Predicting the gas-tightness of grain storage structures

D.D. MANN[1], D.S. JAYAS[1], W.E. MUIR[1] and N.D.G. WHITE[1,2]

[1]Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, Canada R3T 5V6; and [2]Cereal Research Centre, Agriculture and Agri-Food Canada, 195 Dafoe Rd., Winnipeg, MB, Canada R3T 2M9. *Received 20 July 1998; accepted 10 August 1999.*

Mann, D.D., Jayas, D.S., Muir, W.E. and White, N.D.G. 1999. **Predicting the gas-tightness of grain storage structures**. Can. Agric. Eng. **41**:259-265. Fumigation with carbon dioxide (CO_2) can be a viable alternative to synthetic chemical control of stored-product insects, but storage structures must be well-sealed for the method to be efficient. Because the degree of gas-tightness is not consistent for all sealed bins, it would be beneficial if the gas-tightness could be determined before the start of a CO_2 fumigation. The hypotheses tested were that leakage area could be calculated from a measurement of pressure decay time and that gas loss during a fumigation could be predicted from the calculated leakage area. Wheat-filled pilot bins with holes of known areas were used to validate the relationship between pressure decay time and leakage area. The mathematical model predicted leakage areas in the pilot bins with errors ranging from -17.5 to 23.1%. Predicted gas losses from pilot bins filled with polyethylene pellets were inconsistent with the observed gas losses. Gas loss decreased as the initial CO_2 concentration decreased.

La fumigation des céréales avec du gaz carbonique peut représenter une alternative viable au contrôle chimique des insectes dans les produits entreposés, mais à condition que les structures d'entreposage soient étanches. Parce que le degré d'étanchéité au gaz varie d'un silo à l'autre, il serait intéressant de pouvoir établir l'étanchéité d'une structure donnée avant de débuter la fumigation. L'hypothèse testée était que la superficie par où le gaz s'échappe pouvait être calculée à partir de la mesure du temps de dépressurisation, et que la quantité de gaz perdue au cours de la fumigation pouvait être prédite à partir de la superficie par où le gaz peut s'échapper. Des silos expérimentaux, remplis de blé, et avec des trous dont la superficie était connue, furent utilisés pour valider la relation entre le temps de dépressurisation et la superficie par où le gaz s'échappe. Le modèle mathématique prédisait la superficie par où les gaz s'échappent avec des erreurs allant de -17.5 à 23.1%. Les pertes de gaz des silos expérimentaux remplis de pastilles de polyéthylène prédites par le modèle mathématique ne correspondent pas aux pertes de gaz observées. Les pertes de gaz ont diminué à mesure que la concentration initiale de gaz carbonique diminuait.

INTRODUCTION

The presence of stored-product insects in stored grain is a concern to grain storage managers because insects cause contamination and damage to stored grain. Synthetic chemical insecticides and fumigants have been used for controlling stored-product insects over the past several decades, but are now being restricted or banned due to health (Garry et al. 1989) and environmental (Haines 1995) concerns. Also, insects are developing resistance to chemicals (Price and Mills 1988; Fields 1992). Alternate control methods must be developed to protect stored grain from insects.

Controlling insects by altering the concentrations of atmospheric gases inside the storage environment is known as modified atmosphere storage of grain. The Australians have successfully used modified atmospheres in large, central storage facilities (Banks et al. 1980; Ripp 1984), but the storage structures required extensive sealing. Most grain storage structures are not manufactured to be gas-tight, but must be made gas-tight if modified atmosphere storage is to be effective and economical.

Sealing methods that improve the gas-tightness of welded-steel hopper bins have been developed (Mann et al. 1997). Two welded-steel hopper bins of identical make and model, sealed using the same method, did not exhibit the same level of gas-tightness. Due to differences in commercially available bins and in levels of workmanship associated with sealing these bins, it is likely that all bins will have different levels of gas-tightness. Therefore, a method is required that can be used to measure the gas-tightness of any bin.

