ASAE D272.3 MAR1996 (R2007)
Resistance to Airflow of Grains, Seeds, Other Agricultural Products, and Perforated Metal Sheets

American Society of
Agricultural and Biological Engineers

STANDARD

ASABE, 2950 Niles Road, St. Joseph, MI 49085-9659, USA ph. 269-429-0300, fax 269-429-3852, hq@asabe.org

Resistance to Airflow of Grains, Seeds, Other Agricultural Products, and Perforated Metal Sheets

Approved by the ASAE Committee on Technical Data; adopted by ASAE 1948; revised 1954, 1962; reconfirmed by the ASAE Electric Power and Processing Division Technical Committee December 1968, December 1973, December 1978, December 1979; revised December 1980; reconfirmed December 1985; revised by the Grain and Feed Processing and Storage Committee; approved by the Food and Process Engineering Institute Standards Committee March 1987; reconfirmed December 1991; reaffirmed December 1992, December 1993, December 1994, December 1995; revised March 1996; reaffirmed December 2001, January 2007.

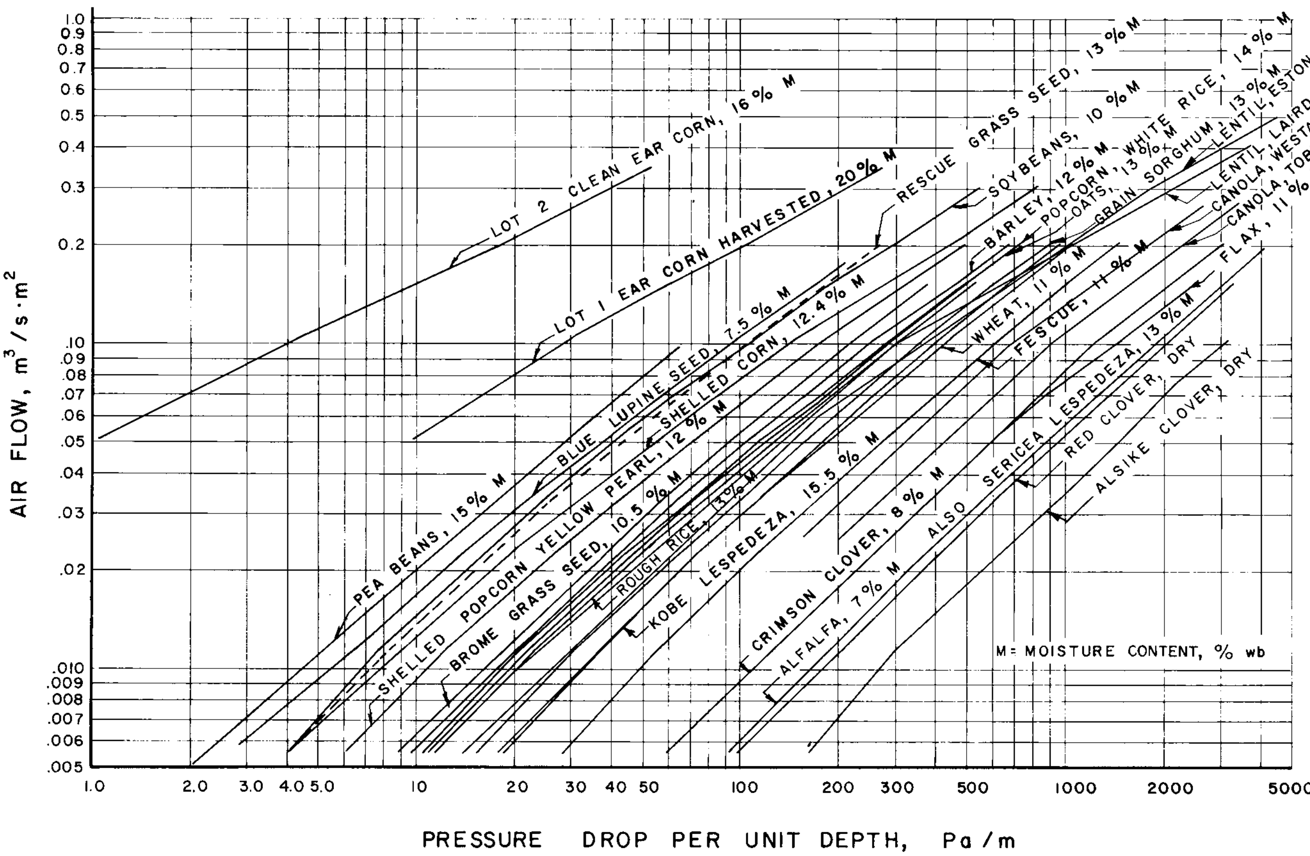
Keywords: Airflow, Drying, Grains, Seeds

1 Purpose and scope

1.1 These data can be used to estimate the resistance to airflow of beds of grain, seeds, and other agricultural products, and of perforated metal sheets. An estimate of this airflow resistance is the basis for the design of systems to dry or aerate agricultural products.

