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MILL PRESSURIZATION TEST QUANTIFIES FUMIGANT LEAKAGE RATES DURING SULFURYL FLUORIDE AND METHYL BROMIDE FUMIGATION OF COMMERCIAL FLOUR MILLS

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ABSTRACT

During six fumigation trials in five commercial flour mills building pressurization tests were conducted after sealing by professional fumigators to quantify sealing quality or gas tightness of mills. The equivalent leakage areas (ELAs) of the mills were determined based on the pressurization test results. In order to account for the size differences of the mills, specific ELAs were calculated by dividing the ELAs by the corresponding mill volumes. The specific ELAs ranged from 0.041 to 0.108 cm^2/m^3. The half loss times (HLTs) determined from average fumigant concentration readings were between 2.88 and 47.48 h. In general, the fumigation trials in the structures that had lower specific ELAs yielded longer HLTs. These results suggested that specific ELAs can be used for quantification of sealing quality prior to structural fumigation and for predicting HLTs.

Key words: Flour mills, sulfuryl fumigation, sealing quality, pressurization test, gas tightness, half loss time, fumigation efficacy

INTRODUCTION

The concept of precision fumigation, especially with sulfuryl fluoride is designed to optimize the amount of fumigant usage based on gas tightness of a structure quantified by half loss time (HLT), species and stage of stored product insect to be controlled, and temperature of the structure being fumigated, among other things. HLT for a structure is assumed when sulfuryl fluoride is used for the very first time, because of lack of gas monitoring data that shows actual gas leakage rates from the structure. It is well known that gas leakage rates during structural fumigation depend on the sealing quality and prevailing weather conditions. Chayaprasert et al. (2012) have shown that for a pilot mill at Kansas State University (9628 m^3) treated with methyl bromide and sulfuryl fluoride, HLTs were inversely related only to wind speed and not any other weather conditions measured. The work of Chayaprasert et al. (2012) was based on a building pressurization test after sealing prior to each of three fumigations with methyl bromide and three with sulfuryl fluoride. This and other seminal work by Chayaprasert (2007), Chayaprasert et al. (2008) and Chayaprasert and Maier (2010) showed that a simple building pressurization test can be used to gauge gas tightness of a structure based on computational fluid dynamics models and assumed weather conditions. These model simulations have been validated with limited field trials in commercial facilities. In commercial facilities, factors in addition to wind speed may also influence sulfuryl gas leakage rates. The present investigation was designed to provide additional field validation data to determine if building pressurization tests can be used to accurately assess sealing quality based on six fumigations in five commercial flour mills. The goal was to explore if building pressurization test can be generally used as a quantitative tool for measuring gas tightness of commercial flour mills prior to fumigation.

MATERIALS AND METHODS

Six fumigation trials were conducted in five different flour mill structures (Mills 1, 2, 3, 4, and 5) located in Indiana, Kansas, and Montana, USA. Details of the mill fumigations are given in Table 1. The volumes of the mill facilities ranged from 8,495 to 28,317 m^3. Mill 1A and Mill 1C were two buildings constructed adjacent to each other and were fumigated on the same day. Mill 2 was fumigated twice within a four month period. Sulfuryl fluoride (SF) was used in the first five fumigation trials. Methyl bromide (MB) was used to fumigate Mill 4 in the sixth trial. Due to high leakage rates, additional gas had to be introduced during fumigation.

Table 1. Mill volumes and fumigation details

Fumigation details	Fumigation trial					
	1	2	3	4	5	6
Mill ID	1A	1C	2	2	3	4
Mill volume (m^3)	8,495	9,911	28,317	28,317	13,592	14,158
Number of mill floors	5	4	6	6	7	7
Mill location	Indiana	Indiana	Indiana	Indiana	Kansas	Montana
Fumigation dates in 2011	Apr 22-23	Apr 22-23	May 28-29	Sep 3-4	Sep 4-5	Sep 17-18
Exposure time (h)	23	23	24	23.5	23.5	24
Fumigant	SF	SF	SF	SF	SF	MB
Initial fumigant amount (kg)	624	510	907	907	567	295
Top-up amount (kg)[a]	397	284	113	113	0	68
No. gas monitoring points	5	4	6	4	7	7

[a]Additional gas introduced during fumigation.

Ambient conditions inside the fumigated mill were recorded every 10 min using HOBO® H8 temperature loggers (Onset Computer Corporation, Bourne, Massachusetts, USA)). The outside weather conditions were recorded using a HOBO® U30 weather station. Five temperature loggers were installed at 1.52 m above each floor of the mill. The weather station was installed on the roof of the mill. The weather station monitored ambient temperature and relative humidity, barometric pressure, solar radiation, and wind speed and direction. However, only the wind speed and ambient temperature data were incorporated in the analysis of this study. A number of 4.3 mm inner diameter nylon tubes were placed in the mill for monitoring fumigant gas concentrations over time. Generally one tube was placed on each floor to measure gas concentrations at a height of 0.91 m. Fumigation concentrations were recorded manually every hour throughout the exposure time. The Spectros Instruments Single Point Monitor (Spectros Instruments, Hopedale, Massachusetts, USA) was used for measuring gas concentrations in fumigations 1 to 4 and the Fumiscope (Key Chemical and Equipment, Clearwater, Florida, USA) was used in fumigations 5 and 6.