The pressure decay test is commonly used to assess the gas-tightness of a storage structure. The storage structure is pressurized to an initial value (above atmospheric) and then the pressure decays to some pre-determined value (typically equal to one-half of the initial value). The time for the pressure to decay gives an indication of the gas-tightness of the storage structure, but does not yield the actual rate of gas loss. If the bin does not meet the pressure decay standard, the usual recommendation is to improve the sealing. This procedure is very inflexible. In cases where additional sealing may be cost-prohibitive, it would be beneficial if the farmer or storage manager could predict the fumigation duration required to kill the insects based on the expected rate of gas loss from the bin. The time required to kill insects can be calculated if the rate of concentration decay is known (Mann et al. 1999).

It was hypothesized that the rate of gas loss from a storage structure could be related to its pressure decay time, using a common factor of leakage area. The measured pressure decay time from a pressure decay test would be substituted into a mathematical model to yield the leakage area of the storage structure. The calculated leakage area could then be substituted into a second mathematical model to yield the rate of gas loss. Finally, the rate of gas loss could then be used to calculate the duration of fumigation necessary to achieve complete mortality.

The objective of this paper was to present a theoretical relationship between pressure decay time and gas loss rate, followed by experimental validation in pilot bins.

MATHEMATICAL MODEL

Relationship between pressure decay time and leakage area

The pressure decay time (the time for the pressure to decay from an initial value to a value equal to one-half of the initial value; both above atmospheric pressure) can be calculated as the volume of air expelled from the bin to reduce the pressure by one-half divided by the average rate of volume flow leaving the bin:

$$t = \frac{V_L}{Q_L} \quad (1)$$

where:

t = pressure decay time (time for the pressure to decay from an initial value to a value equal to one-half of the initial value) (s),

V_L = volume of air expelled from the bin to reduce the pressure by one-half (m^3), and

Q_L = average volume flow rate (m^3/s).

The ideal gas law can be used to calculate the volume of air leaving the bin (V_L). The number of moles of air in the bin at the initial pressure is:

$$n_{P_d} = \frac{(P_d + P_{atm})V}{RT_K} \quad (2a)$$

where:

n_{P_d} = number of moles at gauge pressure P_d (mol),

P_d = initial pressure (i.e., gauge pressure at the start of the decay test) (kPa),

P_{atm} = atmospheric pressure (kPa),

V = interstitial bin volume (dm^3),

R = universal gas constant (8.314 kPa dm^3 mol^{-1} K^{-1}), and

T_K = temperature (K).

The number of moles of air in the bin when the pressure decays to $\frac{1}{2}P_d$ is:

$$n_{\frac{1}{2}P_d} = \frac{\left(\frac{P_d}{2} + P_{atm}\right)V}{RT_K} \quad (2b)$$

where: $n_{\frac{1}{2}P_d}$ = number of moles at pressure $\frac{1}{2}P_d$ above atmospheric (mol).

Assuming the volume and temperature both remain constant, the number of moles of air expelled from the bin is:

$$n_{P_d} - n_{\frac{1}{2}P_d} = \frac{(P_d + P_{atm})V}{RT_K} - \frac{\left(\frac{P_d}{2} + P_{atm}\right)V}{RT_K} = \frac{P_d V}{2RT_K} \quad (3)$$

and the volume of air (m^3) to be expelled from the bin is:

$$V_L = \frac{P_d V M_{air}}{2RT_K \rho_{air}} \quad (4)$$

where:

M_{air} = mass of one mole of air (0.029 kg) and

ρ_{air} = air density (kg/m^3).

To calculate the average volume flow rate leaving the bin, it was assumed that the air leaves the bin through a circular hole in the bin membrane. The sum of the velocity head and pressure head is constant if points 1 and 2 are at the same height (point 1 is located inside the bin directly in front of the centre of a hole through the bin wall; point 2 is located at the centre of the hole through the bin wall).

$$\rho_{air}\frac{v_1^2}{2} + P_1 = \rho_{air}\frac{v_2^2}{2} + P_2 \quad (5)$$

where:

ρ_{air} = air density (kg/m^3) (incompressible flow is assumed),

v_1 = velocity of air inside the bin directly in front of a hole through the bin wall (m/s),

v_2 = velocity of air through a hole in the bin wall (m/s),

P_1 = pressure inside the bin (kPa), and

P_2 = pressure on the outside of the hole (kPa).

