Closed loop fumigation systems in the south-western United States

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Abstract

'Closed Loop Fumigation' [CLF] was developed and used in the early 1920s for methyl bromide fumigation in the U. S. and other major grain producing areas. A 'new' low power closed loop fumigation process using low volume blowers and duct systems was developed for commercial phosphine fumigation use in the late 1970s by James Cook. He patented the process in 1980.

CLF installations were installed in wheat storage structures at Kansas and Oklahoma elevators in the mid-to-late 1980s and data were recorded. CLF systems were installed at Oklahoma elevators in 1993 as part of a demonstration project funded by the Oklahoma Department of Commerce. Design and economic data have been developed on some CLF systems installations and operations.

New design methods for installing plumbing and blowers for increased operating flexibility were developed to reduce installation and operating costs. Multiple tanks have been connected to one blower and blowers are moved from site to site to minimise capital investment. Preliminary results have been documented on operating procedures and costs.

Benefits of CLF systems are: 1. reduced worker exposure; 2. quicker fumigation response time; 3. lower operating cost for fumigants through reduced labour and possible lower fumigant requirement; 4. reduced regulation compliance costs; and 5. potentially better fumigation efficacy with the same management expertise.

Background

Closed loop fumigation (CLF) was originally known as a recirculation process developed for methyl bromide fumigation in the U.S. and other major grain-producing areas. Reports cite recirculation of methyl bromide as early as the 1920s.

A new low power, low volume closed loop gas recirculation fumigation process using centrifugal blowers and duct systems was developed in the late 1970s for commercial fumigation using phosphine tablets, pellets, packets, or strips. James S. Cook of Houston, Texas received U.S. Patent No.4,200,657 on this process on 29 April 1980 (Cook 1980).

CLF Benefits

Although initial installation costs of CLF systems are substantial, financial payback can be relatively short, and elevator worker satisfaction is enhanced. Compared with conventional probe and tarp fumigation methods, management of CLF fumigation is simplified due to: (1) improved timing for multiple tank fumigations; (2) reduced labour; (3) reduced housekeeping; (4) less grain damage losses and operating expenses from handling compared with fumigation while turning; (5) reduced fumigant cost; and (6) faster fumigation response, application, and purge timing.

CLF Fumigation Procedures

In CLF, phosphine pellets are preferred over tablets because of quicker, more uniform gas release. Pellets can be placed on the grain surface, probed into the grain 10–20cm, 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 ash recovery. Pellets or tablets enclosed in packets, blankets or strips can be used to recover phosphine dust. After placing or probing the phosphine pellets and sealing the structure, the CLF blower is turned on. It pulls the gas mixture from the storage head space through a small diameter (7–15 cm) duct, pipe or hose into the suction side of the blower, then pushes the gas through a duct into the base of the storage, forcing it up through the grain back to the storage bin headspace. The blower is usually operated 5–8 days, depending on grain and weather conditions.

Well designed CLF systems mix the gas and air thoroughly. In a tightly sealed silo or grain tank, fumigant use may be reduced to 50–75% of amounts (or minimum label rates in some cases) used in conventional probe and tarp 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 and application time by a group of workers can be reduced to a few hours using two or three people. Fumigant pellet placement for all storage units can be made the same day. By fumigating all storage units at the same time, reinfestation of fumigated storages by insects migrating from adjacent non-fumigated tanks or silos is eliminated. Fumigant reductions of 25–50% are reported with improved results, due to continuous recirculation and uniform distribution. In some cases, operators find they are able to reduce dosages to minimum label rates, depending on the facility.

Gas Distribution Designs

Typical pipe sizes are 10 cm internal diameter connected to the inlet and outlet of a 0.0746 kW (0.10 hp) blower, and 12.7–15.25 cm, suction and pressure piping for a 0.375 kW (0.5 hp) blower. At piping junction tees or crosses, 12.7 cm pipes may be used for lateral conduits requiring reduced gas flows. A 0.0746 KW blower will produce about 5.5–6.0 m^3/minute (about 190–210 cfm) while the 0.375 kW blower will deliver 20–23 m^3/minute (700–800 cfm). Air 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.

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Concrete silos

In 4.5–7.6 m inside diameter concrete or steel silos, an open bottom pipe or tube that discharges at the bottom of the vertical sidewall or extends downslope to the centre of the silo is the typical design. Figure 1 shows three pipe and blower configurations in one-way sloped or cone hopper bottom silos. In 9.0–15.0 m diameter concrete silos, 2, 3, or 4 pressure pipes spaced evenly around the tank or silo perimeter manifolded to a single blower provides better gas distribution. In hopper bottom tanks, a single pipe run down the slope to within 0.6–1m of the bottom of the hopper provides excellent uniformity as the hopper acts as a gas distribution funnel.

