Guidelines for sealing steel grain bins for fumigation

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Abstract

Eleven 1.8m by 2.7m galvanized bolted steel bins were assembled and bolted to the top of 2.1m square welded steel base frames. During assembly, adhesive backed closed cell foam strip was used between all wall and roof panels to form wall and roof sheet seams, and inside the roof cap to form a circular cap seal.

A 15cm diameter flanged transition (used for aeration and grain unloading equipment) penetrated the sidewall centered 15cm above the base A 5cm ID PVC bioassay sample recovery pipe assembly penetrated the sidewall 15cm below the eave. Five bins were piped from roof openings to a blower mounted on the flanged transition to recirculate ECO_2FUME phosphine gas. Gas sample and thermocouple test points were installed in all 10 gas test bins and the check bin. Smoke, soap spray and an ATI Porta Sens PH_3 digital leak detector were used during pressure testing to detect and seal leaks Wall seams, penetrations, and base joints were silicone sealed

The objective for sealing bin, to hold a half-life of 25 mm water column for one minute, was achieved in all bins Leakage rates from ECO_2FUME bins ranged from 2.52 ppm/hour to 3.60 ppm/hour, averaging 3.02 ppm/hour during 117 hours of testing After bins were kept sealed for 28 days, PH_3 gas readings ranged from 30 to 65 ppm in all ten bins, adequate for killing all life stages of stored product insects

Background

Public demand for food grain without pesticide residues and clean air concerns about releasing chemicals into the atmosphere is placing more emphasis on bolted steel grain storage bins that are better sealed than bolted bins that have been assembled in the past Historically, galvanized steel storage tanks have been bolt assembled with no sealing of joints on the sidewalls and roofs Concrete base to sidewall junctions have not been adequately sealed to hold gas atmospheres.

Eave gaps of 0 5 to 1 0cm are typical construction between roof and sidewall, to allow under-roof condensate to drip outside the bin. Roof vents are screened to keep out birds. Roof caps, roof access hatches and sidewall entry doors are metal to metal contact with no provision for sealing Unload conveyors are open to the atmosphere A major concern for improved sealing of bins is that aeration or drying fans are almost always totally open to the atmosphere with only a safety fan guard or rodent screen over the inlet orifice. So, insects have a direct entry into aeration ducts or under floor plenum areas

To develop procedures and guidelines for how to seal large steel bins to hold a gas or an atmosphere, or just to exclude insect pests, it is best to start with a small prototype and work up to larger field scale models, like the process of solving other engineering problems The need for research in the sealing of grain storage structures was discussed in the sealed storage section of the CAF in Nicosia Cyprus in 1996

The opportunity to seal and test some small bins was presented in the Fall,6 1996 and in 1997 when BOC Gases, USA decided to register a cylinderized gas form of phosphine gas developed by BOC Gases, AUS in conjunction with CSIRO's work on the Siriflo process using liquid phosphine with the trade name, Phosfume™ Since Phosfume™ was already a registered trade name in the U S., BOC Gases, USA developed the name ECO2FUME™ fumigant gas

ECO_2FUME™ fumigant gas is not temperature dependent, so a fumigation can be conducted quickly at predictable high, medium or low dosages and concentrations in storage or building spaces In the process of setting up their field research plan to test ECO_2FUME and document efficacy with known stored grain insects, BOC Gases, USA, contacted OSU faculty to conduct laboratory and field research. A research agreement was developed

The steel components for twelve 1.8 m by 2.7m, 5 tonne bins were obtained and prepared for assembly A 2.1m flat steel base with 15cm side angles was designed and welded with the top surface fabricated from 0.5cm thick steel plating for the top The steel plate was supported with two cross channels welded as part of the base frame assembly to

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prevent deflection under the 5-tonne grain load.