According to the law of conservation of mass, the volume flow rate through two sizes of openings remains constant assuming the density does not change (i.e., incompressible flow):

$$v_1 A = v_2 a \quad (6)$$

where:

A = cross-sectional area of the bin (m^2), and

a = cross-sectional area of the hole (m^2).

The term v_1 can be eliminated from the equation by substituting Eq. 6 into Eq. 5:

$$v_2^2 = \frac{2(P_1 - P_2)/\rho_{air}}{\left[1 - \left(\frac{a}{A}\right)^2\right]} \quad (7)$$

The ratio a/A approaches zero because the cross-sectional area of the hole is small compared with the cross-sectional area of the bin. The pressure inside the bin (P_1) is equal to ($P_{bin} + P_{atm}$). Similarly, P_2 is equal to the atmospheric pressure, P_{atm}. A factor of 10^3 is required because the pressure is recorded in kPa. Substitution of these values and simplification yields:

$$v_2 = \left[\frac{(2\times10^3)P_{bin}}{\rho_{air}}\right]^{\frac{1}{2}} \quad (8)$$

To account for a friction loss through an orifice, an experimental orifice coefficient, C_d, is introduced to yield the velocity through the orifice opening:

$$v_2 = C_d\left[\frac{(2\times10^3)P_{bin}}{\rho_{air}}\right]^{\frac{1}{2}} \quad (9)$$

If the Reynolds number is above 20 000 and the diameter ratio is less than ≈ 0.5, the value of C_d is approximately constant and has a value of 0.61 (Geankoplis 1983). Fox and McDonald (1985) recommend a C_d value of 0.60 when a/A → 0.

The volume flow rate, Q_L, is equal to the velocity times the cross-sectional area of the hole.

$$Q_L = v_2 a = C_d a \left[\frac{(2 \times 10^3) P_{bin}}{\rho_{air}} \right]^{1/2} \tag{10}$$

The volume flow rate is proportional to the pressure inside the bin, and therefore, will decrease as the pressure inside the bin decreases. For this investigation, an average volume flow rate is required. A representative value for internal pressure (P_{bin}) can be calculated as the integral of the pressure decay relationship divided by the pressure decay time:

$$P_{bin} = \frac{\int_0^{t_0} P(t)dt}{t_0} \tag{11}$$

where: t_o = the observed pressure decay time (s).

Substitution of Eqs. 4 and 10 into Eq. 1 yields:

$$t = \frac{\dfrac{P_d V M_{air}}{2RT_K \rho_{air}}}{C_d a \left[\dfrac{(2 \times 10^3) P_{bin}}{\rho_{air}} \right]^{1/2}} \tag{12}$$

Rearranging Eq. 12 allows leakage area to be calculated as a function of pressure decay time:

$$a = \frac{\dfrac{P_d V M_{air}}{2RT_K \rho_{air}}}{C_d t \left[\dfrac{(2 \times 10^3) P_{bin}}{\rho_{air}} \right]^{1/2}} \tag{13}$$

Relationship between gas loss and leakage area

During a pressure decay test, pressure is the driving force causing the movement of air molecules from the bin. During a fumigation, however, gas loss occurs because of a concentration gradient. If a bin is well sealed, only small holes remain through which the gaseous CO_2 must exit.

Bernardini (1989) describes the movement of gaseous molecules from one vessel (empty except for the gaseous molecules) to another through a hole of known area. The number of molecules passing through the hole in a short time is given by:

$$\Delta N = \frac{N}{V_c} a v_m \Delta t \tag{14}$$

where:

ΔN = number of molecules passing through the hole in a short time, Δt,
N = initial number of molecules inside the container,
V_c = volume of the container (m^3),
a = cross-sectional area of the hole (m^2),
v_m = velocity of the molecules (m/s), and
Δt = time interval (s).