Figure 2 illustrates the piping setup for CLF blowers to vent phosphine gas from the storage. If explosion-proof motors, switches, wiring conduits, and controls are used that meet electrical codes, the entire piping system can be mounted inside the silo with the blower mounted on roof or wall brackets, or inside elevator head houses with the motor mounted on the floor. If explosion-proof components are not used, all motors, switches, junction boxes, and wiring must be mounted outside the bin or elevator head house in open air. Suction pipes are not required for blowers mounted in the headspaces unless blowers are used for venting Fig. 2.

Grain pressures in 30–40 m grain depths place great stress on piping mounted inside silos, so fastening pipes securely to inside walls is critical. Pipe mounted to inside walls should be securely fastened at 1 m intervals. If an interior ladder is available, mounting the duct against the wall and ladder brackets or side rails provides construction convenience and structural stability.

Warning. PVC pipe should not be used inside silos, due to static electricity generated by sliding grain on plastic pipe, unless each pipe is well 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. If an outside blower is used for purging, disconnect the suction hose at the blower inlet, open the roof hatch and turn the blower on.

For external CLF blower assembly, the suction pipe must be extended through the silo roof into the head space (Fig. 2). The pressure pipe can be installed through the roof and along the inside wall to the base [e.g. secured to the ladder siderail down the wall], or it can be installed down the outside of the tank and enter the grain inside the tank at the base of the wall. The blower can be installed near the base with a long suction pipe and a short pressure pipe, or on top of the silos with a short suction line and a long pressure line. If aeration systems are involved, the external pressure pipe can be extended through the aeration blower manifold, or can be manifolded from one main line down the side of the tank to two or more aeration blower transitions.

Steel tanks

On 20–40 m diameter tanks with multiple aeration blower and transition positions, a CLF piping system design using two or three small blowers with short pressure pipe runs and small suction piping may be simpler and less expensive than trying to use one large blower with extensive larger piping or hose systems. Getting uniform gas distribution is more difficult in large diameter tanks than it is in tall silos, where the silo diameter is much smaller than the grain depth (Fig. 3).

Based on Cook's patent (Cook 1980), recirculation systems should be designed to provide a gas flow range of 0.0024–0.0064 m^3/minute/m^3(0.003–0.008 cfm/bu).

Higher gas flow rates of 0.004–0.0064 m^3/minute /m^3(0.005–0.008 cfm/bu) will offset poor distribution duct patterns and accelerate getting lethal gas levels to all parts of the storage. Figure 4 shows the CLF system modified so blowers are used for venting the gas when fumigation time has been completed. Tanks with aeration systems should use aeration blowers to vent the fumigant gases. Immediately after venting is completed, operators should reseal aeration blower openings to keep insects from reinfesting the storage at the base level.

On a 10600 m^3(300 000 bushel) welded steel tank in Kansas City, two 0.062 kW (1/12 hp) centrifugal blowers were plumbed to 15 cm (6 inch) PVC suction pipes fitted to openings half way up the roof slope. The outlet of each of the blowers was plumbed by flexible hose to 10 cm (4 inch) pressure pipes manifolded to three aeration blower duct transitions per blower, placed symmetrically around the tank base. Figures 3 and 4 illustrate the layout concept for welded steel tanks.

Construction piping options

Construction costs vary widely based on the difficulty of installing piping through roofs and securing the pipes to the sidewalls internally. External pipe mounting on steel tanks is relatively simple as brackets can be spaced 2.4–3.6 m (8–12 feet) apart. Self-tapping or threading bolts can be used to fasten pipe mounting brackets on corrugated steel tanks with thinner steel walls. Pneumatic conveyor piping brackets may be used for CLF piping. Galvanized angles or channels with standard U-bolts or formed all-thread U-bolts make a good anchoring scheme. Piping half-bands welded to angles for welding or bolting to bins or silos are another alternative. Used aluminum irrigation pipe may be available at salvage prices in some areas for CLF systems use; 10, 12.7 and 15 cm diameter aluminum tubing or pipe make good CLF gas flow ducts and irrigation tube connectors make suitable joints pipe.

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 0.0056–0.008 m^3/minute/m^3 (0.007–0.010 cfm/bu) range.

One key to CLF is sealed structures that hold an adequate gas level to maintain 150–200 ppm for at least 48 hours so gas can penetrate kernels and kill insect larvae and eggs. Commercial fumigators claim a complete kill of all insect stages is possible at 125–150 ppm if held for 3–4 days. Low grain/air temperatures cause slow gas release which can extend CLF blower operation from 5–8 days, which makes sealing critical. If tanks are well sealed with good aeration ducts, CLF systems with 0.373–0.0746 kW blowers will work satisfactorily on 8800–10600 m^3 (250000–300000 bu.) tanks. The 0.373 kW blower can provide adequate gas flow for two large tanks (Noyes 1993).

