Advances in recirculation fumigation technology in the U.S.A.

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Abstract

Phosphine recirculation or 'closed loop' fumigation (CLF) systems for concrete silos make CLF of 500 to 1,000 tonne concrete silos competitive with CLF systems on 5,000 - 10,000 tonne steel tanks. By manifolding two to 20 silos into one interconnected volume, volumes of 10,000 - 20,000 tonnes can be fumigated.

Flat topped silos have 10 cm by 20 cm external under-roof wall vents, and a roof-to-wall gap below the roof, that must be sealed to use CLF in silos. Interior under-roof vents between silos are used for gas flow between all silos, and from one silo through a vertical suction pipe to the CLF blower mounted at ground level.

One 0.5 - 1.5 kW centrifugal blower pushes gas through pressure piping manifold systems to silo bases through aeration ducts, unload spouts or base manhole covers. Unload spout slide gates beneath all silos must be sealed. Hoses/pipes to empty silos are shut off to avoid gas short-circuiting.

Using CLF to eliminate moving ('turning') grain to fumigate with automatic pellet dispensers reduces grain handling shrinkage losses. By using lower dosages and reduced grain dust loss, a concrete CLF has a pay back of 2 - 4 years.

Concrete CLF benefits: (1) Reduced grain handling damage and shrinkage; (2) Lower dosages; (3) Faster fumigation of all silos and bins; (4) Less labor; (5) Safer for workers; (6) One CLF blower used at multiple sites, lowers costs. (7) Less PH3 in Environmental; (8) Higher efficacy; reduced insect resistance; (9) Reduced housekeeping with concrete silo CLF; (10) Reduced overall cost of fumigation.

Background

Recirculation fumigation was developed and used in the early 1920's for methyl bromide fumigation in the U.S and other major grain producing areas. A closed system recirculation fumigation process or 'Closed Loop Fumigation' (CLF) using low power, low volume blowers and piping or duct systems was developed for commercial phosphine fumigation use in the late 1970's by James Cook, who patented the process in April, 1980.

CLF installations were installed in wheat storage structures at several Kansas and Oklahoma elevators in the mid-to-late 1980's and data were recorded. Additional CLF systems were installed at Oklahoma elevators from 1993 through 1997 as demonstration projects funded by the Oklahoma Department of Agriculture (ODA) and Region VI, U.S. Environmental Protection Agency (USEPA). Design and economic data were developed on CLF systems installations and operations during the project.

During these commercial grain elevator demonstrations of CLF, new methods were developed for installing plumbing and blowers for increased operating flexibility to reduce installation and operating costs. These new CLF system designs focus on the use of one CLF blower to recirculate phosphine gas through two or more large steel tanks.

During the past 3 years, CLF manifold systems have been designed and installed at Oklahoma and Texas grain elevators to incorporate the storage volume of from 3 to 17 concrete silos that operate with one CLF recirculation blower. Thus, concrete facilities with combined grain volumes of 5,000 - 10,000 tonnes (185,000 - 370,000 bu) can be fumigated simultaneously with CLF, equivalent to the volume of one or two 5,000 tonne (185,000 bu) steel tanks. Blowers are moved from site to site within a company to minimize capital investment. Preliminary results have been documented on operating procedures and costs.

CLF Benefits

Compared to conventional probe and tarp fumigation methods, or turning grain to fumigate with automatic pellet dispensers in concrete silo facilities, management of CLF fumigation is simplified, and elevator worker safety and satisfaction is enhanced. CLF systems benefits and advantages are:

(1) Reduced grain handling damage and shrinkage by eliminating moving grain between silos while
fumigating, improved profit

(2) Reduced dosages because of improved gas distribution uniformity and efficacy, and thus lower fumigant costs.

(3) Reduced labor due to presealing, then fast sealing of remaining openings and fast dosage speeds up timing for multiple tank fumigations.

(4) Worker safety is improved as CLF minimizes confined space entry.

