Minimum Air Flow Requirements for Drying Grain with Unheated Air

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MECHANICAL ventilation with unheated air may be used for drying grain and offers certain advantages over heated air. This method is usually considered less expensive (except possibly for the large grain producers), requires less supervision, and generally presents less fire hazard than drying with heated air. However, the effectiveness of unheated air drying is dependent on weather conditions.

In addition to the uncontrollable weather factor, the moisture ranges through which grain is to be dried and the rate at which the drying air is supplied are important factors influencing the effectiveness of unheated air drying. The air-flow rate used greatly affects both the equipment required and the operating cost. For example, increasing the rate of air flow from 2 to 4 cfm per bu through the same depth of grain will increase the power required about six fold, while the drying rate can only be doubled. Thus it becomes important to establish the minimum rate of air flow which can be expected to dry the grain without objectionable quality deterioration during the drying process. Actually the controlling factor is the maximum length of time the grain can be held with excess moisture before drying is completed.

This paper is a progress report of a series of five tests conducted to determine the air flow rates required for drying wheat and shelled corn with unheated air under Indiana weather conditions. Also included in the tests was a comparison of the effectiveness of continuous and intermittent ventilation for unheated air drying.

TEST PROCEDURE

Eight lots of grain of 16 bu each were used in each test series. Three test series were run with shelled corn and two with wheat. The shelled corn tests were conducted in the fall of 1950, 1951, and 1952, and the wheat tests in the summer of 1951 and 1952.

Air-flow rates chosen for the drying tests ranged from a high of 4 cfm per bu, which previous experience had shown was usually adequate, down to a minimum of ½ cfm per bu. The air-flow rates used for the 1950 shelled corn test and the 1951 and 1952 wheat tests were ½, 1, 2, and 4 cfm per bu. For the 1951 and 1952 shelled corn tests, air-flow rates of 1, 2, 3, and 4 cfm per bu were used.

The initial grain moisture content of the test lots was approximately 25 percent for shelled corn and 20 percent for wheat. These moisture levels were selected as being near the maximum moisture level at which the respective grains would ordinarily be harvested. Air-flow rates satisfactory for drying grain at these moisture levels would be more than adequate for grain at lower initial moisture levels.

One fan was operated continuously and supplied air to 4 lots of grain at the four selected air-flow rates. A second fan was controlled with a humidistat and operated intermittently. This fan supplied air to four lots of grain at air-flow rates identical to those supplied by the fan operated continuously. The intermittent fan operated only when the relative humidity of the air was below 70 percent in the tests in 1950 and 1951. The controlling point was raised to 85 percent relative humidity in the 1952 tests.

Air volume was controlled in the first series of shelled corn tests by setting the static pressure in the air-entrance plenum according to the known relation between resistance pressure, air flow, and depth of grain. In later tests, volumetric measurements of the air with a vane anemometer were also made. Although the precision of the air-volume measurements was not established, the measured volume was approximately that predicted from the static pressure reading. The air-flow rates were based on the number of bushels by volume at the initial moisture level.

Results of the drying tests were determined from samples drawn from each lot of grain with a standard sampling probe. Moisture content, viability, fat acidity, and commercial damage determinations were made from the samples. Sampling was done at varying intervals depending on the rate of drying and the rate of change in the condition of the grain. The grain was weighed when the test started and again when removed from the test bins. Grain temperatures were taken weekly with three thermocouples spaced uniformly down the vertical centerline of the bin.

EQUIPMENT

The tests were made in two identical bins of four compartments each. Each compartment was 2 ft square and 6 ft deep. A false perforated floor was installed one foot above the bottom of each compartment leaving a grain depth of 5 ft. Each bin was equipped with a small multivane blower driven by an electric motor. The fan delivered air to a plenum which served each of the four compartments. An adjustable slide was installed over a series of orifices between the fan plenum and the individual compartment plenum under the grain. The selected air volumes for each compartment were controlled by adjustment of the slide covering the orifices.

The equipment was located inside of an unheated building at the Purdue Electric Farm. The building, formerly an ear-corn crib, had slatted sidewalls. The drying air was drawn from the outside through metal pipes and the humidistat controlling the intermittent fan was installed outside of the building in a small instrument shelter.