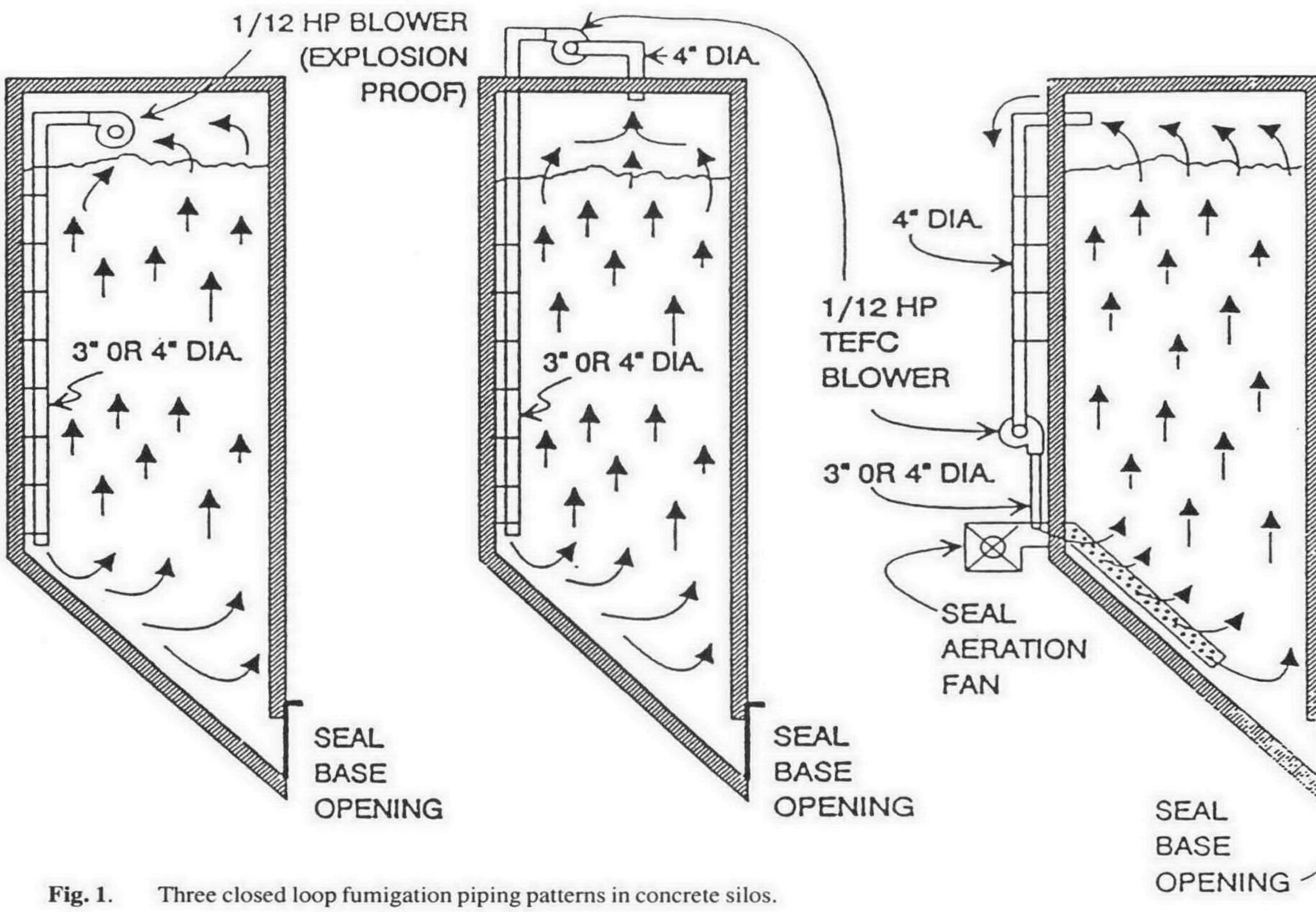

Fig. 1. Three closed loop fumigation piping patterns in concrete silos.