(5) Faster fumigation of all silos and bins by presealing of bin cave gaps, silo wall to roof junction, exterior silo vents, wall cracks, bolt holes, doors, blowers, etc and leaving them sealed year-round. Aeration fans are sealed except when used. Roof vents are unsealed except to fumigate. Conveyors, vents and down spout openings are the primary openings to be sealed to start CLF.

(6) One small blower ( $US 350 - 500) can be moved to several sites, minimizing capital expense.

(7) Less phosphate released to the atmosphere due to more efficient fumigation and lower dosages required with CLF.

(8) Higher efficacy—most CLF users get complete kill with less dosage by more timely fumigation with better sealed structures. This reduces the insect resistance to phosphine.

(9) Eliminating moving or ‘turning’ grain from one silo to another to fumigate in concrete silo facilities will reduced housekeeping, grain damage and shrinkage.

(10) Reduced overall cost of fumigation. Reduces commercial fumigator costs and makes his work more efficient. Commercial fumigators can service more customers more efficiently.

**CLF Fumigation Procedures**

In CLF, phosphate pellets are preferred over tablets because of quicker, more uniform gas release. Pellets can be placed on the grain surface, walked or probed into the grain 0.3 - 0.6 m (1 - 2 ft), or placed in a shallow layer (not over 2 pellets or tablets deep) on a board, tarp, metal or plastic sheet on the grain for better ash recovery. Pellets or tablets enclosed in packets, blankets or sachets can be placed on the surface or buried in shallow trenches, then removed later to recover phosphate dust. After placing or probing the phosphate pellets and sealing the structure, the recirculation blower can be started immediately, or gas can generate for 1 - 2 hours before the CLF blower is turned on.

Although phosphate gas could be recirculated in either direction, the typical method is for the blower to pull or suck the gas/air mixture from the storage head space through a vertical 4, 5 or 6 inch ID metal pipe, PVC pipe, or plastic tubing. The suction piping from the system is connected to a centrifugal blower inlet, then the blower pushes the gas through a duct into the base of the storage, forcing it up through the grain back to the storage bin head space. The blower is initially operated 1.5 to 2 days to thoroughly mix the gas, then is shut off for a day or two. After one or two days, the blower is operated again for a few hours every day or two until the fumigation is complete.

In well sealed silos or grain bins that use CLF, fumigant use is reduced by 35 to 50 percent or more of amounts (or minimum label rates in some cases) used in conventional fumigation methods. CLF should not be used on poorly sealed storages

With the CLF system in place, response time to begin fumigation of a large number of silos or storage tanks requiring several days preparation time by several workers can be reduced to a few hours using two or three people, if bins or silos are sealed except for vents and conveyors.

Phosphine pellets for all storage units can be placed in the grain the same day that the decision was made to fumigate. By fumigating all storage units at the same time, reinestation of fumigated storages by insects migrating from adjacent non-fumigated tanks or silos is eliminated.

Fumigant reductions of 35 - 50% are routinely reported with improved results, due to uniform gas distribution from recirculation. In some cases, operators find they are able to reduce dosages below conventional fumigation minimum label rates, depending on the facility.

**Gas Piping System Designs**

Typical pipe sizes are 10 cm (4 inches) ID connected to the inlet and outlet of 0.19 to 0.38 kW (0.25 to 0.5 HP) centrifugal blowers, and 12.5 to 15 cm (5 to 6 inch) pressure and suction piping for 0.56 to 1.12 kW (0.75 to 1.5 HP) blowers. At piping junction tees or crosses, 10 cm (4 inch) ID pipes may be used for lateral conductors requiring reduced gas flows.

A 0.1 kW (0.125 HP) blower will deliver about 5.6 m³/mm (200 cfm), a (0.5 HP) blower about 11.2 m³/mm (400 cfm), a (1.0 HP) blower about 19.6 m³/mm (700 cfm) and a (1.5 HP) unit will deliver about 23.8 m³/mm (850 cfm) at 0.25 to 0.5 kPa (1 - 2 inches water column) pressure. These gas velocities are so low in grain that there is little flow resistance from the grain. Tube, hose or pipe sidewall flow resistance produces most of the blower pressure loss. Permanent plastic pipe fittings are recommended for the hard plumbing for direction changes, except when connecting suction and pressure pipe manifolds to the centrifugal blower.

