



**AgEcon** SEARCH  
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search

<http://ageconsearch.umn.edu>

[aesearch@umn.edu](mailto:aesearch@umn.edu)

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

*No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.*

File copy  
New  
Revised  
Slightly revised  
Reprint  
Supersedes  
Date received

Reg. No. 1529

10

Ag84Mr

4/29/69

52-T-88-69 <sup>Sta</sup>  
MRR-841

# COMPARISON OF CONCURRENT-FLOW, CROSSFLOW, AND COUNTERFLOW GRAIN DRYING METHODS

Marketing Research Report No. 841

Agricultural Research Service  
UNITED STATES DEPARTMENT OF AGRICULTURE

in cooperation with

Purdue University Agricultural Experiment Station



## Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.



## PREFACE

This report discusses results of research conducted to investigate the performance of the three basic types of continuous grain dryers—concurrent-flow, crossflow, and counterflow—and develops and illustrates methods of obtaining optimum dryer designs and operating conditions. The three dryer designs are compared largely on the basis of mathematical simulation and computer analysis. Only the analysis of the concurrent-flow process was verified by laboratory testing. The report is intended for the use of engineers, designers, manufacturers, and others concerned with heated-air drying of grain.

This publication is largely a condensation of an unpublished Ph.D. thesis by the senior author entitled “Predicted Performances and Optimal Designs of Convection Grain Dryers,” Purdue University, Lafayette, Ind.

Leo E. Holman, formerly Investigations Leader, Transportation and Facilities Research Division, Agricultural Research Service, assisted in the general supervision of the research and in the preparation of this report.

This report is assigned Journal Paper No. 3285 by the Purdue University Agricultural Experiment Station.

# CONTENTS

	Page
Summary . . . . .	1
Introduction . . . . .	1
Review of literature . . . . .	2
Concurrent-flow drying tests . . . . .	3
Experimental procedures . . . . .	3
Results . . . . .	3
Quality evaluations . . . . .	6
Simulated drying tests . . . . .	9
Concurrent-flow drying . . . . .	9
Crossflow drying . . . . .	10
Counterflow drying . . . . .	11
Comparison of dryer performances . . . . .	11
Dryer design projections . . . . .	15
Optimum drying-bed depths with selected air horsepower . . . . .	15
Dryer size . . . . .	15
Dryer performance at other than design conditions . . . . .	17
Literature cited . . . . .	19
Appendix . . . . .	19
Laboratory dryer description and performance . . . . .	19
Corn quality evaluation methods and results . . . . .	19

# COMPARISON OF CONCURRENT-FLOW, CROSSFLOW, AND COUNTERFLOW GRAIN DRYING METHODS

By T. L. THOMPSON, *assistant professor, Agricultural Engineering Department, University of Nebraska*;<sup>1</sup> G. H. FOSTER, *agricultural engineer and investigations leader, Transportation and Facilities Research Division, Agricultural Research Service*; and R. M. PEART, *professor, Agricultural Engineering Department, Purdue University*

## SUMMARY

Mathematical grain drying models were formulated to predict the performance of the three basic types of continuous grain dryers—concurrent-flow, crossflow, and counterflow. The model for concurrent-flow drying was verified by laboratory drying tests with shelled corn. The quality of the laboratory dried corn was evaluated in terms of brittleness and wet process milling. In concurrent-flow drying, the drying air temperature was the variable that had the greatest effect on millability of the corn and the method of cooling affected the susceptibility of kernels to stress cracks and to breakage. Counterflow cooling immediately following drying was not an adequate substitute for delayed cooling in reducing the brittleness of the dried corn. Acceptable corn quality was obtained with drying air temperatures up to 300° F., airflow rates of 50 to 90 cubic feet of air

per minute per square foot of drying-bed area, and grain depths of 2 and 4 feet.

General performance graphs were developed from results of simulation tests to study, predict, and optimize each design. The performance characteristics of the three types of grain dryers were found to be significantly different. Crossflow dryers overdried the grain where the air entered and underdried it on the exhaust side. With the concurrent-flow and counterflow methods, each kernel of grain was subjected to the same drying conditions; thus, the entire lot was dried to a uniform moisture content. The concurrent-flow process removed most of the moisture during the initial stages of drying, and a built-in tempering period relieved some of the drying stress. Counterflow dryers removed more moisture per foot of drying bed than either of the other two dryers.

## INTRODUCTION

Heated-air grain dryers are used on many farms and at most grain elevators in the Midwest. Field shelling of corn places a heavy seasonal load on these drying systems because most of this corn has to be dried before it is acceptable for market or storage.

Many attempts have been made to speed up grain drying processes. Grain dryer capacity can be increased by using higher drying air temperatures, but the quality of the dried grain is generally lowered.

Of the many sizes, shapes, and configurations of dryers, there are only three basic continuous-flow types—crossflow, concurrent-flow, and counterflow (fig. 1). In a crossflow dryer, the drying air flows perpendicular to the flow of grain; in a concurrent-flow dryer the air flows in the same direction as the grain; and in a

counterflow dryer the air flows in the opposite direction to the movement of grain.

The principal objectives of the research were to develop mathematical models to represent concurrent-flow, crossflow, and counterflow drying; to verify the mathematical model with laboratory testing; to determine the effect of concurrent-flow drying on the quality of dried corn; and to develop and illustrate methods of obtaining optimum dryer designs and operating conditions. This report gives the results of the concurrent-flow laboratory drying tests and discusses simulated drying tests with each of the three methods.

Concurrent-flow drying was chosen for detailed study because of preliminary indications that this method maintained a grain quality better than that of the other two drying methods. Further drying tests comparing all three methods are needed to fully evaluate their effect on grain quality.

<sup>1</sup> Mr. Thompson was at Purdue University when the research for this report was being conducted.

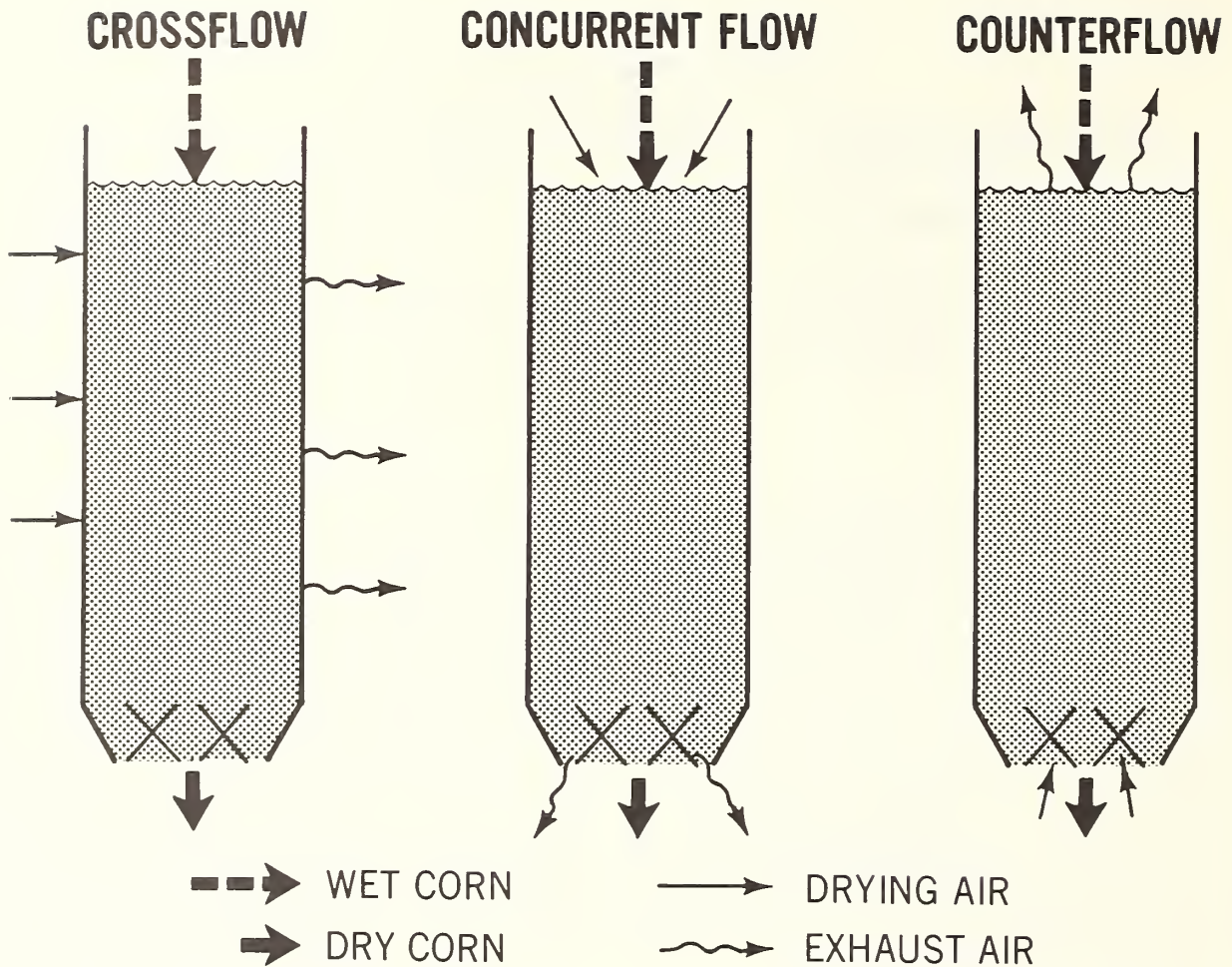


Figure 1.—Direction of grain and airflow in three basic types of grain dryers—crossflow, concurrent-flow, and counterflow.

## REVIEW OF LITERATURE

A few investigators have studied methods that increase the capacities of grain dryers. Others have related drying capacity and methods to the maintenance of dried grain quality. Few research results have been reported on the performance of the concurrent-flow drying process.

Thompson and Foster (7)<sup>2</sup> reported that shelled corn dried with heated air at 140° to 240° F. was two to three times more susceptible to breakage than the same corn dried with unheated air. Drying speed, expressed in terms of moisture loss in percentage points per hour, was the most significant factor in stress crack development. When drying speeds exceeded 8 to 10 percentage points per hour, puffing of the kernels decreased the test

weight of the corn and was considered more damaging than stress cracks.

Tuite and Foster (9) reported the effect of artificial drying on the hygroscopic properties of corn. Corn dried at temperatures of 140° F. and above supported a higher equilibrium relative humidity than corn on the same moisture dried with room air. They recommended that artificially dried corn be stored at a moisture content 0.5 to 1 percent lower than naturally dried corn to prevent mold development.

MacMasters and others (5) studied the effect of drying on the suitability of artificially dried corn for starch production. On the basis of recovery and quality of the starch, acceptable processing was obtained in the laboratory when corn reached temperatures as high as 160° F. during drying. However, corn reaching temperatures above 140° F. during drying showed a definite

<sup>2</sup> Underscored numbers in parentheses refer to Literature Cited, p. 19.

decrease in viability and was less suitable for use in starch production.

Foster (2) reported results of drying tests with field-shelled corn both in field-scale and in laboratory dryers. Starch yields decreased with increased drying temperatures (up to 290° F.); however, there was no significant effect due to batch versus continuous drying methods, initial moisture content, or airflow rate.

Foster (1) developed the dryeration process, which increases the drying capacity of conventional dryers and improves the quality of the dried corn. The process, which is a combination of drying and aeration, utilizes the heat that is in the corn after drying. Without first being cooled, the corn is removed from the dryer and placed in a temporary holding bin to temper. Delaying the cooling of the heat-dried corn until after a 4- to 8-hour tempering period reduces the brittleness of the corn by 50 percent as compared to the same corn cooled rapidly after drying.

Schroeder and Peart (6) used dynamic programming to determine the optimum air allocation to various stages of drying in a continuous-flow grain dryer. Better procedures for utilizing the drying air and obtaining higher drying capacities were investigated.