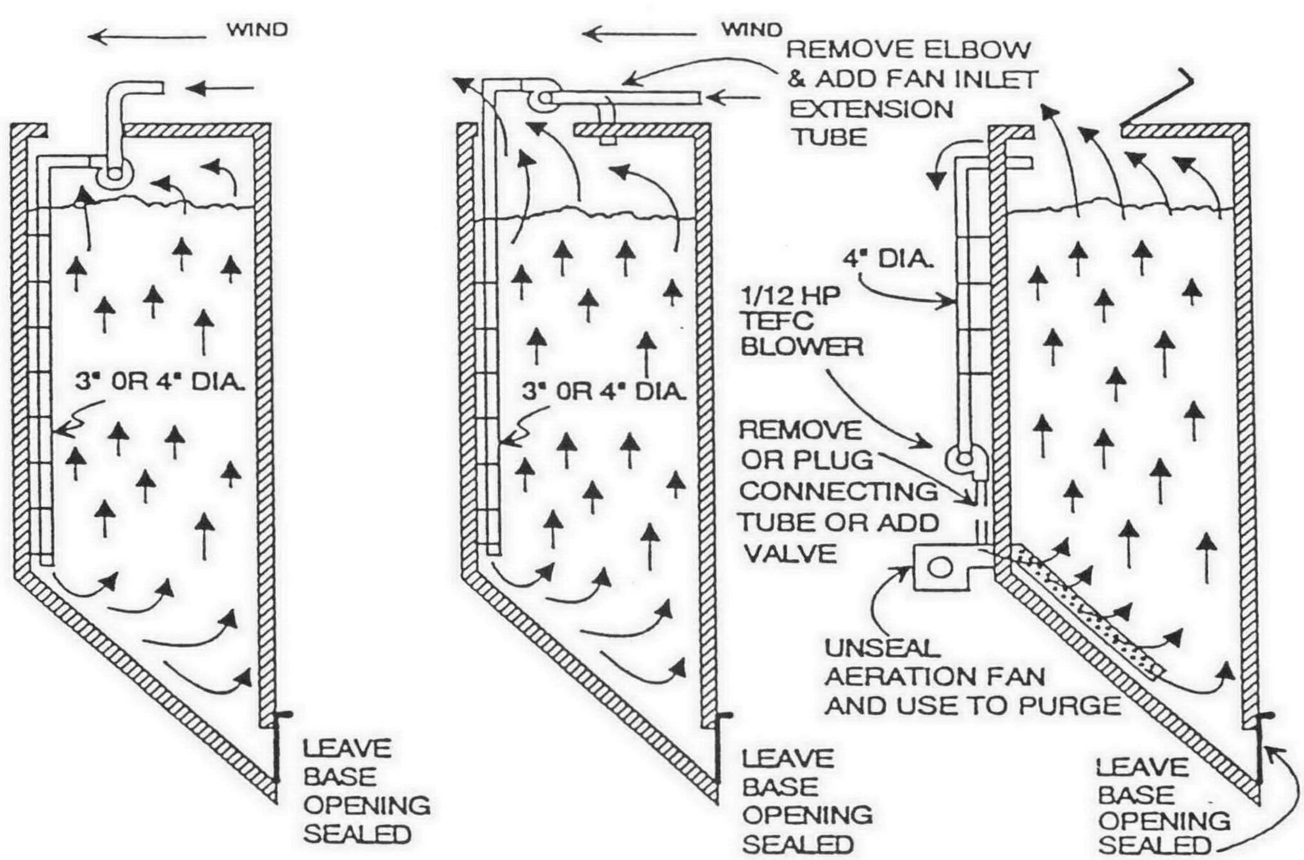

Fig. 2. Three closed loop fumigation piping patterns set for venting of fumigant gases.