1.2 Data are included for common grains, seeds, other agricultural products, and for perforated metal sheets, over the airflow range common for aeration and drying systems.

2 Empirical curves

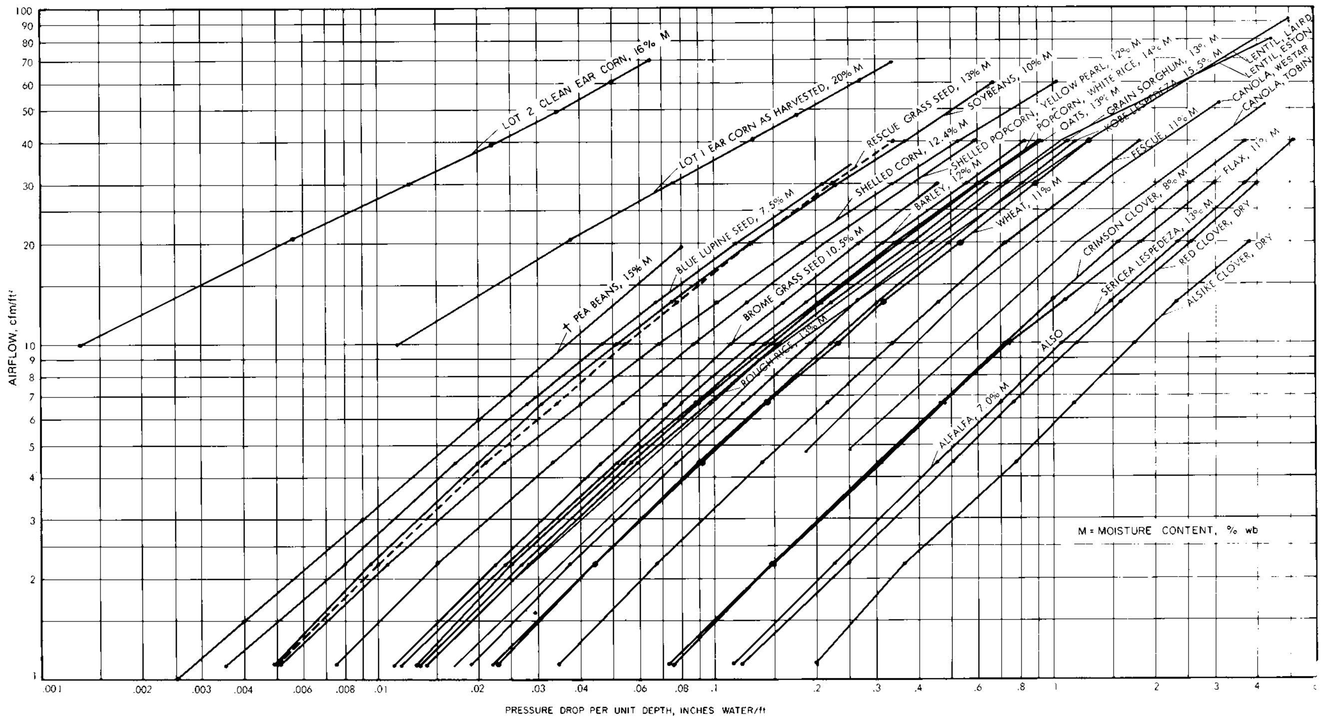


NOTE – This chart gives values for a loose fill (not packed) of clean, relatively dry grain. For a loose fill of clean grain having high moisture content (In equilibrium with relative humidities exceeding 85%), use only-80% of the indicated pressure drop for a given rate of air flow.

Packing of the grain in a bin may cause 50% higher resistance to air flow than the values shown. White rice is a variety of popcorn.

The pressure drop for airflow through bulk grain in the horizontal direction has been measured for wheat and barley (Kumar and Muir, 1986); canola (Jayas et al., 1987); corn (Kay et al., 1989); alfalfa pellets (Sokhansanj et al., 1990); flaxseed (Jayas et al., 1991); and bird's foot trefoil, canary seed, fababeans, lentils, meadow fescue, oats, timothy, and tara peas (Alagusundaram et al., 1992). The pressure drop in the horizontal direction may be 60% to 70% of the pressure drop for airflow in the vertical direction. For some seeds, however, the difference between the pressure drops for the horizontal and vertical airflows may be nonexistent.