Henderson and Henderson (3) presented a computational procedure for analysis of deep-bed drying, using the digital computer and thin-layer drying theory. Results from the procedure were compared to experimental results, and the effects of several parameters on the drying process were investigated.

Ives (4) applied thermodynamic relations to drying with through-air-circulation at steady state flow conditions to determine certain limiting and equilibrium values. He then used dimensional analysis and similitude to design experiments for observing the time required to dry corn with the counterflow process. Some useful prediction equations were developed, and their practical application was illustrated by example.

## CONCURRENT-FLOW DRYING TESTS

### Experimental Procedures

Laboratory drying tests were conducted to evaluate the effect of concurrent-flow drying on dryer performance and corn quality. An experimental dryer (see Appendix for description and illustration (fig. 13) of dryer) was constructed to operate with various airflow rates, drying-bed depths,<sup>3</sup> input drying air temperatures, and grain flow rates.

The 1964 test series included three drying air temperatures, 200°, 300°, and 400° F.; two drying-bed depths, 2 and 4 feet; two airflow rates that were equivalent to supplying 5 and 10 air horsepower<sup>4</sup> for each 100 bushels of corn dried per hour; and two initial corn moistures, 18 and 23 percent.<sup>5</sup> The results were measured by dryer performance and the quality of the grain after drying. Preliminary simulation results were used to select the airflow rates used in the tests. The supply of corn for the tests at 18-percent moisture was limited, and only the tests with high airflow rates were performed.

The 1965 series consisted of tests at airflow rates of 50 and 70 cubic feet of air per minute per square foot of drying-bed area (c.f.m./ft.<sup>2</sup>) with drying air temperatures of 200° and 250° F.; and tests at airflow rates of 70 and 90 c.f.m./ft.<sup>2</sup> with drying air temperatures of 300° and 350° F. Counterflow cooling and delayed cooling similar to that used with the dryeration (1)

process were compared. Three inverted V-shaped exhaust air ducts were placed in the drying column to accommodate counterflow cooling (see Appendix). A small fan attached to the grain discharge hopper forced cooling air up through the unloader and through 1 foot of grain in the drying column. All 1965 tests were performed with a drying-bed depth of 2 feet and a cooling-bed depth of 1 foot.

### Results

Tables 1 through 4 summarize performance results of the experimental concurrent-flow drying tests. Table 1 shows the effect of drying air temperature on dryer performance; tables 2, 3, and 4, the effects of depth of drying bed, airflow rate, and initial moisture content of corn on performance. A summary of each test is presented in appendix tables 12, 13, 14, and 15.

The concurrent-flow drying process removed most of the moisture during the first part of the drying period. During the 1964 drying tests, the average moisture content of the corn was as follows:

Type of sample	Percent moisture content
Initial (before drying) . . . . .	23.2
From midpoint of drying column. . . . .	14.7
Final (after drying) . . . . .	13.7

An average of 8.5 percentage points of moisture was removed during the first half of the drying period and only 1.0 percentage point during the second half.

<sup>3</sup>Drying-bed depth = thickness of grain in the direction of the airflow.

<sup>4</sup>Air horsepower = 0.00157 x c.f.m. x total pressure in inches of water.

<sup>5</sup>Moisture contents of corn are given on wet basis throughout report.

TABLE 1.—Effect of drying air temperature on dryer performance

Year	Drying air temperature	Average total airflow	Average drying capacity	Average moisture content		Approximate final corn temperature <sup>1</sup>
				Initial	Final	
	<sup>o</sup> F.	C.f.m.	Bu./hr.	Percent	Percent	<sup>o</sup> F.
1964. . . .	200	127	1.40	22.7	13.7	116
	300	176	2.64	23.7	13.6	144
	400	205	4.36	23.4	13.9	162
Average . .	—	169	2.80	23.2	13.7	141
1965. . . .	200	157	1.55	24.1	13.2	127
	250	158	2.38	23.0	13.2	147
	300	209	3.60	22.7	13.8	165
	350	209	5.48	22.5	14.3	175
Average . .	—	183	3.25	23.1	13.6	154

<sup>1</sup> Temperature of corn leaving the drying bed.

TABLE 2.—Effect of depth of drying bed on dryer performance

Year	Depth of drying bed	Average total airflow	Average drying capacity	Average moisture content		Approximate final corn temperature <sup>1</sup>
				Initial	Final	
	Feet	C.f.m.	Bu./hr.	Percent	Percent	<sup>o</sup> F.
1964 . . . .	2	182	3.10	22.5	13.3	151
	4	157	2.49	24.0	14.2	131
1965 . . . .	2	183	3.25	23.1	12.4	154

<sup>1</sup> Temperature of corn leaving the drying bed.

TABLE 3.—Effect of airflow rate on dryer performance

Year	Airflow rate	Average total airflow	Average drying capacity	Average moisture content		Approximate final corn temperature <sup>1</sup>
				Initial	Final	
	C.f.m.	C.f.m.	Bu./hr.	Percent	Percent	<sup>o</sup> F.
1964 . . . .	Low <sup>2</sup>	141	2.56	23.2	13.6	141
	High <sup>2</sup>	198	3.03	23.3	13.9	140
1965 . . . .	C.f.m./ft. <sup>2</sup>					
	50 <sup>3</sup>	133	1.75	24.3	12.4	136
	70 <sup>3</sup>	182	2.18	22.8	12.8	138
	70 <sup>4</sup>	182	3.81	22.5	13.1	173
	90 <sup>4</sup>	236	5.26	22.6	14.3	167

<sup>1</sup> Temperature of corn leaving the drying bed.

<sup>2</sup> Low airflow equivalent to 5 air hp. and high airflow equivalent to 10 air hp. per 100 bushels of corn dried per hour. Airflow in c.f.m./ft.<sup>2</sup> of drying bed ranged from 40 to 100.

<sup>3</sup> Drying air temperatures were 200° and 250° F.

<sup>4</sup> Drying air temperatures were 300° and 350° F.

TABLE 4.—Effect of initial moisture content on dryer performance

Year	Initial moisture content	Average total airflow	Average drying capacity	Average final moisture content	Approximate final corn temperature <sup>1</sup>
	Percent	C.f.m.	Bu./hr.	Percent	° F.
1964 . . . . .	23.2	198	3.03	13.9	140
	18.0	198	5.23	13.4	143
1965 . . . . .	23.1	183	3.25	13.6	154

<sup>1</sup> Temperature of corn leaving the drying bed.

During these tests, the temperature of the air surrounding the kernels was considerably lower than the temperature of the heated air entering the drying column. Figure 2 shows interseed air temperature versus corn depth for three drying air temperatures—200°, 300°, and 400° F. The entering hot drying air came in contact with the cool wet corn and the air immediately began to cool. The high rate of moisture removal at the

start of drying further reduced the drying temperature. Tables 1 through 4 also summarize the effect of each drying treatment on final grain temperature. Figure 3 and table 2 show that final grain temperatures were lower with increasing depths of drying bed.

In the 1965 laboratory tests, more moisture was removed with delayed aeration cooling than with counterflow cooling immediately following drying.

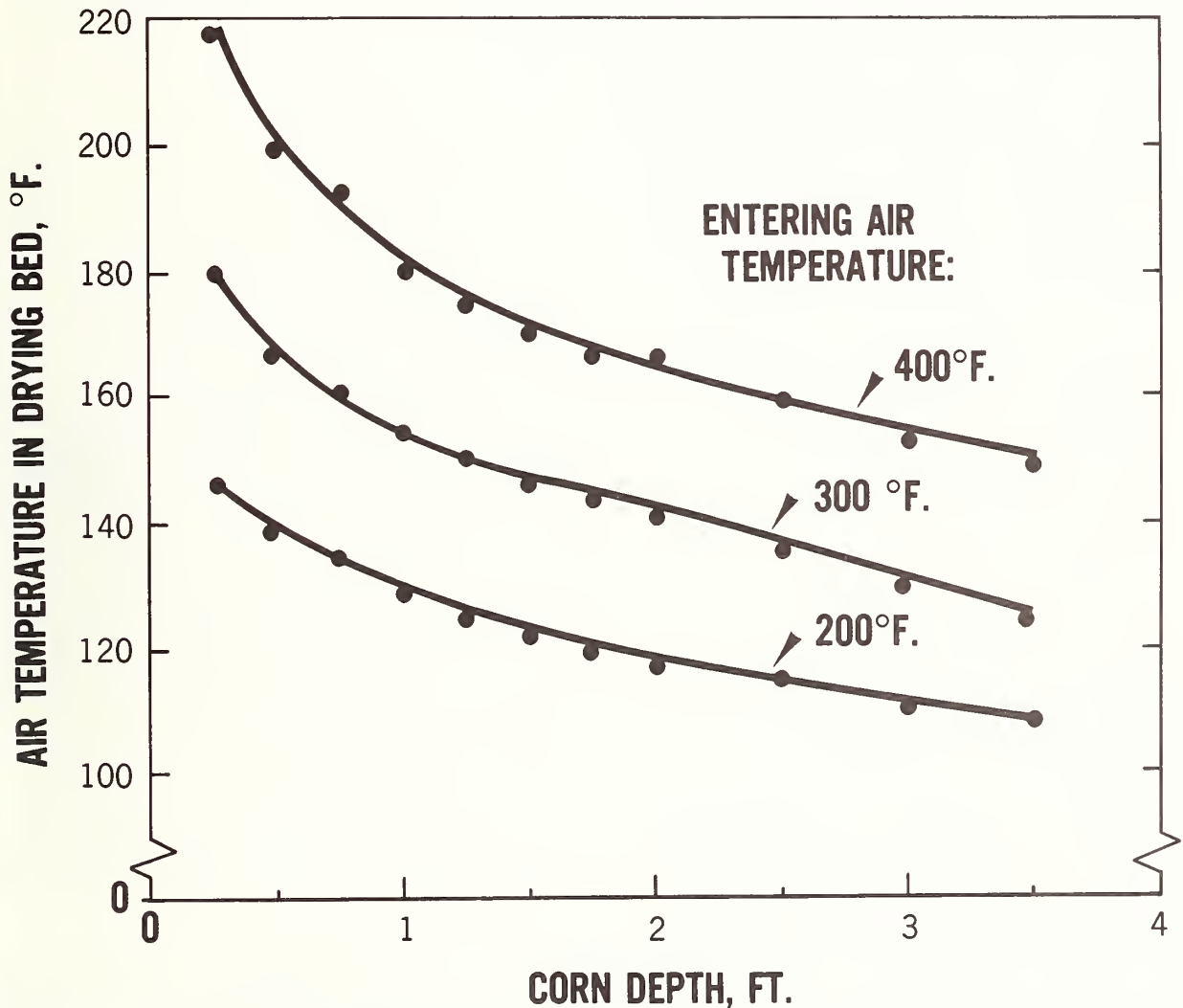


Figure 2.—Air temperatures versus depth of drying bed in experimental concurrent-flow dryer.