Construction costs vary widely based on the difficulty of installing piping through roofs, manhole covers, exterior sidewall vents, securing the vertical pipes to the sidewalls, etc. External pipe mounting on steel tanks is relatively simple as brackets can be spaced 3 to 6 m (10 to 20 ft)
Manifold Piping Alternatives

Used aluminum irrigation pipe may be available at salvage prices in some areas for CLF systems use; 10, 12.5 or 15 cm (4, 5 or 6 in) diameter aluminum (used irrigation pipe) tubing or pipe make good CLF gas flow ducts and irrigation tube connectors make suitable pipe joints. Non-perforated 4 inch and 6 inch ID black plastic flexible drainage hose is a very inexpensive material that eliminates pipe elbows and works well for low volume gas handling.

Transition adapters make the connection between this hose and PVC pipe of the same nominal ID, so that duct taping the joints makes a strong, tight connection. For small diameter laterals from the main line to connect with individual concrete silos, 5 or 7.5 cm (2 or 3 in) ID schedule 40 PVC and soft flexible nylon covered water hose (type that can be flattened and rolled up) make an inexpensive pressure system. When a silo is empty, the short connecting section of nylon hose can be clamped between two plates or boards, or can be bound with a hose clamp to restrict flow through the silo.

Non-perforated four inch black flexible corrugated plastic tubing used for under ground drainage is an economical method of gas recirculation piping. It can be connected to the blower through tubing to hose adapters or by using rubber transition adapters to 10 - 15 cm (4 - 6 inch) lengths of PVC pipe, then connecting the PVC pipe to flex hoses. Flexible black plastic hose (Hancor drainage hose used in Oklahoma and Texas CLF plumbing installations) and adapters for connecting the corrugated hose to PVC pipe make good transitions from pipe to hose. Tube to pipe joint adapters are taped to provide a gas tight seal. These black flex hose appears to hold up well over several years of permanent outdoor use to sunlight.

Do not use rubber connectors between pipe fittings that are permanently installed. Most rubber adapters or fittings break down rapidly when exposed to outdoor ambient conditions, resulting in leaks that have to be repaired. However, they work well when used for short term connections of the CLF blower to the permanent CLF suction and pressure piping manifolds for use for 7 - 10 days for a fumigation. Then, the blower and adapters should be disconnected and stored inside. Suction and pressure pipe manifold connectors should be sealed to prevent insect, bird or rodent entry into the storage structure.

Concrete Silos

If silos are close together, they can be plumbed externally like bolted steel tanks. If silos are slip-form or jump-form poured as an annex, it is better to operate several silos as a unit as illustrated in Figure 1 or Figure 2. In the top view of both figures, the internal under-roof connecting vents are used as ducts for gas flow between silos, and from all silos to one silo where one suction pipe is connected through a roof manhole cover, Figure 1, or through an exterior under-roof vent, Figure 2. In both designs, all other exterior under-roof vents are sealed while the interior vents are left unsealed. The suction piping is positioned so that it can be attached to the side rail of an exterior ladder or other vertical means of support to minimize construction costs such as crane or bucket truck rental.

Figure 1 shows a silo annex with an external aeration system. In this design, the suction piping connects to the inlet of the blower, while the pressure pipe is plumbed directly into the existing aeration piping manifold, saving expenses of separate CLF manifold.

Existing aeration piping should be carefully checked and sealed at all seams, tees, valves and junctions for leaks. While aeration systems can tolerate leaks, CLF systems cannot.

Figure 2 illustrates the piping setup where the CLF blower outlet pressure piping is routed into the unload conveyor tunnel. A 5 cm flexible pressure hose connects laterally to a screened manifold mounted on the side of each silo discharge spout above the rack and pinion slide gates. The flexible hose connection between the pipe and manifold allows each silo outlet to be 'shut-off' when empty to keep gas from short circuiting by clamping plates across the hose.

