Static Pressure Drop Across a Bed of Corn Mixed with Fines

E. Haque, G. H. Foster, D. S. Chung, F. S. Lai
MEMBER ASAE — ASSOC. MEMBER ASAE

ABSTRACT

THE static pressure drop across a column of corn mixed with fines (broken grain and other matter that will pass through a 4.76 mm (12/64 in.) diameter round-hole sieve) was measured for determination of the effect of fines on the resistance to airflow. The relationship was determined for a range of airflows. In experiments with a loosely filled column of corn mixed with uniformly distributed fines, the pressure drop increased linearly with increases in fines up to about 20 percent.

A modification of the relationship between pressure drop and airflow through clean corn, found by Hukill and Shedd (1955), and an equation which is easier to use than the modified Hukill-Shedd equation are presented. Pressure drops predicted by both equations agreed closely with those observed across beds composed of various percentages of fines and whole corn.

INTRODUCTION

Air pressure, required to force air through a bed of grain, is dissipated continuously due to friction and turbulence. The pressure drop depends on air velocity, surface texture and shape of the particles, the number, size, and configuration of voids, the variability of particle size, and the depth of the product bed (Brooker et al., 1974). If foreign particles are smaller than the grain, resistance to airflow is increased; if foreign particles are larger than the grain, resistance to airflow is reduced (Shedd, 1953).

Nonuniform distribution of fines in bulk grain occurs when bins are filled (Stephens and Foster, 1976) and this nonuniformity contributes to nonuniform distribution of the air used for aeration and drying. Unfortunately, adequate data relating amount of fine material in corn to its airflow resistance are not available.

The objectives of this study were:

1 To determine airflow resistance of corn containing various levels of fines.

2 To develop models that will predict the effect of fines on airflow resistance.

EQUIPMENT AND METHODS

A clear plastic, cylindrical, vertical column having an internal diameter of 20.3 cm (8 in.) and an external diameter of 21.6 cm (8.5 in.) was used for the containment of test grain. Sections were added to the column in increments of 30.5 cm (12 in.) and sleeves connected the sections. A plenum chamber (Fig. 1), consisting of a cube with 45.7 cm (18 in.) sides, was made of mild steel plate. Air was supplied by a rotary blower connected to a variable speed control unit capable of varying the airflow rate to the plenum through a 2.54 cm (1 in.) diameter galvanized iron pipe. A rotameter capable of measuring up to about 0.017 m^3 of air per second (36 cfm) was used. Pressure taps were spaced 30.5 cm (12 in.) apart along the column. We used first 15.2 cm (6 in.) of grain column above the top of the plenum chamber to smooth out the airflow; therefore, we did not measure

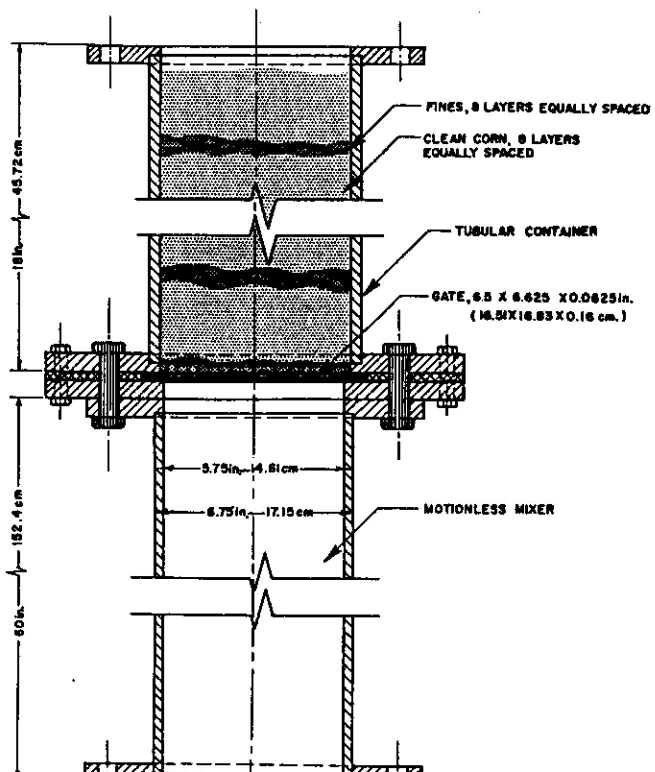

FIG. 1 Arrangement of fines and clean corn in tubular container fastened with motionless mixer.

