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MANIFOLDING AND SEALING INSTALLATION METHODS FOR MANIFOLDED PHOSPHINE RECIRCULATION SYSTEMS IN MULTIPLE CONCRETE SILOS IN US GRAIN ELEVATORS

R.T. NOYES, P. KENKEL, J.T. CRISWELL AND G.W. CUPERUS
Entomology Department, Oklahoma State University,
Stillwater, Oklahoma, USA

ABSTRACT

The closed loop fumigation (CLF) or phosphine (PH_3) recirculation (PGR) system using a low volume blower and piping system in each tank was patented by James Cook of Houston, TX, in 1980. In 1991, to make CLF more effective, OSU researchers manifolded two large steel tanks (2,000–10,000 t/tank) to one small (0.1 to 1.5 kw) CLF blower. In 1995, manifolded PH_3 recirculation (MPR) system designs for concrete silos were developed. In 1996, 3–18 concrete silos were manifolded to a single blower to operate as 1,500 to 10,000-t storage units at five grain elevators.

At four elevators, all under-roof external wall vents were sealed. Suction pipes connected to only one side or end silo. Gas from all silos flowed through open under-roof internal vents between silos to CLF blower suction pipes. Blower pressure piping manifolds connected to the base of each silo in a variety of plumbing schemes. Silo roof vent and silo base sealing problems required a variety of techniques. In this project, sealing closed openings, gaps and cracks in order to minimize leakage considerably rather than to provide a gastight seal.

There are several benefits to CLF-MPR systems. Smaller work crews are required, thus reducing worker exposure. The response to fumigation is quicker. The cost of fumigant is lower. There are fewer regulations to comply with. The systems achieve better efficacy with less fumigant and less management expertise. Finally, blowers can be moved from site to site, minimizing investment costs.

BACKGROUND

Closed loop fumigation (CLF) was used for methyl bromide fumigation in the early 1920's in the US and other grain producing countries. A closed recirculation process for phosphine (PH_3) fumigation using small, low-power centrifugal blowers and piping systems operating at low pressures was developed in the 1970's and patented by James S. Cook of Houston, TX, in April, 1980. Initial CLF system designs used one blower for each storage tank or silo. This blower was operated throughout the fumigation period.

MANIFOLDED PHOSPHINE RECIRCULATION SYSTEMS ON STEEL TANKS

In the early 1990's, CLF systems in Oklahoma were designed by manifolding two large steel tanks (2,000- and 10,000-t/tank) to operate from a single blower in order to make them more cost effective (Noyes and Kenkel, 1994). Multi-tank installations are called manifolded PH_3 recirculation (MPR) systems.

To further reduce costs, an Oklahoma commercial grain company that owns several country elevators has installed CLF piping systems on steel storage tanks at each location, but they transport their CLF blowers from one elevator site to the next when the storage tanks at each elevator site need to be fumigated.

At 3–4 tank elevator sites at US country elevators, a single CLF blower can recirculate PH_3 on a single set of manifolded tanks for the initial pellet-release period (24–48 h), then be shut off and moved to the next set of tanks. The CLF blower is sized to produce one complete gas-volume exchange in 2–4 h; initial recirculation should be 24–30 h. At 5–10 h/complete gas exchange (2.5–5 gas cycles per day), initial recirculation of 30–40 h is recommended (Noyes and Kenkel, 1994; Noyes *et al.*, 1996a).

If the CLF blower is needed to recirculate gas on another set of tanks, it can be disconnected and the suction and pressure manifold pipes capped off or sealed. It can then be connected to the CLF piping manifold on the next set of tanks and the PH_3 released. Because fumigation of the second set of tanks cannot take place within 1–2 d of fumigating the first set of tanks, the complete facility is fumigated together. Some elevator managers prefer to install a blower for each set of tanks at an elevator site so that fumigations of all tanks are started at the same time.

MANIFOLDED PHOSPHINE RECIRCULATION SYSTEMS ON CONCRETE SILOS

In 1995, the multiple storage MPR system design concept was expanded through a US EPA grant to include concrete silos in Oklahoma and Texas. This project included 17 grain elevators with 12 steel tank systems and 5 concrete silo CLF/MPR model systems (Noyes *et al.*, 1996a, b).

