AIRFLOW RESISTANCE OF CLEANINGS REMOVED FROM CORN

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ABSTRACT
A study was conducted to determine airflow resistance of cleanings removed from corn by screening and by aspiration. Cleanings were divided into fractions and then tested for airflow resistance in a 239-mm-diameter column. Coefficients for the modified Ergun equation were developed to predict airflow resistance of various sizes and size combinations of cleanings for airflows from 0.06 to 30.5 m³/m² min.

INTRODUCTION
A grain quality factor increasingly in the public eye today is foreign material. Newspapers and farm literature frequently contain articles explaining why grain-importing countries no longer want "dirty" U.S. grain. In 1984 corn export shipments, BCFM (broken corn and foreign material, defined as particles that pass through a 4.8-mm-diameter, round-hole sieve plus non-grain material larger than 4.8 mm), was the corn grade factor most often near the grade limit (FGIS, 1985). Besides lowering grain value and acceptance, fines (broken corn and other matter that will pass through a 6.4-mm-diameter, round-hole sieve) support mold development during storage (Hill et al., 1981), provide a good environment for insects, and also increase airflow resistance (Grama et al., 1984).

REMOVAL OF FINES
Removal of fines has been proposed as a means of enhancing corn quality and market acceptance. One analysis predicted that cleaning by use of a 4.8-mm diameter (or smaller) screen would yield a net profit to the operation (Bern and Hurburgh, 1990).

When fines are removed by aspirator separation, cleaning is dependent upon particle density and shape as well as particle size (Kice, 1985). Aspirator separation may not remove all fines without also taking some whole kernels. But it has the advantage that particles removed probably are of less value than those left (Uhl and Lamp, 1966). Also, material removed may have properties different from the fines removed by screening.

SIZE DEFINITION AND DISTRIBUTION OF FINES
Grama et al. (1984) collected and analyzed 16 3000-g random samples of mixtures of corn and fines previously dried in different country elevators in Iowa, South Dakota, and Minnesota. The samples were divided into seven size fractions by use of a Carter Dockage Tester equipped with round-hole sieves of different sizes. The size definition and distribution of fines are shown in Table 1. The average size distribution of fines in Table 1 was used in this research as representative of the size distribution of fines in corn.

Airflow resistance information is necessary for rational design of aeration systems for stored fines. Such information exists for mixtures of shelled corn and fines (Grama et al., 1984; Haque et al., 1978) but was not found in the literature for fines removed from corn.

OBJECTIVES
The specific objectives of this study were to:
- Determine airflow resistance of individual sizes and grades (mixtures of sizes) of fines removed from shelled corn by screening.
- Determine airflow resistance of liftings removed from shelled corn by aspiration at different aspiration airflow settings.

EXPERIMENTAL PROCEDURES
FINES PREPARATION
About 270 kg of dry fine material at 13.6% moisture* was separated from yellow dent corn of unknown genotype obtained from the ISU Ankeny Research Center at Ankeny, Iowa, with a portable, rotating screen cleaner equipped with a square-hole screen of size 6.4 mm on side (inside measure). Fines were divided into size fractions by use of a Carter Dockage Tester. The percentages of size 1 through size 7 were 27.2, 32.2, 22.6, 12.4, 2.4, 1.2, and 2.0, respectively.

Another lot of about 230 kg of 13.3% moisture fines from yellow dent corn of unknown genotype was obtained from the West Central Co-op grain terminal at Jordan, Iowa. These fines also were divided into size fractions by use of a Carter Dockage Tester. From size 1 to size 7 the percentages were 4.9, 12.8, 16.6, 20.0, 18.2, 9.0, and 18.5, respectively. To obtain adequate quantity of individual sizes, the two lots were mixed in a ratio of about 4:3.

