	5.99	470	7.10	495	8.22
9	54"	24¾"	32,738	343	4.90	370	6.28	395	7.59	418	8.98	440	10.40
10	60"	27¾"	40,417	309	6.05	333	7.75	355	9.35	376	11.10	396	12.80
11	66"	30"	48,904	281	7.32	303	9.37	323	11.30	342	13.40	360	15.50

*From Bulletin F-50 (6-1-34) Buffalo Forge Company.

suited to the particular conditions may require much more power than that needed by a properly selected unit. An examination of the following table will show that a fan will deliver more air per horsepower hour if operated with a reasonable outlet velocity. Because of this fact operating costs may be reduced sufficiently by the use of a fan of adequate capacity to do more than offset the difference in original cost between a fan operating at its maximum output and one operating under optimum conditions.

Air flow in the shelled-corn drier. Air circulation in the shelled-corn drier must be regulated in order to maintain the most satisfactory relation between the fresh air being admitted to the circulating system, the air being discharged from the system, and the air that is recirculated. From 20 to 25 per cent of the air in the drying system is constantly being replaced by fresh air and the moisture is being carried away by the discharged air.

Figure 11 shows a suggested arrangement for the shelled-corn drier. Heated air from the furnace is blown into the space between the corn columns, and passes through the corn into the collecting duct for the discharged air. A portion of this air is then returned to the fan, where it is mixed with some incoming fresh air and reheated. Air which is not returned to the fan is discharged through openings at the top of the column. The amount of air recirculated is regulated to maintain a relative humidity of approximately 70 per cent in the air discharged from the drier. A hygrometer must be located in the discharged air stream (see Figure 17). The hygrometer consists of two ordinary thermometers, one of which is covered with a soft cloth wick. The wick is kept moist by water from a reservoir.

Relative humidity. The per cent relative humidity is readily obtainable from Figure 16, when the wet bulb and dry bulb temperatures are known.

On the humidity chart shown, the horizontal lines represent dry-bulb temperatures and the curved lines running diagonally across the chart represent the wet-bulb temperatures. For any given wet- and dry-bulb temperatures the intersection of the two lines gives the relative humidity by moving along a vertical line to the edge of the chart. For example, assume that a stream of air flows over the hygrometer and that the dry-bulb temperature is 140° Fahrenheit and the wet-bulb temperature 100° Fahrenheit. The two lines intersect one-half way between the vertical lines for 24 and 26 per cent relative humidity. We have then a relative humidity of 25 per cent at a dry-bulb temperature of 140° Fahrenheit and a wet-bulb temperature of 100° Fahrenheit.

The relative humidity of the air discharged from the drier is controlled by the fresh-air intake. The fresh-air intake should be as near to the fan as possible and should have an area equal to approximately 50 per cent of the cross-sectional area of the recirculation duct. It is necessary to have a slide gate for adjusting the amount of air which enters through this intake. If the recirculation duct is kept entirely open at all times, the control gate on the fresh-air intake is the only air adjustment necessary for the drier. If this valve is opened too far, the hygrometer will show that the relative humidity of the air on the discharge side of the drier is lower than the recommended relative humidity of 70 per cent. If the fresh-air intake valve is not opened sufficiently, this will be indicated by an excessively high relative humidity of the air discharged from the drier.

Drier heating plant. Farm dehydrators are usually equipped with some type of hot-air furnace using either wood, oil, coal, gas, or sawdust for fuel. In Oregon the most commonly used fuel is wood because of its general availability and low cost.

The capacity of a furnace must be adequate to supply heat for the particular job for which it is installed. In order to have capacity, the furnace must have sufficient grate area to burn the amount of fuel required, and it must have sufficient radiation area to dissipate the heat to the air which is circulated around the furnace. The ratio of the heating surface to the