Warning: PVC pipe should not be used inside silos, due to static electricity generated by direct contact with sliding gran, unless each pipe is grounded by a knowledgeable electrician. Continuous grounding must be installed in PVC plastic pipe to continually discharge static voltage to a positive ground such as metal water piping or concrete reinforcing bars.

Plastic PVC pipe is a popular duct material for use on the outside of storages due to light weight, chemical resistance, low cost, and ease of fabrication and assembly. Schedule 40 PVC pipe used for outdoor application in direct sunlight should contain a UV inhibitor material and be rated for outdoor use in direct sunlight.
Fig. 1. Manifolded phosphine fumigation system pulls gas from the exterior under-roof vent of one concrete silo and recirculates the gas through base inspection door of each silo.
Fig. 2. Manifolded phosphine fumigation system pulls gas from the roof hatch of one concrete silo and recirculates the gas through discharge spouts in the tunnel/basement under each silo.
Steel Tanks

On 20 to 30 m (70 to 105 ft) diameter steel bins with multiple aeration blower and transition positions, a CLF piping system design using one blower connected to each aeration duct is the preferred piping method. Where two, three or four steel bins are close together, one blower can be manifolded with suction and pressure piping to circulate gas in all tanks simultaneously, or to any combination. Empty bins can be disconnected from the system. Flexible tubing can be used to connect bin manifolds where bins are 5 – 10 m (15 – 30 ft) apart. These tubes can then be removed between fumigations for service vehicle traffic.

Getting a uniform gas distribution is more difficult in large diameter tanks than in tall silos, where the silo diameter is much smaller than the grain depth. Based on Cook’s patent (1980), recirculation systems should be designed to provide a gas flow range of 0.2 to 0.5 m³/hr/tonne (0.003 to 0.008 cfm/bu). Higher gas flow rates of 0.5 to 1.2 m³/hr/tonne (0.008 to 0.02 cfm/bu) will help offset poor distribution duct patterns and accelerate getting lethal gas levels to all parts of the storage.

On an 8,000 tonne (300,000 bu) welded steel tank in Kansas City, two 0.058 kW (0.08 HP) centrifugal blowers that produced about 4.2 m³/min (150 cfm) per blower or 8.4 m³/min (300 cfm) total airflow, which provided about 0.06 m³/hr/tonne (0.001 cfm/bu), performed very satisfactorily. The same blower was used on a 540 tonne (20,000 bu) concrete silo at a flow rate of 0.5 m³/hr/tonne (0.008 cfm/bu). This blower could have handled eight 540 tonne (20,000 bu) silos manifolded at the same rate of 0.06 m³/hr/tonne (0.001 cfm/bu) used on the welded steel tank.

Two 5,000 tonne (185,000 bu) bins in central Oklahoma (Figure 3) are operated by a 0.75 kW (1 HP) blower delivering 19.6 m³/min (700 cfm). The gas flow rate is 0.25 m³/hr/tonne (0.0035 cfm/bu), a very suitable recirculation rate.

Sealing Structures

Sealing bin or silo openings is a key factor in CLF system operation. Welded steel and concrete tanks are usually sealed better than bolted steel tanks unless the bolted tanks were well caulked. Roof to sidewall air gaps and the space between roof panel ridges and fill rings are critical sealing
areas in corrugated steel tanks. Exposed roof panel ends under the fill ring flashing collects grain dust and makes a natural breeding place for insects. These openings should be sealed with a foam sealer. For standard bolted tanks without intensive caulking, recirculation airflow rates should be higher than for welded steel or concrete tanks, in the 0.0056 to 0.008 m³/min/m² (0.007 to 0.010 cfm/bu) range.