The velocity, v_m, in Eq. 14 is the molecular velocity which is dependent upon the temperature of the gas. It was hypothesized, for the conditions of this research, that the velocity of the CO_2 molecules moving through a hole could be approximated by the mass average flow of CO_2 using the principle of diffusion:

$$v_m = \frac{D \Delta C}{\rho_{CO_2} \Delta x} \tag{15}$$

where:

D = diffusion coefficient of CO_2 into air (m^2/s),
ΔC = concentration gradient across the opening (kg/m^3),
ρ_{CO_2} = density of CO_2 (kg/m^3), and
Δx = thickness of the boundary (m).

The diffusion coefficient varies with temperature. Holsen and Strunk (1964), as tabulated by Geankoplis (1983), obtained diffusion coefficients of 14.2×10^{-6} m^2/s at 3°C and 17.7×10^{-6} m^2/s at 44°C. We used linear interpolation to obtain values for temperatures between 3 and 44°C.

The presence of granular material in the pilot bin was contrary to the stated assumption of an empty vessel. The volume of the container, V_c, was approximated by the headspace rather than the entire air space because Eq. 14 assumes that the gaseous molecules are moving from one empty vessel to another.

Thus far, the CO_2 molecules escaping from the headspace have been accounted for, but the CO_2 molecules entering the headspace from the bulk of granular material have not been considered. The diffusion coefficient of CO_2 through wheat is 4.11×10^{-6} m^2/s (Singh et al. 1985), approximately one-third of the value for CO_2 through air. Because the CO_2 molecules take longer to travel through a porous bulk than through the headspace, the number of CO_2 molecules entering the headspace from the porous bulk was assumed to be equal to the ratio of the two diffusion coefficients (i.e., $D_{CO_2\ through\ grain}$: $D_{CO_2\ through\ air}$) times the number of CO_2 molecules escaping from the headspace.

The velocity varies with the concentration gradient (Eq. 15). As the gradient decreases due to leakage (the ambient CO_2 concentration was assumed to be constant), the velocity decreases reducing the number of molecules passing through the hole (Eq. 14). Consequently, the velocity and number of molecules passing through the hole should be calculated on an iterative basis using short time intervals.

The total mass of CO_2, G, lost from the pilot bins was calculated using:

$$G = \frac{\sum \left(\frac{N}{V_c} a v_m \Delta t \right) M}{6.022 \times 10^{23}} \tag{16}$$

To calculate a daily rate of gas loss, the total mass of CO_2 lost could be calculated for each consecutive 24 h period.

Table I. Observed pressure decay times (means of five replications) for pilot bins with holes of known diameters. The pilot bins were partially filled with wheat yielding air space volumes of 0.055, 0.099, and 0.194 m^3 for pilot bins A, B, and C, respectively.

Pilot bin	Hole diameter (mm)	Observed pressure decay time, t_o (s)
A	0.6	51
	0.8	26
	1.1	18
	1.3	11
	1.5	10
B	0.6	115
	0.8	50
	1.1	33
	1.3	19
	1.5	17
C	0.6	240
	0.8	105
	1.1	65
	1.3	45
	1.5	40

MATERIALS and METHODS

Relationship between pressure decay time and leakage area

To validate the mathematical relationship between pressure decay time and leakage area (Eq. 13), experiments were conducted in pilot bins with known leakage areas. Oil drums were selected for pilot bins because they could be sealed well (i.e., the leakage area could be controlled). The calculated volumes of the drums were 0.118 m^3 (drum A), 0.212 m^3 (drum B), and 0.437 m^3 (drum C). The drums were partially filled with wheat (drum A was 88% filled, drum B was 87% filled, and drum C was 91% filled). The porosity of the wheat was assumed to be 0.39 (Muir and Sinha 1988), resulting in air space volumes of 0.055, 0.099, and 0.194 m^3, respectively.

Automobile tire valves were mounted onto the tops of the drums to allow the bins to be pressurized using an air compressor. Holes of known diameter were made in thin brass plates soldered to brass fittings that were screwed into threaded openings in the tops of the drums. A second brass fitting was inserted for pressure measurement. One type T, copper-constantan thermocouple was inserted into each drum for temperature measurement.