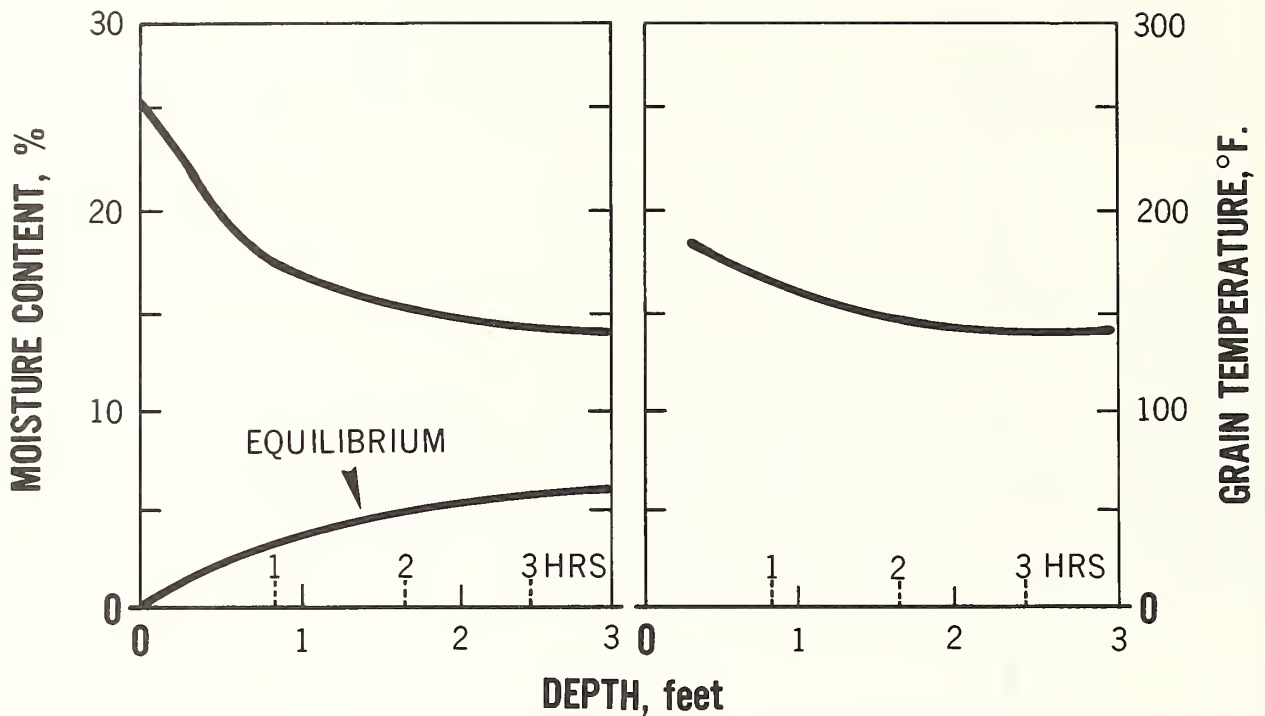


Figure 3.—Typical concurrent-flow dryer simulation results. (Dry air temperature = 250° F.; airflow = 60 c.f.m./ft.<sup>2</sup>; initial moisture content = 25 percent.)

During these tests, the average moisture results were as follows:

Type of sample	Percent moisture content
Initial .....	23.1
Final (removed from dryer before cooling) .....	13.6
Final (cooled with counterflow cooler) ..	13.2
Final (cooled slowly after 4-hour temper) .....	12.4

An average of only 0.4 percentage point of moisture was removed from the corn with counterflow cooling immediately following drying, while 1.2 percentage points were removed with delayed cooling as used in the dryeration process.

The results of the concurrent-flow drying tests may be summarized as follows: (1) Air and corn rapidly approached the same temperature during the first few inches of travel through the drying bed, and then temperatures of both gradually decreased as the corn moved on through the dryer; and (2) as the corn gave off moisture and the air cooled, the relative humidity of the air increased, which slowed down the rate of drying. Thus, the concurrent-flow drying process has "built-in tempering" to relieve some of the drying stresses.

### Quality Evaluations

Corn samples from the concurrent-flow tests were evaluated for stress cracks, breakage, humidex,<sup>6</sup> and for wet process millability. Brief descriptions of these quality tests are presented in the Appendix.

Tables 5 through 9 summarize the quality results by the following treatments: Drying air temperature, drying-bed depth, initial corn moisture, airflow rate, and cooling method. Because the 1964 tests with corn at 18-percent moisture were performed only at the high airflow rates, the initial moisture comparisons were made only with these airflows, and the airflow comparisons were made from the tests with corn at 23-percent moisture. With these exceptions, a given level of treatment was repeated for each level of the other treatments included in the tests. The results presented are an average of all tests at a given treatment level. Corn quality data on individual tests are given in the Appendix.

Table 5 shows the effect of the drying air temperature on corn quality. The millability score decreased as the temperature increased. In 1964, only the tests at the drying air temperature of 200° F. produced millability

<sup>6</sup>Humidex is a term that indicates, by the use of a base curve, the deviation of the measured equilibrium relative humidity (ERH) of a corn sample from the standard ERH of corn.

TABLE 5.—Effect of drying air temperature on corn quality

Year	Drying air temperature	Millability score	Kernels with checked stress crack pattern	Breakage	Humidex
	° F.	Number	Percent	Percent	Percent
1964 . . . . .	200	88.8	45.3	14.5	-0.1
	300	73.4	39.0	15.8	1.9
	400	54.3	27.8	14.0	2.4
Control . . . . .	-	91.7	6.8	6.7	-1.8
1965 . . . . .	200	94.8	79.3	18.4	1.5
	250	83.9	72.7	15.0	2.3
	300	79.6	57.2	12.7	2.4
	350	72.2	56.1	14.1	3.1
Control . . . . .	-	98.0	4.0	6.1	-1.0

TABLE 6.—Effect of depth of drying bed on corn quality

Depth of drying bed (feet)	Millability score	Kernels with checked stress crack pattern	Breakage increase		Humidex
			23 <sup>1</sup>	18 <sup>1</sup>	
	Number	Percent	Percent	Percent	Percent
2 . . . . .	72.2	44.9	8.4	3.1	1.6
4 . . . . .	72.2	29.8	7.7	1.9	1.2
Control . . . . .	91.7	6.8	-	-	-1.8

<sup>1</sup> Percent of moisture content of corn before drying.

TABLE 7.—Effect of initial moisture on corn quality

Initial moisture (percent)	Millability score		Kernels with checked stress crack pattern		Breakage		Humidex	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
	Number	Number	Percent	Percent	Percent	Percent	Percent	Percent
23 . . . . .	91.7	69.4	6.8	36.8	6.6	14.3	-1.6	1.2
18 . . . . .	89.4	86.7	3.2	39.1	3.4	5.9	-1.8	.1

TABLE 8.—Effect of airflow rate on corn quality

Airflow rate (c.f.m.)	Millability score	Kernels with checked stress crack pattern	Breakage	Humidex
	Number	Percent	Percent	Percent
Low <sup>1</sup> . . . . .	75.0	37.8	15.3	1.6
High <sup>2</sup> . . . . .	69.4	36.8	14.3	1.2
Control . . . . .	91.7	6.8	6.7	-1.8

<sup>1</sup> Equivalent to 5 air horsepower for each 100 bushels of corn dried per hour.

<sup>2</sup> Equivalent to 10 air horsepower for each 100 bushels of corn dried per hour.

TABLE 9.—Counterflow cooling versus delayed cooling of corn

Sample No. <sup>1</sup>	Sound kernels	Checked kernels	Millability score	Breakage	Humidex
	<i>Percent</i>	<i>Percent</i>	<i>Number</i>	<i>Percent</i>	<i>Percent</i>
I . . . . .	78.3	4.0	98.0	7.1	-1.0
II . . . . .	1.9	64.4	82.6	14.6	2.5
III . . . . .	19.1	38.2	84.8	11.2	2.5

<sup>1</sup> Sample description I - corn (control sample) dried with room air; II - corn cooled immediately after drying with counterflow cooler; and III - corn cooled slowly after 4-hour tempering period.

scores above the minimum acceptable level of 80.<sup>7</sup> In 1965, the millability scores were 5 to 10 points higher than those in 1964. In the 1965 tests, the millability score of corn dried at 200° and 250° F. was above the acceptable level and the score of corn dried at 300° F. was only slightly below that level.

Most of the damage to milling quality occurred in the first half of the drying period. The average millability scores for samples taken as the corn entered the dryer, at the midpoint, and at the discharge of the drying column were 91.7, 73.5, and 72.2, respectively. Figure 3 shows that temperatures of the air surrounding the corn were higher during the first part of the drying period than during the last part. These results support the contention that excessive temperature is the major cause of reduced millability, and that damage occurs during the first stages of drying if the temperature is high enough.

Table 5 also shows that the percentage of checked kernels decreased as the drying air temperature increased. This decrease is contrary to indicated trends at drying air temperatures lower than those used in these tests, but agrees in part with previous experiments (7). There was some puffing of the kernels, as indicated by visual inspection and reduced test weights. The physical characteristics of the puffed kernels were changed such that stress cracks either did not occur or were not visible with the simple candling procedures used. In the 1964 tests, the test weight of the corn was reduced 1.3, 1.8, and 2.2 pounds per bushel with the 200°, 300°, and 400° F. drying air temperatures, respectively, compared with the control samples dried with ambient air.

There was no appreciable difference in the amount of breakage due to the drying air temperature used. The humidex evaluations showed that the average shift in equilibrium relative humidity (ERH) was greater with higher drying air temperatures.

<sup>7</sup>Watson and Hirata (10) stated that millability scores of 65 to 75 for steeped corn are essential for acceptable wet-milling. More recently, Watson indicated that this minimum acceptable level should probably be raised to 80 (personal consultation with G. H. Foster).

The relation of the depth of the drying bed to corn quality is shown in table 6. The percentage of checked kernels, the amount of breakage, and the average shift in ERH were less in corn dried with the 4-foot drying-bed depth than with the 2-foot depth. The airflow rates used for the tests with a 2-foot drying bed averaged 20 percent higher than those used for the 4-foot tests. This difference in airflow may account for some of the differences in checked kernels and breakage.

The depth of the drying bed did not affect the millability score. This supports the thesis that most of the damage to millability occurs during the initial stage of concurrent-flow drying.

Since the built-in tempering period was longer and the corn less susceptible to stress cracks and breakage at the greater bed depths, it follows that there were some benefits from the tempering inherent in the concurrent-flow drying process.

Table 7 compares the effect on corn quality of drying at two different initial moisture levels. Only results of tests with the higher airflow rates were used for this comparison. There was more damage to millability, more breakage, and a greater shift in ERH in the corn dried from the higher initial moisture. The number of stress cracks formed was about the same for both initial moistures. The corn with 23-percent moisture had started to mold before it was used for the drying tests, so quality data are given in table 7 for the initial (controls) as well as for the final dried samples.

Table 8 shows that the millability score was somewhat lower at the higher airflow rate but that there was essentially no difference in the number of stress cracks or amount of breakage observed.

Table 9 compares the results of tests with counterflow cooling and with delayed cooling. Samples cooled slowly after a 4-hour tempering period had 20 percent fewer stress cracks and 3 percent less breakage than samples cooled immediately with the counterflow cooler. These results indicate that a concurrent-flow dryer with a counterflow cooler is not an adequate substitute for delayed cooling for reducing the brittleness of dried corn.

# SIMULATED DRYING TESTS

Drying is a continuous process with changes in grain moisture, air and grain temperature, and humidity of the air all occurring simultaneously. These changes occur at varying rates at different locations in the drying bed. The basic simulation approach used for this study was to calculate the drying performed in a thin layer of corn and then to combine many thin layers to form the drying bed. The air and corn temperatures at any point in the bed were determined by heat balance calculations.

## Concurrent-Flow Drying

In the concurrent-flow dryer, the deep-bed simulation consisted of simulating the movement of layers of corn through the dryer in the same direction as the flow of drying air. The procedure consisted of calculating the moisture changes in one layer of corn as it traveled through the dryer. The average exhaust air and corn conditions (temperature, humidity, and moisture content) were calculated for a layer in each position. Then the exhaust air from that layer was used as the input air to the same layer, which had moved to the next position for the next time period. This process was continued until the desired depth was obtained. A detailed description of the mathematical model used was presented by Thompson and others (8).

Figure 3 presents the results of a typical simulated drying test showing how the moisture and temperature of the corn vary with drying time and depth of drying bed. These simulated results substantiate experimental results reported under "Results," namely, that (1) most of the moisture is removed during the first part of the drying period; (2) as the corn gives off moisture and the drying air cools, the relative humidity of the air and the

equilibrium moisture content<sup>8</sup> increases and the rate of drying is reduced; and (3) the drying air and corn rapidly approach the same temperature.

