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Horizontal and Vertical Airflow Resistance of Shelled Corn at Various Bulk Densities

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horizontal airflow resistance for wheat and barley was 63% and 47% of designed for vertical flow. Their results indicated that horizontal airflow testing, and the other bin was test bins of 1 m^2 each; one bin was designed for horizontal and vertical airflow resistance of uncleaned and cleaned wheat and cleaned barley. They used two test bins of 1 m^3 each; one bin was designed for horizontal airflow testing, and the other bin was designed for vertical flow. Their results indicated that horizontal airflow resistance was 63% and 47% of vertical airflow resistance for wheat and barley respectively.

Jayas et al. (1987) studied horizontal and vertical airflow resistance of canola (rapeseed). They tested clean canola and canola mixed with foreign material. Horizontal airflow resistance varied from 50 to 70% of vertical airflow resistance; for practical purposes it was estimated as 60% of the resistance of vertical airflow.

Segerlind (1982) solved the nonlinear airflow equation to predict pressure and velocity distribution by means of finite-element analysis. His technique made use of separate horizontal and vertical airflow resistance prediction equations.

Greenkorn (1983), in a discussion of flow through porous media, mentions the importance of four parameters for relating pressure drop and superficial velocity for an anisotropic (oriented) medium; these four parameters are (1) porosity, (2) permeability, (3) tortuosity, and (4) connectivity. If these parameters are different for each direction, then different airflow resistances are likely.

The unsymmetrical shape of the corn kernel suggests that it may have differing horizontal and vertical resistances, as did barley in the study of Kumar and Muir. If horizontal resistance was less than vertical resistance, it would indicate that more lateral airflow than vertical airflow occurs around common aeration ducts. It also implies that large piles of grain stored outdoors may be aerated more efficiently by vertical tower aerators than by ordinary horizontal aeration ducts. No reports comparing vertical and horizontal airflow resistance of shelled corn were found in the literature.

OBJECTIVE
The objectives of this study were to (1) measure horizontal and vertical airflow resistance of shelled corn at various bulk densities, (2) formulate pressure-drop prediction equations for horizontal and vertical airflow, and (3) determine appropriate multipliers between horizontal and vertical airflow resistance.

EXPERIMENTAL APPARATUS
An experimental system was assembled that permitted bi-directional measurement of airflow through a column of grain and the air pressure drop across the grain column.

Test Corn
Yellow dent corn of unknown genotype was obtained from the Iowa State University Grain Quality Laboratory. It was cleaned over a 4.8-mm round-hole sieve using a Carter dockage tester. It had a test weight of 752.7 kg/m^3.

Airflow Apparatus
Components of the experimental system included an airflow measurement system, pressure differential
Fig. 1—Test chamber (in horizontal position with lid removed).

Grain Test Chamber

The grain test chamber was based upon the design described by Kumar and Muir (1985). It was designed for use in either the horizontal or vertical position. The chamber was constructed of 19-mm plywood. In the horizontal position (Fig. 1), two perforated steel panels served as end walls and the test chamber plywood served as floor and sidewalls. Foam rubber 19 mm thick was placed over the top of the grain to prevent air leakage between the top grain surface and the lid. The removable panel, which compressed the foam rubber, was then replaced on top of the test chamber and secured. For vertical position tests, the front perforated steel panel was removed, and the lid secured in place. The chamber in this position was then rotated so that the front end in Fig. 1 became the top. The floor of the chamber in this position was a perforated steel panel. The top grain surface was open to air. A pressure tap was located in the plenum chamber beyond the second steel panel to measure pressure drop across the grain column. The test chamber had interior dimensions of 203 mm between plywood walls and 305 mm between perforated steel floors for the horizontal testing and 381 mm from perforated floor to top of test column for vertical testing.

Air entered at the free end of the test chamber and passed through the column of grain. The air exited and passed through Styrene tubing, through the airflow meter, and out through the blower which operated at a negative pressure. The system was operated at a negative pressure to prevent blower heat from warming the test corn.

EXPERIMENTAL PROCEDURE

Vertical and horizontal airflow tests were run at “loose,” “medium” and “tight” bulk densities. For each of the six tests, pressure drop across the test chamber was measured at each of eight airflow rates.

The corn was dropped from a funnel-shaped dump hopper into the test chamber. In vertical testing, corn was dropped through the open end, and for horizontal testing corn was filled with the top lid removed (as in Fig. 1). For the vertical tests, the initial drop height was 0.686 m. For the horizontal tests, initial drop heights varied from 0.368 m to as much as 1 m. The chamber was not filled to the top as some room was needed for the 19-mm foam rubber. Initial drop height was defined as the distance between the opening of the grain hopper and the floor of the test chamber. As the test chamber filled, actual drop distance decreased. No attempt was made to keep drop height constant while filling or to account for any differences caused by a varying drop height.

The chamber was weighed and the volume of grain was measured by measuring from the top of the box to the level grain surface to allow for calculation of bulk density. If bulk density was too low, it was increased to the proper value by tapping the sidewalls of the box to settle the corn and decrease its volume.

After all mass and volume measurements, the chamber was carefully transported to the airflow apparatus. The Styrene air tubes were butted together and sealed with duct tape.

The eight flow rates tested for each horizontal and vertical test ranged from 0.76 to 28.6 m³/min. The order of testing was from least to greatest bulk density in each position and from greatest to least airflow rate at each bulk density. The testing went from highest to lowest airflow rate so that any air leaks could be detected immediately at the high airflow rate. Approximate flow rates tested were 28.5, 20.5, 12.5, 10.0, 8.0, 6.0, 4.0 and 2.5 m³/min for horizontal tests and 27.5, 20.0, 12.5, 10.0, 7.5, 4.0, 2.0 and 1.0 m³/min for vertical tests. One test per airflow rate at each bulk density was performed.