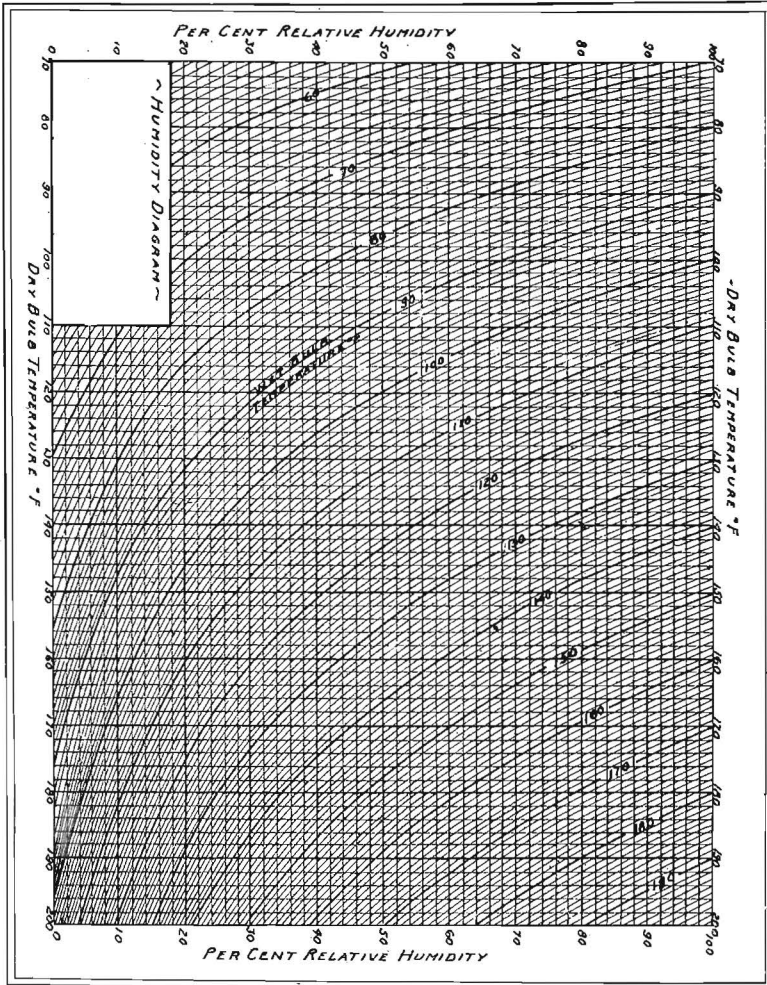


Figure 16. Humidity diagram

grate area for heavy duty furnaces designed for operation with forced-air circulation should not be less than 30 to 1 and may be as high as 50 to 1.

Table 4 gives the square feet of heating surface required to heat 1,000 cubic feet of air per minute from a condition of 68° Fahrenheit dry bulb and 60° Fahrenheit wet bulb to various temperatures. In the preparation of

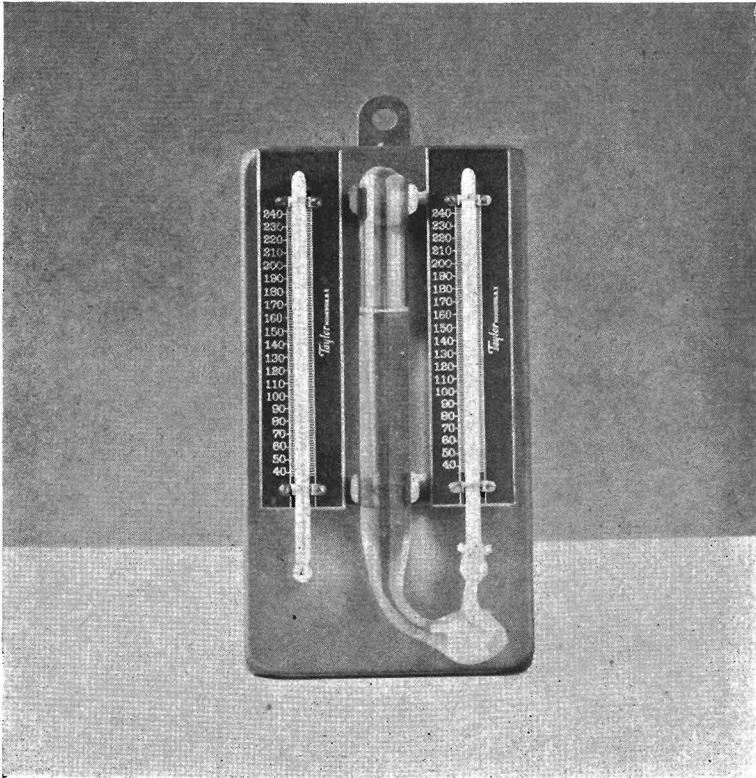


Figure 17. Hygrometer for determining relative humidity.

Table 4. HEATING SURFACE REQUIRED FOR 1,000 CUBIC FEET OF AIR PER MINUTE.