Each of the concurrent-flow laboratory tests was simulated on the computer using the observed drying conditions as input data. Table 10 compares the average experimental results for the 1964 tests with those predicted by the computer. The air and grain temperatures observed at various points in the drying column (bed) were about the same as those predicted by the computer model for the test series with an input air temperature of 200° F. At 300° and 400° F., the computer model predicted air and grain temperatures from 5° to 20° F. higher than those measured in the laboratory dryer. The deviation between the predicted and the observed corn moisture contents averaged less than 1 percentage point.

Table 11 compares the average experimental results for the 1965 tests with those predicted by the computer. Corn temperatures at the end of the drying tests were up to 7° higher than those predicted by the simulation model, while those at a depth of 1 foot were 10° to 20° higher than predicted. From 1 to 3 percentage points more moisture were removed experimentally than the simulated results predicted. A constant error in airflow measurement probably accounted for some of this deviation.

The same mathematical drying model that was used for the concurrent-flow simulations was also used to predict drying results for the crossflow and counterflow drying processes. The procedure was the same with calculations made for each thin layer of corn.

<sup>8</sup>Equilibrium moisture content is the point at which corn is in moisture equilibrium with the surrounding or interseed air.

TABLE 10.—Concurrent-flow results for 1964 tests on corn—experimental versus predicted

Drying air temperature (° F.)	Temperature of corn						Average moisture content of corn			
	Predicted for bed depth, in feet			Experimental for bed depth, in feet			Predicted for-		Experimental for-	
	1	2	3 <sup>1</sup>	1	2	3 <sup>1</sup>	Midpoint of drying bed	Final	Midpoint of drying bed	Final
	° F.	° F.	° F.	° F.	° F.	° F.	Pct.	Pct.	Pct.	Pct.
200 . . . . .	134	125	117	136	123	115	15.2	13.8	14.3	13.3
300 . . . . .	174	159	146	167	151	135	15.0	13.2	14.8	13.9
400 . . . . .	207	185	174	190	171	155	14.7	12.6	14.5	13.7

<sup>1</sup> Average of three tests.

TABLE 11.—Concurrent-flow results for 1965 tests on corn—experimental versus predicted

Drying air temperature (° F.)	Temperature of corn				Moisture content of corn	
	Predicted for bed depth, in feet-		Experimental for bed depth, in feet-		Predicted	Experimental
	1	2	1	2		
	° F.	° F.	° F.	° F.	Percent	Percent
200 . . . . .	138	129	147	127	16.1	13.2
250 . . . . .	154	141	172	147	15.5	13.2
300 . . . . .	178	161	191	165	14.9	13.8
350 . . . . .	186	166	202	173	15.9	14.3

**Crossflow Drying**

In a crossflow dryer, the drying air travels perpendicular to the grain flow. If we assume no appreciable mixing or movement of corn from layer to layer, infinitely long layers of corn pass through the dryer and the drying air flows in a direction normal to the corn layers. This type of dryer was simulated by calculating the air and moisture changes as the drying air passed from one layer of corn to the next.

Each layer was dried for a short time interval. The exhaust air from one layer was used as the input drying air for the next. The process was then repeated with many drying intervals until the desired average final moisture was reached. The time that each kernel was subjected to the drying air and the depth of the group of thin layers were used to calculate the grain flow rate through the dryer.

A batch-type dryer was considered to be a type of crossflow dryer where groups of thin layers of corn were stacked one upon another with the drying air flowing up through the stack.

Results of crossflow simulation tests show that corn on the input air side was overdried and corn on the exhaust air side underdried when the average moisture content of the corn reached the desired level (fig. 4). Normal practice is to mix all grain together to obtain the desired final moisture. The average equilibrium moisture content to which the corn could be dried decreased as drying progressed (fig. 4). The equilibrium moisture content varied with time and position in the drying bed according to the temperature and relative humidity of the drying air surrounding the kernels. Figure 4 shows that after half an hour of drying time, corn temperatures on the input air side were approximately equal to the input air temperature. The average corn temperature and the exhaust air temperature increased as the corn dried.

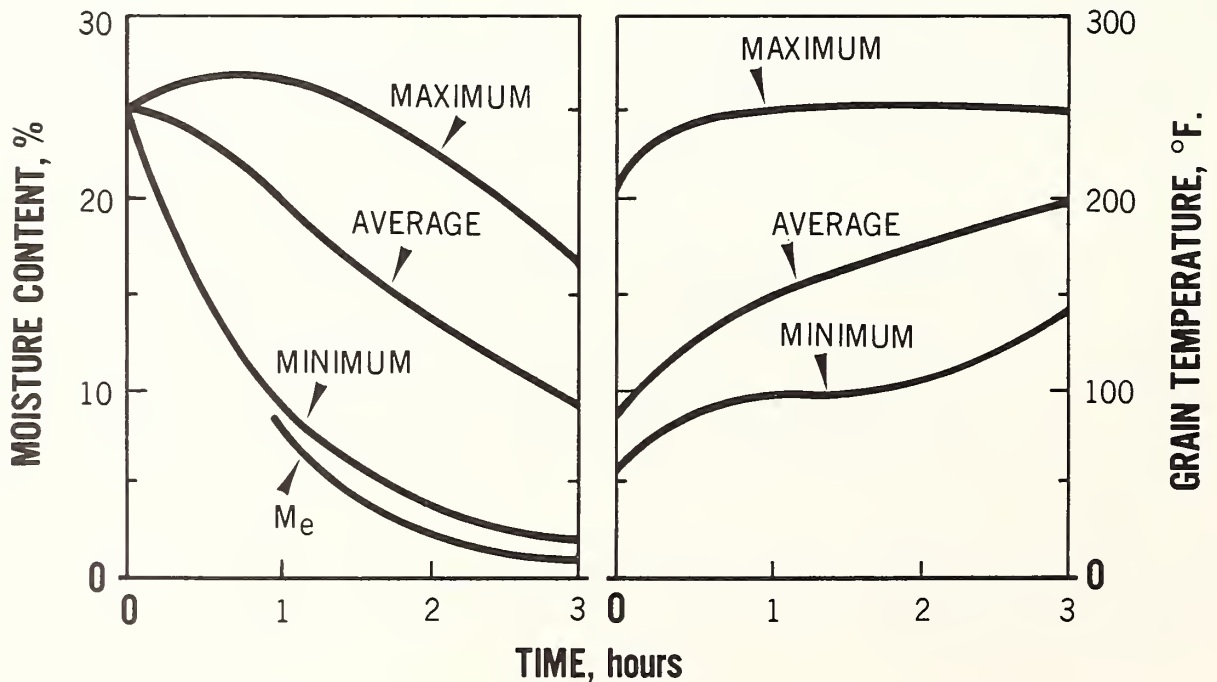


Figure 4.—Typical crossflow dryer simulation results. (Dry air temperature = 250° F.; airflow = 60 c.f.m./ft.<sup>2</sup>; initial moisture content = 25 percent.)

## Counterflow Drying

In a counterflow dryer, the drying air and the corn travel through the dryer in opposite directions. The counterflow process was simulated by considering the corn in the dryer as a group of thin layers with the drying air blowing up through the layers and envisioning that at each time interval a new layer was placed on the top of the stack and a layer removed from the bottom.

Figure 5 presents typical results of a counterflow simulation test. In the counterflow drying zone, the rate of moisture removal was approximately constant. The

equilibrium moisture content decreased as the corn moved through the dryer and maintained a constant or perhaps increasing drying stress on the kernels. Figure 5 shows that a counterflow dryer is similar to a counterflow heat exchanger. The air and the corn, while traveling in opposite directions, exchanged heat energy throughout the whole drying bed. Depending on the bed depth, the drying air is exhausted at approximately the wet bulb temperature of the heated air entering the drying bed, while the grain is discharged at a temperature only a few degrees below the incoming air temperature.

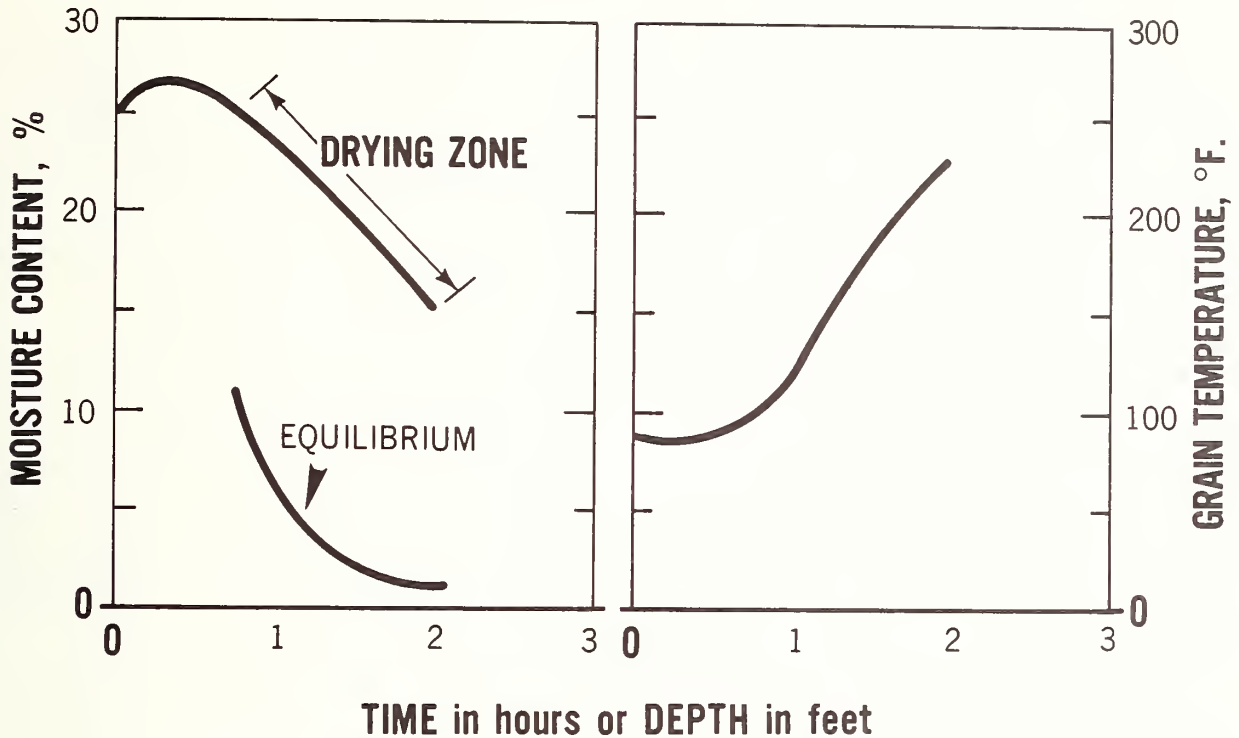


Figure 5.—Typical counterflow dryer simulation results. (Dry air temperature = 250° F.; airflow = 60 c.f.m./ft.<sup>2</sup>; initial moisture content = 25 percent.)

## COMPARISON OF DRYER PERFORMANCES

The performance of any grain dryer depends on the initial and final heat content of the air and the grain and the amount of moisture removed. The drying air has to supply enough energy to heat the grain to the final grain temperature and evaporate the desired amount of moisture.

The overall performance of a dryer can be illustrated with a plot of grain flow rate versus airflow rate. Figures 6, 7, and 8 show the predicted performance of crossflow, concurrent-flow, and counterflow grain dryers, respectively, while drying corn from 25-

15-percent moisture with an initial drying air temperature of 250° F. and initial corn temperature of 50° F. The figures show the effect of depth of drying bed and airflow rate on dryer performance and efficiency.

For any given depth of drying bed, the grain flow rate increased as the airflow rate was increased. Curves were plotted in the figures to relate the drying efficiency of the process with any airflow rate and bed depth. This drying efficiency is the drying rate expressed as a percentage of the maximum rate of moisture removal possible when the drying air is cooled to its wet bulb

temperature, but disregarding any temperature change of the grain. With any bed depth, the drying efficiency decreased as the airflow rate increased.