Prior to fumigant release after sealing the structure, a building pressure test was conducted to quantify sealing quality using the E3 blower door fan setup (Infiltec, Waynesboro, Virginia, USA) installed at an exit door. The mills were pressurized between 5 and 80 Pa depending upon their size and prevailing weather conditions. The airflow rate through the fan and the pressure differences between inside and outside of the mills were recorded. These values were used to quantitatively determine gas tightness of the mills using procedures described in Chayaprasert et al. (2012).

The pressurization test data were used to calculate the equivalent leakage areas (ELA), A_L (cm^2), of the mill structures. These ELAs quantitatively indicated the gas tightness of the structures. First, for each mill structure, the correlation between the airflow rates, Q (m^3/s), through the blower door fan and the pressure raises, p (Pa), in the structure was determined using Eq. 1 (ASHRAE, 2001):

$$Q = bp^n \tag{1}$$

where b is the flow coefficient and n is a dimensionless pressure exponent. The ELA was then calculated using Eq. 2 (ASHRAE, 2001):

$$A_L = 10,000 Q_r \frac{\sqrt{\rho / 2p_r}}{C_D} \tag{2}$$

where Q_r is the predicted airflow rate (m^3/s) at the reference pressure difference, p_r (Pa). The predicted airflow rate was calculated using Eq. 1 by assuming p_r = 10 Pa. The discharge coefficient, C_D, and the air density, ρ (kg/m^3), were assumed equal to 1 and 1.15, respectively.

To calculate the HLT the recorded gas concentration data from all monitoring points were averaged, yielding one gas concentration curve for each fumigation trial. The average data points where concentrations were increasing due to gas releases were discarded, resulting in sections of decreasing concentration curves. These sections of decreasing concentration curves were then fitted to the first-order kinetic equation (Eq. 3) (Cryer, 2008; Chayaprasert et al., 2008):

$$C_t = \frac{C_i}{2^{\frac{t}{HLT}}} \tag{3}$$

where, C_t is the current concentration (g/m^3) at the elapsed time t (h) and C_i is the initial concentration (g/m^3).

RESULTS AND DISCUSSION

The pressure difference and airflow rate relationships from the pressurization tests are shown in Fig. 1A and Table 2.

The steeper curves imply that higher airflow rates were needed to produce the same levels of pressure increase in the flour mills. These curves can be used for comparisons of gas tightness between the flour mills after correcting data for differences in mill sizes. The average fumigant concentration curves during all six fumigation trials are shown in Figs. 1B to 1D. The slopes of the concentration curves from fumigations 1 and 2 were steeper than those of the other curves (Fig. 1B), implying shorter HLTs. On the other hand, the somewhat flat concentration curves of fumigations 3 and 4 in Mill 2 (Fig. 1C) suggested longer HLTs.

Table 2. Pressurization test results, average ambient conditions, and HLTs

Trial	b	n	A_L (cm^2)	A_L/V (cm^2/m^3)	Temp difference Mean ± SD (°C)	Wind speed Mean ± SD (m/s)	HLT (h)
1	0.077	0.697	919	0.108	4.67 ± 2.37	3.04 ± 1.15	3.19-4.72
2	0.058	0.672	653	0.066	3.15 ± 2.03	3.04 ± 1.15	2.88-9.19
3	----[a]	----[a]	----[a]	----[a]	9.37 ± 2.07	5.34 ± 1.43	47.48
4	0.049	0.990	1148	0.041	11.43 ± 5.34	3.56 ± 2.06	19.42-23.66
5	0.140	0.478	1009	0.074	12.81 ± 4.23	4.30 ± 1.27	10.15
6	0.099	0.692	1168	0.083	10.98 ± 3.59	3.74 ± 1.92	3.98-5.25

[a]Invalid pressurization test data.