Temperature of heated air ° F.	B.t.u. per minute required	Square feet of heating surface required
100°	573	9.8
120°	930	16.0
140°	1,289	22.1
160°	1,647	28.3
180°	2,002	34.5
200°	2,360	40.5
220°	2,720	46.7

Note: The square feet of heating surface is based upon a heat transfer of 3500 B.t.u. per square foot per hour* to the air forced over it. The air is assumed to be at an initial condition of 68° Fahrenheit dry bulb and 60° Fahrenheit wet bulb. The relative humidity is 61 per cent.

*A. S. H. & V. E. Guide—1937.

this table it was assumed that the furnace had a ratio of heating surface to grate area of from 30 to 50 to 1, and that there was forced circulation of air around the furnace.*

COST OF DRYING SHELLED CORN

Fuel cost. The amount of heat required to dry one ton of shelled corn from 30 per cent moisture content to 12 per cent moisture content in a continuous-process drier was found to be approximately 1,334,000 B. t. u. The following data were taken from several experimental tests.

Table 5. HEAT REQUIRED TO PRODUCE 1 TON OF DRY CORN.
(Undried Corn at 30 per cent Moisture, Dry Corn at 12 per cent)
Data from the Experimental Drier.

Run number	Column thickness	Temperature of drier air ° F.	Air pressure on column in inches of water	Corn dried per hour pounds	Heat required to dry one ton of corn B. t. u.
30	4"	140	.48	31.9	1,390,390
26	4"	160	.46	43.7	1,140,970
10	4"	180	.41	54.0	1,893,660
29	4"	200	.47	76.3	1,072,730
36	4"	120	.80	21.8	1,252,880
35	4"	140	.80	20.6	2,316,748
33	4"	160	.78	48.7	1,262,440
12	4"	180	.79	93.9	945,120
34	4"	200	.80	75.2	1,179,870
19	2"	120	.44	18.9	1,264,490
16	2"	140	.44	29.2	1,402,330
18	2"	160	.44	40.1	1,027,010
17	2"	180	.45	49.4	1,173,730
22	2"	200	.43	56.8	1,321,130
20	2"	120	.77	19.5	1,403,010
15	2"	140	.68	29.2	1,402,330
14	2"	160	.64	36.2	1,412,568
13	2"	180	.59	62.3	1,095,252
21	2"	200	.66	63.9	1,388,340
Average of all trials					1,333,946

A 500 pound per hour shelled-corn drier operating near Corvallis required approximately 1 cord of wood to turn out 7 tons of shelled corn at 12 per cent moisture content from an initial condition of 30 per cent moisture (see Figure 18). This would amount to 60 cents per ton of dry shelled corn with Douglas Fir wood at \$4.00 per cord.

Power cost. The power cost for driving the fan, operating the grain-removing mechanism, and elevating the grain into the drier was approximately 40 cents per ton at an electrical rate of 3 cents per kilowatt hour.

Interest and depreciation. The depreciation cost will depend on the original cost of the drier, the type of materials used in construction, and the care used in servicing and maintaining equipment. Fifteen per cent of the cost of the drier appears to be a reasonable annual charge against its operation for interest and depreciation. This amount divided by the tonnage of corn dried per season will give the approximate per-ton cost chargeable against fixed expenses.

*A. S. H. & V. E. Guide—1937.

The following costs were incurred in the construction of a shelled-corn drier built on a farm four miles south of Corvallis in the fall of 1937, with a capacity of six tons of dry shelled corn per 24-hour day.

Labor: entire drier.....	\$ 400.00
Lumber: entire drier.....	275.00
Foundation	25.00
Heating plant	225.00
Fan (used)	120.00
Ratio motor	38.00
Elevator motor (used).....	25.00
Elevator belt and cups (used).....	20.00
Corn sheller	130.00
Miscellaneous expense	10.00
Sheet metal work	82.00

Total cost of constructing the corn drier.....\$1,350.00

Allowing an additional \$150.00 to take care of possible differences in the cost of materials, the drier could undoubtedly be duplicated for \$1,500.00.

Summary of drying costs. The following costs of corn drying were determined from the operation of a shelled-corn drier on a farm near Corvallis, where approximately 100 tons were dried in the fall of 1937.