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DISCUSSION OF RESULTS

The data collected on the 40 tests include some 1200 determinations of grain moisture content, germination, fat acidity and kernel damage. In addition, regular measurements of resistance pressure were made and a continuous record of psychrometric data charted. The data on drying rate and weather conditions shown in Figs. 1 and 2 are typical of that collected in each test.

The data on all of the tests were summarized as presented in Tables 1 and 2 for easier comparison between individual tests. The more important factors considered in evaluating minimum air-flow rates for drying grain and reported in Tables 1 and 2 are as follows:

1 The length of the drying period required
2 The amount of grain deterioration during drying
3 Method of ventilation—continuous or intermittent
4 Weather conditions during drying

Length of the Drying Period Required. The moisture content of both wheat and corn dropped in a fairly uniform manner until it was about 15½ to 16 percent. After it reached this level, changes were irregular and apparently were determined by atmospheric conditions more than by air-flow rates. An exception to this was the 1950-51 shelled corn tests in which the drying was obviously too slow except at the 4-cfm continuous rate. For this reason the length of the drying period reported in Tables 1 and 2 is the number of days required to reach 15½ percent, even though drying is not completed at this time. The tests did not show a relation between the rate of air flow and the drying time during this final period, that is, from 15½ to 13 percent moisture. The results indicate that continuous ventilation cannot be relied upon to reduce the grain moisture to a storable moisture level of 13 percent and that intermittent ventilation is usually more effective than continuous ventilation for drying the grain from 15½ to 13 percent moisture.

The time required to reduce the moisture content of wheat from 19.2 to 15½ percent varied from 5 to 74 days in these tests. In general, the drying time reported increased about in proportion to the decrease in the air-flow rates used. The two wheat drying test series were started July 18, 1951, and July 9, 1952. Soft red winter wheat of the same variety was used both years. In 1951 the wheat was harvested when the moisture content first reached about 20 percent, while in 1952 it had field dried to below 14 percent but was later rewetted by rain and dew

The time required to reduce the moisture content of corn from around 25 to 15½ percent varied from 18 to 168 days in the tests reported. The moisture removed from the shelled corn amounted to about 2¼ times that removed from the wheat. In the four tests with continuous fan operation and the same air-flow rates, the time required to dry the shelled corn averaged about three times that for the wheat for the same years. Although the average relative humidity was only slightly higher during the corn drying tests, the average temperature was 30 to 40 deg lower.

All the shelled corn tests were started late in the fall during the last part of the normal harvesting season. The 1950 test was started November 17, more than two weeks later than the 1951 and 1952 tests. The average temperature during the 1950 test was below freezing and averaged only 24 F during the first 42 days of the test period. The time required for drying in 1950 was about twice as long as that reported in 1951 when the temperatures were 33 to 41 F.

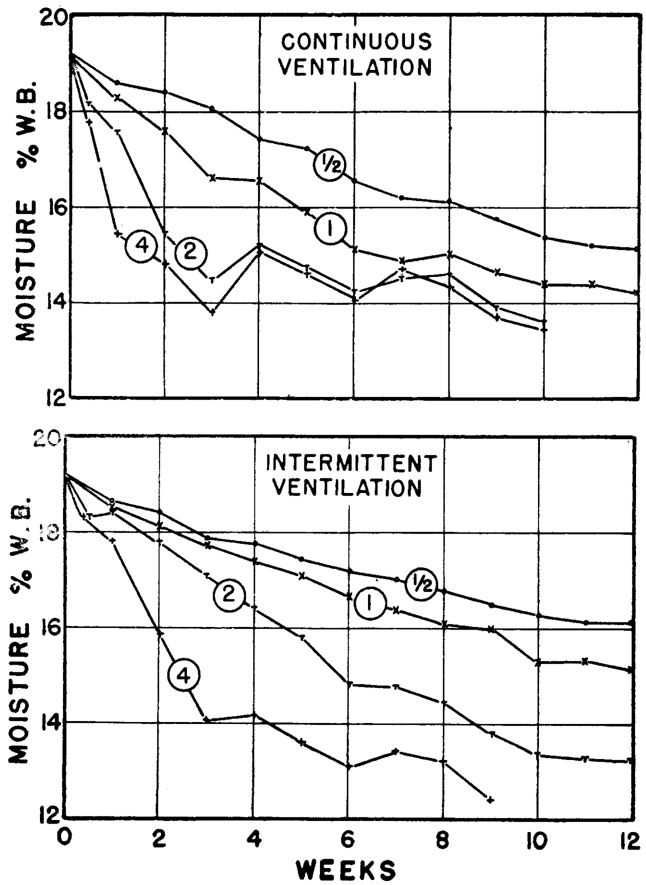

Fig. 1 Rate of moisture reduction of wheat ventilated continuously and intermittently at air-flow rates of ½ to 4 cfm per bu, July 16 to October 8, 1951