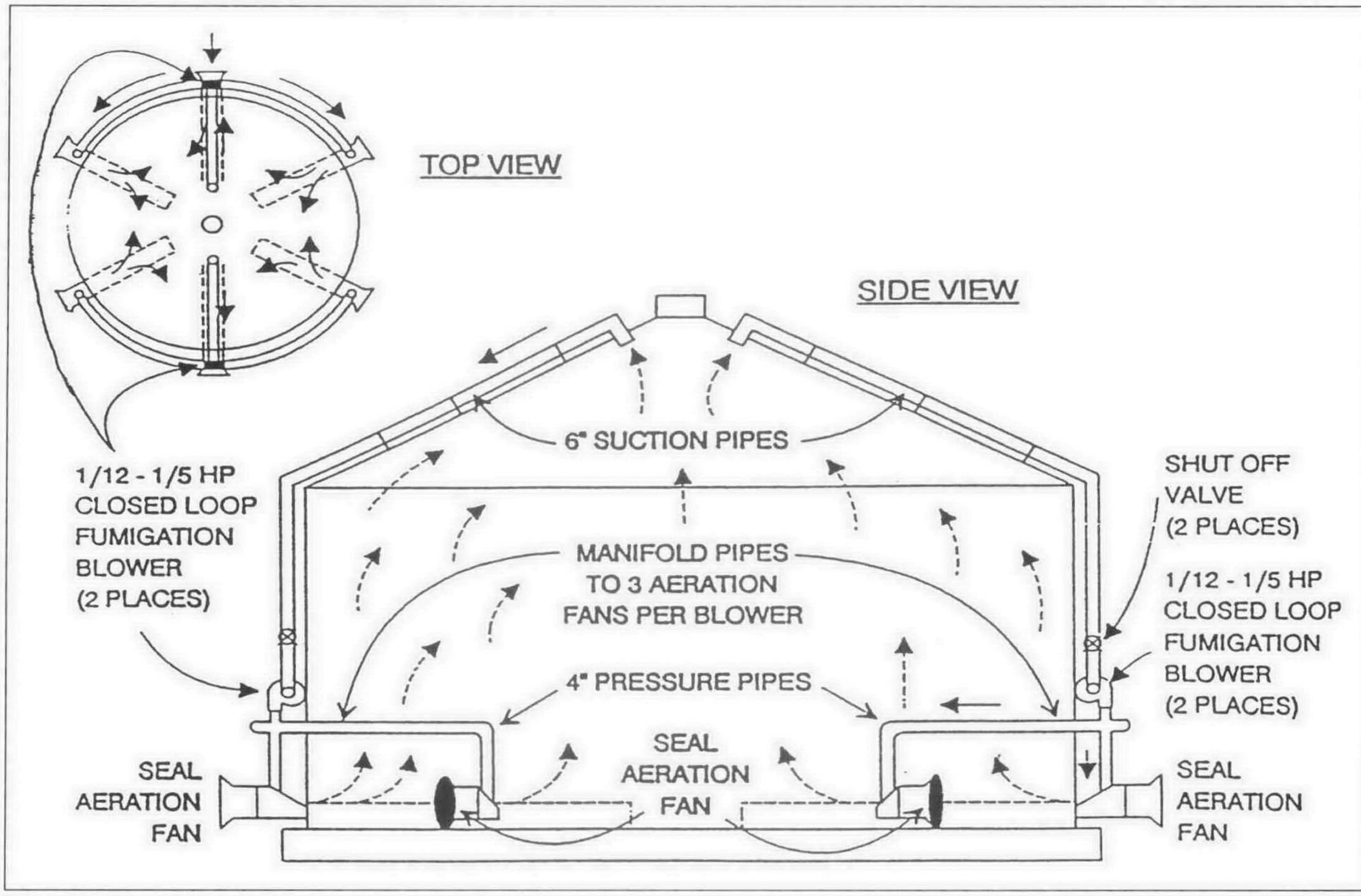

Fig. 3. Large steel tank with closed loop fumigation pipes connected to aeration ducts.