Almost all steel tanks are equipped with aeration, which makes installing MPR easy. To be competitive with steel tanks, concrete silos must use MPR systems with 2–20 concrete silos manifolded to a single blower to operate as one large storage unit. Two of the silo systems in the five elevators that installed MPR on concrete silos, in 1996, included aeration. The smallest MPR concrete system involved three 500-t aerated silos (1,500-t total on the CLF blower), each separated by non-fumigated, non-aerated silos.

Figure 1 illustrates a simplified version of the MPR system design, where the suction pipe is connected to an exterior under-roof vent at the end or side of the elevator. Figure 2 shows the suction pipe connected to a silo roof inspection port cover on one silo. Where possible, the vertical suction pipe should be mounted beside, or connected to the side rail

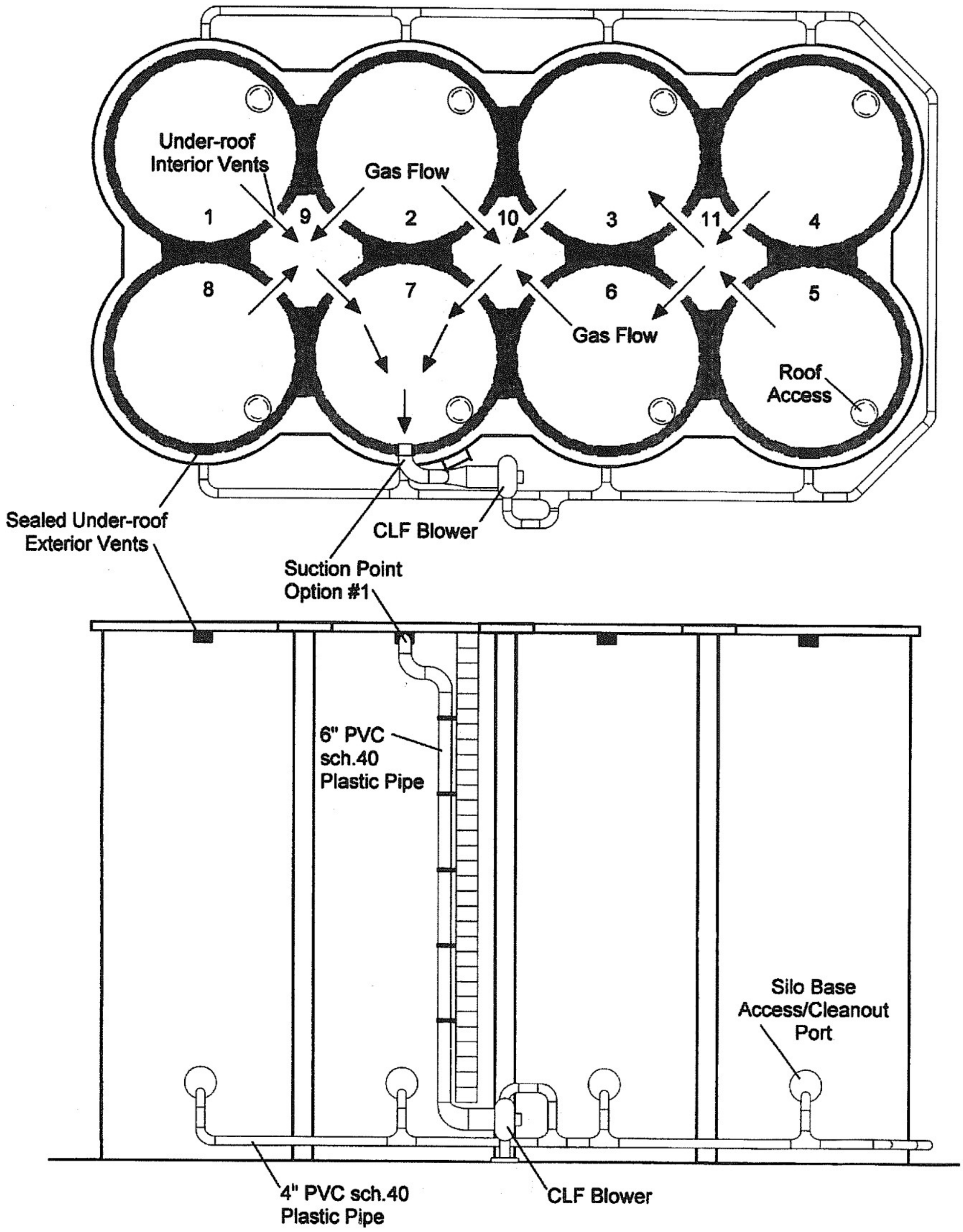

Fig. 1. Manifold phosphine fumigation system pulls gas from the exterior under-roof vent of one concrete silo and recirculates the gas through the base inspection door of each silo.