Figure 1 – Resistance to airflow of grains and seeds (SI Units) (Shedd's data)

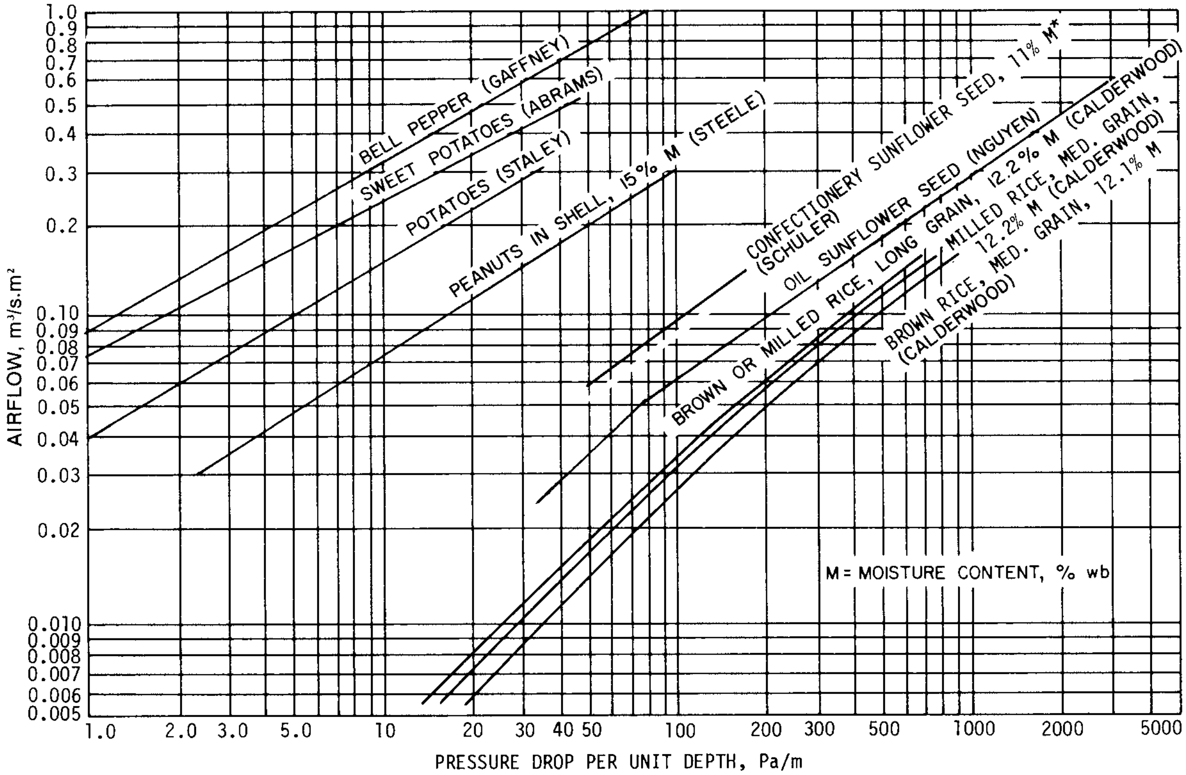


NOTE – This chart gives values for a loose fill (not packed) of clean, relatively dry grain. For a loose fill of clean grain having high moisture content (in equilibrium with relative humidities exceeding 85%), use only 80% of the indicated pressure drop for a given rule of air flow. Packing of the grain in a bin may cause 50% higher resistance to air flow than the values shown.

When foreign material is mixed with grain no specific correction can be recommended. However, it should be noted that resistance to air flow is increased if the foreign material is finer than the grain, and resistance to air flow is decreased if the foreign material is coarser than the grain.