Article was submitted for publication in June 1977; reviewed and approved for publication by the Electric Power and Processing Division of ASAE in December 1977. Presented as ASAE Paper No. 76-3528.

The authors are: E. HAQUE, Graduate Research Assistant, Agricultural Engineering Dept., Kansas State University, Manhattan; G. H. FOSTER, Research Leader, US Grain Marketing Research Center, USDA-ARS, Manhattan, KS; D. S. CHUNG, Associate Professor, Agricultural Engineering Dept., Kansas State University, Manhattan; F. S. LAI, Research Chemical Engineer, US Grain Marketing Research Center, USDA-ARS, Manhattan, KS.

Acknowledgments: The first author's (EH) contribution was financially supported by the USDA-ARS. The authors gratefully acknowledge the suggestions of H. B. Pfost, Sam Maurer and B. S. Miller.

This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 21, No. 5, pp. 997, 998, 999, 1000, 1978)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

TABLE 1. DISTRIBUTION OF PARTICLES SIZES OF FINES IN CORN BED.

Tyler sieve series	Size (mm) d_i	Weight fraction, W_i, retained on sieve*	$\frac{W_i}{d_i}$
5	4	0.0132	0.0033
6	3.36	0.1886	0.0561
7	2.83	0.1746	0.0617
8	2.38	0.1429	0.0600
9	2.00	0.0869	0.0434
10	1.68	0.0939	0.0559
12	1.41	0.0607	0.0430
14	1.19	0.0447	0.0376
16	1.00	0.0376	0.0376
20	0.84	0.0402	0.0479
28	0.59	0.0548	0.0929
32	0.50	0.0162	0.0324
35	0.42	0.0134	0.0319
42	0.35	0.0127	0.0363
48	0.0297	0.0080	0.0269
60	0.0250	0.0064	0.0256
65	0.210	0.0023	0.0110
80	0.177	0.0035	0.0198
100	0.149	0.0000	0.0000
Pan	—	0.0000	0.0000
		Total 1.0060	0.7233

$$\text{Equivalent diameter of fines} = \frac{1}{0.7233} = 1.38 \text{ mm}$$

*Average of seven samples.

pressure drops in this section. Pressure drops above this section of column were measured by a hook gage manometer that can detect changes of 0.01 mm of water.

We used a motionless mixer to insure uniform distribution of fines in the test corn. The internal diameter and the length of the mixer were 14.6 cm (5 3/4 in.) and 152.4 cm (5 ft), respectively. The mixer had six elements. A tubular container, made of clear plastic, 15.2 cm (6 in.) internal diameter and 45.7 cm (18 in.) long, held the test grain on top of the motionless mixer (Fig. 1). This container had a removable slide gate at the bottom and could be fastened on top of the mixer. The container was placed, with its slide gate closed, on a work table and filled manually with eight alternate layers each of fines and clean corn, beginning with fines as the cotton layer. We weighed the corn and fines to be placed in respective layers to obtain the desired percentage of fines. The filled container was fastened to the top of the mixer, and the entire assembly (Fig. 1) was positioned coaxially on top of the test column, leaving about 1.2 cm (0.5 in.) between container and mixer. We removed the slide gate at the bottom of the container quickly to drop the grain and fines into the test column. Since fine materials were smaller than the grain, it took longer for the fines to travel the length of the motionless mixer than it did for the clean corn, resulting in a mixing effect. Only one pass through the motionless mixer was used since the mixing was judged visually to be satisfactory.

