Natural-Air Corn Drying with Stirring: I. Physical Properties Effects

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Abstract
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Disciplines
Agriculture | Bioresource and Agricultural Engineering

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Natural-Air Corn Drying with Stirring:  
I. Physical Properties Effects

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ABSTRACT

STIRRED and unstirred natural-air corn dryers were monitored during two drying seasons. Data are presented on airflow resistance, bulk density, fines production, and fines movement. Stirring initially decreased airflow resistance 50%. Airflow resistance increased in stirred bins and decreased in unstirred bins as corn dried. Stirring produced a small amount of fines and moved fines toward the floor.

INTRODUCTION

Questions from farmers indicate a growing interest in using grain stirrers in natural-air drying bins. Unfortunately, we lack the research needed to give them management recommendations. We know that stirring wet, spreader-placed corn once greatly reduces airflow resistance (Bern et al., 1982). But what happens to airflow resistance after repeated stirring? Are bulk density changes responsible for airflow resistance changes? Do stirrers damage corn and produce fines, or do they just shift existing fines toward the floor (Israel, 1979; Baker et al., 1979)? And what role do fines play in airflow resistance changes?

To try to answer these questions, we collected data from three natural-air bins during two drying seasons (1982-83 and 1983-84). Our objective was to quantify bulk density, airflow resistance, and airflow changes, and fines production and movement in stirred and unstirred bins during drying.

EQUIPMENT

We collected data from three 5.5-m diameter bins (hereinafter referred to as “east”, “center”, and “west”) at the Iowa State University Woodruff Farm 9 km southwest of Ames. Each bin was equipped with full perforated drying floor, a David Bin Level model 918 grain spreader,* a depth scale attached inside the bin wall, and a Magnehelic pressure gauge connected to a piezometer ring with three taps into the underfloor plenum.

In 1982-83, airflow was provided by Caldwell 3.7- to 5.2-kW, 610-mm diameter, (5- to 7-hp, 24-in.) axial-flow fans. Because the fan motors were not original equipment, we tested the fans in place on the bins rather than using the manufacturer’s published performance data. We followed AMCA Standard 210-74 (AMCA, 1975), except that no straighteners were used in the inlet duct. In 1983-84, we replaced the east bin fan with a Rolfes 2.2-kW, 457-mm, (3-hp, 18-in.) axial-flow fan and used the manufacturer’s published data. We assumed that, at any given plenum static pressure, all airflow predicted by fan test data actually flowed through the corn.

The east and center bins contained Sukup Stir-Up, single-auger grain stirrers. The augers were bare, 51-mm diameter, right-hand screws with 25-mm diameter shaft and constant 70-mm pitch. They turned at approximately 513 r/min and followed a spiral pattern at an average horizontal speed of 4.22 m/h. The stirrers were capable of blending a full bin of corn to a uniform moisture (±1 percentage point) with 24 to 48 h of operation.

PROCEDURE

In both years, each bin was filled in October with about 75 t of uncleaned, wet corn. Moisture content was about 25% (wet basis) in 1982-83 and about 20% in 1983-84. Loads were alternated between bins to obtain similar initial fines and moisture profiles. We took pelican samples as wagons were unloaded to determine initial fines and moisture content. The 72-h, 103 C air-oven procedure was used for these moisture tests.

Drying fans were started during bin filling and operated continuously until average daily temperatures fell below freezing (early December in 1982, mid-November in 1983). We aerated the bins once during winter 1982-83 and twice during winter 1983-84 and completed drying in April in both tests. Pelican samples taken as bins were emptied were analyzed for final fines and moisture content.

During drying, we recorded plenum static pressures nearly every day and corn depths at least once a week. Depth readings were always taken just before a bin was stirred and immediately after stirring and hand leveling of the corn. Fines and moisture contents at five depths (top; 1.2 m, 2.4 m, and 3.6 m down; and floor) were monitored by probing each bin, in three locations, once a week. Subsamples from the three locations at each depth were mixed to give one composite sample at each depth. A Cargill Prob-A-Vac was used to obtain samples, and a DICKEY-john GAC II used to measure moisture.

Stirring plans for the bins are given in Table 1.

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*Reference to a company or product name is for specific information only and does not imply approval or recommendation of the product by Iowa State University to the exclusion of others that may be suitable.