Objectives

A primary objective of the study was to develop and test small steel bins to see if a 25.4mm water column (0.249 kPa) pressure, could be held for a half-life decay to 12.7 mm (0.1245 kPa) during a 1 minute test period as a leakage standard for bolted steel bins. This was a proposed standard that was suggested by the author as a stringent target standard for sealing grain and bulk product storage structures for the U S. at the 1996 CAF in Cyprus.

A second primary objective of this research was to compare ECO_2FUME^{TM} fumigant gas with a leading phosphine pellet, Degesh Phostoxin™ for labeling purposes Tests compared daily gas levels between minimum dosage rates for commercial steel tanks for Phostoxin™ and ECO_2FUME^{TM} fumigant gas targeted at 200 ppm during a 7-day period

Material Specifications and Sealing Techniques

The bin sidewalls were made of two half round sections approximately 1.1 m wide per bin sheet. The sidewalls were two sections high or approximately 2.1m with overlap to the roof junction. For initial sealing of the bin sidewall vertical and horizontal section joints, a commercial adhesive backed, closed cell foam strip, approximately 4.0cm wide by 0.5cm thick was purchased from Brock Manufacturing Company, Milford, Indiana, USA. This material is a Brock Mfg. Co standard sidewall joint sealing compound It is usually attached to the underneath steel sheet of each overlap joint using the adhesive backing, the overlaid and clamped by the joint seam bolts. Brock recommends rubber washered head bolts. When bolts are torqued down, the rubber washer compresses against the bolt threads and seals the hole for bolt. The joint bolts compress the foam to a thickness of about 1.0 – 1.5mm of thickness, providing a dense gasket material.

The major point of concern for leakage from a bolted steel bin with well sealed sidewall joint seams and base are roof hatches and vents, sidewall doors, conveyor and fan transition openings. For these small bins, the roof fill hatch was the only standard opening in the bin. Additional openings for this research was a 15cm diameter by 15cm long tube with square bolt flanges welded to each end of the base service access tube that bolted to the sidewall of the bin, 15cm on center above the steel base, and a 5cm PVC bioassay sample pipe assembly that was silicone sealed through a 5cm hole, 15cm on center from the top of the wall.

Sealing Methods – Roof Hatch

The 0.5m roof hatch was the major concern It had a rolled lip with a top lip edge diameter of about 0.5cm. The initial plan was to use a Brock Mfg. Co. pneumatic bin hatch fill ring seal, a 3.5 cm black dense foam ring split along the length about 70% through the diameter. This round dense foam seal material slides down over the fill ring lip, and the two ends overlap about 1 – 2cm, and must be compressed to butt against each other, providing a tight joint seal.

In theory, this seal works well, but the hinged roof fill opening cover tends to contact the raised foam ring next to the hinge with a scrubbing motion, causing the sponge gasket to compress unevenly, twist and warp out of shape. It was difficult to get a satisfactory seal, even with additional weight on the roof. As an alternative, the 0.5cm thick by 4.0cm wide foam gasket material used for the sidewall joint seems was notched about 1cm in from one side, then was curved and attached to the bottom of the lid to form a seal ring. The adhesive bond held well as the hatch lid was virtually flat against the lip of the roof opening when it made contact. By adding approximately 20 kg of weight to each hatch cover, an excellent seal was obtained, even with repeated hatch openings.

Sealing Methods – Bin Ring to Steel Base

The bottom ring of the bin was not a standard bin wall base ring sheet with 90 degree angle 5 cm (2 in) wide flanged foot. Instead, the bottom of the sheet was a sharp edge, like a hopper tank sidewall with no hopper attached. Thus, sealing the sidewall to the steel base was a problem. Initially, a 5cm (2 in) square asphalt impregnated open cell foam material used by Brock Mfg. Co. to fit under standard steel bin wall base ring footings was used, but even though the base ring was anchored to the steel base using four steel angle bolt brackets positioned at 90 degree intervals around the base ring, the sharp edged wall sheets were hard to keep centered on the foam. When successfully centered and tested, the open cell foam leaked smoke severely.