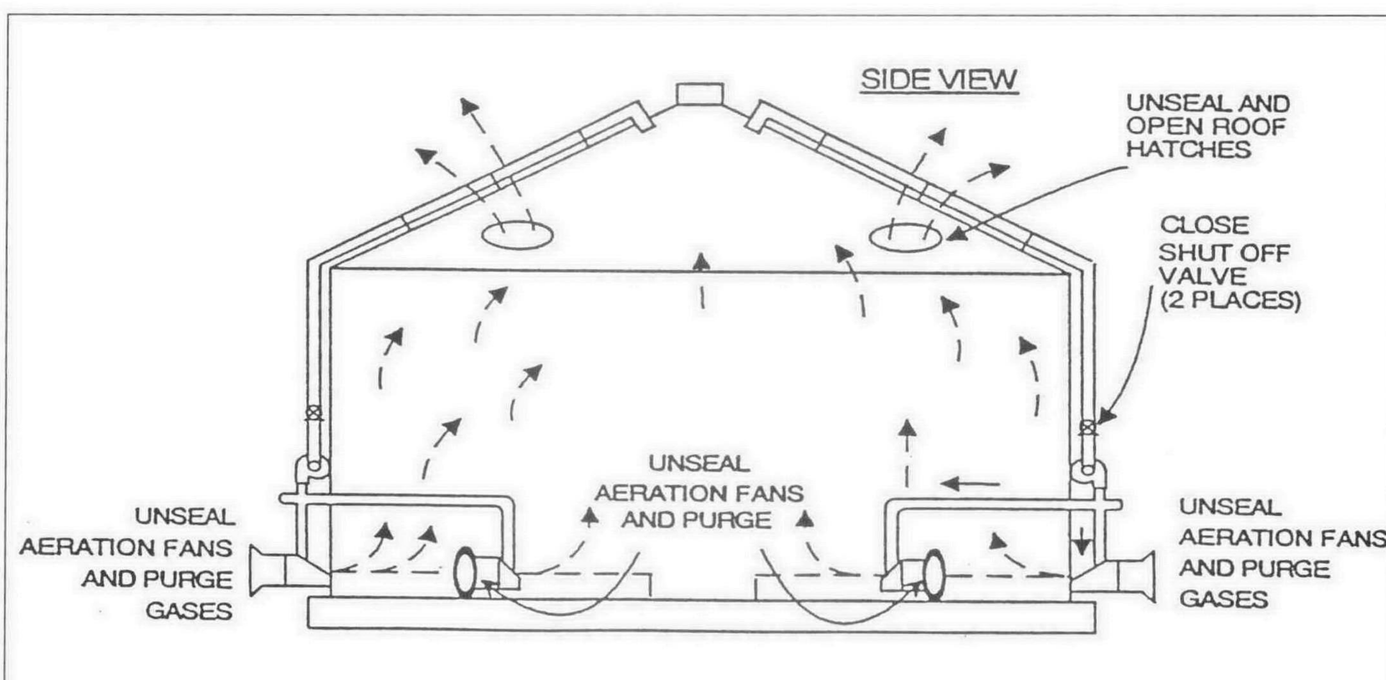

Fig. 4. Large tank with closed loop fumigation system used for venting fumigant gas.

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/roof joints and eaves during construction.

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 chemical deterioration. Aluminum or plastic wheels and housings are preferred because they are also spark resistant. Steel blower wheels and housings should be coated with epoxy or other tough, spark resistant materials.

Gas flow rates range from 0.0016–0.008 m^3/minute/m^3 (0.002–0.010 cfm/bu) to provide a total air change every 50–200 minutes or about 6–24 changes per day. According to Cook's patent (1980), 0.00056 m^3/minute/m^3 (0.0007 cfm/bu), a 0.0746 kW blower delivering 5.95 m^3/minute in a 10,620 m^3 tank (210 cfm in a 300000 bushel tank), is a satisfactory air flow. Normal aeration at 0.08 m^3/minute/m^3 (0.1 cfm/bu) moves one air change in a full bin in 5 minutes, 20 times faster than a CLF blower delivering 0.004 m^3/minute/m^3 (0.005 cfm/bu), which requires 100 minutes.

Low gas flow rates of 0.0016–0.004 m^3/minute/m^3 [0.002–0.005cfm/bu] with air exchange times of 250–100 minutes [4.16–1.67 hours/cycle] are quite low relative to tank or silo volume.

A basic closed loop fumigation system blower and duct design for a single 6 m × 30–40 m concrete silo is a 0.0622–0.0746 kW centrifugal blower with a 10 cm inlet and outlet that operates at 250–500 Pa (1/2 inch water column, [W.C.]) static pressure at a rated airflow of 160–190 m^3/minute, or about 0.004–0.008 m^3/minute/m^3 through 700–1800 m^3 silos and tanks; this would provide one air exchange every 1–2 hours or 12–24 air changes per day.

In concrete silos where internal vents are difficult to seal, combining the silos into a larger storage volume may simplify the installation and reduce installation expense. Suction and pressure pipes from multiple silos can be manifolded to one larger blower to simplify operation and reduce control costs.

For 1770–3540 m^3 concrete silos (50000–100000 bushels), 0.125–0.250 kW blowers delivering 7–10 m^3 (250–350 cfm) at 250–375 Pa (1–1.5 inches W.C.) combined suction and positive static pressures are recommended. Steel tanks with 3500–14000 m^3 (100000–400000 bushels) volume may use one 0.188–0.377 kW blower or use two lower hp blowers, depending on the layout of the aeration system and the piping required to get good gas distribution.

Gas Level Monitoring

To develop valuable historical use date, monitor gas concentration levels daily at key locations in the storage throughout the fumigant recirculation period during the first time that a new CLF system is used. Records of previous gas level readings provide valuable management data. Operators should probably use high label rates (at least 75% of maximum dosages) during the first application of the new system, to make sure gas levels are adequate. If initial gas readings are sufficiently high, application levels may be reduced by stages during future fumigations. If satisfactory gas levels and kill results warrant, application can be reduced to minimum label rates.

However, if fumigant levels drop below minimum recommended levels during the first 24–48 hours of operation due to gas leakage, more fumigant may have to be added. If fumigant must be added, it should be done by workers wearing appropriate personal protective equipment, or by pouring pellets through a small roof opening using a long probe tube which can be moved to distribute the pellets across the grain surface. Workers should stand up wind of the pour spout and use caution.

Purging phosphine with standard aeration blowers can be done in a few hours. If CLF blowers are used, at least 1–3 days of continuous blower operation should be used. Exhaust air should be sampled from tank head spaces through tubes run through bin wall openings to make sure the air inside is safe for personnel entry. Appropriate personal protection equipment should be used when remote sampling tubes are not used and gas levels are sampled directly from silo or tank head spaces or from the exhaust air.