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TRANSACTIONS of the ASAE
TABLE 1. STIRRING PLANS FOR FIELD TESTS

<table>
<thead>
<tr>
<th>Bin</th>
<th>1982-83</th>
<th>1983-84</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>48 h during filling</td>
<td>48 h during filling</td>
</tr>
<tr>
<td></td>
<td>48 h/wk during drying</td>
<td>48 h/wk during drying</td>
</tr>
<tr>
<td></td>
<td>48 h @ ~15.5% avg. MCWB*</td>
<td>48 h @ ~15.5% avg. MCWB*</td>
</tr>
<tr>
<td>Center</td>
<td>48 h after filling</td>
<td>48 h during filling</td>
</tr>
<tr>
<td></td>
<td>48 h @ ~20% avg. MCWB†</td>
<td>48 h @ ~15.5% avg. MCWB†</td>
</tr>
<tr>
<td></td>
<td>48 h @ ~15.5% avg. MCWB‡</td>
<td>48 h @ ~15.5% avg. MCWB‡</td>
</tr>
<tr>
<td>West</td>
<td>No stirring</td>
<td>No stirring</td>
</tr>
</tbody>
</table>

*Actually stirred at 14.1% MCWB.
† Actually stirred at 18.9% MCWB.
‡ Actually stirred at 15.8% and again at 15.3% MCWB (three stirrings instead of two).
§ Actually stirred at 13.7% MCWB.

AIRFLOW RESISTANCE CHANGES

The following terminology is used to discuss airflow resistance changes.

**SCM:** Shedd’s curve multiplier is the ratio of measured static pressure per unit grain depth to that predicted by Shedd (1953) at the same airflow. (Shedd’s data is now part of ASAE Standard D272.1 (ASAE, 1985)). This ratio is often called the “pack factor”. But “pack factor” is also used to described bulk density changes in storage bins. To avoid confusion, we use the more descriptive term Shedd’s curve multiplier.

**SCR:** Shedd’s curve multiplier ratio (or just Shedd’s curve ratio) is the ratio of Shedd’s curve multiplier calculated at a given point during a drying test to that calculated at the beginning of the test (SCM). For stirred bins, SCM is not calculated until the first stirring period is complete. Because stirring decreases airflow resistance, SCM for stirred bins is much lower than SCM for unstirred bins. Note that simple ratios of pressure drop per unit grain depth could not be used, because pressure drop is a function of airflow. Airflow was not constant in this test and is fan specific. Using a ratio of Shedd’s curve multipliers makes presentation of our results independent of airflow and fan type.

**SEM:** Stirring effect multiplier was defined by Bern et al. (1982) as the ratio of Shedd’s curve multiplier just before a stirring period to Shedd’s curve multiplier just after. If stirring decreases airflow resistance, SEM is less than one.

**AR:** Airflow ratio is the ratio of airflow at a given time during a drying test to initial airflow (Q). For stirred bins, Q is measured after the first stirring period is complete. Airflow ratios are fan specific. Their primary use is to show trends in airflow during a drying test.

**PR:** Points of moisture removed. PR is calculated by subtracting average corn moisture content (percent wet basis) from initial moisture content. PR is used to indicate drying progress. Drying time is not used because it depends heavily on weather and varies greatly from year to year. Actual corn moisture is not used, because it depends on initial moisture.

Trends in airflow and airflow resistance during our drying tests are shown in Figs. 1, 2, and 3. By using airflow ratio, Shedd’s curve multiplier ratio, and points of moisture removed, we can plot results from both years on common graphs — even though harvest moisture and drying weather were quite different.

Most computer simulations of grain drying assume constant airflow resistance and airflow in unstirred bins throughout the drying season. But our airflow resistance,
Bulk density generally changes as corn dries (Maiwald, 1979) and stirring is known to affect bulk density (Bern et al., 1982). Bern and Charity (1975) showed that airflow resistance is a function of bulk density. They developed an equation that is now included in ASAE Standard D272.1 (ASAE, 1985). For our airflows, this version of the equation applies:

\[
SP/d = -0.998 + 0.888 (BD/KD)^2 q + 0.000511 (BD/KD)^2 q^2

(1-BD/KD)^3
\]

where \(SP/d\) = static pressure per unit grain depth, \(\text{Pa/m}\)

\(BD\) = bulk density, \(\text{kg/m}^3\)

\(KD\) = kernel density, \(\text{kg/m}^3\)

\(q\) = airflow, \(\text{L/s-m}^2\)

We calculated expected Shedd’s curve multipliers by dividing airflow resistance given by the equation, by Shedd’s airflow resistance at the same airflow. We used Shedd’s curve multipliers to avoid the problem of variable airflows. We estimated average, in situ bulk density in each bin once a week. First, corn volume was calculated from bin diameter and the weekly corn depth reading. Next, corn mass was estimated by using average corn moisture to adjust for water removal. Then, bulk density was calculated by dividing corn mass by volume.