For a given temperature and airflow rate, there is a maximum effective corn depth for the maximum performance of a counterflow dryer (figs. 5 and 8) when corn of a given initial moisture level and temperature is dried. Water is condensed from the drying air onto the cold incoming corn when depths greater than the maximum effective depth are used and dryer performance is not improved. The maximum performance is

shown in figure 8 for the drying conditions given and for an incoming corn temperature of 50° F.

Figure 9 shows the average final corn temperatures for each of the three drying methods at the same drying air temperature. The final corn temperature was lower with concurrent-flow drying than with either crossflow or counterflow drying. Figure 3 shows that the grain temperature was highest during the initial stages of concurrent-flow drying. However, the temperatures dropped rapidly to levels lower than that for either crossflow or counterflow drying.

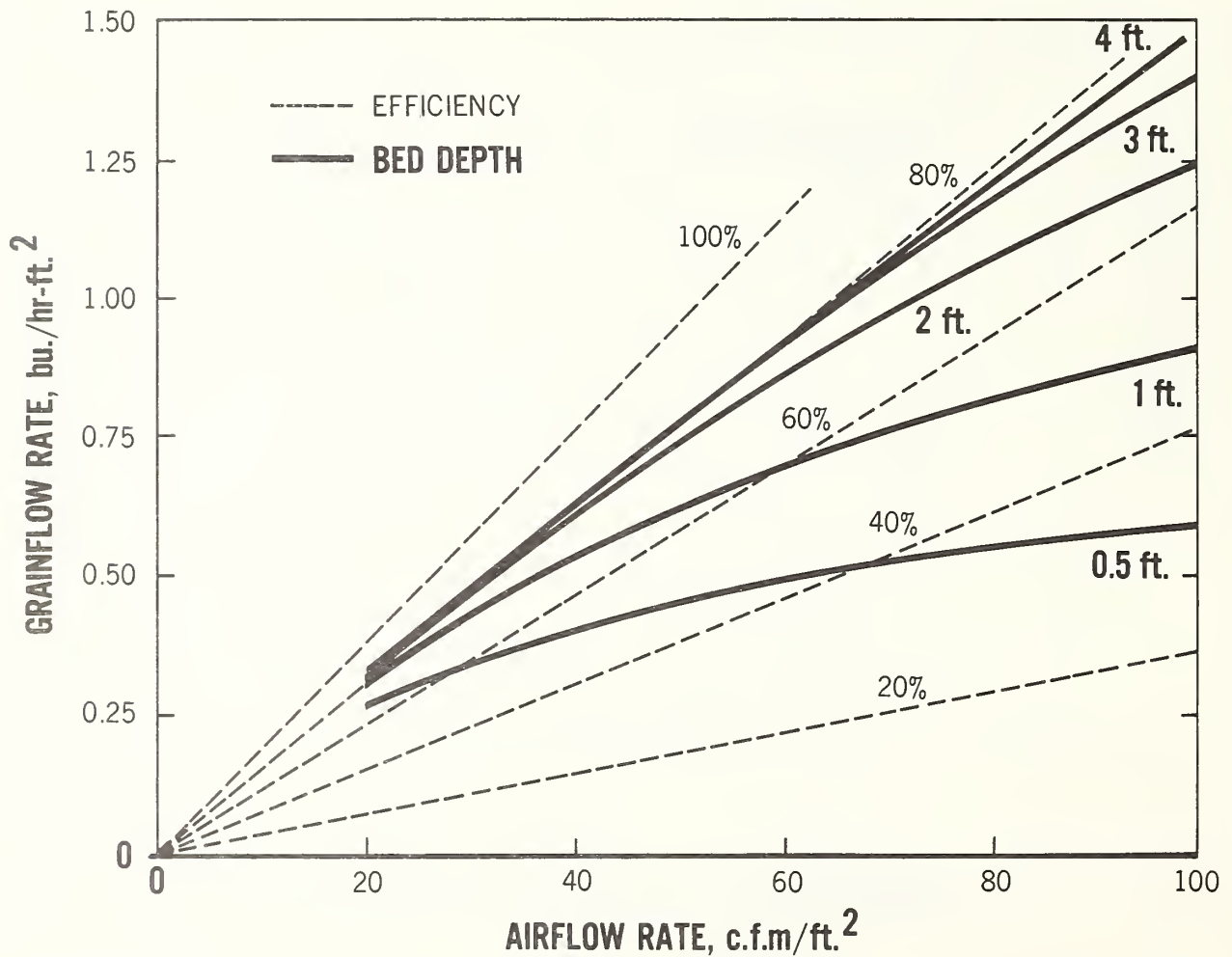


Figure 6.—General performance of crossflow dryer. (Drying air temperature = 250° F.; initial moisture content = 25 percent; final moisture content = 15 percent.)

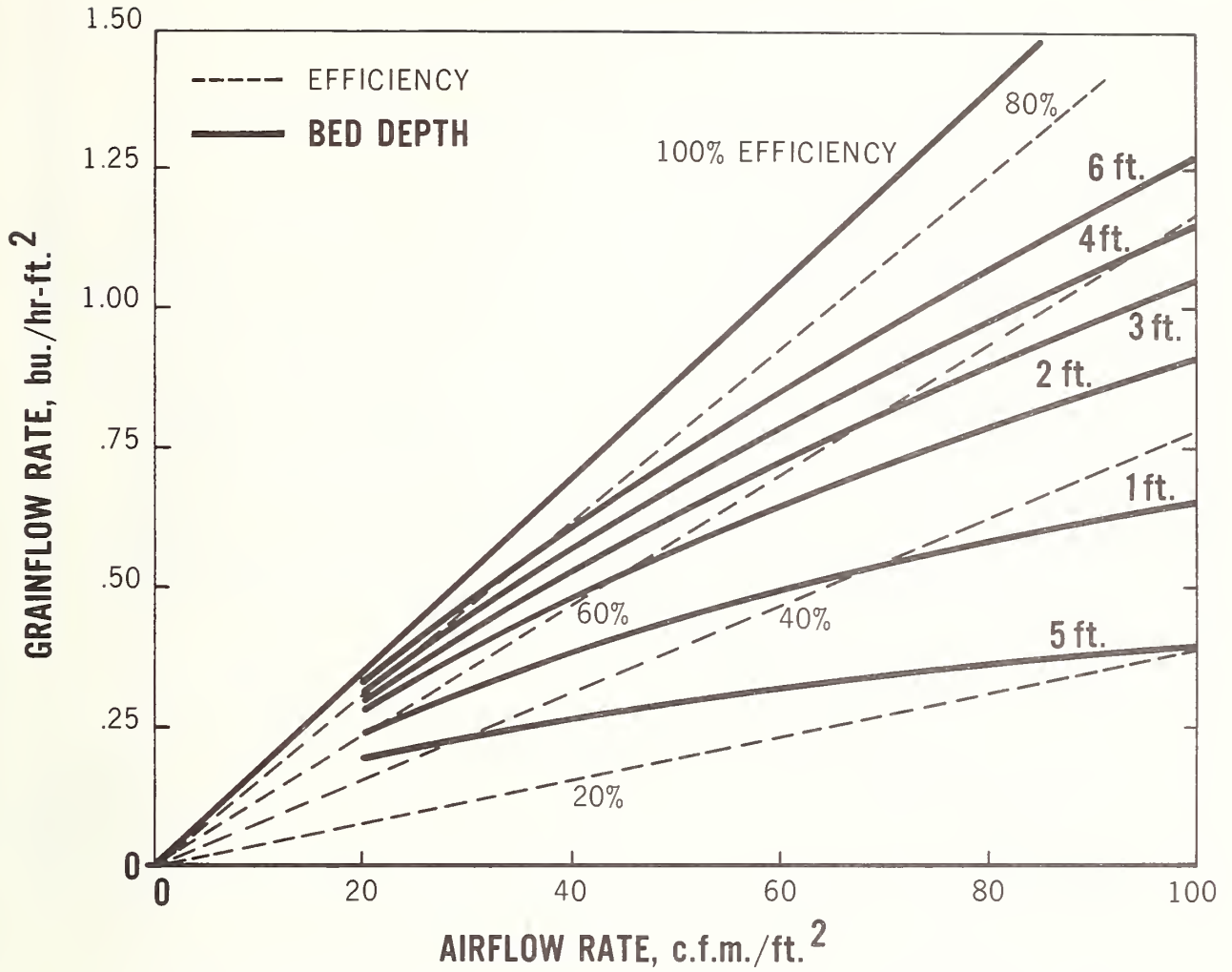


Figure 7.—General performance of concurrent-flow dryer. (Drying air temperature = 250° F.; initial moisture content = 25 percent; final moisture content = 15 percent.)

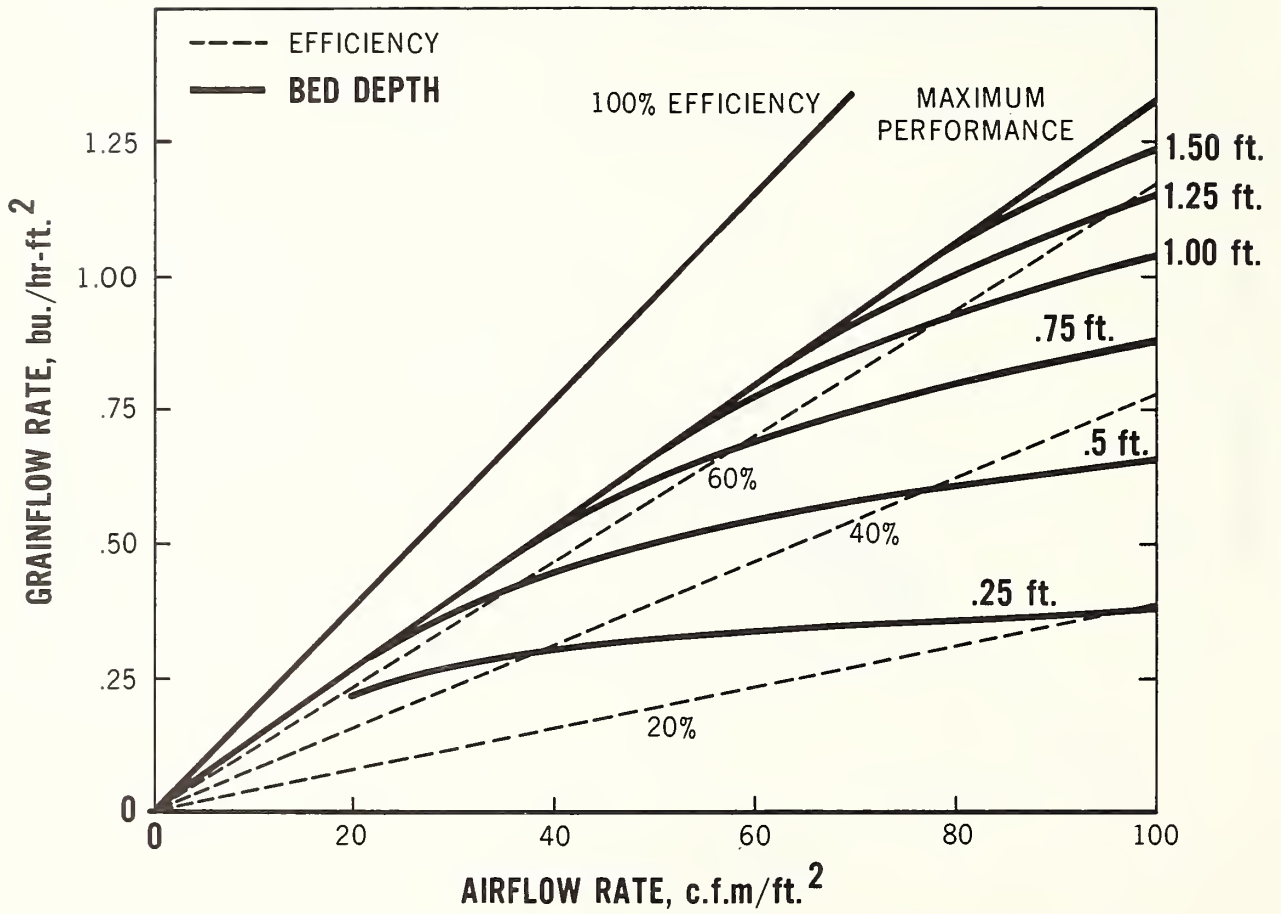


Figure 8.—General performance of counterflow dryer. (Drying air temperature = 250° F.; initial moisture content = 25 percent; final moisture content = 15 percent.)