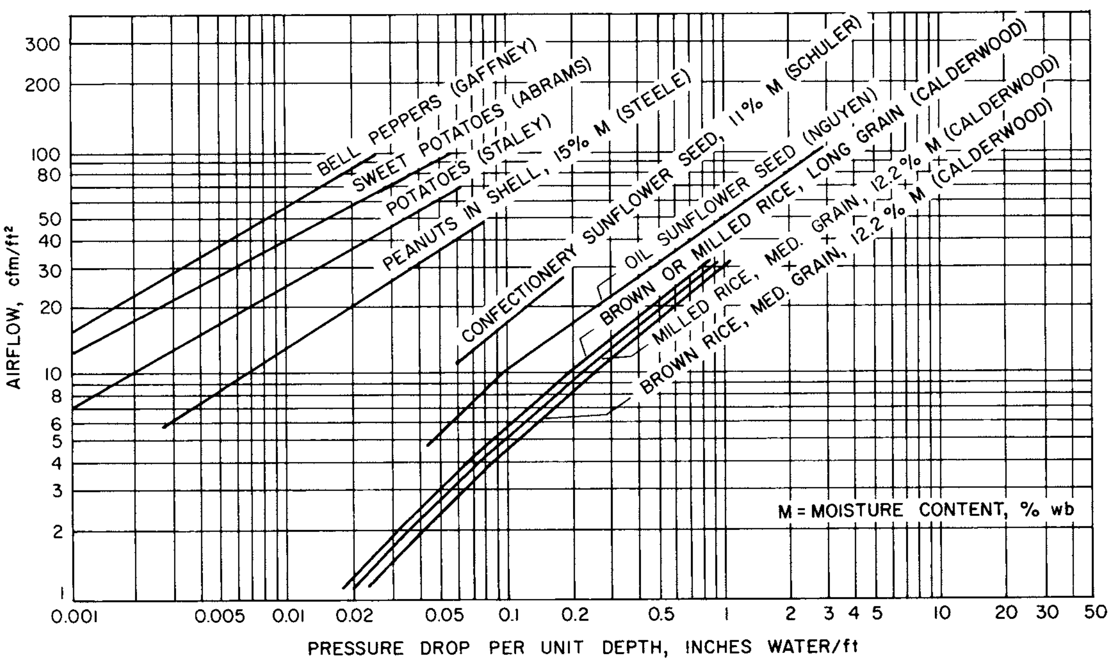
The pressure drop for airflow through bulk grain in the horizontal direction has been measured for wheat and barley (Kumar and Muir, 1986); canola (Jayas et al., 1987); corn (Key et al., 1989); alfalfa pellets (Sokhansanj et al., 1990); flaxseed (Jayas et al., 1991); and bird's foot trefoil, canary seed, fababeans, lentils, meadow fescue, oats, timothy, and tara peas (Alagusundaram et al., 1992). The pressure drop in the horizontal direction may be 60% to 70% of the pressure drop for airflow in the vertical direction. For some seeds, however, the difference between the pressure drops for the horizontal and vertical airflows may be nonexistent.

Figure 2 – Resistance to airflow of grains and seeds (Inch-pound units) (Shedd's data)



NOTES: Rice: Clean, loose-fill. A packing operation which raised the bulk density by 14-17 percent resulted in pressures 2.3 to 3.4 times those for loose fill.

Figure 3 – Resistance to airflow for other agricultural products (SI units)



NOTES: Rice: Clean, loose-fill. A packing operation which raised the bulk density by 14 to 17 percent resulted in pressures 2.3 to 3.4 times those for loose fill.

Figure 4 – Resistance to airflow of other agricultural products (Inch-pound units)