The foam base strips were removed and the 0.063 to 0.125 inch gap between the sidewall sheet and steel base was successfully sealed inside and outside using a silicon-caulked bead. Other leak points were the four steel angle bolt clips that anchored the bin to the steel base. The bolts were the leak source, so these were also sealed with silicone caulk.

Sealing Methods – Bin Wall Seams, Sidewall Tube Entries, Recirculation System

Although the bin ring joints were all carefully gasketed with

the Brock Mfg. Co adhesive backed closed cell foam strips, some very small leaks were hard to locate, so the decision was made to apply a small silicone caulk bead along each bin ring joint.

The 15cm OD flanged inlet tube and 5cm OD PVC bioassay tube were both sealed with silicone beads to eliminate chances of leaks at those points The final sealing to control leakage was the recirculation blower. After sealing around the mounting flange with silicone caulking, a leak was found on each of the 5 bins used for ECO_2FUME at the recirculation blowers. The gas was leaking directly through the blower shaft bearing and through the motor windings. A double plastic bag was placed around the blower and carefully taped sealed to contain the gas leak through the blower windings.

Pressure Test Method

A larger centrifugal blower than those used for was mounted to a 5 cm PVC pipe and ball valve assembly The ball valve and pipe assembly was pressure tested to 103 kPa (15 psig) with no loss of pressure, to confirm that there was no leakage through the ball valve. A flanged plate with threaded connector was adapted to the ball valve assembly, then bolted to the 15cm square flanged transition to the base of the blower. With the blower mounted to the piping, the blower was started and readings were taken from a precision manometer. The blower produced about 28 – 30 mm of water column. With the blower operating at steady state on the manometer, the ball valve was closed, then the blower was shut off The time of decay from 25 mm to 12.5mm (1.0 inch to 0.5 inch) water column was observed. All 12 bins were pressure and time decay tested. When leakage rates exceeded the rate needed, half-life decay occurred in less than 60 seconds, more sealing was conducted, until all 12 bins met or exceeded the desired standard.

Sealing Results – Pressure Sealing Guidelines for Small Bolted Steel Bins

The following guidelines suggested for small bolted steel bins have general application to larger bolted steel bins:

(1) An adhesive backed 4 cm wide by 0.5 cm thick closed cell foam joint strip supplied by Brock Mfg. Co. provides good sealing qualities when used between bolted steel bin wall sheet junction overlaps

(2) Make sure all metal surfaces are thoroughly clean and dry before applying the adhesive backed foam strip to assure long-term adhesion.

(3) The adhesive backed closed cell foam joint strip should have a silicone bead applied where one strip butts against another strip to eliminate leakage channels.

(4) Apply a silicone caulk bead at the outer wall sheet edge in the proximity of foam strip butt joints to further insure sealing

(5) Use the adhesive backed foam as a bin fill cap seal ring gasket by making a 1 cm slit at 3 – 6 cm spacing to allow the foam strip to bend to conform to the curved inner lip of the fill ring lid Measure the ID of the fill ring cover or lid, and the OD of the fill ring to make sure that the foam strip gasket will be contacted at all points by the lip of the fill ring with the lid in the closed position. If the difference between the ID of the cap and the OD of the fill ring is 3 cm or less, place the foam strip against base of the fill cap with the edge of the gasket against the sidewall of the lid or cover and secure with the adhesive backing.

(6) Keep all holes for tubes or pipes that penetrate sidewall sheets as tight as possible in clearance to minimize gap between tube and wall sheet that must be sealed. Use precision pull-through knockout punches for holes, then use a rotary grinder to enlarge the opening.

(7) Use rubber washer headed bin bolts to seal the hole for bolt openings. Inspect each rubber washer after the bolt is torqued down to see if a failure of the washer has occurred. Test all bolts for leakage during leak tests, if leaks persist.