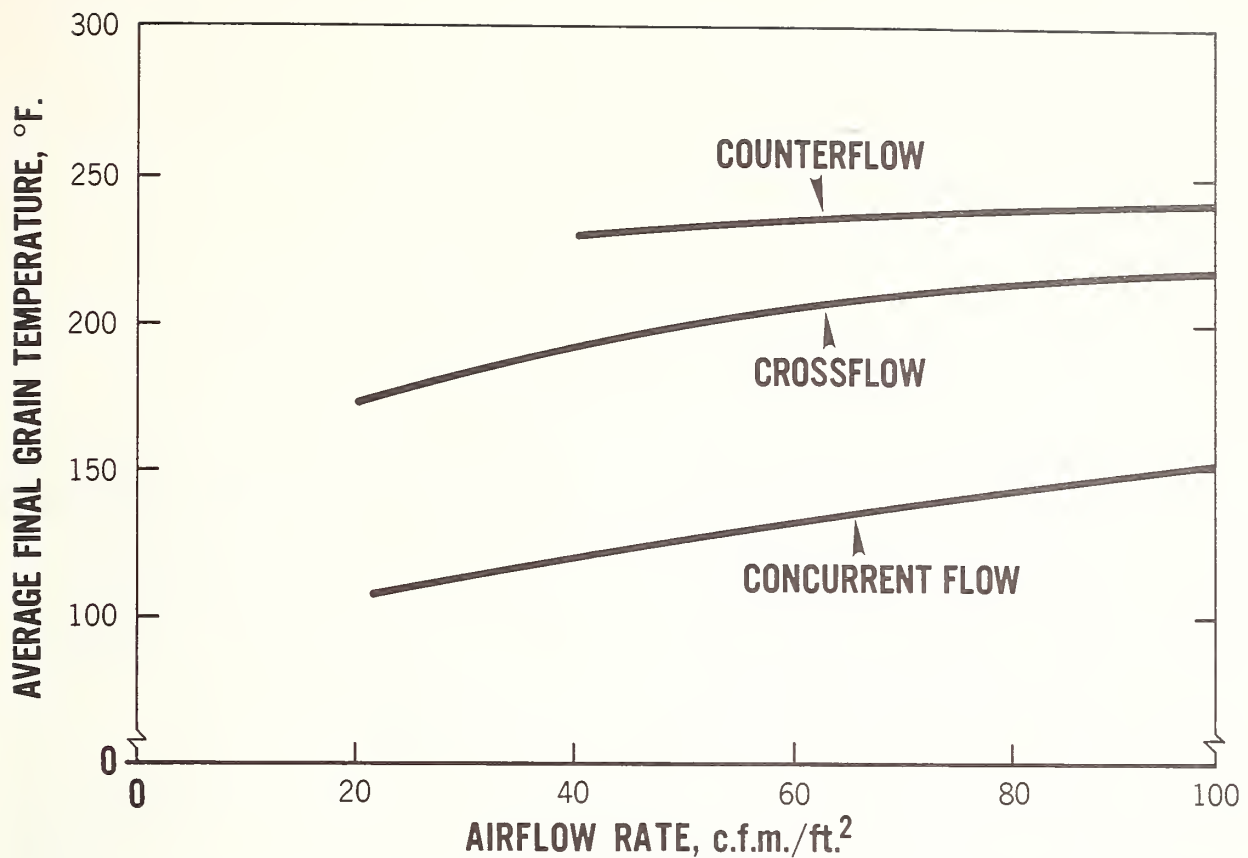


Figure 9.—Comparison of final grain temperature in the three basic continuous-flow drying methods. (Drying air temperature = 250° F.; initial moisture content = 25 percent; final moisture content = 15 percent.)

## DRYER DESIGN PROJECTIONS

Figures 10, 11, and 12 illustrate a few of the dryer design projections possible. These examples are for a concurrent-flow dryer operating at the drying conditions shown. Additional simulations and analyses are required for other drying conditions or dryer designs.

### Optimum Drying-Bed Depths With Selected Air Horsepower

The horsepower necessary to force the drying air through the grain is an important consideration in the design of a dryer. This is especially true for dryers operating with high airflow rates and deep drying beds.

Figure 10 shows the air horsepower required for concurrent-flow dryers to dry corn at the rate of 100 bushels per hour for various combinations of airflow and bed depth. (The lines superimposed on the general performance graphs are lines of constant air horsepower per 100 bushels per hour drying capacity.)

The curves of constant horsepower per 100 bushels per hour in figure 10 show the greatest grain flow rates

at drying-bed depths of about 2-1/2, 3, and 3-1/2 feet for 5, 10, and 15 horsepower, respectively. These are the optimum bed depths with the given air horsepower limitations. For example, with a restriction of 5 horsepower per 100 bushels per hour, the peak grain flow rate is 0.6 bushel per hour per square foot of bed area.

Relationships similar to those in figure 10 can be plotted on the basis of constant horsepower per 100 square feet of drying-bed area.

### Dryer Size

The optimum bed depths in figure 10 also indicate the minimum bed area needed to dry 100 bushels per hour with the given air horsepower limitations. The curves in figure 11 are based on operating a concurrent-flow dryer with drying air at 250° F., using optimum bed depths obtained from figure 10, and drying the corn from 25- to 15-percent moisture. Each of the dotted lines representing horsepower per 100 bushels per hour of drying capacity represents the peak of the horsepower

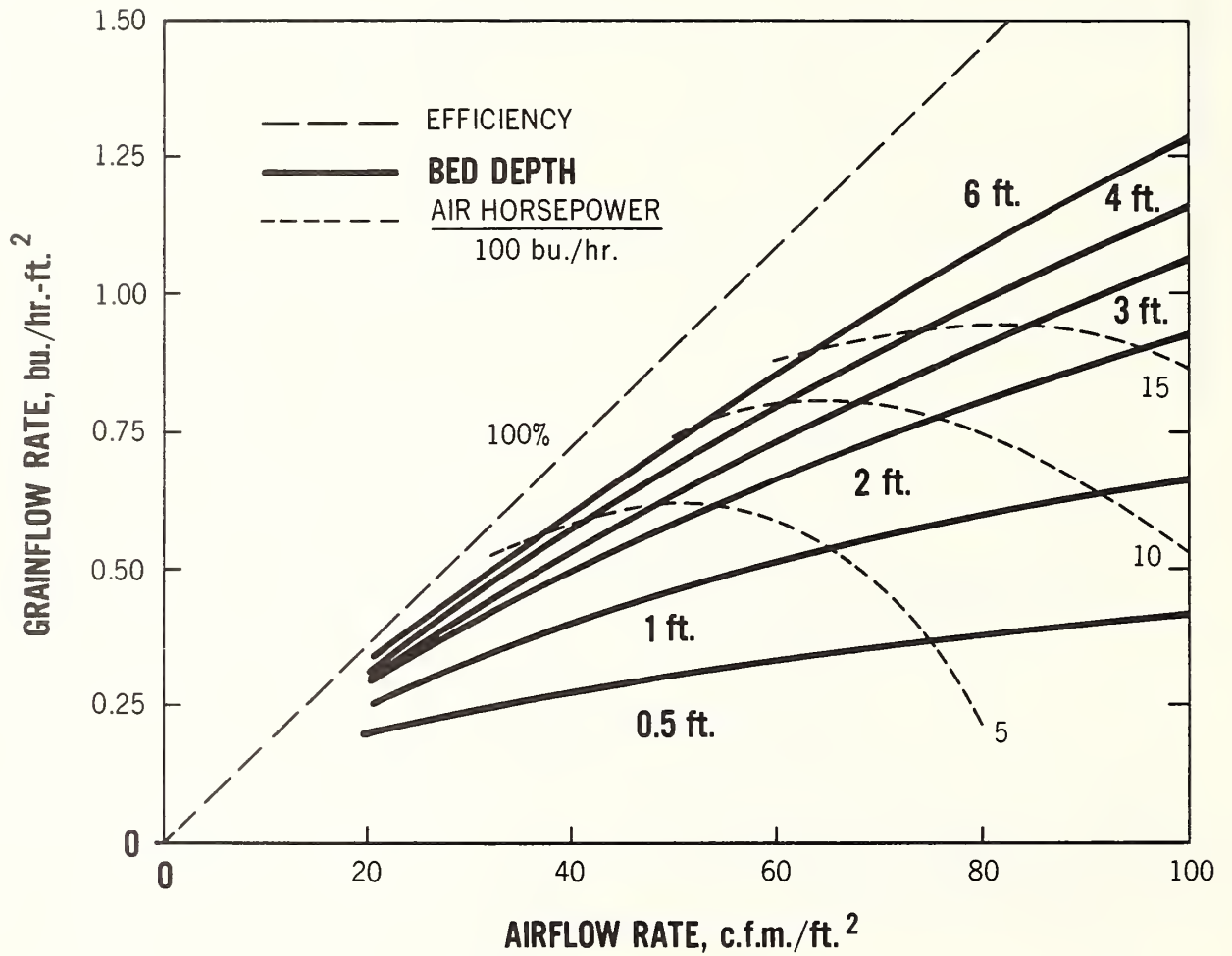


Figure 10.—General performance of concurrent-flow dryer with air horsepower limitations. (Drying air temperature = 250° F.; initial moisture content = 25 percent; final moisture content = 15 percent.)

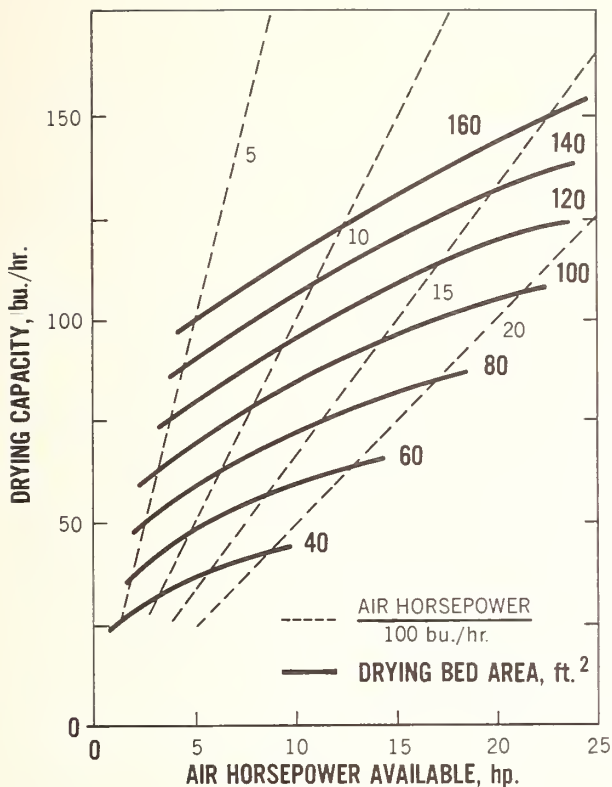


Figure 11.—Cross-sectional area of drying bed needed in a concurrent-flow dryer for various combinations of drying capacities and available horsepower. (Drying air temperature = 250° F.; initial moisture content = 25 percent; final moisture content = 15 percent.)

curve in figure 10. The figure is useful for determining the drying-bed area needed for a desired drying capacity with a given total fan horsepower available. For example, with 15 horsepower available and 100 bushels per hour desired, about 107 square feet of area is needed. This is based on an optimum bed depth of about 3-1/2 feet and airflow rate of about 82 c.f.m./ft.<sup>2</sup> from figure 10. A point on figure 11 that is, for instance, halfway between the dotted lines for 10 and 15 horsepower per 100 bushels per hour would have an optimum bed depth between 3 and 3-1/2 feet.