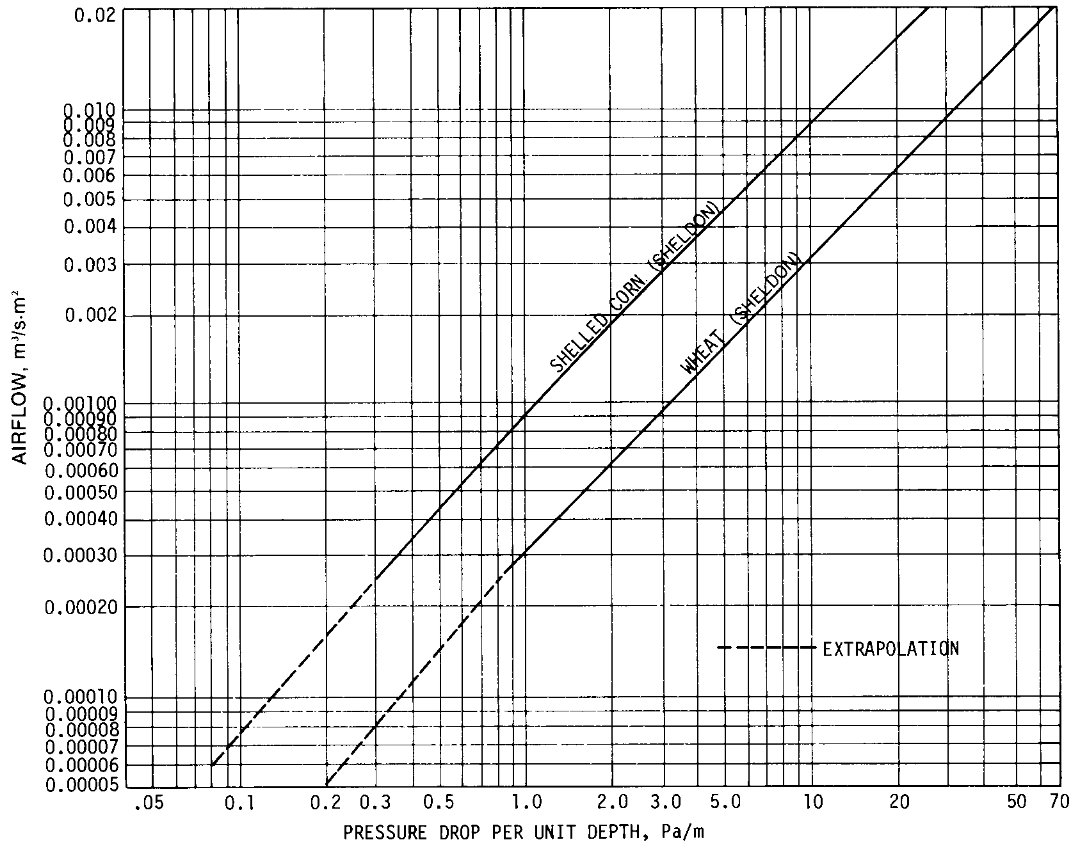


Figure 5 – Resistance to airflow of shelled corn and wheat at low airflows (SI units)

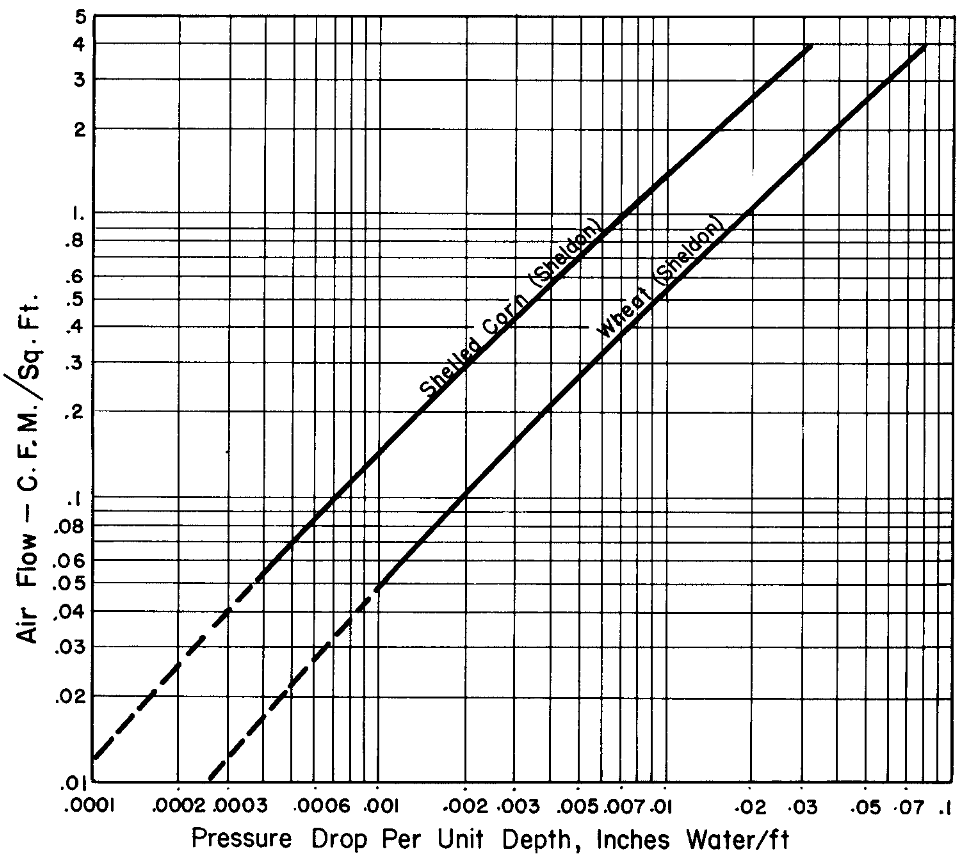
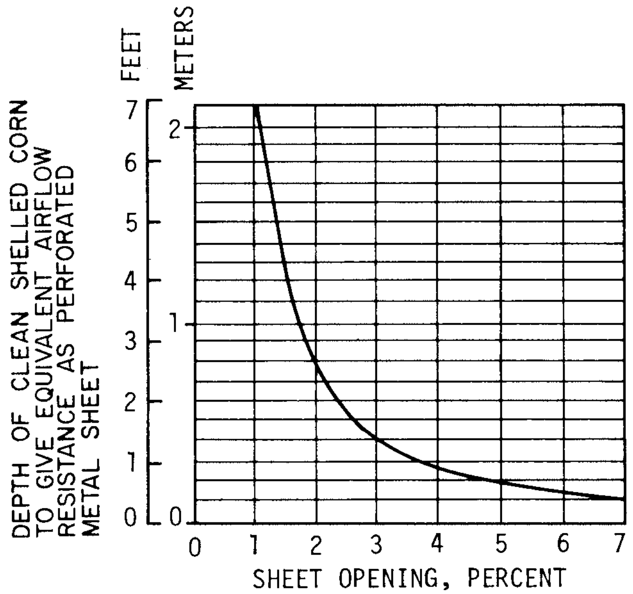