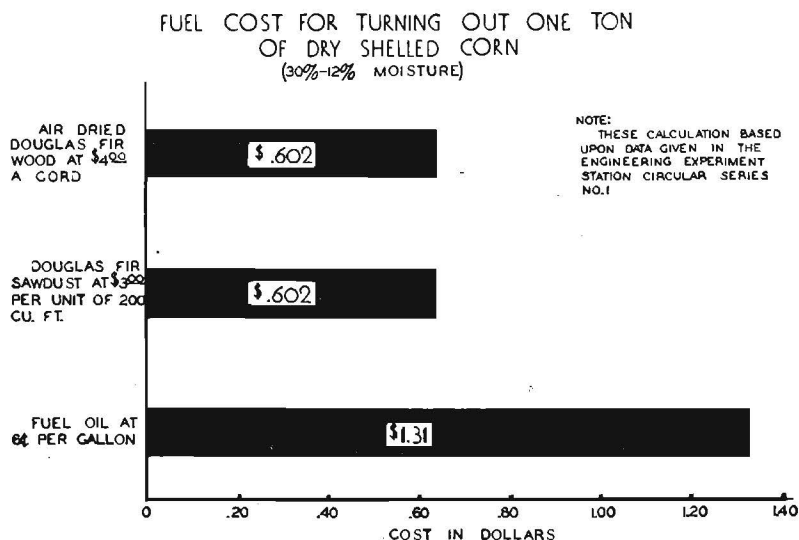


Figure 18.

Table 6. CORN-DRYING COST PER TON.
Shelled-Corn Drier—Capacity 500 lbs. per hour

	At 100 ton per year 17 days operation	At 200 ton per year 32 days operation
<i>Operating cost</i>		
Fuel (fir wood @ \$4.00 cord).....	.60	.60
Electric Power @ .03 per kwh.....	.40	.40
Labor @ .40 per hour.....	1.60	1.60
<i>Fixed expense</i>		
Interest and depreciation (15 per cent on \$1500)	2.25	1.12
Total cost per ton.....	\$4.85	\$3.72

OPERATING THE SHELLED-CORN DRIER

When the continuous-process, shelled-corn drier is started the columns and hopper can be filled with undried corn. The rolls for removing the corn from the drier should not be started until the corn in the columns is dry.

Two to three hours may be required for drying out the columns. When the corn in the columns is dry, the draw-off mechanism can be started. For a 4-inch column, 6 feet high, a roll made according to the specifications given in this bulletin should turn about one revolution per minute with the drier operating at a temperature of 170° Fahrenheit (see Figure 6). Some method for accurately determining the moisture content of the dried corn is necessary.

Brown-Duvel* moisture-testing equipment is relatively inexpensive and the procedure for making moisture determinations is easily acquired. The rate at which the corn is being removed from the drier should be varied until the dry corn is at 15 per cent moisture content. After the drier has been adjusted, only slight changes in the rate of removing corn from the drier will be necessary. To shut down the drier for short periods the draw-off mechanism should be stopped while the columns are filled with corn. On resuming drying operations, the drier can be warmed up to operating temperature in a short time and the corn-removing mechanism started.

When starting the drier with full columns of undried corn, it will be necessary to open the fresh-air intake considerably more than when operating under normal drying conditions. When warming up the drier after it has been stopped with full columns of partly dry corn, the fresh-air opening can be closed. When the rolls for removing the dry corn are started, the fresh-air inlet should be opened to the normal operating position.

Grade standards for shelled corn. Primarily, the purpose of corn drying is to reduce the moisture content of the corn sufficiently to produce a marketable product. The following data are taken from the Handbook of Official Grain Standards of the United States, Form No. 90, Revised Sept. 1934.

*Can be obtained through Seed Trade Reporting Bureau, 1018 Wabash Avenue, Chicago, Illinois.

Table 7. STANDARDS FOR CORN.

Grade number	Minimum test wt. per bushel	Maximum limits—in per cent			
		Moisture	Cracked corn and foreign material	Damaged kernels	
				Total	Heat damage
	<i>Pounds</i>				
1	54	14.0	2	3	0.1
2	53	15.5	3	5	.2
3	51	17.5	4	7	.5
4	48	20.0	5	10	1.0
5	44	23.0	7	15	3.0

Sample grade: Sample grade shall include corn of the class Yellow corn, or White corn, or Mixed corn, that does not come within the requirements of the grades from No. 1 to No. 5, inclusive; or that contains stones and/or cinders; or that is musty or sour, or heating or hot; or that has any commercially objectionable foreign odor; or that is otherwise of distinctly low quality.