The experimental procedure consisted of pressurizing the pilot bins to a gauge pressure of 1.5 kPa with an air compressor. Internal pressures were recorded at 1-s intervals for drums A and B and at 5-s intervals for drum C until the pressure decayed by one-half (i.e., to 0.75 kPa). Pressure was measured using a digital micromanometer (Model MP6KSR, Neotronics of North America, Gainesville, GA) which was connected to a data acquisition system. The pressure decay tests were repeated five times for each of the five hole sizes (i.e., 0.6, 0.8, 1.1, 1.3, and 1.5 mm diameter) in each of the three pilot bins (A, B, and C).

Relationship between gas loss and leakage area

To validate the predictions of the derived relationship between gas loss and leakage area, the pilot bins were purged with gaseous CO_2 and the subsequent decay of CO_2 concentration was measured (gas loss occurred through holes of known areas). Experiments were initially conducted using the three wheat-filled pilot bins. Observed gas losses were inconsistent, possibly due to sorption of CO_2 by the wheat kernels and an insufficient number of gas sampling sites within the grain bulk. These experiments were described by Mann (1998).

The experimental apparatus was then modified to address the limitations described in the previous paragraph. The three pilot bins of different sizes were replaced with five pilot bins of identical size (equal to drum B, 0.212 m^3 in volume). The pilot bins were instrumented with semi-rigid nylon tubing (3.2-mm outside diameter, 2.0-mm inside diameter) placed near the top, middle, and bottom of the drums for removal of gas samples (the sampling lines were purged before a sample was withdrawn). The five pilot bins were connected through a two-stage pressure regulator attached to a single cylinder of compressed CO_2. Three type T, copper-constantan thermocouples were placed inside each pilot bin (i.e., near the top, middle, and bottom).

A second modification was to replace the wheat with Dowlex 2027A polyethylene resin pellets of a size and shape similar to wheat kernels (it was assumed that their porosity was similar to that of wheat kernels, i.e., 0.39; Muir and Sinha 1988). The pilot bins were filled to a depth of 0.63 m with the polyethylene pellets, leaving a headspace of 0.051 m^3 and a total air space volume of 0.114 m^3. It was assumed that the polyethylene pellets would not sorb any CO_2.

The leakage area was confined to circular holes of known diameter made in thin brass plates soldered to brass fittings screwed into the tops of the drums. During purging, the brass fittings were removed, but were inserted immediately after purging was completed. Temperatures were measured and gas samples were collected and analyzed at daily intervals for 14 d. Gas samples were analyzed using a gas chromatograph (Model 8430 Matheson Gas Products, East Rutherford, NJ) equipped with a thermal conductivity detector and operated isothermally (oven and detector) at 40°C using helium as a carrier gas. The column was stainless steel (2 m long) and packed with Porapak Q. Five hole sizes were tested: 0.6, 0.8, 1.1, 1.3, and 1.5 mm diameter.

RESULTS and DISCUSSION

Observed pressure decay times

Observed pressure decay times were obtained directly from the data files stored by the data acquisition system. Pressure decay time was the time taken for the pressure to decay from 1.5 to 0.75 kPa (Table I). For each pilot bin, pressure decay time decreased with increasing hole size. For constant hole diameter, pressure decay time increased with increasing bin volume.