Venting Fumigant with CLF Blowers

Once fumigation is complete, tanks or silos must be adequately aerated before workers can re-enter storage units or grain can be shipped. For storages with aeration, unseal roof vents and use aeration blowers to vent gas, then reseal blowers to block reinfestation of the silo or tank at the base level.

Warning. Keep all personnel away from open CLF system exhaust tubes or vents when using aeration or gas recirculation systems to purge tanks or silos of fumigant to avoid phosphine gas poisoning. Exhaust tubes should be ducted outside away from personnel areas.

When using CLF blowers for purging silos or tanks, open vents or hatches must be located away from the fresh air supply of the blowers. The fresh air supply may need to be ducted to the blower from several feet away so exhaust air is not recirculated. Prevailing winds need to be considered and tall standpipes may need to be used to avoid dilution of fresh air. If blowers are inside the storage as shown in Figure 2, the blower air supply must be controlled from outside to avoid the need for self-contained breathing apparatus equipped personnel to change the piping before venting or purging the fumigant. (Noyes 1993) On external mounted blower and piping systems where the tank or silo has no aeration system, remove the suction return pipe and open roof exhaust vents or doors and operate the blower to purge the tank.

For storages without aeration, use CLF blowers for forced air purging (Figs 2 and 4). Storages can be purged much faster and to much lower gas levels using CLF blowers than by conventional gravity draft venting. Storage bases can remain sealed, minimizing insect reinfestation.(Noyes et al. 1989a,b) CLF blowers that provide 0.0016–0.0064 m^3/minute/m^3 (0.002–0.008 cfm/bu) airflow should be operated continuously for 1–3 days when venting storages because of non-uniform air distribution. Operate aeration systems rated at 0.04–0.4 m^3/minute/m^3 (0.05–0.5 cfm/bu) 3–5 hours for venting.

Regardless of the method of venting the gas, monitor the air quality or gas level in each storage structure with appropriate gas sampling equipment, preferably through remote sampling tubes, before entering the storage. Air samples must be taken at entrances and in work areas of the storage and recorded to confirm that the fumigant has been satisfactorily purged. Workspace air samples should be taken and data recorded before workers resume normal re–entry, to ensure safe concentration levels of phosphine gas below the 0.225 ppm (0.3 ppm × 0.75 — phosphine gas monitoring tube accuracy is ± 25%) for phosphines.

Field Test Results

In well sealed storage structures, closed loop systems require less fumigant than conventional probe and tarp fumigation methods. Field data from closed loop systems in operations in Texas, Oklahoma, and Kansas are listed in Tables 1 and 2 (Noyes et al. 1989a,b) Table 1 is a comparison of type and quantity of phosphine in small sealed volume tests using 0.19 m^3 (50 gallon) barrels. Table 2 is an analysis of the standard fumigation process (non recirculation) compared with closed loop fumigation on a 10600 m^3 (300000 bushel) welded steel tank. Uniformity was greatly improved throughout the grain mass with CLF.

Installation and Operation Economics

For steel tanks, preliminary construction and installation cost estimates are about US$2500–US$3000 for a 7000–10000m^3 steel tank, or about US$ 0.30–0.45/m^3, or about US$0.40–0.60/t. Because concrete silo volumes are smaller and the structures taller, installation cost per unit volume is substantially higher than for steel. Cost estimates for CLF systems in concrete silos are US$750–1000 for a 400–600 m^3 concrete silo, or about US$1.20–1.50/$m^3$, or about US$1.60–2.00/t. (Noyes et al. 1989a,b)

On a unit volume basis, it costs about 2–4 times as much to install CLF in concrete silos as in steel tanks. Silo costs estimates are high because each is treated as an individual storage unit with its own plumbing, blower and controls. However, if several silos are plumbed together into combined volumes that are similar in size to individual steel tanks where fewer, larger powered blowers and controls are used, installation costs may be reduced to a level more competitive with large steel tanks. One large vertical standpipe from the top of silos down the outside to ground level serving 6–8t concrete silos should be more economical than individual pipes (Kenkel et al. 1993, 1994)

Also, if an elevator with concrete silos is currently turning 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 labour associated with turning.