Figure 6 – Resistance to airflow of shelled corn and wheat at low airflows (Inch-pound units)



NOTES: When sheet openings amount to 20 percent, no additional resistance to airflow is produced.
A large number of small perforations is preferred to a smaller number of large perforations for the same amount of opening.
The curve shown is based on tests of sheets having width of perforations from 1 to 3.3 mm (0.04 to 0.13 in.).

Figure 7 – Resistance to airflow of perforated metal sheets when supporting grain (Henderson)

3 Airflow resistance equation

$$\frac{\Delta P}{L} = \frac{aQ^2}{\log_e(1+bQ)}$$

where:

ΔP	=	pressure drop, Pa or inches or water;
L	=	bed depth, m or ft;
a	=	constant for particular grain (see table 1);
Q	=	airflow, $m^3/s{\cdot}m^2$ or cfm/ft^2;
b	=	constant for particular grain (see table 1).

4 Effect of fines on resistance to airflow of shelled corn

4.1 An effect of adding fines to shelled corn is an increase in the airflow resistance of the corn. The pressure drop per unit bed depth can be corrected to account for fines using this equation:

$$\text{SI units:} \left(\frac{\Delta P}{L}\right)_{\text{corrected}} = \left(\frac{\Delta P}{L}\right)_{\text{clean}} (1+(14.5566-26.418Q)(\text{fm}))$$

$$\text{Customary units:} \left(\frac{\Delta P}{L}\right)_{\text{corrected}} = \left(\frac{\Delta P}{L}\right)_{\text{clean}} (1+(14.5566 - 0.1342Q)(\text{fm}))$$

where:

ΔP	=	pressure drop, Pa or inches of water;
L	=	bed depth, m or ft;
Q	=	airflow, $m^3/s{\cdot}m^2$ or cfm/ft^2;
fm	=	decimal fraction of fines, by weight.

NOTE – Range of applicability: 0.076 to 0.20 $m^3/s \cdot m^2$ (15 to 40 CFM/FT^2) and $0 \leqslant \text{fm} \leqslant 0.2$. Broken grain and other matter which passed through a 4.76-mm (12/64-in.) round-hole sieve are defined as fines. (Hague)

5 Effect of bulk density on resistance to airflow of shelled corn

5.1 An increase in bulk density causes an increase in the airflow resistance per unit bed depth of the corn. The pressure drop per unit bed depth can be predicted as a function of airflow rate and corn bulk density by use of this empirical equation:

$$\frac{\Delta P}{L} = X_1 + X_2 \frac{\left(\frac{\rho_b}{\rho_k}\right)^2 Q}{\left(1-\frac{\rho_b}{\rho_k}\right)^3} + X_3 \frac{\left(\frac{\rho_b}{\rho_k}\right) Q^2}{\left(1-\frac{\rho_b}{\rho_k}\right)^3}$$

where:

ΔP	=	pressure drop, Pa or inches of water;
L	=	bed depth, m or ft;
p_b	=	corn bulk density, kg/m^3 or lb/ft^3;
p_k	=	corn kernel density, kg/m^3 or lb/ft^3;
Q	=	airflow, $m^3/s{\cdot}m^2$ or cfm/ft^2;
X_1, X_2, X_3	=	constants (see table 2 or table 3).