In the unstirred bin, bulk density decreased both years as corn dried (Fig. 4). Even though initial densities were similar, initial Shedd’s curve multipliers differed considerably — 2.35 in 1982-83 with 25% moisture corn vs. 1.76 in 1983-84 with 20% corn. The Bern and Charity equation shows that the difference in Shedd’s curve multiplier was apparently caused by a difference in kernel density. We estimated (but did not measure) initial kernel density to be about 1150 kg/m^3 the first year and 1200 kg/m^3 the second. Corn variety was the same both years, but drier growing season weather and lower harvest moisture the second year undoubtedly affected kernel density.

For a given kernel density, the Bern and Charity equation predicts decreasing airflow resistance (and thus

\[
KD = \text{kernel density, kg/m}^3
\]

\(q\) = airflow, \(\text{L/s-m}^2\)

\(BD\) = bulk density, \(\text{kg/m}^3\)

\(K\text{D} = \text{kernel density, kg/m}^3\)

\(q\) = airflow, \(\text{L/s-m}^2\)

\(SP/d\) = static pressure per unit grain depth, \(\text{Pa/m}\)

\(BD\) = bulk density, \(\text{kg/m}^3\)

\(KD\) = kernel density, \(\text{kg/m}^3\)

\(q\) = airflow, \(\text{L/s-m}^2\)

The equation published by ASAE contains an error — the denominator of both the second and third terms should have an exponent of 3.

**BULK DENSITY CHANGES**

Bulk density changes were considered a possible explanation for observed airflow resistance changes.

Fig. 4—In situ bulk density of unstirred corn during drying.
Shedd’s curve multiplier) with decreasing bulk density. Data from the unstirred bin for 1982-83 roughly follows that trend (Fig. 5). The trend for 1983-84 is less clear. Results predicted by the Bern and Charity equation are shown on Fig. 5 for reference. The curves assume constant airflow and kernel density, but in reality, both factors changed as corn dried.

Table 2 and Fig. 6 show bulk density and airflow resistance changes in the stirred bins. In 1982-83, the first stirring period in the center bin decreased bulk density 5.0%, cut airflow resistance in half (SEM = 0.50), and increased airflow 41.3%. In a similar test, Bern et al. (1982) found that bulk density decreased 7.9%, SEM = 0.50, and airflow increased 33.4%. After the first stirring period, bulk density and airflow resistance changes in both stirred bins were somewhat unpredictable. Airflow resistance changes caused by changes in kernel orientation and fines were no doubt superimposed on bulk density effects. Data points in Fig. 6 did cluster along Bern and Charity curves, though.

In fall 1982, the east bin was stirred during filling, whereas the center bin was stirred after the bin was full. This was done to determine whether stirring after filling and during filling have the same effect on airflow. Evidently, they do. Center bulk density and Shedd’s curve multiplier before stirring were similar to those in the west bin (BD_{center} = 781 and BD_{east} = 782 kg/m^3, SCM_{center} = 2.43 and SCM_{east} = 2.35), but after stirring, bulk density and SCM were similar to those in the east bin (BD_{center} = 777 and BD_{east} = 764 kg/m^3, SCM_{center} =

![Fig. 5—Shedd's curve multiplier vs. in situ bulk density for unstirred corn. Curves are calculated from Bern and Charity (1975) equation using airflow = 86.25 L/s·m^2. KD = kernel density.](image1)

![Fig. 6a—Shedd's curve multiplier vs. in situ bulk density for corn stirred weekly. Curves are calculated from Bern and Charity (1975) equation using airflow = 110.4 L/s·m^2. KD = kernel density.](image2)

![Fig. 6b—Shedd's curve multiplier vs. in situ bulk density for corn stirred three times. Curves are calculated from Bern and Charity (1975) equation using airflow = 110.4 L/s·m^2. KD = kernel density.](image3)