* Moistures are wet basis.
TABLE 1. Distribution of fines in country elevator corn samples (Grama et al., 1984)

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>% Fines</th>
<th>% Finer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 6.4</td>
<td>33.4%</td>
<td>47.2%</td>
</tr>
<tr>
<td>2 5.6</td>
<td>26.8%</td>
<td>32.1%</td>
</tr>
<tr>
<td>3 4.8</td>
<td>18.1%</td>
<td>21.1%</td>
</tr>
<tr>
<td>4 4.0</td>
<td>10.1%</td>
<td>14.5%</td>
</tr>
<tr>
<td>5 3.2</td>
<td>5.0%</td>
<td>12.1%</td>
</tr>
<tr>
<td>6 2.4</td>
<td>3.0%</td>
<td>8.1%</td>
</tr>
<tr>
<td>7 1.8</td>
<td>0.5%</td>
<td>12.0%</td>
</tr>
</tbody>
</table>

TABLE 2. Definition of fines grades*

<table>
<thead>
<tr>
<th>Grade</th>
<th>Definition</th>
<th>Size combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6+6+5+4+3+2+1</td>
<td>7+6+5+4+3+2+1</td>
</tr>
<tr>
<td>2</td>
<td>6+6+5+4+3+2</td>
<td>7+6+5+4+3+2</td>
</tr>
<tr>
<td>3</td>
<td>6+6+5+4+3</td>
<td>7+6+5+4+3</td>
</tr>
<tr>
<td>4</td>
<td>6+6+5+4</td>
<td>7+6+5+4</td>
</tr>
<tr>
<td>5</td>
<td>6+6+5</td>
<td>7+6+5</td>
</tr>
<tr>
<td>6</td>
<td>6+6</td>
<td>7+6</td>
</tr>
</tbody>
</table>

* From Grama et al., 1984.

TABLE 3. Percentage size distribution of aspiration liftings

<table>
<thead>
<tr>
<th>Liftings level</th>
<th>Aspirator airflow (m^3/min)</th>
<th>Sizes*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>28.6 13.0 20.1 15.5 10.3 5.4 3.4 5.4</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.98 17.1 14.0 18.9 16.6 13.3 7.6 4.8 7.7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.27 0.0 16.9 22.8 20.1 16.0 9.1 5.8 9.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.93 0.0 15.5 13.6 23.7 18.1 12.0 8.9 18.2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8.00 6.6 5.2 3.6 2.0 1.0 0.6 1.0</td>
<td></td>
</tr>
</tbody>
</table>

* Sizes defined in Table 1.
† Size 0 = particles passing over 6.4-mm sieve.
‡ Mixture of grade 1 fines and corn before aspiration.

TABLE 4. Fluidization airflow rate at first drop height (m^3/m^2 min)

<table>
<thead>
<tr>
<th>Test material</th>
<th>Size, grade or level No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 3 4 5 6 7</td>
</tr>
<tr>
<td>Size (fines)</td>
<td>&gt;30.5 &gt;30.5 &gt;30.5 &gt;30.5</td>
</tr>
<tr>
<td>Grade (mixture)</td>
<td>&gt;30.5 &gt;30.5 &gt;30.5 &gt;30.5</td>
</tr>
<tr>
<td>Level (liftings)</td>
<td>&gt;30.5 &gt;30.5 &gt;30.5 &gt;30.5</td>
</tr>
</tbody>
</table>

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PREPARATION OF ASPIRATION SAMPLES

Aspiration was used to separate a shelled corn-fines mixture into two fractions (liftings and heavies). To simulate a corn-fines mixture, a 6.4-mm, round-hole sieve and grade 2 consisted of fines through a 5.6-mm sieve and so on.

PLACING OF TEST MATERIAL INTO AIRFLOW RESISTANCE TEST COLUMN

Individual sizes of fines were combined in Grama’s ratios (Table 1) and then poured through a Boerner divider several times for mixing. Test material (mixed-grade fines, individual size fines, or liftings) was poured into a 239-mm-diameter column with a movable slide gate at the bottom. This column was mounted atop a 239-mm-diameter airflow resistance test column. Quick removal of the slide gate allowed the test material to fall into the airflow resistance test column from a drop height measured from the slide gate to the floor of the test column of 649 mm, 1355 mm, or 1990 mm. Drop height was changed to vary bulk density of the test material.

UNIFORMITY OF SIZE DISTRIBUTION IN TEST COLUMN

A uniformity test was conducted to determine to what extent segregation of test material by size occurred during dropping. In this test, a sack probe was inserted at four different levels into the test column while it held grade 1 fines (the worst possible case). Size distributions at four sampling levels were not found to be significantly different and uniformity was judged adequate.