Roof to sidewall air gaps are also a problem on concrete silos as many roof decks were cast separately, then set on top of the concrete silo walls. Often, these junctions were not caulked or sealed. Sealing the silo roof/wall cracks and external vent openings is best done when the silo is filled to within 1 - 2 m (3 - 6) feet of the roof so the grain can be used as a work platform. If the roof deck to wall gap is very close, 0.15 to 0.5 cm (1/16 to 3/16 in), a food-grade silicone caulking may be suitable. If the gap is larger, 0.3 to 1.0 cm (1/8 to 3/8 in) and variable, a foam spray is preferable to minimize cost. Use a foam spray on the exterior vent openings, building it up from the bottom. An alternative is to cut plywood or steel plates with 'J' bolts that can hook around the vertical bars, be pulled up tight, then silicone, or cut a close fitting plate and use a silicone bead around the edges to hold it in place.

It is important that CLF be used in 'sealed' structures that can maintain 150 - 200 ppm of phosphine gas for at least 72 hours so gas can penetrate kernels and kill insect larvae, pupae and eggs. Commercial fumigators claim a complete kill of all insect stages at 75 - 100 ppm if held for 3 - 4 days. Low grain/air temperatures sometimes cause slow gas release which can extend a CLF operation from 5 to 8 days, which makes sealing critical. If tanks are well sealed with good aeration ducts, CLF systems with 0.37 - 0.56 kW (0.5 - 0.75 HP) blowers work satisfactorily on 4,000 - 8,000 tonne (150,000 - 300,000 bu) bins. A 0.75 kW (1.0 HP) blower provides adequate gas flow for two 8,000 tonne (300,000 bu) bins. (Noyes, 1993)

Corrugated steel tanks lose gas continually during fumigation if sidewall seams and eave gaps, roof vents, aeration blowers, unload conveyors, sidewall entry doors, and bolt holes are not well sealed. With gas leaks, too much fumigant may be lost, especially if high winds cause serious in-flow of air and leakage or out-flow of air and gas, diluting gas levels. New bolted steel tanks to be used with CLF should be carefully sealed for gas leaks at wall and roof panel joints with a closed cell adhesive back foam strip during construction.

Eaves and fill ring roof panel gaps can be foam sealed. Base to sidewall junctions should be sealed with silicone caulk or other flexible urethane type polymer seals that retain their plasticity over long periods of time and withstand UV radiation from sunlight. Distribution of the gas is also very important. The key is that the base duct system must provide fairly uniform distribution. The lower the gas flow rate, the more critical the uniformity of gas distribution becomes.

Blower Specifications

Blowers used for phosphine gas handling should be manufactured from materials that are resistant to chemicals. Aluminum or plastic wheels and housings are preferred as they are also spark resistant. Steel blower wheels and housings should be coated with epoxy or other tough, spark resistant materials. Centrifugal blowers have assembly seams or joints. Each blower should be leak tested during operation to make sure the seams are completely sealed. A leaky CLF blower can pump a lot of fumigant gas out of the storage structure in 1 - 2 days.

Gas flow rates range from 0.12 - 0.6 m³/hr/tonne (0.002 to 0.010 cfm/tonne) is recommended to provide a total air change every 50 to 200 minutes or about 6 to 24 changes per day. Lower gas flow rates are effective, they just require more time to develop uniform gas levels. According to Cook's patent (1980), 0.042 m³/hr/tonne (0.0007 cfm/tonne) from a 0.0746 kW (1/10 HP) blower delivering 5.9 m³/min (210 cfm) in an 8,000 tonne (300,000 bu) tank is a satisfactory air flow.

Normal aeration airflow at 6 m³/hr/tonne (0.1 cfm/tonne) displaces one air change in a full bin of grain with 40% air void space in 5 minutes, 20 time faster than a CLF blower delivering 0.3 m³/hr/tonne (0.005 cfm/tonne), which requires 100 minutes. Table 3 illustrates a range of blower sizes, power requirements and airflows for a series of blowers suitable for use in gas recirculation systems. (Noyes, 1993)

Installation and Operating Economics

If installed by local elevator workers, the installation costs of CLF systems are relatively small, with direct costs for the materials as the primary expense. If commercial millwrights or contractors do the installation, costs may be two to three times the cost of the project done by local elevator workers. But, with either method of installation, the financial payback can be relatively short, and elevator worker safety and satisfaction is enhanced.