Grain Deterioration During Drying. The maximum length of the drying period, and hence the minimum air-flow rate for a given set of drying conditions, is limited by

TABLE 1. SUMMARY OF WHEAT DRYING TESTS

(Initial Moisture, 19.2 percent)

Fan operation	Air flow rate, cfm per bu	Days to dry to 15½% moisture 1951	1952	Grain deterioration index * 1951	1952	Average Air Conditions Temperature, deg F 1951	1952	Relative humidity % 1951	1952
	4	7	5	1.1	0.3	74	77	72	70
Continuous	2	14	15	2.0	1.8	75	78	74	76
	1	41	24	3.8	3.5	72	77	75	74
	½	68	44	5.2	6.2	68	74	75	75
	4	15	12	2.7	2.3	81	82	54	64
Intermittent**	2	36	22	4.5	4.1	79	83	55	64
	1	74	40	6.8	5.8	75	79	54	60
	½	Drying not complete at end of test period							

* Grain deterioration index = decrease in percent germination ÷ 10 + increase in fat acidity index ÷ 10 + increase in percent commercial damage. The deterioration reported was for the entire test period.

** Intermittent fan operation limited to periods when relative humidity was below 70 percent in 1951 tests and below 85 percent in 1952 tests. Fan operated from 31 to 36 percent of total time in 1951 and from 48 to 61 percent in 1952.

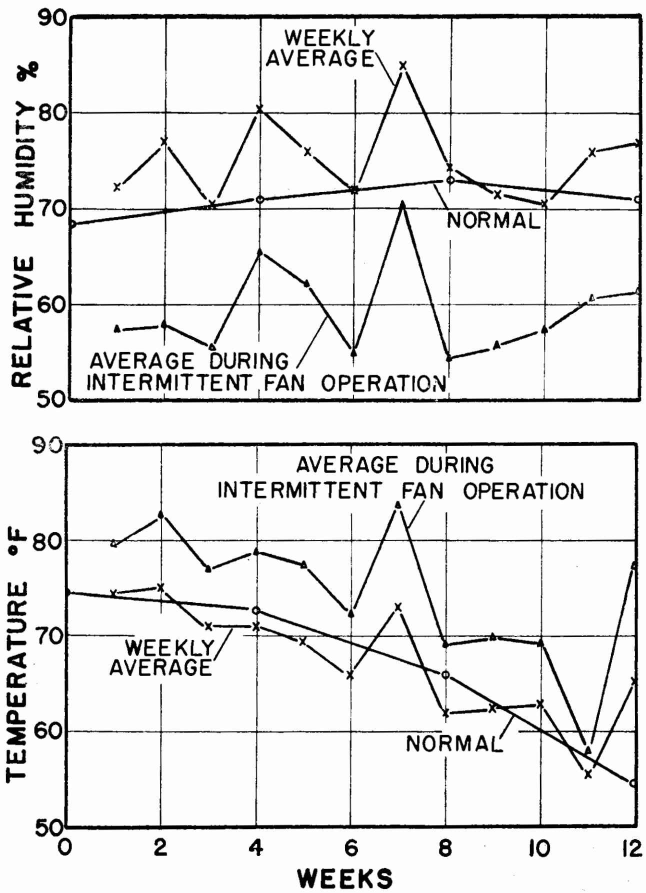

Fig. 2 Average weekly temperature and relative humidity during wheat drying tests, July 16 to October 8, 1951

the amount of grain deterioration that is acceptable. Grain deterioration may proceed to a point where mold growth seriously limits the passage of air through the grain. This occurred in two lots of shelled corn in 1950 which were ventilated at an air-flow rate of ½ cfm of air per bushel. Self-heating followed and the grain was removed from the test bin.

The three measures of grain deterioration used—viability, fat acidity, and commercial damage—were combined into a deterioration index with each measure having about equal weight. The deterioration expressed by this index increased with an increase in drying time in each test series. The relation of grain deterioration to drying time is shown graphically in Fig. 3. Although the drying time was reported as the number of days to reach 15½ percent moisture, the deterioration reported was for the entire test period.