Summary of operating characteristics desired in a shelled-corn drier:

1. A temperature of from 160 to 175° Fahrenheit should be maintained for drying corn for feeding purposes.
2. A minimum of 100 cubic feet of air per minute per square foot of column area should be forced through the corn column.
3. The relative humidity of the air discharged from the drier should be kept at 70 per cent.
4. The corn should be dried so that the moisture content does not exceed 15.0 per cent.

DRYING EAR CORN

The drying of ear corn has been practiced by a few Oregon corn growers for several years. In the ear-corn drier the corn is placed in bins with slatted bottoms and heated air is forced through the bin of corn. This type of drier requires much greater floor space and a furnace of approximately 100 per cent greater heating capacity than that required by a shelled-corn drier of the same output of dry shelled corn. If seed corn is to be dried artificially, the bin type ear-corn drier is recommended.

Natural-draft driers. Ear-corn driers may be classified as natural-draft driers and forced-draft driers. The natural-draft driers are used only for drying corn from a rather limited acreage, probably 10 to 15 acres as a maximum. These driers require no fan or motor for the forced draft and are less expensive, although they dry much more slowly. They are often used as a combination drier and storage. Quite often there is a building on the farm which can be converted at small expense into a drier of this type. The building should have sufficient height to permit building the kiln floor at least ten feet above the ground in order to have satisfactory movement of the heated air through the corn. A side-hill location is desirable, if there is room for a roadway on the upper side; as this facilitates loading the corn into the drier from the wagon or truck. A natural-draft drier should not be loaded to a depth greater than 12 inches. If this type of drier is used as a combination drier and storage, a second 12-inch loading can be placed on the first after the first is sufficiently dried for safe storage. A third 12-inch loading can be made by following this procedure.

The weight of a cubic foot of undried ear corn at 30 per cent moisture is approximately 30 pounds and the weight of a cubic foot of dry ear corn is approximately 25 pounds. Ear corn shrinks 17 to 20 per cent in volume while drying, however, and therefore a cubic foot of undried ear corn will not produce a cubic foot of dry ear corn. A cubic foot of dry ear corn weighing 25 pounds should produce approximately 20 pounds of shelled corn. Undried ear corn at 30 per cent moisture will ordinarily produce 55 to 60 per cent of its green weight in dry shelled corn.

AIR VELOCITIES RESULTING FROM STATIC PRESSURES ON KILNS OF EAR CORN

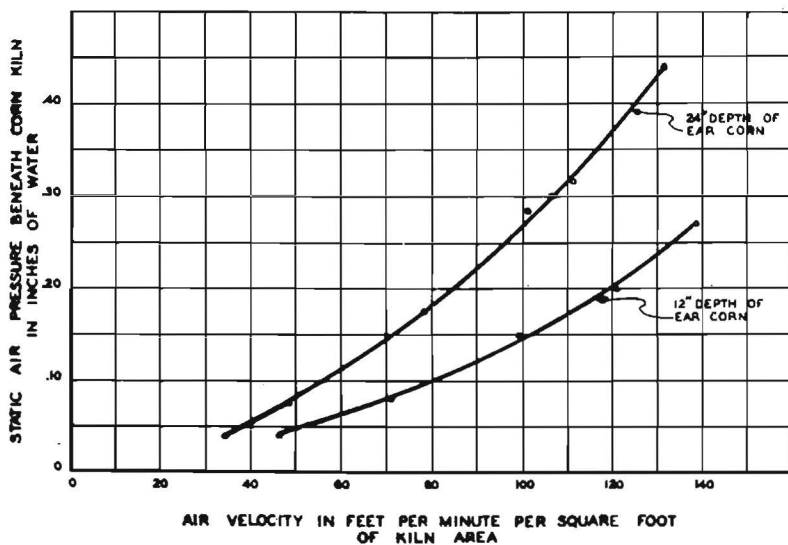


Figure 19.

Forced-draft drier. Certain data have been taken which will assist in the design of a forced-draft drier for ear corn. In order to select a fan for a drier, the quantity of air required and the static pressure necessary to force air through corn must be known. It was found that an air velocity of from 50 to 75 feet per minute through the kiln would produce satisfactory results. Figure 19 consists of a graph made from experimental data and gives the static pressure developed in forcing certain quantities of air through ear corn.