Table 1 – Values for constants in airflow resistance equation

Material	Value of *a* (Pa·s²/m³)	Value of *b* (m²·s/m³)	Range of *Q* (m³/m²s)	Reference
Alfalfa	6.40×10^4	3.99	0.0056–0.152	Shedd (1953)
Alfalfa cubes	1.27×10^3	22.99	0.13–3.15	Sokhansanj et al. (1993)
Alfalfa pellets	1.80×10^4	68.72	0.0053–0.63	Sokhansanj et al. (1993)
Barley	2.14×10^4	13.2	0.0056–0.203	Shedd
Brome grass	1.35×10^4	8.88	0.0056–0.152	Shedd
Canola, Tobin	5.22×10^4	7.27	0.0243–0.2633	Jayas and Sokhansanj (1989)
Canola, Westar	4.55×10^4	9.72	0.0243–0.2633	Jayas and Sokhansanj (1989)
Clover, alsike	6.11×10^4	2.24	0.0056–0.101	Shedd
Clover, crimson	5.32×10^4	5.12	0.0056–0.203	Shedd
Clover, red	6.24×10^4	3.55	0.0056–0.152	Shedd
Corn, ear (lot 1)	1.04×10^4	325.	0.051–0.353	Shedd
Corn, shelled	2.07×10^4	30.4	0.0056–0.304	Shedd
Corn, shelled (low airflow)	9.77×10^3	8.55	0.00025–0.0203	Sheldon et al. (1960)
Fescue	3.15×10^4	6.70	0.0056–0.203	Shedd
Flax	8.63×10^4	8.29	0.0056–0.152	Shedd
Lentils, Laird	5.43×10^4	36.79	0.0028–0.5926	Sokhansanj et al. (1990)
Lespedeza, Kobe	1.95×10^4	6.30	0.0056–0.203	Shedd
Lespedeza, Sericea	6.40×10^4	3.99	0.0056–0.152	Shedd
Lupine, blue	1.07×10^4	21.1	0.0056–0.152	Shedd
Milkweed pods	2.11×10^3	4.65	0.06–0.4	Jones and Von Bargen (1992)
Oats	2.41×10^4	13.9	0.0056–0.203	Shedd
Peanuts	3.80×10^3	111.	0.030–0.304	Steele
Peppers, bell	5.44×10^2	868.	0.030–1.00	Gaffney and Baird (1975)
Popcorn, white	2.19×10^4	11.8	0.0056–0.203	Shedd
Popcorn, yellow	1.78×10^4	17.6	0.0056–0.203	Shedd
Potatoes	2.18×10^3	824.	0.030–0.300	Staley and Watson (1967)
Rescue	8.11×10^3	11.7	0.0056–0.203	Shedd
Rice, rough	2.57×10^4	13.2	0.0056–0.152	Shedd
Rice, long brown	2.05×10^4	7.74	0.0055–0.164	Calderwood (1973)
Rice, long milled	2.18×10^4	8.34	0.0055–0.164	Calderwood
Rice, medium brown	3.49×10^4	10.9	0.0055–0.164	Calderwood
Rice, medium milled	2.90×10^4	10.6	0.0055–0.164	Calderwood
Sorghum	2.12×10^4	8.06	0.0056–0.203	Shedd
Soybeans	1.02×10^4	16.0	0.0056–0.304	Shedd
Sunflower, confectionery	1.10×10^4	18.1	0.055–0.178	Schuler (1974)
Sunflower, oil	2.49×10^4	23.7	0.025–0.570	Nguyen (1981)
Sweet potatoes	3.40×10^3	6.10×10^8	0.050–0.499	Abrams and Fich (1982)
Wheat	2.70×10^4	8.77	0.0056–0.203	Shedd
Wheat (low airflow)	8.41×10^3	2.72	0.00025–0.0203	Sheldon et al.

NOTE – The parameters given were determined by a least square fit of the data in Figures 1 to 6. To obtain the corresponding values of (a) in inch-pound units (in H_2O min²/ft³) divide the above a-values by 31635726. To obtain corresponding values of (b) in inch-pound units (ft²/cfm) divide the above b-values by 196.85. Parameters for the Lot 2 Ear Corn data are not given since the above equation will not fit the data.
Although the parameters listed in this table were developed from data at moderate airflows, extrapolations of the curves for shelled corn, wheat, and sorgbum agree well with available data (Stark and James) at airflows up to 1.0 m³/s · m².

Table 2 – Value for constants (SI units) for equation in clause 5.1

Airflow range, m³/s·m²	X_1	X_2	X_3
$0.027 \leqslant Q \leqslant 0.13$	−0.998	88.8	511
$0.13 \leqslant Q \leqslant 0.27$	−10.9	111	439
$0.27 \leqslant Q \leqslant 0.60$	−76.5	163	389

Table 3 – Values for constants (inch-pound units) for equation in clause 5.1

Airflow range, cfm/ft³	X_1	X_2	X_3
$5.3 \leqslant Q \leqslant 26.3$	−0.0012	5.53×10^{-4}	1.62×10^{-5}
$26.3 < Q \leqslant 52.5$	−0.013	6.94×10^{-4}	1.39×10^{-5}
$52.5 < Q \leqslant 117$	−0.094	10.2×10^{-4}	1.23×10^{-5}

NOTE – Range of applicability: 732 to 799 kg/m³ (45.7 to 49.9 lb/ft³) (corn bulk density) 0.027 to 0.60 m³/s · m² (5.3 to 117 cfm/ft²) (Bern and Charity).