Drying time appears to account for most of variation in grain deterioration in the wheat-drying tests. The deterioration rate in the corn-drying tests, while appreciably lower than that for wheat, varied widely between tests. The initial condition of the corn when harvested ranged from good quality corn in 1951 to exceptionally poor quality with a high percentage of immature or "chaffy" corn in 1952. This undoubtedly accounted for some of the variation.

A deterioration index of 2 was arbitrarily chosen as the maximum permissible for establishing minimum air-flow rates for satisfactory drying. For wheat, this limit was exceeded only when the drying period extended beyond 12 to 14 days. This limit was not exceeded in any of the corn tests where the moisture was reduced to 15½ percent within 30 days. The slower rate of deterioration in the corn may be due to inherent differences in the resistance to deterioration of corn and wheat, but more likely to differences in the air temperatures prevailing during the wheat and corn-drying tests. The corn also had a higher initial moisture—a condition normally considered conducive to higher deterioration rates.

After about 10 days of drying, visible mold formed on the surface of those lots of wheat that had not dried to about 15½ percent by that time. The appearance of mold on the wet shelled corn occurred after about 20 days. The moldy wheat lacked the luster of clean wheat and formed an objectionable dust when handled after drying was stopped. This dusty condition was not considered as commercial damage by the local grain inspector. The mold damage on the corn, if serious enough, was counted as commercial damage.

Continuous or Intermittent Ventilation. Continuous ventilation was more effective for drying high moisture grain to the 15½ percent level. For further reducing the moisture content below 15½ percent, intermittent ventilation was more dependable and faster in most of the tests. In the 1951 tests, the drying time for reducing the moisture content of the grain to 15½ percent with continuous ventilation was approximately one-half that for intermittent ventilation at the same air-flow rate. Increasing the controlling point of the humidistat from 70 percent relative humidity in the 1951 tests to 85 percent in the 1952 wheat tests altered this relationship very little. However, the drying time was reduced in the 1952 shelled corn tests when the controlling point of the intermittent ventilation was raised to 85 percent. This reduction was more evident in the tests completed during the first part of the drying period when the relative humidity was below average.

The relative effectiveness of continuous or intermittent ventilation for drying grain of moisture contents below about 15½ percent was much more dependent on favorable

TABLE 2. SUMMARY OF SHELLED CORN DRYING TESTS

(Initial moisture 1950, 25%; 1951, 24.5%; 1952, 26.5%)

Fan operation	Air flow rate, cfm per bu	Days to dry to 15½% moisture			Grain deterioration index *			Average Air Conditions Temperature, deg F			Relative humidity, %		
		1950	1951	1952	1950	1951	1952	1950	1951	1952	1950	1951	1952
Continuous	4	42	20	18	4.0	0.5	1.8	24	34	46	77	79	72
	3	--	27	26	--	1.6	1.8	--	34	45	--	80	76
	2	77	41	46	10.6	2.1	6.2	26	37	42	76	77	79
	1	154	**	**	28.7	8.9	11.7	31	33	38	77	82	84
Intermittent	4	110	49	21	17.2	2.0	0.6	22	41	50	63	58	65
	3	--	**	40	--	6.7	4.4	--	39	47	--	61	65
	2	168	**	**	46.7	10.8	6.8	34	39	45	62	61	67
	1	***	**	**	***	30.8	17.2	***	39	45	***	61	67

NOTE: Intermittent fan operation limited to periods when relative humidity was below 70 percent in 1950 and 1951 tests, and below 85 percent in 1952 tests. The fan operated 20 percent of the total time in 1950, 24 percent in 1951, and 69 percent in 1952 in the tests with the 4 cfm per bu air-flow rate.

* Grain deterioration index = decrease in percent germination ÷ 10 + increase in fat acidity index ÷ 10 + increase in percent commercial damage. The deterioration was reported for the entire test period.

** Moisture content above 15½ percent at end of test period of 24 weeks in 1950 and 12 weeks in 1951 and 1952.
*** Test discontinued after grain started heating.