Very satisfactory results have been obtained by using multiblade axial flow fans in ear-corn driers. The static pressure necessary to force air through the corn need not exceed .2 of an inch of water pressure.

A table giving the performance of one line of multiblade fans has been included in order to facilitate the selection of a fan of the proper size (see Table 8).

Table 8. PERFORMANCE OF 8-BLADE PROPELLER WHEELS 30° ANGLE—OPERATING AGAINST RESISTANCE.*

Size	Static press. inches	R.P.M.	Volume	H.P.	R.P.M.	Volume	H.P.	R.P.M.	Volume	H.P.
18" ....	.25	774	690	.20	954	1,140	.31	1,240	2,070	.52
	.50	1,094	970	.55	1,346	1,610	.86	1,754	2,920	1.46
24" ....	.25	580	1,220	.35	715	2,025	.54	930	3,760	.92
	.50	1,820	1,725	.99	1,010	2,860	1.53	1,315	5,190	2.59
30" ....	.25	464	1,910	.55	572	3,160	.85	744	5,730	1.43
	.50	653	2,690	1.54	809	4,470	2.39	1,050	8,100	4.04
36" ....	.25	387	2,750	.79	477	4,560	1.22	620	8,260	2.07
	.50	547	3,880	2.22	673	6,430	3.44	877	11,680	5.83
48" ....	.25	290	4,880	1.40	358	8,100	2.16	465	14,680	3.68
	.50	410	6,900	3.96	505	11,440	6.12	658	20,760	10.40
60" ....	.25	232	7,630	2.19	286	12,600	3.38	372	22,940	5.75
	.50	327	10,780	6.19	405	17,880	9.56	525	32,440	16.20
72" ....	.25	194	11,000	3.16	239	18,240	4.88	310	33,040	8.28
	.50	274	15,520	8.88	337	25,730	13.80	439	46,720	23.30
84" ....	.25	166	14,960	4.28	205	24,800	6.60	266	44,960	11.20
	.50	235	21,120	12.10	289	35,040	18.80	376	63,560	31.70

*From "Fan Engineering"—Buffalo Forge Company.

Many questions may arise in the consideration of an ear-corn drier which can be answered by referring to the following data which were taken on one kiln of ear corn that was filled to a depth of thirty inches with undried corn. These values will not be exact for all conditions, as they are based upon only one test, but may be useful in estimating different quantities.

Volume of undried corn in kiln, 22.5 cu. ft.

Total weight undried ear corn in the kiln, 640.5 lbs.

Total weight dry ear corn in the kiln at 9.7 per cent moisture content, 462 lbs.

Weight of cleaned dry shelled corn at 9.7 per cent moisture content, 396 lbs.

Amount of cleanings and cobs at 14.3 per cent moisture content, 66 lbs.

*Weight of wet cobs in undried corn, 117.5 lbs.

Weight of dry cobs in corn, 44 lbs.

*Weight per cu. ft. undried ear corn in kiln, 28.5 lbs.

*Weight per cu. ft. dry ear corn in kiln, 24.6 lbs.

Moisture per cent undried, 27.8 per cent.

*Per cent green cobs in the total undried weight, 18.35 per cent.

*Per cent dry cobs in the total dry weight, 10.5 per cent.

Water evaporated from cob, 73.5 lbs.

Water evaporated from grain, 97.0 lbs.

*Per cent shrinkage in volume of ear corn, 16.7 per cent.

Weight per bushel of dry shelled corn at 9.7 per cent moisture content, 55.43 lbs.

*Weight per bushel on a basis of 14 per cent moisture content, 58.8 lbs.

*Values which have been calculated—other values observed.

PLANS FOR A FORCED-DRAFT, EAR-CORN DRIER

The Oregon Agricultural Experiment Station has designed an ear-corn drier that has a capacity of three tons of dry shelled corn per day. A drier of this type has been in operation for three years on a farm near Corvallis and rather complete operating data have been obtained. The same drier can be used to dry walnuts and filberts without modification.

The drier has two adjacent bins (9 feet x 13 feet) with an air-tight partition between them and with controls from the heating plant so that bins can be operated separately or simultaneously. This makes it practical to load or unload one bin while drying is continuing in the other bin. The bins are usually loaded on alternate days because under most conditions it requires more than 24 hours to dry ear corn. When loaded to a depth of three feet each bin will hold sufficient ear corn to produce three tons of dry corn after it has been shelled.