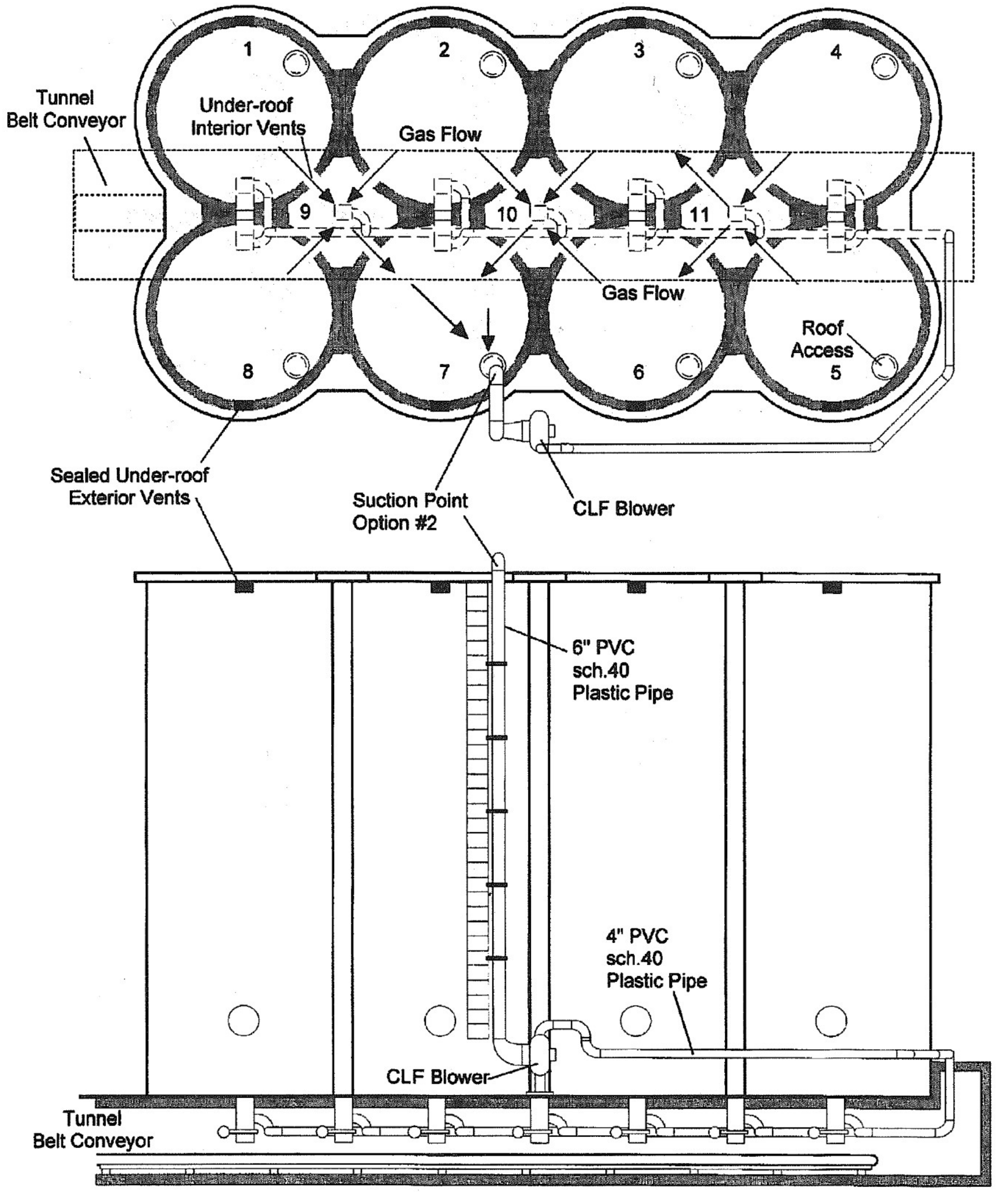

Fig. 2. Manifold phosphine fumigation system pulls gas from the roof hatch of one concrete silo and recirculates the gas through the discharge spouts in the tunnel/basement under each silo.