At high levels of fines, the fines tended to concentrate near the cylinder wall in a pattern of a double helecoid. More than one pass through the mixer improved the uniformity of fines distribution, and we used multiple passes in tests to obtain data for mixtures in which fines exceeded 20 percent.

The total depth of corn ranged from 1.092 m (3 ft, 7 in.) to 1.143 m (3 ft, 9 in.), but only 0.914 m (3 ft) was used for pressure-drop measurements. Pressure taps were numbered consecutively from 0 to 3, starting at the top. Pressure readings from taps (3 to 2), (2 to 1), and (1 to 0) were measured and averaged.

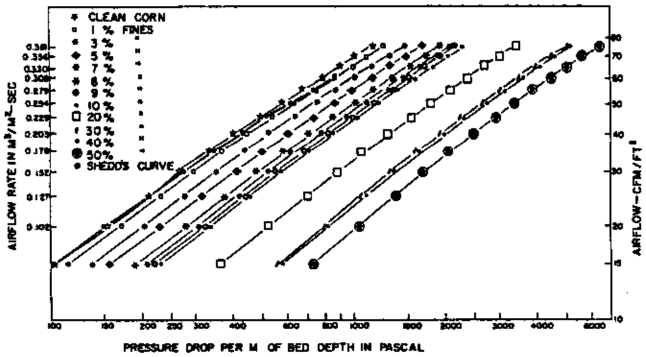

FIG. 2 Resistance of a mixture of corn and its fines to airflow.

MATERIALS

The corn used in this experiment was a hybrid yellow dent that was harvested in 1975. It was dried with natural air from an initial moisture content of 23 percent wet basis (w.b.) to a final moisture of 12 percent w.b. at an airflow rate of 0.06 m^3/s per m^3 of grain. It was cleaned by use of a standard dockage tester. Approximately 10 percent of the cleaned corn kernels showed visible signs of breakage. Both fines and clean corn were separated from the same lot of corn. Fines were defined as broken grain and other matter that passed through a 4.76 mm (12/64 in.) diameter round-hole sieve. The distribution of particle sizes of fines is given in Table 1.

The method of determining equivalent diameter of nonuniform particles, as shown in Table 1, was suggested by Reboux (Leva, 1959). Size distribution of fines seemed to be trimodal, due to the presence of weed seeds and material from the corn plant, but the fines were typical of those found in corn subjected to normal handling procedures. Moisture content of the fines was 11 percent w.b.

RESULTS AND DISCUSSION

For 12 levels of fine materials and 13 airflow rates, we plotted the pressure-drop data against airflow rate, using log-log coordinates (Fig. 2). Twelve different curves, one for each level of fines, were fitted to the data by inspection. The plots represent a family of parallel curves that conform to the shape of the curve presented by Shedd (1953). For clean corn, our experimental curve followed closely that of Shedd. The pressure drop increased with increased percentages of fines for the same airflow rate.

We attempted to develop models that would represent the experimental data. When the pressure-drop values were plotted against percentage of fines for all 13 airflow rates (Fig. 3), it appeared that the two variables might be linearly related for the airflows used in the tests.

Hukill and Shedd (1955) found the following relationship between pressure drop and airflow through clean corn:

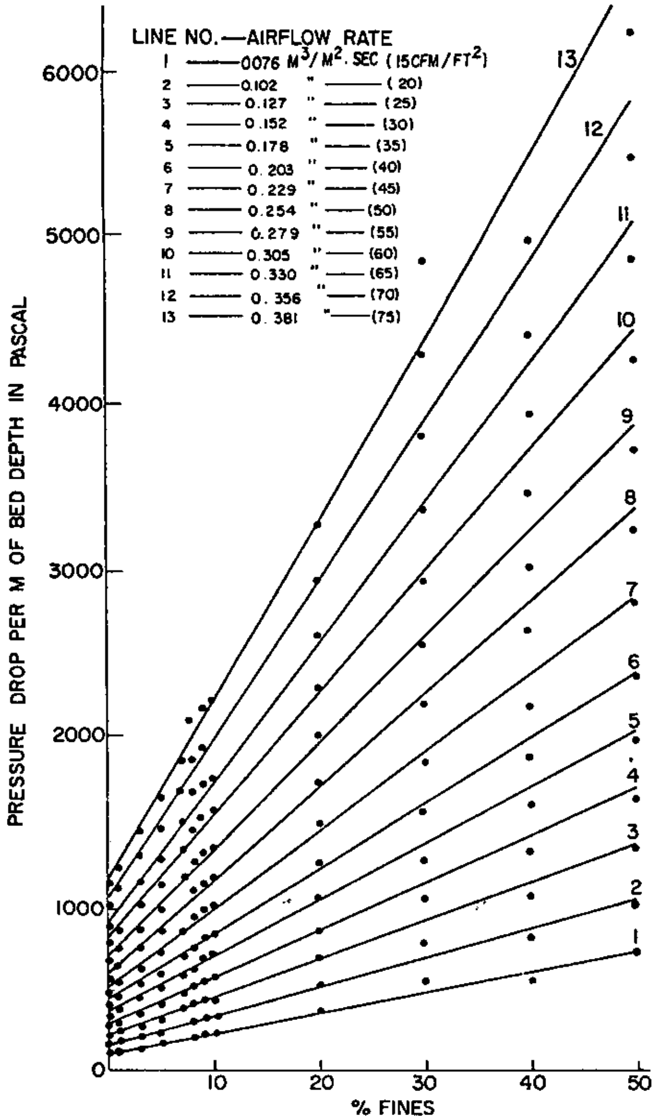

FIG. 3 Regression of corn fines on resistance to air flow.

$$\Delta P = \frac{aQ_a^2}{\ln(1+bQ_a)} \quad [1]$$

where:

ΔP = the static pressure drop per foot depth of grain in inches of water;

Q_a = airflow rate in cfm per ft²; a and b are constants for the range of Q_a from 2 to 40 cfm per ft² for each kind of grain.

Equation [1] in metric system for corn is:

$$\Delta P = \frac{20529.535\, Q_a^2}{\ln(1+30.597\, Q_a)}, \quad [1a]$$

where

ΔP = in Pascal per m (3.28 ft) of bed;

Q_a = in m³/s per m².

We modified equation 1a and tested it as a model to represent the experimental data from this study. To arrive at the modified equation, we fitted straight lines 1 through 6 (Fig. 3) by the least-squares method.

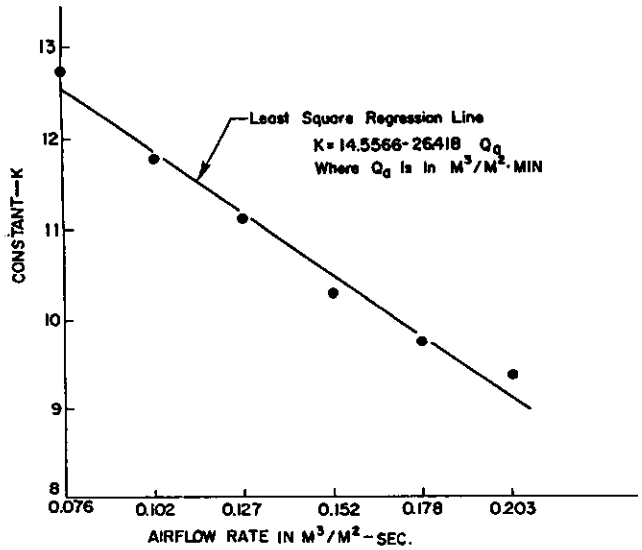

FIG. 4 Constant K of equation [2] as a function of airflow rate.

Because the Hukill-Shedd equation is valid up to $Q_a = 0.203$ m³/(s-m²) (40 cfm/ft²), the remaining lines (7 through 13) were excluded from the least-squares analysis and then fitted by inspection.