**Table 2. Effect of Stirring on Bulk Density, Airflow, and Airflow Resistance**

<table>
<thead>
<tr>
<th>Bin</th>
<th>Stirring period*</th>
<th>Average moisture (% wet basis)</th>
<th>Bulk density† (kg/m^3)</th>
<th>% Change</th>
<th>Airflow (L/s·m^2)</th>
<th>% Change</th>
<th>Shedd's curve multiplier Before</th>
<th>SEM‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before/After</td>
<td>Before/After</td>
<td></td>
<td>Before/After</td>
<td></td>
<td>Before/After</td>
<td></td>
</tr>
<tr>
<td>East 1982-83</td>
<td></td>
<td>24.7/23.9</td>
<td>782/781</td>
<td>-0.4</td>
<td>36.1/34.2</td>
<td>-9.9</td>
<td>1.15</td>
<td>1.18</td>
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<tr>
<td></td>
<td></td>
<td>20.5/20.0</td>
<td>775/777</td>
<td>-0.2</td>
<td>36.4/34.1</td>
<td>-13.6</td>
<td>1.39</td>
<td>1.31</td>
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<tr>
<td></td>
<td></td>
<td>19.5/19.0</td>
<td>782/781</td>
<td>-0.1</td>
<td>31.2/34.6</td>
<td>+11.0</td>
<td>1.91</td>
<td>0.81</td>
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<td></td>
<td></td>
<td>18.4/18.0</td>
<td>781/777</td>
<td>-1.0</td>
<td>31.6/33.4</td>
<td>+5.7</td>
<td>1.81</td>
<td>0.93</td>
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<td></td>
<td></td>
<td>17.6/17.1</td>
<td>775/777</td>
<td>-0.6</td>
<td>34.4/34.4</td>
<td>0.0</td>
<td>1.59</td>
<td>1.01</td>
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<tr>
<td></td>
<td></td>
<td>17.1/16.0</td>
<td>777/762</td>
<td>-2.0</td>
<td>30.1/35.9</td>
<td>+19.0</td>
<td>1.84</td>
<td>0.85</td>
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<tr>
<td></td>
<td></td>
<td>16.0/16.0</td>
<td>763/760</td>
<td>+0.9</td>
<td>34.0/36.0</td>
<td>+6.3</td>
<td>1.58</td>
<td>0.95</td>
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<tr>
<td>Center 1982-83</td>
<td></td>
<td>24.5/23.9</td>
<td>787/777</td>
<td>-5.0</td>
<td>27.1/38.3</td>
<td>+41.3</td>
<td>2.43</td>
<td>0.50</td>
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<tr>
<td></td>
<td></td>
<td>18.9/18.0</td>
<td>774/779</td>
<td>+0.6</td>
<td>35.7/37.3</td>
<td>+0.5</td>
<td>1.47</td>
<td>0.92</td>
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<tr>
<td>East 1983-84</td>
<td></td>
<td>19.5/19.0</td>
<td>782/777</td>
<td>-0.5</td>
<td>23.4/24.3</td>
<td>+4.2</td>
<td>1.45</td>
<td>0.99</td>
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<td>15.5/15.0</td>
<td>792/788</td>
<td>-1.2</td>
<td>36.2/36.4</td>
<td>+0.8</td>
<td>1.25</td>
<td>1.05</td>
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<tr>
<td></td>
<td></td>
<td>15.3/15.0</td>
<td>796/788</td>
<td>-1.0</td>
<td>36.4/38.6</td>
<td>+6.2</td>
<td>1.26</td>
<td>0.89</td>
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<tr>
<td>Center 1983-84</td>
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<td>19.3/19.0</td>
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<td></td>
<td>37.7</td>
<td></td>
<td>1.12</td>
<td></td>
</tr>
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<td>801/792</td>
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<td>36.2/36.4</td>
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<td>1.25</td>
<td></td>
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<tr>
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<td>15.3/15.0</td>
<td>796/788</td>
<td></td>
<td>36.4/38.6</td>
<td></td>
<td>1.26</td>
<td></td>
</tr>
</tbody>
</table>

* Each stirring period equals about 48 h.
† Bins were filled by using mechanical spreaders.
‡ Stirrer operated during bin filling.
§ Stirring effect multiplier = (SCM after stirring)/(SCM before stirring)
¶ Airflow produced by a 610-mm axial-flow fan with 3.7- to 5.2-kW motor.
# Airflow produced by a 407-mm axial-flow fan with 2.2-kW motor.

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1.21 and SCM_{rest} = 1.18). On the basis of this result, corn producers should definitely operate their stirrers during filling. Starting a stirrer after a bin is full is difficult, can damage the stirrer, and could cause personal injury.

FINES
Because fines usually increase airflow resistance, we monitored their production and movement within the bins. Small fines were defined as particles passing through a 4.8-mm (12/64-in.) round-hole sieve, large fines were particles between 4.8- and 6.4-mm (16/64-in.) sieves, and total fines were the sum of the two. Small fines usually compose the largest part of BCFM (broken corn and foreign material), and so can affect corn value. Corn price is generally discounted if BCFM exceeds 3% of weight.