Particle density data were obtained with a Beckman Model 930 Air Comparison Pycnometer. Moisture content of the sample was determined before and after trials with a Motomco 919 moisture meter.

RESULTS AND DISCUSSION

Airflow resistance data for all six tests are listed in Table 1. Kernel density for six random samples of the test corn averaged 1287.7 kg/m³. Moisture content was 16.3% wb.

Airflow resistance data were fitted to the Ergun equation (Ergun, 1952) simplified to:

$$\frac{\Delta P}{L} = K_1 + K_2 \frac{(\rho_b / \rho_k)^2}{(1 - \rho_b / \rho_k)^3} V + K_3 \frac{(\rho_b / \rho_k)}{(1 - \rho_b / \rho_k)^3} V^2$$
TABLE 1. Horizontal and Vertical Airflow Data

<table>
<thead>
<tr>
<th>Airflow Pressure drop</th>
<th>Vertical loose</th>
<th>Airflow Pressure drop</th>
<th>Vertical medium</th>
<th>Airflow Pressure drop</th>
<th>Vertical tight</th>
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<td>765.4 kg/m^3 m^3/m^2-min Pa/m</td>
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<td>30.2</td>
<td>1.10</td>
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</tbody>
</table>

In this equation:

\[ \Delta P/L = K_1 + K_2 \left( \frac{\rho_s}{\rho_k} \right)^2 + K_3 \left( 1 - \frac{\rho_s}{\rho_k} \right)^2 \]

where:

- \( \Delta P/L \) = Pressure drop per unit bed depth, Pa/m
- \( \rho_s \) = Bulk density, kg/m^3
- \( \rho_k \) = Kernel density, kg/m^3
- \( V \) = Superficial fluid velocity, m^3/m^2-min

\( K_1, K_2, K_3 \) = Ergun equation coefficients

The equation was fitted by using the RS/1 software package system on the Iowa State University computer system (ISU Computation Center, 1984) using multiple correlation techniques. Values obtained for \( K_1, K_2, \) and \( K_3 \) for shelled corn at all bulk densities are listed in Table 2.

Figure 2 is a graph of predicted horizontal and vertical airflow resistances curves at a bulk density of 793.0 kg/m^3. The predicted vertical airflow resistance curve is a concave down shaped curve and follows the shape of Shedd’s curve for shelled corn. The predicted horizontal airflow resistance curve is concave down at greater airflows, but then becomes concave upward as airflow decreases, diverging from the general shape of Shedd’s curve and the predicted vertical curve. These two curves are similarly shaped at all bulk densities, so only one graph is needed to show the trend for all bulk densities.

Because the curves are not exactly parallel, it was not possible to determine a single multiplier between them. A ratio between the predicted horizontal and vertical resistances was found for each airflow. Equations were fitted using curve-fitting methods available on RS/1. The curve of best fit was a cubic equation using the natural logarithm of the superficial air velocity. The general form of the equation is:

\[ H/V = C_1 + C_2 (\ln V) + C_3 (\ln V)^2 + C_4 (\ln V)^3 \]

where:

- \( H/V \) = Ratio of horizontal and vertical airflow resistance (horizontal multiplier)
- \( C_1, C_2, C_3, C_4 \) = Coefficients for equation
- \( V \) = Superficial fluid velocity, m^3/m^2-min

Table 3 contains the coefficients \( C_1, C_2, C_3, \) and \( C_4 \) at three bulk densities, as well as the \( R^2 \) value of each equation.

For airflow rates above 6 m^3/m^2-min up to the upper value of airflow tested, the three curves are tightly grouped and nearly constant in value. It would be appropriate to choose a multiplier of 0.58 for horizontal resistance. For airflow rates below 6 m^3/m^2-min down to the lower value of airflow tested, the three curves diverge slightly and are not constant in value. A multiplier of about 0.45 for horizontal resistance would be

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TABLE 3. Horizontal/Vertical Ratio Equation Coefficients

<table>
<thead>
<tr>
<th>Bulk Density</th>
<th>C_1</th>
<th>C_2</th>
<th>C_3</th>
<th>C_4</th>
<th>R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>765.5 kg/m^3</td>
<td>-0.37333</td>
<td>0.98356</td>
<td>-0.33321</td>
<td>0.03679</td>
<td>0.9996</td>
</tr>
<tr>
<td>793.0 kg/m^3</td>
<td>-0.14849</td>
<td>0.78824</td>
<td>-0.27270</td>
<td>0.03026</td>
<td>0.9995</td>
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<tr>
<td>802.7 kg/m^3</td>
<td>-0.07889</td>
<td>0.72782</td>
<td>-0.25396</td>
<td>0.02823</td>
<td>0.9995</td>
</tr>
</tbody>
</table>

appropriate in this range, although it does cause some error at either extreme of this range of airflow rates.

Differences in air pathway sizes and lengths may have caused the airflow resistance differences. Corn kernels tend to lie with major axes approximately horizontal; this could cause different sizes and lengths of air pathways. Larger, shorter and straighter air pathways have less resistance to airflow. This evidently is the situation for horizontal airflow.

The pressure drops at the three lowest airflow rates for the vertical "tight" were less than the corresponding pressure drops for vertical "medium". The higher bulk density should have had a higher pressure drop, but such was not the case. The reason for this is not known.

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

1. Airflow resistance of shelled corn is greater in the vertical direction compared with the horizontal direction at each bulk density tested.
2. For airflow from 6 to 28.6 m^3/m^2-min, pressure drop per unit bed depth for horizontal flow is about 0.58 times that for vertical flow. For airflows from 6 to 0.76 m^3/m^2-min, the horizontal airflow resistance multiplier is about 0.45.

References