MEASUREMENT OF PARTICLE AND BULK DENSITIES

The volume of kernels or particles was measured by a Beckman model 930 air comparison pycnometer. The weight of the particles was measured on a balance with an accuracy of 0.001 g. Particle density is this weight divided by the volume measured by the pycnometer. The average of six tests was taken as the particle density of a sample.

Bulk density of test mixtures was measured in the test column by use of the procedure from Bern (1973).

FLUIDIZATION AIRFLOW RATE

At a certain air velocity, test material begins to fluidize in the airflow resistance test column. When the fluidization
air velocity was less than 30.5 m$^3$/m$^2$ min, it was the upper limit of the airflow resistance tests. Table 4 contains results of tests conducted to determine when this occurs.

**AIRFLOW RESISTANCE TESTS**

Airflow resistance of test mixtures was measured at airflow rates of about 0.06, 0.12, 0.24, 0.48, 0.96, 1.92, 3.84, 7.68, 15.3, and 30.5 m$^3$/m$^2$ min or up to the fluidization airflow rate if this rate was lower than 30.5 m$^3$/m$^2$ min. Air temperature and airflow meter inlet pressure were recorded, and airflow was corrected to standard conditions (21° C and 1 atmosphere). See Grama et al. (1984) for a description of the airflow test apparatus.

**RESULTS**

Airflow resistance of fines of seven individual sizes, six grades (mixtures), and four aspiration levels (liftings) were tested at three drop heights with two replications. Complete test results are listed in Yang (1987). Replications of a drop height did not often result in an identical bulk density. Also, air velocity varied slightly from one drop height or replication to another. It was convenient, therefore, to treat the tests as six different bulk densities instead of three averages of drop heights.

Two airflow tests were conducted on clean corn kernels. Corn was dropped into the column from 649 mm and had an average bulk density of 725 kg/m$^3$.

**DATA ANALYSIS AND MODEL FITTING**

The modified Ergun equation (Ergun 1952) was chosen as a suitable model for fitting airflow resistance data. The Ergun equation form has been used successfully by several researchers to describe airflow resistance through granular material (Bern and Charity, 1975; Bakker-Arkema et al., 1969; Patterson et al., 1971). Ergun’s equation is of the form

$$P = \frac{A(1 - E)^2 V}{L} + \frac{B(1 - E) V^2}{E^3}$$

(1)

where $P$ is pressure drop across a bed of depth $L$, $V$ is apparent fluid velocity, $E$ is fraction of voids, and $A$ and $B$ are constants. It can be shown that

$$E = 1 - \frac{\text{BD}}{\text{PD}}$$

(2)

where BD is bulk density, and PD is particle density.

To avoid overestimation of pressure drop at low air velocities, it was necessary to fit the equation at each of two airflow ranges (0.06 to 7.68 m$^3$/m$^2$ min and 7.68 to 30.5 m$^3$/m$^2$ min). Bern and Charity (1975) used a similar procedure.

For each size or grade or aspirator level of fines, particle density was nearly constant, and, therefore, any change in voids was assumed to be caused by a change in bulk density.

Statistical analysis was done on the ISU mainframe computer by use of the Statistical Analysis System (SAS Institute Inc., 1983). Estimates of coefficients $A$ and $B$ for each of the text conditions are shown in Table 5. All multiple correlation coefficients ($R^2$) exceeded 0.99. For sizes, grades and levels, coefficients $A$ and $B$ were significant contributors to airflow resistance.

Conclusions can be drawn:

1. Airflow resistance of individual sizes or size grades of fines is predictable by equation 1 and sizes and levels

![Figure 1](http://example.com/figure1.png)

**Figure 1—Airflow resistance prediction of corn and sized fines.**
grades coefficients of Table 5. Small sizes or grades have greater resistance to airflow. Bulk density has a significant effect on the resistance of fines removed by screening.

2. Fines separated by low aspirator airflow consist of more small particles and have greater resistance to airflow. Resistance prediction can be made by equation 1 and levels coefficients of Table 5. Bulk density also has a significant effect on airflow resistance.

REFERENCES


Kice, J. 1985. Skilled air manual for milling and other industries. Kice Metal Products Co., Inc., Wichita, KS.