Fines Movement
Figs. 7 and 8 show top-layer and floor fines concentration, and also average fines concentration over all five depths probed, after each week of drying. Linear regressions were performed on the stirred-bin data and probabilities that line slopes are nonzero are listed on the figures. Positive slopes indicate an increase in fines concentration. Zero slope means no change.

As expected, hardly any variation in fines concentration with depth was observed in the unstirred bin, so that data is not shown. In the bin stirred 48 h/week (Fig. 7), floor fines concentration increased faster (greater slope) than average fines concentration. Either stirring moved fines toward the floor or more fines were produced near the floor. The fact that floor samples were actually taken below the ends of the stirring augers supports the fines movement hypothesis.

Fig. 8b also indicates downward fines movement from stirring, although data from the center bin were quite scattered and not very reliable. Floor data taken at 140 h were so unreasonable that the values were omitted from analysis. High variability in the floor-fines data might have been caused by an interaction between fines moisture content and vacuum-probe characteristics. At low moistures, the probe probably exaggerated fines content. (Hurburgh et al. (1979) found that samples drawn in by vacuum contain excess fines.) But after periods of rewetting, fines tended to stick together and probably were underrepresented in probe samples.

Visual observations made as bins were emptied supported probe results: there were definitely more fines at the bottom of the stirred bins. High fines concentration caused the last corn in the bins to flow poorly, and the 10-cm layer below the ends of the stirring augers had a very high fines concentration.

It seemed that increasing fines concentration near bin floors would increase airflow resistance. But data from Grama et al. (1984) show that, in theory, airflow resistance of the entire bin depth is the same whether fines are uniformly distributed through a bin or concentrated in one layer (for concentrations up to 10%, at least). In practice, though, fines on the bin floors crusted together and undoubtedly did increase airflow resistance. Unfortunately, we were not equipped to measure airflow resistance of the crusted layer.

Fines Production
Probe samples (Figs. 7 and 8) and pelican samples (Table 3) indicate an increase in average fines
concentration in all three bins during drying. The increase in fines in the unstirred bin probably was from fill and unload auger damage, drying-stress damage, and size decrease of particles as they dried. We assumed these factors to be the same in all three bins and calculated net fines increase from stirrer damage by subtracting fines increase in the unstirred bin from fines increase in the stirred bins (Table 3). Net fines production from stirring was similar for the two stirred bins — about 800 kg dry fines (0% moisture).

Although net fines production was similar for the two stirred bins, fines production per hour of stirring was much lower for the bin stirred more hours. The most likely explanation is that rate of fines production decreases with time. Stirrers probably break kernels that are cracked during harvesting and bin filling. Once the previously cracked kernels are broken by the stirrers, only sound kernels remain, and rate of fines production decreases. This would give lower fines production per hour for stirrers operated more hours.

Average final BCFM levels in the stirred bins were well below 3%. The last load or two removed from the stirred bins, however, did exceed 3%. If the value of a bin of corn is based on average properties of all loads, stirring is not likely to cause fines discounts. But if loads are valued individually, stirring could cause fines discounts on some loads.

Using fines airflow resistance data from Grama et al. (1984), final Shedd's curve multiplier ratios should have been 1.24, 1.25, and 1.10 in our east, center, and west bins, respectively — if a fines increase had been the only change (i.e., no bulk density, moisture, or kernel orientation changes). Measured final SCRs were 1.32, 1.33, and 0.77. Evidently the fines increase was supplemented by other factors in the stirred bins and offset by other factors in the unstirred bin.

### CONCLUSIONS

In our field tests of stirred and unstirred natural-air dryers:

- Airflow resistance decreased about 20% as 25% moisture, spreader-placed corn dried in unstirred natural-air bins.
- Stirring 25% moisture, spreader-placed corn initially decreased airflow resistance 50% and increased airflow more than 40%.
- Effects on airflow were the same whether corn was stirred during or after bin filling. This implies that stirrers should be operated during bin filling to avoid start-up difficulties.
- After the first stirring period, additional stirring increased airflow resistance, but it was still less than airflow resistance in unstirred bins.
- After the first stirring period, bulk density changes did not fully explain airflow resistance changes. Changes in kernel orientation and fines probably offset bulk density effects.
- Spreader-placed 25% moisture corn had about the same initial bulk density as spreader-placed 20% moisture corn, but the wetter corn had a much higher initial Shedd's curve multiplier — 2.35 for 25% corn vs. 1.76 for 20% corn. The drier corn probably had greater kernel density and porosity.
- Stirring augers produced BCFM at an average rate of about 1.7 dry kg/h of stirring for each stirring auger.
- Stirring moved fines toward the drying floor. Fines on the floor formed a crust the might have increased airflow resistance.

### References