Table 1. Phosphine comparison tests [raw data from field tests]

Day	Date	Time	Temperature		Hours	ppm
		Test 1 — 1 Pellet Phostoxin/0.189 m^3 (50 gallon) barrel				
Fri.	10-02-87	3:30 p.m.			0	0
	10-02-87	4:30 p.m.	18.3°C	65 °F	1	45-50
Mon.	10-05-87	9:30 a.m.	14.4 °C	58°F	66	excess of 50
Wed.	10-14-87	9:30 a.m.	13.9°C	57°F	282	excess of 50
		Received high range tubes Friday morning				
Fri.	10-16-87	1:30 p.m.	15.0°C	59°F	334	450
		Friday 4:45 pull plug from hose				
Mon.	10-19-87	8:30 a.m.	11.7°C	53°F	401	450
		Forced out with air				
		Test 2 — 1 Pellet Fumitoxin/0.189 m^3 (50 gallon) barrel				
Mon.	10-19-87	10:00 a.m.	12.2 °C	54• F	0	0
	10-19-87	2:00 p.m.	10.6°C	51°F	4	175
	10-19-87	4:45 p.m.	11.1°C	52°F	6.75	510
	10-19-87	7:00 p.m.	11.1°C	52°F	9	525
	10-19-87	10:00 p.m.	10.6°C	51°F	12	505
Tue.	10-20-87	8:00 a.m.	12.2°C	54°F	22	600
	10-20-87	4:00 p.m.	13.9°C	57°F	30	550
		31 hours 5:00 p.m. remove both caps				
Wed.	10-21-87	8:30 a.m.	11.1°C	52°F	46 1/2	0
		Test 3 — 2 Pellets Fumitoxin/0.189 m^3 (50 gallon) barrel				
Wed.	10-21-87	1:45 p.m.	13.3°C	56°F	0	0
	10-21-87	2:15 p.m.	13.3°C	56°F	1/2	21
	10-21-87	4:45 p.m.	16.7°C	62°F	3	100
Thur.	10-22-87	7:45 a.m.	13.3°C	56°F	18	1190
	10-22-87	9:45 a.m.	13.3°C	56°F	20	1200
	10-22-87	11:45 a.m.	15.6 °C	60°F	22	1080
		(Different tubes)				
	10-22-87	4:45 p.m.	18.9°C	66°F	27	900-1050
Wed.	10-28-87	1:45 p.m.	18.9°C	66°F	168	1080-1200

Source: Mike Stringer, Mgr., Fairfax Elevator, Union Equity Cooperative Exchange, Kansas City, Kansas, 1988.

Table 2. Comparison of recirculation vs. non-recirculation on 10600 m^3 (300000 bu.) welded steel tank.

	No recirculation—ppm[a]							
	10/27 19 hrs	10/27 25 hrs (windy)	10/28 43 hrs	10/28 49 hrs (2 days)	10/29 67 hrs	10/29 73 hrs (3 days)	10/30 93 hrs (4 days)	11/2 162 hrs (7 days)
Headspace	300	325	175	400	500	475	525	325
3 m	20	0	15	0	10	20	75	400
6 m	0	0	0	0	0	0	20	375
9 m	125	100	200	175	200	200	250	325
12 m	275	400	425	400	450	450	575	300
Fan	400	175	625	500	2100	1125	1000	1000
	Recirculation—ppm[b]							
	10/27 19 hrs	10/27 25 hrs (1 day)	10/28 43 hrs (windy)	10/28 49 hrs (2 days)	10/29 67 hrs	10/29 73 hrs (3 days)	10/30 93 hrs (fans off) (4 days)	11/2 162 hrs (7 days)
Headspace	200	425	675	800	1000	950	1050	350
3 m	125	125	650	500	850	775	825	650
6 m	190	275	575	600	850	825	875	625
9 m	210	275	600	650	900	875	925	525
12 m	300	425	450	750	950	950	1100	310
Fan	300	400	700	700	950	925	900	150

[a]30 flasks—24 probed into surface, 6 in aeration ducts.
[b]30 flasks broadcast on the surface.

Preliminary estimates indicate that CLF systems installed in steel tanks will pay back in 6–8 years if the system results in lower fumigant usage. While it may take 20–30 years for fumigant savings to equal the cost of installing a CLF system in concrete silos, costs will 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. Additional benefits of timeliness, labour reduction, easier management and safety are subjective factors that are difficult to place a monetary value on, but do provide significant capital advantages.

CLF operating costs are extremely low. Costs to run 0.062–0.125 kW (1/12–1/6 hp) blowers are about the cost of electricity for a 75–150 w light bulb — less than 2 cents/hour — about 1.5–3.0 kWH/day, or US$0.15–30/day per blower at US$0.10/kWH. A 0.187–0.375 kW (1/4–/2 hp) blower costs about the same to operate as a 200 or 400 w bulb — 2–4 cents/hour or US$0.50–1.00/day

The electrical expense to fumigate and purge a 6 m × 30 m (20 ft by 100 ft) silo with a 0.075 kW (1/10 hp) blower operated 6–10 days for fumigation and purging is about US$1.50–US$2.00. An 8850 m^3 (250000 bu) bin with a 0.187 kW (1/4 hp) blower costs US$3.50–US$10.00 to operate for 6–10 days.

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