of, a ladder going down the side of the elevator. The suction pipe can be clamped to the vertical side rail of the ladder using stainless steel hose clamp bands spaced 3–4 m apart. The PVC plastic pipe extends to within 1–2 m of the ground. Flexible tubing connects the suction pipe to the CLF blower inlet. This makes the construction of the suction pipe from roof to base simpler, often saving the cost of a truck with a hydraulic hoist, a crane, or other expensive equipment.

At all five concrete elevators, under-roof external wall vents had to be sealed, as shown in Figs. 1 and 2. The four large concrete elevator silo systems contained 13, 14 (two elevators) and 17 silos connected to form common storage groups from 6,500–8,500 t/elevator. At these four sites, under-roof interconnecting vents between silos were left open to operate as return-flow gas conduits. Thus, gas could flow through the top of each silo into the silo connected to the suction pipe and then through the suction duct to the CLF blower, as shown in top and side views of Figs. 1 and 2. Interior under-roof vents on the 3-silo system had to be sealed in order to isolate the gas in the fumigated silos from adjacent silos.

The CLF blower outlet pipe manifold system had to connect to the base of all silos in each group. One elevator had aeration ducts connected to six exterior and two interior silos. For that elevator, the CLF blower pressure pipe connected directly to the aeration duct leading to the eight silos. Additional pressure manifolds along the aeration duct connected to the six non-aerated silos through discharge spouts and cleanout doors in driveways.

If all silos at an elevator were to be aerated with individual aeration blowers, then a simple MPR piping system could be installed around the elevator with a "tee" pipe connecting to the inlet or outlet of each blower on the silo sidewall. This would look similar to the plumbing-to-base inspection doors (Fig. 1). If all silos in a group were to be served by a central aeration blower through an external duct, the MPR system would be even simpler — the CLF pressure pipe connecting to the aeration duct.

However, since most concrete silos in the US are not equipped with aeration systems, most concrete MPR systems would usually be more complex than steel storage designs (Noyes *et al.*, 1996a, b). The CLF blower outlet pipe would be manifolded to the base of the silos by a variety of plumbing schemes. The pressure manifold for the 3-silo system involved connections to each of the three aeration blower pressure manifolds. In Fig. 1, pressure piping is shown connected to silo base cleanout or inspection doors on all eight silos.

If the concrete silo has a basement and tunnel belt system, it might be easier to connect MPR piping directly to silo discharge spouts between the tunnel ceiling and the discharge slide gate valve (Fig. 2). This would involve cutting a slot opening in the silo discharge spout. Manifold boxes installed over perforated sheet metal (20–40% opening with 1.5–2.5-mm holes) clamped to the duct sidewall would keep grain out of the gas line and allow gas flow into the base of each silo. Sealing of the discharge spouts below the gas manifold is discussed later.

A 10-cm (4-in) diameter main pipe would distribute gas along the tunnel to 5-cm (2-in) ID branch pipes and flexible hoses teeing off from the main pipe and connecting to the manifold box on each square silo discharge spout. An example of the main pipe that runs along the tunnel to the last silo, feeding gas to each silo discharge spout, is shown in Fig. 2. Three concrete elevators in the EPA study used basement tunnels for discharge conveyor belts under the silos.

At one elevator, a gallery covered part of the concrete silo roof deck, protecting a belt conveyor used to fill the silos. The simplest arrangement for a piping system for this elevator was to place the entire MPR system inside the elevator structure. The vertical suction pipe from one of the end silos was banded to the side rail of an unused inside ladder reaching from the silo roof deck floor to the CLF blower mounted on the ground floor. Because the installation was inside the elevator, an explosion-proof 1.3-kw motor on the CLF blower was used to protect against dust explosions.

Concrete elevators with different silo layouts and conveying designs required special MPR plumbing designs. The five concrete elevators in this program presented a variety of unique storage and duct-sealing problems. The alternative sealing options used at these five elevators covered most of the sealing problems that could be expected in US concrete elevator silo systems.