(8) Steel bin wall base rings should have an angle pressure foot for flat bottom bins. Anchor the base ring to the concrete or steel base. Silicone seal all bolts as they are placed through the wall sheets and base anchor clips Use rubber washered head bolts for all bin wall sections, door frames and other attachments where bolts penetrate the bin wall or roof

(9) Pre-tape sharp metal edges with a cushion material to keep from cutting plastic bags that cover the structure.

(10) Use a professional fumigators plastic bag and use at least double bag thickness to seal roof vents, fans, and other devices that can be sealed. Use Camy 300 04 or Camy 360 adhesive spray to attach the bag openings to the metal that projects through the roof or wall. Leave room for professional fumigators masking tape (high quality) to overlap the bag and over lap the adjacent steel surface, about 50% each Use at least 3 layers of tape with each layer overlapping the steel surface at least 1 cm beyond the previous tape edge

(11) Use smoke-bombs plus a small fan to pressurize bins for visual testing for air or gas leaks.

(12) Develop a flanged inlet to the bin base or plenum that will accommodate a small centrifugal blower. The blower should be capable of pressurizing the bin within 1 to 2 minutes of operation to a pressure level of only 37 to 50mm (1.5 or 2 in) water column.

(13) Adapt a 5 or 7.5cm ball valve assembly, or other suitable leak proof cut-off device to seal the bin while

the blower is still running. The blower should be shut off as soon as the valve or cut-off device is closed.

(14) Warning: Use of a high-pressure centrifugal blower could cause structural damage to the bin being tested.

(15) Attach and secure a tube into the bin and mount an inclined manometer capable of reading 50 – 100mm (2 to 4 in) of water column.

(16) If possible, use CO_2 and a CO_2 leak detector or Phosphine and a sensitive Phosphine leak detector (low range PH3 tubes or electronic digital readout sensor) to check for leaks.

(17) Obvious leak points to check are: bin fill ring/cap or cover area, any roof openings, such as vents, fans, doors, hatches and other appurtenances that penetrate wall or roof surfaces.

(18) Pressurize the structure to above 25mm (1inch) water column. Start recording time as the pressure decay reaches 25 mm, and mark the time when the pressure reaches 12.5 mm.

These guidelines do not comprise an inclusive pressure testing procedure, but will provide a beginning for testing steel bolted structures. Based on the length of time that the small OSU bins held PH_3 at lethal levels, a pressure test for larger structures of 12.5 mm with a half of life decay of 1 minute would appear to provide a reasonable target for sealing new structures.

Field Tests with Two Types of Phosphine Gas

Tests comparing ECO_2FUME and Phostoxin were conducted in eleven 1.8m (6 ft) diameter by 2.7 m (9 ft) high corrugated steel bins assembled on welded steel bases. During bin assembly, special care was used to seal all seams and joints to minimize gas leakage. A 2.4 cm (6 in) diameter flanged transition installed through the sidewall with the transition centerline 2.4cm (6 in) above the base. Blower mounting adapter plates sealed the transition opening. An inverted 'V' duct extends 19 cm (48 in) across the bin from the transition as a gas and aeration duct.

All bins were sealed to hold a half-life of 25 mm (1.0 in) water column for at least one minute as a gas-tightness standard. During pressure testing, smoke bombs and soap spray were used to detect leaks. Wall seams, penetrations, and base joints were silicone sealed.

Five bins were equipped with gas piping from the roof cavity to the recirculation blower inlet for fast recirculation of ECO_2FUME^{TM} fumigant gas, Figures 1 and 2. The five bins used for Phostoxin™ were identical to the five ECO_2FUME^{TM} bins, except for the recirculation blower and piping system. A flat plate was bolted to the 15 cm square flanged transition and silicone sealed. Grain temperatures and insects were monitored in the 10 test bins, and one untreated control bin.