### Dryer Performance at Other Than Design Conditions

After a dryer has been designed, performance curves similar to those shown in figure 12 can be used to determine dryer performance with initial grain moisture contents other than 25 percent, and to determine drying capacities at other airflow rates. The performance curves in figure 12 are based on a concurrent-flow dryer operating with 250° F. drying air, a 2-foot drying-bed depth, and drying corn to 15-percent moisture. Consider, for example, a dryer with a bed area of 100 square feet supplied with an air volume of 6,000 c.f.m. (60 c.f.m./ft.<sup>2</sup> of bed area). The drying capacity for 28-percent moisture corn is 0.5 bushel per square foot or 50 bushels per hour. For 20-percent corn, the capacity is about 124 bushels per hour. If the airflow is increased to 80 c.f.m./ft.<sup>2</sup> the drying capacity for 20-percent corn is increased to about 150 bushels per hour. Graphs similar to this can be made with other drying air temperatures, bed depths, and dryer types.

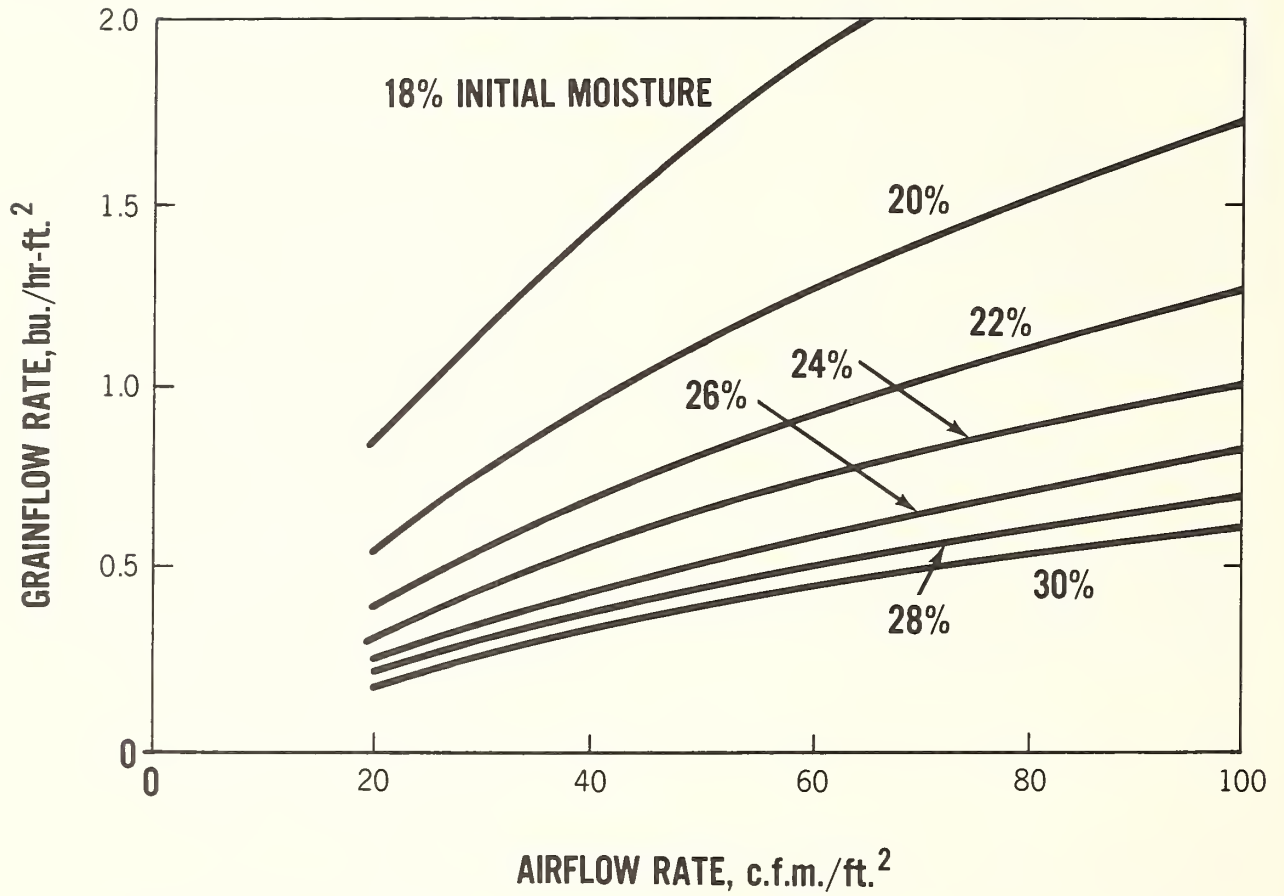


Figure 12.—Performance of concurrent-flow dryer at various initial corn moistures. (Drying air temperature = 250° F.; bed depth = 2 feet; final moisture content = 15 percent.)

## LITERATURE CITED

- (1) FOSTER, G. H.  
1964. DRYERATION—A CORN DRYING PROCESS. PROGRESS REPORT. U. S. Dept. Agr. Agr. Market. Serv. AMS-532, 4 pp.
- (2) \_\_\_\_\_  
1965. DRYING MARKET CORN. Twentieth Ann. Hybrid Corn Indus. Res. Conf. Proc., pp. 75-85.
- (3) HENDERSON, J. M., and HENDERSON, S. M.  
1967. A COMPUTATIONAL PROCEDURE FOR DEEP-BED DRYING ANALYSIS. Amer. Soc. Agr. Engin. Paper 67-316.
- (4) IVES, N. C., HUKILL, W. V., and BLACK, H. M.  
1967. CORN DRYING TIME AT COUNTER-FLOW STEADY STATE. Iowa Agr. and Home Econ. Expt. Sta. Jour. Paper J-5608, Ames, Iowa.
- (5) MACMASTERS, M. M., FINKNER, M. D., HOLZAPFEL, M. M., and others.  
1959. A STUDY OF THE EFFECT OF DRYING CONDITIONS ON THE SUITABILITY FOR STARCH PRODUCTION OF CORN ARTIFICIALLY DRIED AFTER SHELLING. Cereal Chem. 36(3): 247-260.
- (6) SCHROEDER, M. E., and PEART, R. M.  
1967. DYNAMIC PROGRAMMING METHOD OF AIR ALLOCATION IN A GRAIN DRYER. Amer. Soc. Agr. Engin. Trans. 10(1): 96-99.
- (7) THOMPSON, R. A., and FOSTER, G. H.  
1963. STRESS CRACKS AND BREAKAGE IN ARTIFICIALLY DRIED CORN. U.S. Dept. Agr. Market Res. Rpt. 631, 24 pp.
- (8) THOMPSON, T. L., PEART, R. M., and FOSTER, G. H.  
1967. MATHEMATICAL SIMULATION OF CORN DRYING—A NEW MODEL. Amer. Soc. Agr. Engin. Paper 67-313.
- (9) TUIITE, J., and FOSTER, G. H.  
1963. EFFECT OF ARTIFICIAL DRYING ON THE HYGROSCOPIC PROPERTIES OF CORN. Cereal Chem. 40(6): 630-637.
- (10) WATSON, S. A., and HIRATA, Y.  
1962. SOME WET-MILLING PROPERTIES OF ARTIFICIALLY DRIED CORN. Cereal Chem. 39(1): 35-44.

## APPENDIX

### Laboratory Dryer Description and Performance

The experimental laboratory dryer (fig. 13) consisted of an insulated cylindrical drying column 21 inches in diameter, a rotating leveling device floating on the top surface of the corn, and an unloading apparatus to remove the dried corn from the bottom of the dryer. The unloader (fig. 13D) consisted of a circular piece of perforated sheet metal formed into the shape of a helix and supported with solid metal braces on a central shaft. The unloader, which supported the corn column, rotated slowly to cut or separate a thin layer of corn from the bottom of the column.

Wet corn and drying air were continuously metered into the top of the drying column, the corn surface was leveled, and the dried corn was removed by the unloader. Air from the dried grain was exhausted through the perforations in the unloader. The unloader operated intermittently and advanced one-half revolution each time it was energized by a timer. The timer controlled the off period of the unloader and was manually adjusted to maintain the desired corn depth. Thermocouples measured drying temperatures in the center of the drying column.

Data summarizing the results of concurrent-flow drying tests made in 1964 and 1965 are shown in tables 12 and 13.

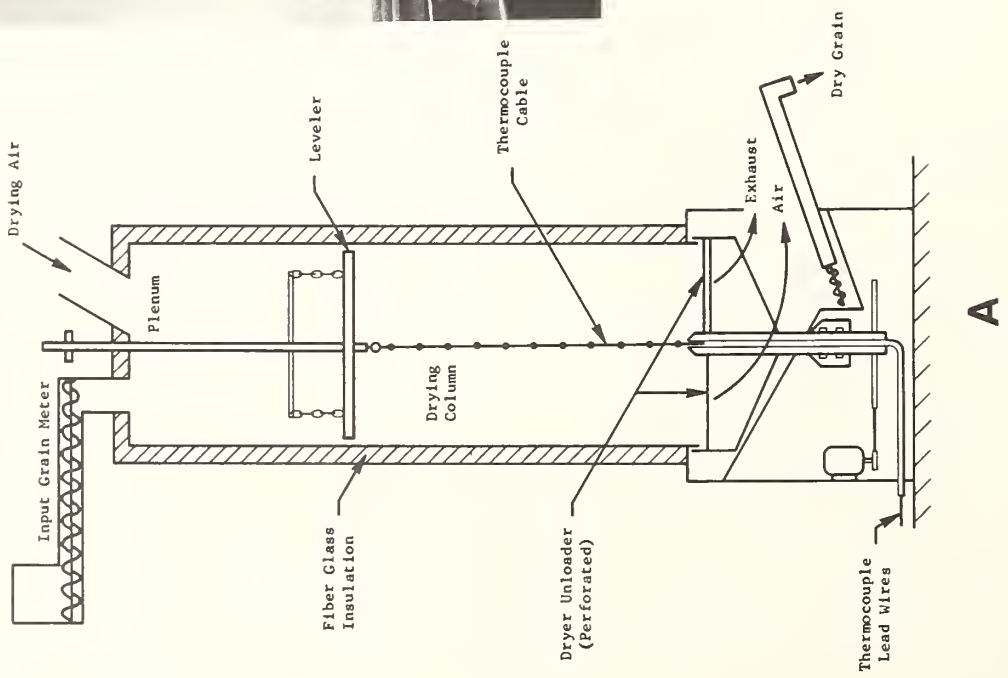
### Corn Quality Evaluation Methods and Results

#### *Stress Crack Analysis*

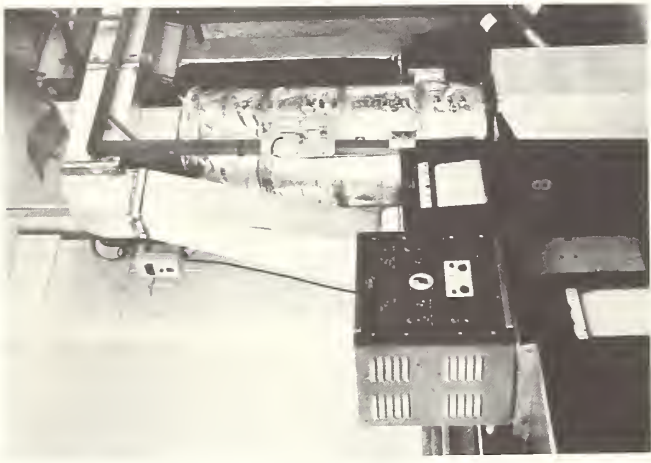
Stress cracks are fissures in the corn endosperm (not the seedcoat) and are readily visible under bright light. They are caused by rapid drying or cooling, or both. Each stress crack analysis consisted of individually candling 50 grams of unbroken kernels and placing them into four categories: (1) No stress cracks; (2) single stress cracks where one fissure extended from tip cap to crown, or one crack completely encircled the kernel; (3) multiple stress cracks where kernels had two or more cracks which did not intersect; and (4) checked kernels having intersecting stress cracks. The percentage of checked kernels was the best single measure of stress crack damage from rapid drying.