CONCRETE SILO SEALING TECHNIQUES

Because concrete silos are usually constructed of reinforced monolithic concrete sidewalls, sealing them generally involves sealing openings on or at the silo roof and at or near the silo base. In 1994, the Australian government required sealed storage structures to be able to build static pressure up to 25-mm water gauge and to sustain a pressure of no less than 12 mm for 3 min for partially filled or full tanks, or 5 min for empty tanks (Andrews *et al.*, 1994).

"Sealing," as used in this study, does not mean the type of pressure sealing specified or required for controlled atmospheres (CA) by the Australian government or for CA and/or modified atmospheres (MA) by other countries. The sealing techniques used in concrete elevators in this EPA project closed openings, gaps and cracks, greatly minimizing leakage. The objective was not to develop a gastight seal or to maintain pressure in the structure. The goal was to seal the structure so that PH_3 would not drain from the structural walls or base due to gravity, and gas loss through the eave and roof areas was minimal. Several openings requiring sealing were in the silo roof, sidewall and base. They were the silo-roof-deck-to-sidewall-joint gap, under-roof exterior vents, under-roof interior vents when MPR fumigated silos were mixed with non-fumigated silos, the roof entrance and inspection hatches, the roof ventilators and ventilation fans or aeration blowers, the downspouts or conveyor fill spouts through the silo roofs, the entry inspection/cleanout ports near silo bases, the aeration blowers at the silo base, the aeration duct manifolds around the silo exteriors and the basement tunnel or driveway discharge spouts.

SILO ROOF DECK TO SIDEWALL JOINT GAP

Flat concrete roof decks cover most US concrete silos. Often, because the roof deck is poured after the sidewalls, a gap exists between the sidewall and roof cold joint or junction. This gap is usually an irregular opening, too narrow for concrete mortar fill, which can cause a high PH_3 leakage rate.

Suggested filling options are expandable foam insulation or silicone caulking material. The selection of sealant depends on the gap size and elevator preference. If gaps are larger than 0.5 cm, foam insulation is preferable. Gaps less than 0.5 cm can be caulked with silicone. If gaps exceed 1.0 cm, expandable foam or cement mortar paste may be used.

UNDER-ROOF EXTERIOR VENT SEALING

Most concrete silos in the US have flat slab roof decks. Exterior under-roof vents are usually about 15 × 30 cm (6 × 12 in) with 1.25 cm diameter vertical steel reinforcing bars placed vertically about 2.5 cm apart. Roof decks usually extend 15–30 cm beyond the outside silo wall, providing rain protection for the open vents.

Before sealing, the wall vent openings had to be cleaned, using compressed air or brushes, of all dirt and trash. The methods suggested for sealing external under-roof vents were spray foam insulation, plates of plywood or steel and concrete mortar fill.

Expanding foam seal

High-density hole filler expanding spray foam is available from home or industrial supply or hardware stores. A 340-g (12-oz) pressurized spray foam can contains about 9,400 cm^3 (575 in^3). One can should therefore fill either about 1.25 vent openings of 15 × 30 cm, 15 cm thick, or about 1.8 vents 10 cm thick.

To fill the vent opening, one starts by building up layers of foam from the base and works toward the top of the opening. The opening should be filled about 40–50% and the foam allowed to expand upward. One should work back and forth on several vents allowing the foam to expand before adding the final layer to seal off the top of the opening.

The foam should be filled in around each steel bar and should cover at least 0.66% of the width of the concrete wall; the foam barrier, with the steel bars of the center of the plug, should be at least 10 cm thick. The steel bars anchor the expanding foam plug. After the opening is filled, to finish the seal a final continuous foam bead should be run around the opening against the concrete. To provide ultraviolet (UV) protection, the outer foam surface should be painted with exterior-grade paint. Once in place, the expanding closed cell foam barrier should provide excellent long-term sealing against gas leaks through the vents.

The expanding spray foam should be applied at temperatures of 15–38°C (60–100°F). It should be tack-free and not sticky after 30–45 min of curing at 22°C (70°F) and fully cured in 6–8 h. Workers who apply spray foam should wear plastic safety gloves, to keep foam off their skin, and avoid breathing fumes from the spray foam.