Recirculation blowers were rated at 0.003 kW (0.004 or 1/250th HP) with a free air capacity of 425 l/min (15 cfm). The blowers delivered about 170 – 200 l/min (6 – 7 cfm) through wheat with 40% or 3.1 m^3(110 ft^3) of void space, providing one gas exchange in 15 – 20 minutes or three to four gas exchanges per hour. Compared to aeration at 63 liters/tonne (1/10 cfm/bu) with five minutes per gas exchange or 12 exchanges per hour, these recirculation blowers delivered about 25 – 21 l/tonne (0.04 to 0.033 cfm/bu). This is 4 to 10 times normal closed loop fumigation recirculation rates of 6.3 – 2.1 l/tonne (0.01 0.004 cfm/bu) suggested by Cook (1980).

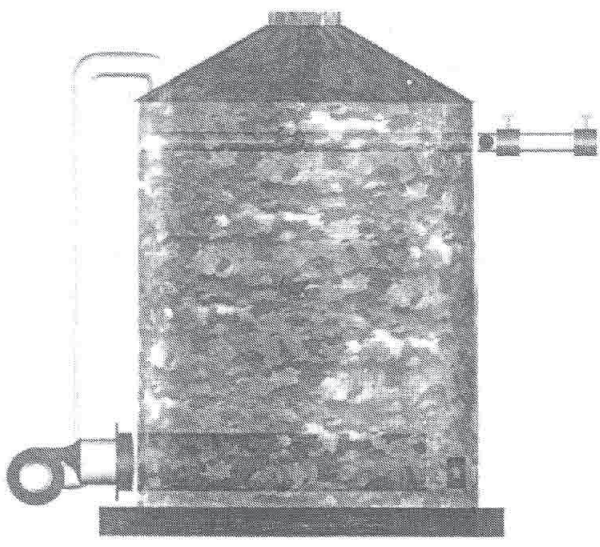

Fig.1. Side view 1.8m×2.1m bin.

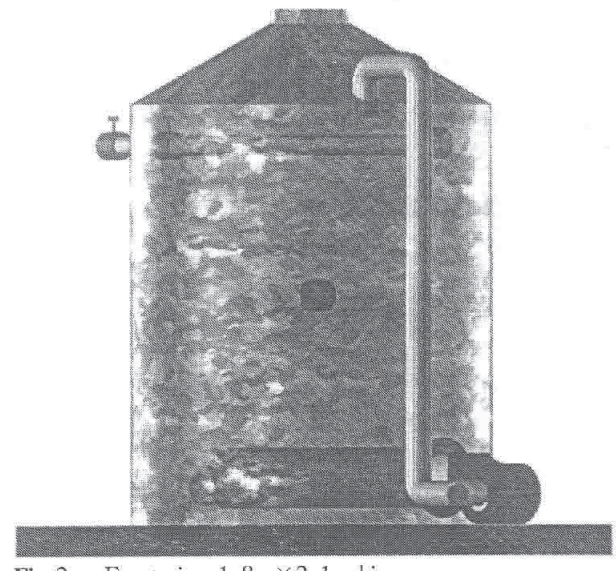

Fig.2. Front view 1.8m×2.1m bin.

Field Test Results

BOC Gases U.S use 200 ppm +/−20% as a conservative initial target for ECO_2FUME^{TM} fumigant gas dosage rates during the 7 day test. The initial dosage of 1.79 grams of ECO_2FUME^{TM} fumigant gas/bin was calculated to produce 200 ppm in the grain interstice space after absorption into 4.76 ton (175 bu) of wheat. For $Phostoxin^{TM}$, the minimum dosage level for vertical commercial grain storage recommended by Degesh labels, 150 pellets per 28.3 m^3 (1,000 ft^3), was used. For the 6.4 m^3 (225 ft^3) sealed bins, 34 pellets were probed into the grain mass center in a pattern recommended by a Degesh representative.

During the seven day test, average gas levels for the four grain sample points in ECO_2FUME^{TM} fumigant gas bins ranged from 274 to 131 ppm. Levels for $Phostoxin^{TM}$ bins ranged from 759+ ppm (some points exceeded 1200 ppm) to 94 ppm.