The bins are loaded through sliding doors on each side of the drier. The sliding doors are well adapted to the adjustment of the opening for the air discharged from the drier.*

The drier is constructed so that from 50 to 80 per cent of the air that passes through the bins of corn can be recirculated to the heating plant. This is desirable both to save fuel and to keep down the size of the heating plant. The amount of air to recirculate is determined by hygrometer readings (see page 22). The relative humidity of the air discharged from the drier should be kept at 65 per cent.

A room adjacent to the drier bins contains the corn sheller. It is placed in the center between the bins and corn can be shovelled into it from either bin. (See Figure 2, page 5 for a photograph of a satisfactory type of sheller.)

The heated air can be forced through the bins of corn by an axial flow multiblade fan. Either a 4-foot or a 5-foot fan is satisfactory for a drier of this size. The 5-foot fan will require less horsepower to deliver the required 12,000 cubic feet of air per minute than the 4-foot fan. Air is blown around the furnace and then to the bins so that there is always a slight pressure around the furnace. This prevents sparks from entering the air stream around the furnace in the event of a break in the furnace wall. This is a worthwhile precaution against damage by fire.

CHARACTERISTICS OF THE EAR-CORN DRIER

The operating characteristics of this ear-corn drier can be summarized as follows:

Capacity. When loaded to a depth of three feet the capacity of the drier is three tons of dry shelled corn at 12 per cent moisture from undried corn at 30 per cent moisture per 24 hours a day when drying at 160° Fahrenheit.

Drying time. The time required to dry the corn varies with the maturity of the corn, the temperature of the air, and the quantity of air circulated. The time may vary from 24 to 40 hours, depending on the air velocity, the drying temperature, and the maturity of the corn. Under the most unfavorable conditions yet encountered the plant will dry the corn in less than 48 hours, making it possible to load one bin every day.

*Plans for a forced-draft, ear-corn drier with a drying capacity of 3 tons of shelled corn per day are available at Oregon Agricultural Experiment Station for a nominal charge.

Moisture content. The determination of the proper moisture content at which to stop the drying process is difficult, until the operator has gained experience in estimating fairly accurately the moisture content of the corn by physical examination. It is recommended that a few moisture tests be made from typical samples of corn from the drier, either by the Brown-Durel method or by some other accurate method to which other samples may be compared by physical examination.

Temperature. A temperature of 160° to 175° Fahrenheit is recommended for drying corn for feed. In drying seed corn the temperature should probably be kept at 100° Fahrenheit. Some investigators have used a temperature of 110° Fahrenheit.

Fan capacity. The fan for this drier must deliver a minimum of 12,000 cubic feet per minute against a total head of not to exceed .2 of an inch of water pressure. This will meet the recommendation of 50 cubic feet per minute per square foot of kiln floor.

Furnace capacity. For drying seed corn where the drying temperature should not exceed 110° Fahrenheit, a furnace with 188 square feet of heating area will be satisfactory. For drying feed corn at a temperature of 160° Fahrenheit a furnace with 326 square feet of heating area will be adequate.

These figures are based upon heating air from 68° dry bulb and 60° wet bulb to the drying temperature.

An ear-corn drier with greater capacity can be constructed along the same plan by increasing the area of the bins, the size of the heating plant, and the size of the fan. Table 9 gives fundamental data necessary for the construction of larger ear-corn drying units.

Table 9. SPECIFICATIONS FOR EAR-CORN DRIERS.

Drier capacity*	Bin dimensions†	Air volume‡	Heating surface§
1 Ton	(4' × 10')	4,000	113—
2 Ton	(6' × 13')	7,800	220
3 Ton	(9' × 13')	11,700	386
4 Ton	(9' × 18')	16,200	450
5 Ton	(10' × 19')	19,000	528
6 Ton	(12' × 19')	22,800	635
8 Ton	(15' × 20')	30,000	835
10 Ton	(19' × 20')	38,000	1,060

*Capacity of drier in tons of dry corn per 24-hour day from undried corn at 30 per cent moisture content.

†Size of bins required for a two-bin drier loaded to a depth of three feet.

‡Cubic feet of air required per minute for both bins.

§Square feet of heating surface required to heat air to 160° F.

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Maud M. Wilson, A.M. Home Economist

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