Annex A
(informative)
Bibliography

Abrams, C. F. and J. D. Fish, Jr. 1982. Air flow resistance characteristics of bulk piled sweet potatoes. Transactions of the ASAE 25(4):1103–1106.

Alagusundaram, K., D. S. Jayas, F. Chotard and N. D. G. White. 1992. Airflow pressure drop relationships of some specialty seeds. Sciences des Aliments 12(1):101–116.

Bern, C. J. and L. F. Charity. 1975. Airflow resistance characteristics of corn as influenced by bulk density. ASAE Paper No. 75-3510. ASAE, St. Joseph, MI 49085.

Calderwood, D. L. 1973. Resistance to airflow of rough, brown and milled rice. Transactions of the ASAE 16(3):525–527, 532.

Gaffney, J. J. and C. D. Baird. 1975. Forced air cooling of bell peppers in bulk. ASAE Paper No. 75-6525. ASAE, St. Joseph, MI 49085.

Hague, E., G. H. Foster, D. S. Chung, and F. S. Lai, 1978. Static pressure across a corn bed mixed with fines. Transactions of the ASAE 21(5):997–1000.

Henderson, S. M. 1943. Resistance of shelled corn and bin walls to airflow. Agricultural Engineering 24(11):367–369.

Hukil, W. V. and N. C. Ives. 1955. Radial air flow resistance of grain. Agricultural Engineering 36(5):332–335.

Jayas, D. S., S. Sokhansanj, E. B. Moysey and E. M. Barber. 1987. The effect of airflow direction on the resistance of canola (rapeseed) to airflow. Can. Agric. Eng. 29(2):189–192.

Jayas, D. S. and S. Sokhansanj. 1989. Design data on resistance of airflow through canola (rapeseed). Transactions of the ASAE 32(1):295–296.

Jayas, D. S. and W. E. Muir. 1991. Airflow-pressure drop data for modelling fluid flow in anisotropic bulks. Transactions of the ASAE 34(1):251–254.

Jayas, D. S., K. Alagusundaram and D. A. Irvine. 1991. Resistance to airflow through bulk flax seed as affected by the moisture content, direction of airflow and foreign material. Can. Agric. Eng. 33(2):279–285.

Jones, D. and K. L. Von Bargen. 1992. Some physical properties of milkweed pods. Transactions of the ASAE 35(1):243–246.

Kay, R. L., C. J. Bern and C. R. Hurburgh, Jr. 1989. Horizontal and vertical airflow resistance of shelled corn at various bulk densities. Transactions of the ASAE 32(2):733–736.

Kumar, A. and W. E. Muir. 1986. Airflow resistance of wheat and barley affected by airflow direction, filling method and dockage. Transactions of the ASAE 29(5):1423–1426.

Nguyen, V. T. 1981. Airflow resistance of sunflower seed. Unpublished term project for AE568 at Iowa State University, Ames, IA. Under the direction of Carl I. Bern.

Schuler, R. T. 1974. Drying-related properties of sunflower seeds. ASAE Paper No. 74-3534. ASAE. St. Joseph. MI 49085.

Shedd, C. K. 1953. Resistance of grains and seeds to air flow. Agricultural Engineering 34(9):616–619.

Sheldon, W. H., C. W. Hall, and J. K. Wang. 1960. Resistance of shelled corn and wheat to low airflows. Transactions of the ASAE 3(2):92–94.

Siebenmorgen, T. J. and V. K. Jindal, 1987. Airflow resistance of rough rice as affected by moisture content, fines concentration and bulk density. Transactions of the ASAE 30(4):1138–1143.

Sokhansanj, S., A. A. Falacinski, F. W. Sosulski, D. S. Jayas and J. Tang. 1990. Resistance of bulk lentils to airflow. Transactions of the ASAE 33(4):1281–1285.

Sokhansanj, S., W. Li and O. O. Fasina. 1993. Resistance of alfalfa cubes, pellets and compressed herbage to airflow. Can. Agric. Eng. 35(3):207–213.

Staley, L. M. and E. L. Watson. 1961. Some design aspects of refrigerated potato storages. Can. Agric. Eng. 3(1):20–22.

Stark, B. and K. James. 1982. Airflow characteristics of grains and seeds. National Conference Publication N:82/8. 242–243. The Institution of Engineers, Australia.

Steele, J. L. 1974. Resistance of peanuts to airflow. Transactions of the ASAE 17(3):573–577.