Wood or steel plate and silicone caulk seal

When using plywood or steel plating, several vent openings should be measured to ensure that they are all uniform in size. A 0.80–0.95 cm (5/16–3/8 in) thick exterior-grade plywood should be used. If the vent opening size is uniform, one should cut the required number of rectangular plywood plates 0–0.15 cm (0 to 1/16 in) undersized. The rough texture of the concrete around the vent opening will allow plywood to be press-fit or hammered against the vertical steel bars.

For loose-fitting plywood or 0.25–0.50 cm steel plating, one should drill a 0.5–0.6 cm diameter hole near the center of the board or plate and insert a "J" bolt (or formed all-thread rod) that can be hooked around one of the vertical steel bars. The nut on the bolt should be tightened to draw the plate tight against the steel bars, then the bolt threads sealed with silicone or similar caulking to keep the nut locked in place. To finish the seal, one should lay a 0.5–0.8 cm bead of silicone or similar caulking sealer material around the wood or steel plate to concrete a junction. The wood or steel caulking seal should then be painted with a suitable exterior-grade all-weather paint.

Concrete mortar

A third option for sealing exterior or interior vents is to fill the openings with an expandable concrete mortar. This may require that one worker be inside the silo to fill the opening while a second worker in safety harness or on scaffolding holds a flat plate or board against the opening during placement of the mortar to assure uniform filling and a tight seal.

UNDER-ROOF INTERIOR VENT SEALING

If fumigated silos are separated by non-fumigated ones, interior under-roof vents need to be sealed. Sealing these vents will probably require that the silos be filled with grain to within 1.5–2 m of the roof. If interior vents have vertical steel "bird" bars, either press-fitting, using plywood or steel plates with "J" bolts and caulking the edges, or using expandable foam similar to that for the exterior vents should be a suitable means of sealing them.

Wood plug seal

If there are no vertical steel bars on interior vents, expandable foam which does not require painting for UV protection should be a good alternative. Because of fumes from the spray foam, workers must be provided with a suitable fresh air supply or venting. When crews are working inside the silos, all electrical equipment should be locked and tagged out and the workers should wear suitable safety harness with security ropes.

For vents without steel bars, another alternative is to cut solid wood blocks or plugs, about 10–12 cm (3.5–4.6 in) thick and slightly undersized in height and length, to fit the openings. The wooden plug should be pushed into the opening and centered on the wall, after which the wood should be caulked to the concrete junction with a heavy silicone caulking (or similar suitable caulking compound) on both sides of the plug to anchor it and seal it securely in place.

ROOF ENTRANCE/INSPECTION HATCHES

Silo roof entrances or inspection hatches typically have shallow round steel or cast iron pans or lids that are set down over a raised steel lip to provide protection from storm water. These lids can be sealed by wrapping 5–10 cm fumigation-quality sealing tape or industrial-quality duct tape around the metal-to-concrete junction. An alternative is the use of expandable foam to fill the space extending from under the lip of the hatch cover to the steel flange ring and then down to the deck, usually a 2.0–3.0-cm gap. The foam should then be painted with a UV-resistant paint for long-term use. This type of sealing can be left in place for long periods if access or inspection entry is not needed.

ROOF VENTILATORS, VENTILATION FANS OR AERATION BLOWERS

Sealing of roof ventilators, fans or blowers should be done as a temporary measure at or near the time of fumigation if these devices are used during the year. A common method of sealing devices that protrude above silo roofs is to place heavy plastic bags over the equipment and seal the bag around the base of the ventilator, fan or blower using either 5–10 cm fumigation tape or a fumigation spray adhesive that will hold the plastic bag against the steel surface.

On some vents or fans, 4–6-mil plastic sheeting may be suitable, with spray adhesive and fumigation tape used to seal the plastic to the steel surfaces. The primary objective is to seal off the opening, preventing air and gas leakage from the structure.

DOWNSPOUTS OR CONVEYOR FILL SPOUTS THROUGH SILO ROOFS

Downspouts or conveyor discharge spouts in the silo system are often the toughest points to seal because of their inaccessibility. Downspouts are steel pipes or tubes that are often cast in place when the concrete roof is poured. To cut sections of the tubing out and flange them for easy removal for sealing may be desirable, but it is an expensive option.