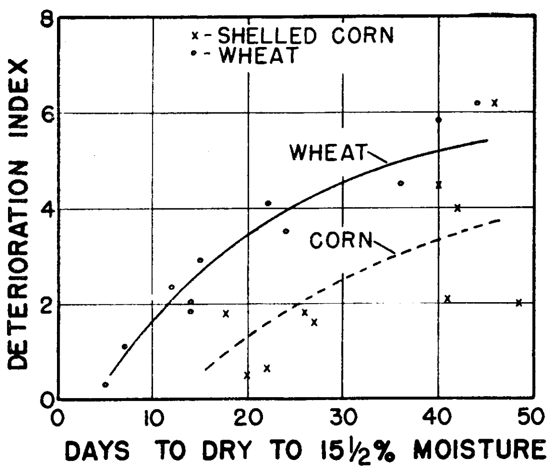

Fig. 3 Relation of grain deterioration to drying time

weather conditions than when grain moistures were higher. For example, in the 1951 wheat tests illustrated in Fig. 1, the lot ventilated at 2 cfm continuously reached 15½ percent moisture in two weeks but remained above 14 percent for nine weeks. In the lot ventilated intermittently at 2 cfm per bu, five weeks was required to reduce the moisture level to 15½ percent, but the 14 percent level was reached at the same time as that ventilated continuously. Contrasted to 1951, favorable weather occurred at the opportune time in 1952, and the lot ventilated at 2 cfm continuously was lowered to 13 percent in less than three weeks. Four weeks were required to reach the same point with 2 cfm intermittently.

Weather Conditions During Drying. The drying capacity as well as the drying potential of natural air is changing continually. There are periods in nearly every day when the drying capacity and potential are negative under Indiana weather conditions. An arithmetic average of temperature and relative humidity were not sufficiently precise for calculating relative drying efficiencies of the tests.

The average relative humidities for the various test periods varied only from about 70 to 80 percent. This variation was insufficient to explain the difference in drying rate between tests at the same air-flow rate. The difference between the average temperature in summer wheat drying and that in late fall corn drying apears to affect both the drying time and the drying efficiency. A complete analysis of the weather data and its effect on drying with unheated air is necessary for wider application of the drying data collected.

General Observations. The increase in commercial damage in all of the wheat tests was less than 2 percent and was not considered an important deterioration factor. Damage increases in shelled corn ventilated at the lower air-flow rates ranged from 15 to 30 percent.

Deterioration was generally higher in the top one foot of grain which dried last. The top one foot of wheat in the 1952 tests showed a deterioration index from 0.9 to 1.8 points higher than the average for the lot, when ventilation was continuous. For the intermittently ventilated lots, the difference ranged from 0.9 to 3.0 points. This difference was less than expected, but was even smaller in some of the shelled corn tests.

There was no evidence of "sick" wheat in any of the tests.

The loss in dry weight during the drying process was negligible in all the wheat tests. In the shelled corn tests, significant dry weight losses occurred in 1950 in the tests in which self-heating occurred. The self-heating started in early April after about five months of ventilation. These lots, removed shortly after heating started, showed a loss in dry weight of 2 to 3 percent. The three tests that were above 15 percent moisture at the end of the 12-week test period in 1952 showed dry weight losses of from 2.4 to 5.0 percent. No heating was observed in these lots. Dry weight changes in all other lots were less than 1 percent.

Measures of static pressure and air volume showed that the static pressure increased as the grain dried. In order to maintain the initial air volume, it was necessary to increase the static pressure periodically throughout the drying period even though the depth was reduced as much as 20 percent from shrinkage.

SUMMARY

1 The minimum air-flow rate for drying grain with unheated air is largely dependent on the limits of grain deterioration that are acceptable. For Indiana conditions, the minimum air flow for drying wheat from 20 percent to 15½ percent moisture without serious deterioration appears to be about 2 cfm per bu; 3 cfm per bu appears to be adequate for drying shelled corn from 25 to 15½ percent moisture in moderate fall weather.

2 The amount of grain deterioration during drying was closely associated with the length of the drying period and the temperature of the drying air.

3 The number of days required to dry grain to 15½ percent moisture with continuous ventilation was only about one-half that of intermittent ventilation where the fan operation was limited to periods when the relative humidity was below 70 percent. Raising the control point to 85 percent in 1952 reduced this difference in shelled corn tests, but had little effect in wheat tests made under summer conditions. A combination of continuous ventilation for grain above 15½ percent and intermittent ventilation for grain below that moisture appears to be the most effective method of fan operation.