For steel tanks, preliminary construction and installation cost estimates were about $ US 2500 to $ US 3000 for a 5,000 - 8,000 (185,000 - 300,000 bu) steel bin, or about $ US 0.30 to $ US 0.37/tonne ( $ US $0.008 to $ US $0.01/tonne) because concrete silo volumes can be combined but plumbing is more complex, installation cost per unit volume may be somewhat higher for concrete than for steel.

When one or more grain 'turning' operations are eliminated in concrete facilities, and grain damage and grain...
dust losses are eliminated, the net result can be a payback as quick or quicker than for steel, where grain damage by additional handling to fumigate is not a factor (Kenkel, et al., 1993)

<table>
<thead>
<tr>
<th>Table 1. Installation Costs of a Closed Loop Fumigation System at an Oklahoma Country Elevator with Four 5,000 tonne (185,000 Bu) Steel Bins.</th>
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<tbody>
<tr>
<td>2 - 0.75 kW (1 HP) TEFC Centrifugal Blowers @ $420/each</td>
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<tr>
<td>15 cm (6 inch) Schedule 40 PVC pipe suction plumbing</td>
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<tr>
<td>Roof outlet flashing</td>
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<td>PVC Pipe Brackets</td>
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<tr>
<td>Miscellaneous hardware (rubber pipe transition boots, bolts, screws, etc.)</td>
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<tr>
<td>Bucket truck rental</td>
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<tr>
<td>Millwright labor (construction foreman and electrician) *</td>
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<tr>
<td>Total Installation Costs</td>
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<tr>
<td>Cost per 185,000 bushel bin</td>
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<td>Cost, cents per bushel</td>
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* Note: Does not include minor amounts of elevator personnel labor.

Table 1 lists the actual installation costs for a CLF system installed on four 5,000 tonne (185,000 bu) corrugated grain bins at a central Oklahoma grain elevator in 1993. This installation used 15 cm (6 in) Schedule 40 PVC pipe for the suction pipe connected from the bin roof head space to the blower inlet, and 10 cm (4 in) ID Schedule 40 PVC pipe for the pressure connections from the blower to two aeration transitions per bin. The total installation cost was $4,633 for 20,000 tonnes (740,000 bu) of storage. The net cost was $US0.068/tonne ($US0.0063/bu). The elevator manager felt he paid for the system costs within two years from reduced fumigant cost, timeliness of fumigations and improved efficacy. (Kenkel, et al., 1994)

CLF systems on concrete silo facilities with 3 to 15 silos have been installed in Oklahoma and Texas during the past 3 years. Based on field experiences to date, concrete CLF systems are projected to range from $US0.025/tonne to $US0.92/tonne ($US0.0007 to $US0.025/bu)

If a concrete elevator transfers grain one additional time to fumigate concrete silos with automatic dispensers, CLF savings will also include the shrink (from grain dust and moisture losses) and conveyor operating costs, plus additional labor associated with grain transfer.

Preliminary estimates indicate that CLF systems installed in steel tanks will pay back in 4 - 8 years if the system results in lower fumigant usage, based on fumigant cost savings. Costs can be paid back in less than 4 years if CLF eliminates an additional grain turning operation. Private application using CLF may also replace the cost of commercial application with some savings to the elevator. Benefits of timeliness, labor saving, easier management and safety are are difficult factors to place a monetary value on, but do provide significant capital advantages.

CLF operating costs are very low. Costs to run 0.38 to 1.2 kW (0.5 to 1.5 HP) blowers are about 10 to 30 kWh per 24 hour day, or $US1.20 to $US3.00/day per blower at $US0.10/kWh for electricity. A 5,000 tonne (185,000 bu) bin with 0.38 kW (0.5 HP) blower costs $US3.50 to $US10.00 to operate for 3 - 5 days.

References

Cook, James S. 1980. Low airflow fumigation method. U S. Patent No 4,200,657 P O. Box 5421, Houston, Texas 77021. Issued April 29. (Note: This patented closed loop fumigation process, known as the 'J-System' purchased from Cook by Degesch America, Inc., P. O. Box 116, Weyers Cave, Virginia 24486.)