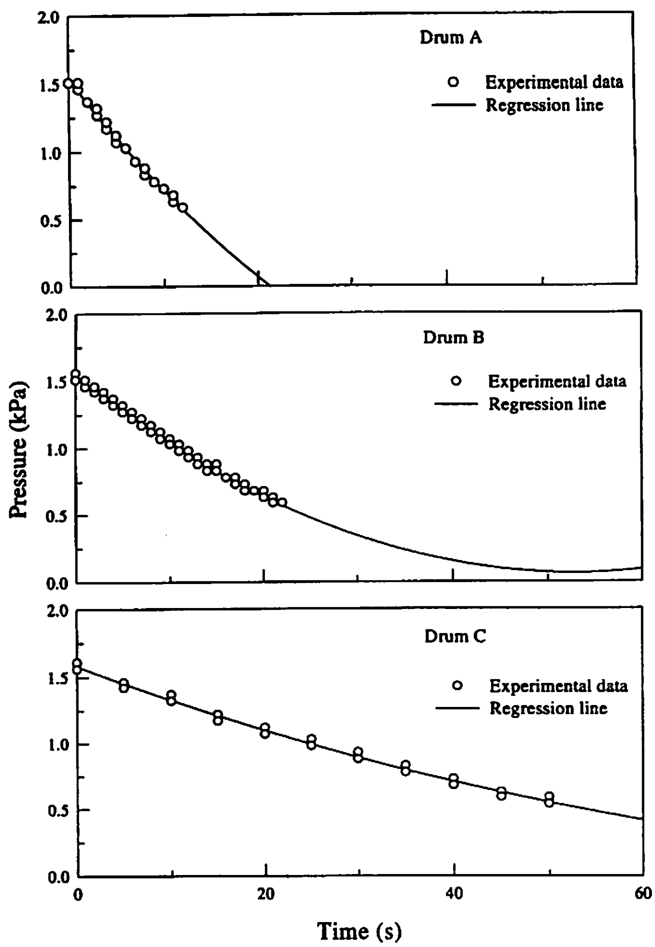

Fig. 1. Pressure decay data from wheat-filled pilot bins (A, B, and C) with circular holes of 1.5 mm diameter. The non-linear regression lines (general form: $P = at^2 + bt + c$) are based on data pooled from five experimental replicates.

Predicted leakage areas

The predicted leakage areas were calculated using Eq. 13, but P_{bin} first had to be calculated. The pressure decay data from the five replicates were pooled and plotted for each pilot bin and each hole size. Pressure decay data from the three wheat-filled pilot bins with a circular hole of 1.5-mm diameter (Fig. 1) were typical of the pressure decay data obtained. Non-linear regression analyses were done for each group of data using SigmaPlot (version 3.02 Jandel Corporation, San Rafael, CA). Equations of the general form $P = a\,t^2 + b\,t + c$ were obtained. Equation 11 was then used to calculate P_{bin} for each combination of pilot bin and hole size. The P_{bin} values were subsequently substituted into Eq. 13 to calculate the predicted leakage areas (Table II).

The analysis procedure described in the previous paragraph is rather cumbersome. Further review of Fig. 1 suggests that it may be possible to approximate the pressure decay relationship using a simple linear fit to the data. For a linear approximation, P_{bin} is equal to ½(1.5 + 0.75) or 1.125 kPa. Predicted leakage areas using a P_{bin} of 1.125 kPa are given in Table II.

Comparison of actual and predicted leakage areas

Leakage areas predicted using the non-linear approximation for P_{bin} were not consistent, with predictions both greater than and less than the actual leakage areas (Table II). Percent errors ranged from -17.5 to 23.1%. Based on these data, it is questionable whether the leakage area in a pilot bin can be predicted using the pressure decay time without further investigation. Possibly the experiment should be repeated with empty pilot bins to eliminate the possible influence of grain on the pressure decay behavior. The leakage areas predicted using the linear approximation for P_{bin}, however, did not introduce any significant error (-20.3 to 19.2%) over the "theoretically correct" non-linear approximation.

Observed gas loss

Mean CO_2 concentrations were calculated based on samples taken from the three locations (top, middle, and bottom) inside each of the five pilot bins. The difference between the mean CO_2 concentration at the start of the experiment and the mean CO_2 concentration at the end of the experiment multiplied by the total air space inside the pilot bins yielded the volume of gaseous CO_2 lost from the pilot bins. Using the average temperature inside the pilot bins, the CO_2 density was calculated. The mass of CO_2 lost was equal to the product of the volume and density.

Observed gas loss was not consistent for all five replicates at each hole size (Table III). These results can be explained by the procedure used to purge the pilot bins with gaseous CO_2. All five pilot bins were purged simultaneously from a single tank of compressed CO_2, with the total gas flow split into five purge lines. Based on the observed initial CO_2 concentrations, it can be concluded that unequal quantities of gaseous CO_2 were purged through each pilot bin. These variations in initial CO_2 concentration influenced the observed gas losses because the number of molecules available to exit through the hole was dependent upon the molecular density (see Eq. 14). In almost all cases, the replicate with the greatest observed gas loss also had the highest initial CO_2 concentration (Table III).