Spouts that project even a short distance through the roof can be sealed with plastic and tape when the silo is filled with grain. If grain distributors are accessible, down spouts may be plugged or sealed with plastic sheet and tape from above the silos. Since this part of the MPR system is under slight negative pressure, sealing of grain-fill points is important, but these points are not as critical from the standpoint of leakage as are silo discharge spouts. However, from a personnel safety standpoint, fumigant leakage up the downspouts can cause safety problems in other parts of the elevator system.

ENTRY INSPECTION/CLEANOUT PORTS NEAR SILO BASES

These round steel or cast iron openings are usually positioned about 2–3 m above ground level. They are used for entry to the silo base for inspection and cleanout. These plates usually fit closely into the reinforced opening frame; therefore, use of a silicone caulk bead or fumigation tape at the crack or gap between the plate and frame should provide a suitable seal.

AERATION BLOWERS AT SILO BASE

Centrifugal aeration blowers at the bases of concrete silos may be installed as either pressure or suction systems. On centrifugal blowers that deliver pressure, the inlet is often shielded by a wire guard to keep rodents and birds out. When a flanged frame covers the inlet, heavy flat plastic sheeting can be used with a light spray adhesive around the sides of the frame which allows the plastic to be secured sufficiently to make taping for final sealing easier. If an easily-unbolted frame is attached to the side of the blower housing, a plastic sheet can be tacked to the side of the housing and the frame replaced over the plastic, providing a good seal. In this case, the plastic should extend beyond the flange so it can be taped down to provide a positive seal.

For suction systems, the blower usually has a gravity-shuttered exhaust that provides weather and pest protection when the blower stops running. These shutters often have flanges that can be removed so that plastic sheeting can be placed over the opening and the shutter replaced, sandwiching the plastic sheeting. Again, the plastic should be extended and the edges sealed with fumigation or duct tape. The alternative is to use a plastic bag over the outlet, which is then sealed with tape.

The blower wheel drive shaft clearance opening through the blower housing sidewall is quite often overlooked on aeration blowers. This clearance opening should be carefully tape-sealed to prevent leakage. All seams on blowers, blower transition ducts, flexible connectors between blower and duct should be checked for leaks. On pressures systems, the blower should be operated and all seams and joints checked for leaks using a soap detergent. Flange to flange connections are often inadequately caulked. Tape or silicone can caulk any leakage points.

AERATION DUCT MANIFOLDS AROUND EXTERIORS OF SILOS

Large aeration blowers can be manifolded to a large steel duct serving several concrete silos. Minor duct leaks, that are not a problem for aeration, can cause serious leakage when the ducts are used for MPR fumigation systems. Leakage points to check and seal are the connecting joints, the seams along the pipes and clearance openings for shut-off or control valve shafts.

A detergent soap solution can be used to check all possible leak points on external or interior ducts (where ducts go through the silo walls to inside silos). Flanges, longitudinal seams and connecting joints can be tape sealed with fumigation tape. Control valve shaft clearance openings should be sealed with silicone caulk. If valves are turned and the caulking disturbed or torn between fumigations, the shaft should be recaulked for future fumigations.

BASEMENT TUNNEL OR DRIVEWAY DISCHARGE SPOUTS

Discharge spouts in basement tunnels or driveways present two primary sealing problems: the outlet opening and the slide gate. Discharge spouts that feed tunnel belts often have dust hoods attached that create a major sealing problem. In some cases, the dust-system hood may have to be reconfigured so it can be disconnected from the discharge spout.

The simplest method of sealing rectangular discharge spouts is to plastic-bag the outlet. Heavy plastic bags that are specifically designed for fumigation vent and blower sealing should be used. Double bagging may be necessary to achieve strength adequate to handle the pressure of the CLF blower outlet that is attached just above the discharge slide gate. A light-tack spray adhesive to help secure the plastic bags for taping may be advisable.

The slide gate area should be silicone-caulk sealed above and below the slide as well as around the rack-and-pinion shaft openings. The CLF blower should be operated without fumigants and a soap detergent used to check for pressure leaks on the bag and silicone-caulk seals. It is imperative that basement tunnel and drive discharge spout seals be extremely tight because of their close proximity to the MPR pressure manifold that cycles the gas to the silos above. Any fumigant leaks at this point will drain the system, rapidly diluting the fumigant mixture.

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