$Phostoxin^{TM}$ bins received an initial dose of 6.8 g PH_3 per bin ECO_2FUME^{TM} fumigant gas bins received an initial dose of 1.79 gm of PH_3 per bin plus an average re-dosage of 1.80 gm per bin, for a total of 3.59 gm per bin. The total minimum to maximum dosage for ECO_2FUME^{TM} fumigant gas ranged from 3.26 to 3.89 g. The total average dosage required to maintain the target gas level for the ECO_2FUME^{TM} fumigant gas bins was 52.9 percent of minimum recommended dosage for phosphine pellets

Leakage rates from the ECO_2FUME^{TM} fumigant gas bins based on gas re-dosage values ranged from 2.52 ppm/hour to 3.60 ppm/hour and averaged 3.02 ppm/hour during the first 117 hours of testing, Figure 3. Re-dosing occurred at intervals when the average gas levels dropped close to or below 20% of the target level, or about 160 ppm, and were designed to increase the dosage to about 20% above the 200 ppm target. Re-dosage, marked across the bottom of the chart, were discontinued at about 112 hours from the start of the 7 day (168 hour) test, and leakage was allowed to occur uninterrupted from that point.

Figure 3 shows the average dosage of the five Phostoxin bins, which had peak concentrations well above the 1,000 ppm limit of the ATI PortaSense test device in certain parts of the bins. But, the average peak concentration for the five bins was about 730 ppm, occurring about 26−27 hours after the Phostoxin pellet dosage was applied as the test started.

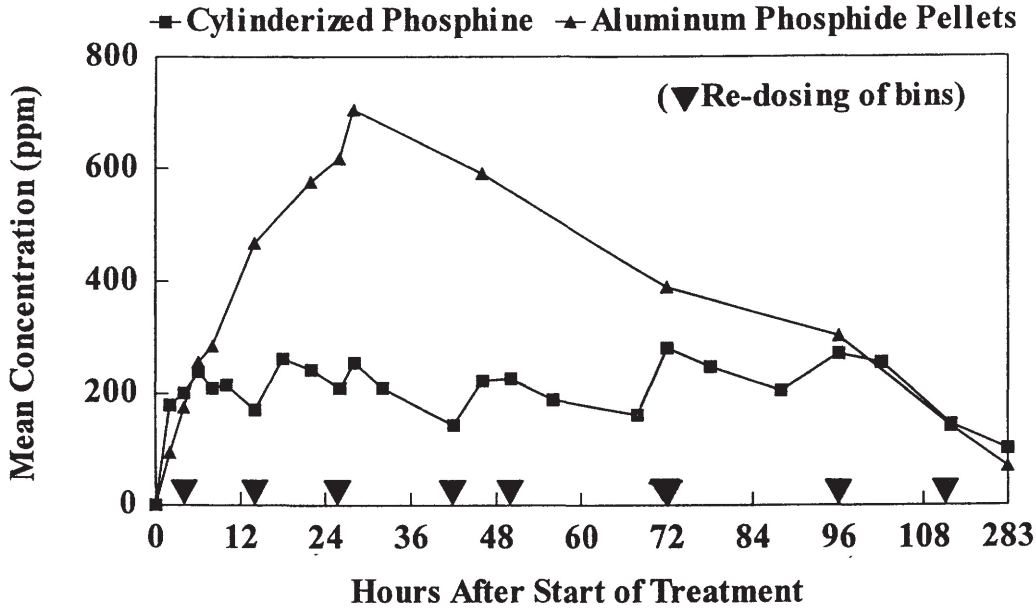

Fig.3. Gas levels during 7 day gas leakage tests of Phostoxin vs ECO_2FUME phosphine gas in sealed bolted stell bins

The bins remained sealed to observe the continued decay of the gas after the 7-day test was concluded After 28 days, gas readings in the 10 bins ranged from about 30 to 65 ppm Thus, all bins remained at gas levels that contained lethal dosages for all stages of grain insects

References

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