Predicted gas loss

The gas loss was predicted using Eq. 16. Actual leakage areas rather than predicted leakage areas were used in the calculations. An approximate velocity of CO_2 through the hole was calculated using Eq. 15. It was assumed that gas loss occurred from the headspace (i.e., volume of 0.051 m^3). The number of CO_2 molecules entering the headspace from the bulk of polyethylene pellets was calculated using the ratio of the diffusion coefficient of CO_2 through grain to the diffusion coefficient of CO_2 through air, times the number of CO_2 molecules escaping from the headspace.

As with the observed gas losses, the predicted gas losses were not consistent for all five replicates at a single hole size (Table III). This was to be expected because the gas loss depends on the concentration of molecules within the pilot bin (Eq. 16).

In general, predicted gas losses did not match observed gas losses (Table III). In some cases the gas loss was under-predicted, but in other cases the gas loss was over-predicted. These results suggest that the mathematical relationships described in this paper are not reliable for calculating gas loss with leakage area.

Table II. Predicted and actual leakage areas for wheat-filled pilot bins. The pilot bins (A, B, and C) had air space volumes of 0.55, 0.099, and 0.194 m^3, respectively.

Pilot bin	Hole diameter (mm)	Actual leakage area (mm^2)	Non-linear approximation for P_{bin}		Linear approximation for P_{bin}	
			Predicted leakage area (mm^2)	Percent error (%)	Predicted leakage area (mm^2)	Percent error (%)
A	0.6	0.26	0.32	23.1	0.31	19.2
B	0.6	0.26	0.25	-3.8	0.25	-3.8
C	0.6	0.26	0.23	-11.5	0.23	-11.5
A	0.8	0.52	0.62	19.2	0.61	17.3
B	0.8	0.52	0.58	11.5	0.57	9.6
C	0.8	0.52	0.53	1.9	0.54	3.8
A	1.1	0.90	0.88	-2.2	0.89	-1.1
B	1.1	0.90	0.87	-3.4	0.87	-3.4
C	1.1	0.90	0.81	-10.0	0.87	-3.3
A	1.3	1.37	1.44	5.1	1.45	5.8
B	1.3	1.37	1.51	10.2	1.51	10.2
C	1.3	1.37	1.22	-10.9	1.25	-8.8
A	1.5	1.77	1.60	-9.6	1.60	-9.6
B	1.5	1.77	1.72	-2.8	1.69	-4.5
C	1.5	1.77	1.46	-17.5	1.41	-20.3

CONCLUSIONS

1. Predicted leakage areas differed from actual leakage areas by as much as 23.1%. The leakage areas predicted using the linear approximation for P_{bin}, however, did not introduce any significant error over the "theoretically correct" non-linear approximation.
2. Observed gas losses depend on the initial CO_2 concentration. Predicted gas losses did not agree with observed gas losses.
3. Further research is required to determine whether the mathematical relationships between pressure decay time and leakage area and between gas loss and leakage area can be used by grain storage managers.

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Table III. Observed and predicted gas loss from the pellet-filled pilot bins with holes of known diameters over a 14-d period.

Hole diameter (mm)	Replicate	Initial CO_2 concentration (%)	Observed gas loss (g)	Predicted gas loss (g)
0.6	1	72.0	12.7	16.9
	2	73.0	52.6	17.4
	3	64.1	32.3	13.7
	4	54.0	23.2	9.9
	5	47.9	25.9	8.0
0.8	1	83.1	51.0	36.4
	2	83.3	47.0	36.5
	3	84.7	55.2	37.7
	4	74.2	35.1	30.2
	5	66.8	39.8	25.3
1.1	1	76.9	52.6	44.7
	2	74.5	51.9	42.6
	3	74.0	47.9	42.1
	4	64.4	38.4	33.9
	5	64.4	47.5	33.7
1.3	1	76.4	42.6	54.0
	2	75.2	39.9	52.8
	3	72.0	35.1	49.6
	4	64.8	29.5	42.6
	5	56.6	23.7	34.7
1.5	1	81.0	44.9	64.7
	2	78.1	39.1	61.6
	3	76.2	33.0	59.5
	4	68.5	27.0	51.4
	5	62.0	27.2	44.7

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