The modified equation was of the form:

$$\Delta P = \frac{20529.535\, Q_a^2}{\ln(1+30.597\, Q_a)} \quad 1+k(fm), \quad [2]$$

where k is a constant for any specific airflow rate.

The percentage of fine materials (fm) is expressed as a decimal. Values of k, calculated by least-squares method of regression analysis, were found to be 12.747, 11.791, 11.142, 10.312, 9.777, and 9.424 for Q_a values 0.076, 0.102, 0.127, 0.152, 0.178, and 0.203 m³/s-m², respectively. The square of correlation coefficient, r^2, for each of the six fitted straight lines was 0.98.

Values of k in equation [2] are dependent on Q_a. When plotted (Fig. 4), they showed a linear relationship between k and Q_a; r^2 for the relationship was 0.98, and k was found to be equal to 14.5566-26.418 Q_a. This expression for k inserted in equation [2] gave the following equation:

$$\Delta P = \frac{20529.535\, Q_a^2}{\ln(1+30.597\, Q_a)} \quad 1+(14.5566-26.418\, Q_a)(fm) \quad [3]$$

Pressure drop, ΔP, predicted by equation [3] agreed closely with the experimental data.

The use of equation [3] to solve for airflow rate is difficult for hand calculation. The following, more useful equation, was developed by application of the nonlinear regression technique.

$$\Delta P = C_1 Q_a + C_2 Q_a^2 + C_3 Q_a(fm), \quad [4]$$

where

C_1 = 436.667

C_2 = 7363.038

C_3 = 22525.819

TABLE 2. COMPARISON OF OBSERVED AND PREDICTED PRESSURE DROPS WITH USE OF EQUATIONS [3] AND [4].

Airflow rate, Q_a: m^3/m^2-s	Pressure drop, ΔP, in Pascal per m of bed depth		
	Observed	Predicted by equation [3]*	Predicted by equation [4]
0.076	226	224	247
0.102	331	329	351
0.127	446	441	460
0.152	561	556	579
0.178	692	690	712
0.203	830	832	849
0.229	1002	—	1002
0.254	1172	—	1158
0.279	1355	—	1323
0.305	1562	—	1505
0.330	1774	—	1689
0.356	1993	—	1891
0.381	2226	—	2093

* Use of equation [3] is limited to values of $Q_a < 0.203$ m^3/m^2-s (40 cfm/ft^2).

For a specific airflow rate, equation [4] gives a linear relationship between ΔP and fm. The advantages of equation [4] over equation [3] are:

1 It is simpler.

2 It can be applied within the range of airflow rates from 0.076 to 0.381 m^3/m^2-s and for an fm content from 0 to 20 percent.

Linear regression analysis gave r^2 values of 0.98 for each of the 13 airflow rates. Pressure drop, ΔP, predicted by equation [4] agreed very well with the experimental data.

With 10 percent fines in the corn, observed and predicted pressure drops (for both equations [3] and [4]) were compared. Results are shown in Table 2.

CONCLUSIONS

The results of this study provide a basis for estimating airflow through grain containing various percentages of fine material. The equations should be useful in estimating nonuniformity of airflow in bulk grain containing a nonuniform distribution of fines.

References

1 Brooker, D. B., F. W. Bakker-Arkema, and C. W. Hall. 1974. Drying cereal grains. The AVI Publishing Company, Inc., Westport, CT.

2 Hukill, W. V., and C. K. Shedd. 1955. Nonlinear airflow in grain drying. AGRICULTURAL ENGINEERING 36:362-366.

3 Leva, Max. 1959. Fluidization. McGraw Hill Book Company, Inc. New York.

4 Shedd, C. K. 1953. Resistance of grains and seeds to airflow. AGRICULTURAL ENGINEERING 34:616-619.

5 Stephens, L. E., and G. H. Foster. 1976. Grain bulk properties as affected by mechanical grain spreaders. TRANSACTIONS of the ASAE 19(2):354-358, 363.