#### *Breakage Evaluation*

Corn samples were subjected to a breakage test in a commercial breakage tester. Samples were conditioned to 13.5 percent moisture and 80° F. in a climate-control chamber. Each sample was then placed in a sealed plastic jar for 24 hours to allow the moisture to disperse evenly throughout the kernel. After screening the sample over a 12/64-inch round-hole sieve, all foreign material including pieces of cob, stalk, and other trash was removed by hand. Then 100 grams of the sample was placed in the



**B** BN 31865



**C** BN 31864



**D** BN 31866

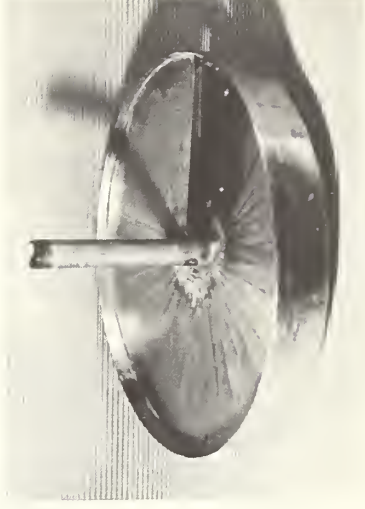


Figure 13.—Laboratory dryer showing—(A) schematic; (B) dryer with inverted “V” exhaust air ducts; and (D) dryer unloader.

TABLE 12.—Summary of 1964 concurrent-flow corn drying tests

[I.S., initial sample; P.S., probe sample removed from midpoint of drying column; F.S., final sample removed hot from dryer]

Test No.	Air temperature	Bed depth	Air horsepower	Drying capacity <sup>1</sup>	Total airflow <sup>2</sup>	Moisture content			Approximate final grain temperature <sup>3</sup>
						I.S.	P.S.	F.S.	
	° F.	Feet	Hp./100 bu./hr.	Bu./hr.	C.f.m.	Pct.	Pct.	Pct.	° F.
21 . . .	200	2	5	1.50	119	22.5	15.1	13.5	120
22 . . .	200	2	10	1.47	168	22.7	14.5	12.7	125
23 . . .	200	4	5	1.12	100	23.0	14.0	13.7	110
24 . . .	200	4	10	1.50	122	22.5	15.5	15.0	108
25 . . .	200	2	10	2.36	169	17.8	13.7	12.5	131
26 . . .	200	4	10	2.00	122	17.5	12.8	12.1	116
31 . . .	300	2	5	2.65	153	22.3	14.3	13.0	152
32 . . .	300	2	10	3.42	235	22.5	15.0	13.0	158
33 . . .	300	4	5	1.79	127	24.8	—	13.5	142
34 . . .	300	4	10	2.71	190	25.2	15.3	15.0	125
35 . . .	300	2	10	4.98	234	18.4	14.5	13.7	158
36 . . .	300	4	10	6.25	188	18.1	15.0	15.2	127
41 . . .	400	2	5	4.57	176	22.0	14.8	14.0	173
42 . . .	400	2	10	5.02	243	22.9	15.3	13.6	177
43 . . .	400	4	5	3.77	172	24.5	14.2	14.0	150
44 . . .	400	4	10	4.07	229	24.0	14.3	14.0	150
45 . . .	400	2	10	7.89	244	18.1	14.7	13.6	175
46 . . .	400	4	10	7.90	230	18.2	13.7	13.5	153

<sup>1</sup> Corrected, 1 bu.<sub>3</sub> = 48.16 lb. dry matter.<sup>2</sup> Corrected, 1 ft.<sub>3</sub> = 0.075 lb. dry air.<sup>3</sup> Temperature leaving the drying column.

TABLE 13.—Summary of 1965 concurrent-flow, corn drying tests

[I.S., initial sample; S.R., sample removed from the dryer before cooling; C.C., sample cooled with the counterflow cooler; S.T., sample cooled slowly after a 4-hour temper]

Test No.	Air temperature	Airflow rate	Drying capacity <sup>1</sup>	Total airflow <sup>2</sup>	Moisture content				Approximate final grain temperature <sup>3</sup>
					I.S.	S.R.	C.C.	S.T.	
	° F.	C.f.m./ft. <sup>2</sup>	Bu./hr.	C.f.m.	Pct.	Pct.	Pct.	Pct.	° F.
205 . . .	200	50	1.44	132	24.7	13.0	12.3	12.3	124
207 . . .	200	70	1.66	182	23.6	13.4	12.7	12.5	130
255 . . .	250	50	2.07	135	24.0	13.0	12.6	12.0	148
257 . . .	250	70	2.70	182	22.0	13.4	13.0	12.7	147
307 . . .	300	70	3.39	182	21.7	13.5	13.0	11.7	163
309 . . .	300	90	3.80	237	23.7	14.1	14.0	12.9	167
357 . . .	350	70	4.24	183	23.4	13.3	13.2	11.8	183
359 . . .	350	90	6.72	235	21.5	15.3	14.6	13.5	167

<sup>1</sup> Corrected 1 bu.<sub>3</sub> = 48.16 lb. dry matter.<sup>2</sup> Corrected 1 ft.<sub>3</sub> = 0.075 lb. dry air.<sup>3</sup> Temperature leaving the drying column.

breakage tester for 4 minutes. The sample was again screened with a 12/64-inch round-hole sieve to remove the broken and fine material resulting from the test. A mechanical sieve shaker agitated the sieve and sample for 2 minutes. Kernels left on top of the sieve were weighed, and the weight loss (from 100 grams) was calculated as the percentage of corn breakage. Two replicates of the breakage test were performed on each sample.

### Millability

Prime starch milling tests were performed on the corn samples using essentially the same procedure as described by Watson and others (10). Dry substance yields of prime starch and cleanup screen residue were calculated as a percentage of the dry weight of steeped grain. The millability score was calculated according to the following formula:

$$\text{Millability score} = 2 (\text{percent prime starch} - 25) - 20 (\text{percent cleanup residue})$$

### Humidex

Tuite and Foster (9) reported that corn dried with heated air supports a higher ERH than corn of the same initial moisture dried with ambient air. The standard ERH base curve was developed previously for corn samples dried without heat. The difference between the measured ERH and the standard ERH, at the same corn moistures, is the humidex (in percentage points). The humidity of the interseed air in equilibrium with a selected corn sample was measured in a closed container equipped with a humidity sensing element.

Results of quality evaluation of the corn dried in the concurrent-flow drying tests are shown in tables 14 and 15.

TABLE 14.—Corn quality evaluations: 1964 concurrent-flow drying tests

[I.R., initial sample dried with room air; P.S., probe sample removed from midpoint of drying column; F.S., final sample removed hot from the dryer]

Test No.	Millability score			Sound kernels			Checked kernels			Breakage			Humidex		
	I.R.	P.S.	F.S.	I.R.	P.S.	F.S.	I.R.	P.S.	F.S.	I.R.	P.S.	F.S.	I.R.	P.S.	F.S.
	No.	No.	No.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
21	90.0	89.4	92.2	33.3	5.2	1.3	2.0	26.4	49.7	6.1	14.5	16.2	-2.6	0.6	-1.0
22	90.0	87.6	89.4	15.8	2.6	.6	20.4	31.8	70.3	5.5	15.2	15.3	-.5	1.0	1.4
23	91.0	90.8	88.2	81.7	9.1	8.8	0	41.6	38.5	6.8	14.6	16.0	-1.7	-.9	.3
24	91.0	90.6	85.4	24.0	7.9	8.7	7.6	30.2	22.6	5.7	12.2	10.7	-1.0	-.5	-1.2
25	89.4	90.0	92.6	71.5	16.2	3.3	4.9	26.8	51.9	3.1	6.1	6.3	-2.4	.2	.3
26	89.4	91.4	92.0	80.3	8.6	1.4	.6	38.9	61.7	2.8	6.4	5.5	-1.7	-.8	-.4
31	92.2	72.0	75.8	33.1	4.5	1.9	7.8	52.6	56.1	6.5	11.8	12.8	-3.4	3.3	1.2
32	92.2	66.8	71.2	57.6	17.0	7.6	2.0	38.4	40.5	5.2	15.1	13.0	-2.9	1.9	2.1
33	91.0	-	80.0	73.8	-	13.4	4.1	-	32.2	8.8	-	18.7	-2.2	-	3.5
34	93.4	81.2	66.8	22.4	8.7	5.9	18.4	34.7	27.0	10.4	18.9	18.9	-1.1	1.4	.9
35	89.4	86.0	90.8	74.0	10.6	2.0	2.8	35.5	45.7	3.2	7.4	6.0	-1.9	.6	.2
36	89.4	91.2	91.4	90.1	38.8	18.5	.7	17.0	8.3	3.7	5.7	4.4	-1.0	-1.3	-2.5
41	92.2	40.8	61.6	41.0	12.4	5.3	8.3	39.9	31.4	5.0	14.4	14.7	-1.3	2.0	2.8
42	90.0	38.8	43.0	21.2	6.0	13.3	6.0	27.8	21.4	4.9	10.7	11.4	-1.9	1.8	3.0
43	93.4	47.4	52.4	56.0	21.9	10.5	5.4	26.0	19.1	8.0	15.6	13.4	-.9	2.2	2.8
44	93.4	-	60.4	84.4	27.0	6.5	.7	21.0	39.2	8.0	19.0	16.5	-2.1	1.0	.9
45	89.4	64.0	73.0	74.8	14.0	14.2	2.8	30.0	28.4	4.1	6.7	7.3	-.9	1.7	1.6
46	89.4	65.2	80.4	69.2	13.4	9.2	4.8	32.4	38.7	3.7	8.6	6.0	-2.8	2.1	1.5

TABLE 15.—Corn quality evaluations: 1965 concurrent-flow drying tests

[I.R., initial sample dried with room air; C.C., sample cooled in dryer with counterflow cooler;  
S.T., sample cooled slowly after a 4-hour temper]

Test No.	Millability score			Sound kernels			Checked kernels			Breakage			Humidex		
	I.R.	C.C.	S.T.	I.R.	C.C.	S.T.	I.R.	C.C.	S.T.	I.R.	C.C.	S.T.	I.R.	C.C.	S.T.
	<i>No.</i>	<i>No.</i>	<i>No.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>	<i>Pct.</i>
205 . . . . .	98.8	95.4	94.8	0.6	0	0.6	35.3	81.3	63.2	12.0	21.8	16.0	0.3	1.0	1.4
207 . . . . .	98.8	94.2	98.0	75.0	0	0	4.7	79.3	60.6	7.4	18.4	14.8	-1.2	2.1	2.6
255 . . . . .	98.8	84.6	90.0	81.0	0	.7	4.8	83.3	53.8	6.7	19.7	16.1	-1.0	2.8	3.4
257 . . . . .	98.6	83.2	90.6	68.6	1.4	10.9	4.3	62.1	38.8	5.7	10.4	9.7	-1.3	1.8	1.3
307 . . . . .	98.6	78.0	78.6	77.9	1.4	21.8	7.6	72.5	42.3	5.9	13.6	10.8	-1.7	.5	2.7
309 . . . . .	97.0	81.2	79.6	83.2	2.9	36.2	0	41.9	24.6	4.5	11.8	9.4	-.8	4.4	2.8
357 . . . . .	97.0	61.2	65.0	92.8	.7	27.0	.7	56.3	24.8	5.7	14.4	7.6	-.1	4.3	3.7
359 . . . . .	97.0	83.2	82.2	69.9	7.1	37.2	5.9	56.0	22.6	6.8	13.7	10.2	-.8	2.0	.9

UNITED STATES DEPARTMENT OF AGRICULTURE  
Agricultural Research Service  
Hyattsville, Maryland 20782

---

Official Business



POSTAGE & FEES PAID  
United States Department of Agriculture