This was actually the case as indicated by the calculated HLTs (Table 2). In fumigation 3, due to insufficient flow rate capacity of the blower door fan the pressure test could not be performed successfully. Except for fumigation 3, the ELAs (i.e., A_L) were between 653 and 1,168 cm^2. In order to account for the size differences of the mills, the specific ELAs (i.e., A_L/V) were calculated by dividing the ELAs by the corresponding mill volumes, V (m^3) (Table 1). A lower ELA value indicated higher gas tightness level. Based on the ELAs, the order of gas tightness levels, from the most to the least gas tight structures, were Mill 2 (fumigation 4), Mill 1C, Mill 3, Mill 4 and Mill 1A. The structures that had the longest to the shortest HLT values were Mill 2 (fumigation 3), Mill 2 (fumigation 4), Mill 3, Mill 4, Mill 1A and Mill 1C. Although the weather conditions during all fumigations were different, the similarity between the orders of the specific ELAs and the HLTs suggested that the specific ELA could be used for quantification of sealing quality prior to fumigation. The primary advantage of ELA is that the ELA of a structure can be determined before the fumigation while the HLT could not be calculated until some fumigant concentration readings are obtained. The air infiltration rate, q (m^3/s), into a building can be estimated based on the building's ELA, temperature difference between the inside and outside of the building, ΔT (°C), and prevailing wind speed, U (m/s) (ASHRAE, 2001):

$$q = \frac{A_L}{1{,}000}\sqrt{c_s \Delta T + c_w U^2} \quad (4)$$

where c_s and c_w are the stack and wind coefficients, respectively. Furthermore, HLT and the infiltration rate are related (Banks et al., 1983; Chayaprasert, 2007):

$$HLT = \frac{V}{q}\frac{\ln(2)}{3600} \quad (5)$$

where V is the volume of the building (m^3). Using Eq. 4 and 5, the HLT of a fumigant in a structure can be predicted in advance. Accurate prediction of HLT would help to optimize the amount of fumigant usage which is one of the focuses of the precision fumigation concept. However, the present study lacks proper replicate fumigations of the same structure under varying environmental conditions. The stack and wind coefficients are different for different structures. The local wind and temperature conditions should be measured to use concepts described in this paper. The financial value of the pressurization test should be justified. In fumigation trials reported here structures that had lower specific ELAs yielded longer HLTs. These results suggested that specific HLTs and ELAs can be used for quantification of sealing quality prior to structural fumigation.

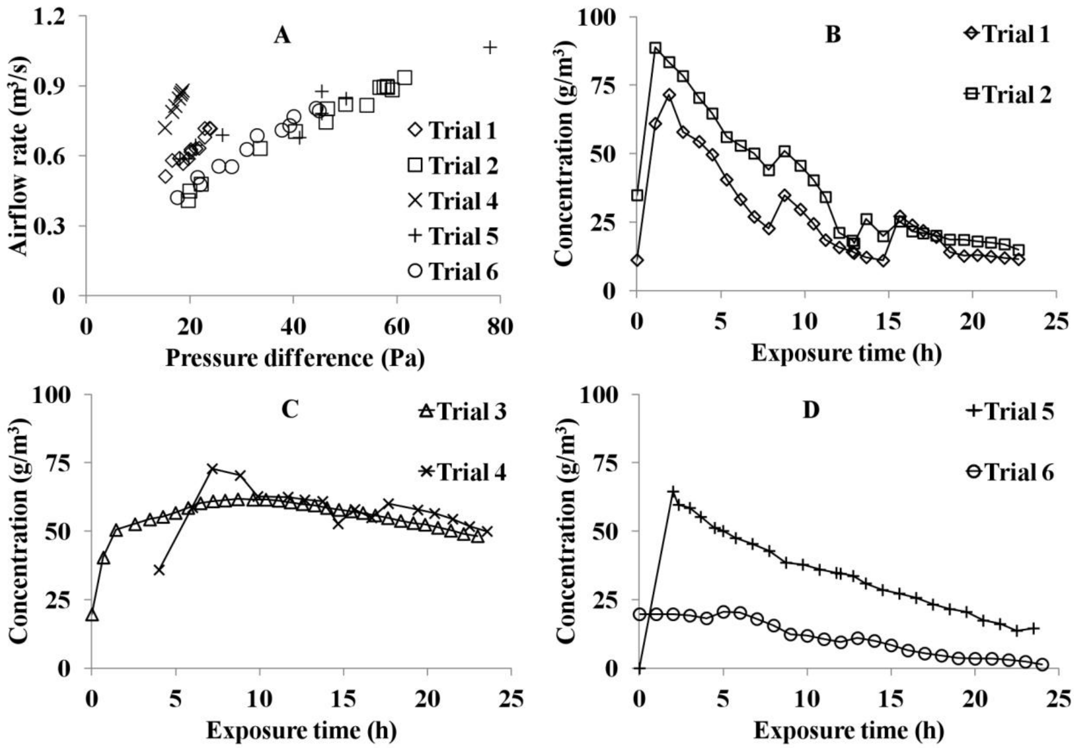

Fig. 1- (A) Pressure difference-airflow rate relationships from the pressurization tests. (B) Average gas concentrations during fumigations 1 and 2. (C) Average gas concentrations during fumigations 3 and 4. (D) Average gas concentrations during fumigations 5 and 6.

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