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Affordable sealing of multiple grain storages – manifolded for CLF

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Abstract

In 1980, James Cook, a research director with Degesch America, patented phosphine (PH_3) recirculation fumigation, labeled the *J-System.* Cook documented phosphine's lower explosive limit (*LEL*) as 18,900 ppm. The *J-System* produced satisfactory results at gas flows from 0.001 to 0.01 cfm/bu (0.062 to 0.62 $m^3h^{-1}t^{-1}$). In 1988-89, I manifolded inlet and outlet gas piping of multiple grain storages of varied volumes to recirculation blowers (providing 0.208-0.104 $m^3h^{-1}t^{-1}$) to circulate gas through combined storages, which I called "Closed Loop Fumigation" - *CLF*. Closed Loop Fumigation established that storage units of variable sizes could be satisfactorily fumigated *as one storage volume*.

Sustainable Economic Sealing uses inexpensive high quality, off-the-shelf sealing materials. It requires strong attention to detail during application. Sealing methods include plugging visible light through walls and roofs, sealing structural joints with expandable adhesive foam, applying exterior grade caulking, using high quality duct tape and 6 mil polypropylene sheeting to seal to fan inlets and outlets, and sealing door facings using spray adhesives. Other leaks are from motor bearing shafts, conveyor covers and outlets, roof wall joints, roof and wall doors, slide gate adjustment rod openings and sleeves, roof vents, fill caps, down spouts, and other air leak points. Sealing grain structures to 'no leak' *pressure standards* to eliminate virtually all leaks may be ideal for *high-value* commodities. But, sealing commercial structures storing *low-value* commodities (wheat, corn, soybeans, field beans, rice) to *pressure standard* tightness is not economically affordable in most countries. Therefore, sealing major and minor leaks of steel bins, concrete silos, or warehouses (where you see points of daylight through walls and roofs) using economical sealing materials can provide affordable fumigations, especially when multiple adjacent storage structures are manifolded using *CLF.* Annual inspection, maintenance, and 'resealing' as needed are vitally important in *sustainable economic sealing.*

Keywords: Sustainable, Affordable, Sealing, Economic, CLF, Recirculation Fumigation, Low Pressure

Background

Phosphine gas was not recirculated until James Cook, a research director with Degesch America, obtained a U.S. Patent (Cook, 1980) on the *J-System* recirculation method. Cook documented that phosphine (PH_3) had a lower explosive limit (LEL) of 18,900 ppm. The *J-System* functioned well using gas flow rates from 0.062 to 0.62 $m^3h^{-1}t^{-1}$ (0.01 to 0.001 cfm/bu).

In 1987, I visited Fairfax Elevator, Kansas City, Kansas, and inspected two *J-Systems* used on a 10,000-t steel tank and a 550-t concrete silo. The steel tank used two 0.062 kW blowers each providing 0.0017 m^3/h gas flow. The concrete silo used one 0.062 kW blower (Noyes et al., 1989). After inspecting Fairfax Elevator's *J-Systems* in 1988, I developed a multiple bin recirculation system for an Oklahoma elevator, combining four 5,000-t steel bins as Oklahoma's first model PH_3 gas recirculation system (Fig. 1A), creating two side-by-side 10,000-t storage volumes, each with a 0.75 kW centrifugal blower (Fig. 1B) providing 0.0085 m^3/h, which I named "Closed Loop Fumigation" - *CLF* (Noyes, 1993).

An important steel bin piping design change from the first *CLF* model system (Fig. 1A) was connecting suction pipes through the bin wall just below the roof using two 90º Sched 40 PVC elbows (Fig. 1C). Suction pipes hang from bin walls, instead of laying on roof slopes. Hole saws cut smooth holes through bin walls, and pipes hang next to wall ladders and roof access doors. Suction pipes are clamped to bin walls or ladder siderails.

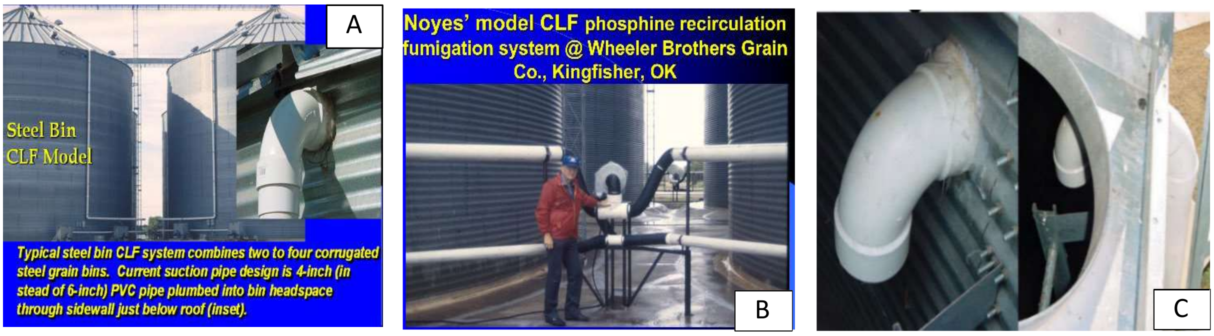

Fig. 1. First *CLF* model (A), caulked suction pipe elbows (B), *CLF* upper suction, lower pressure pipes (C).

Basic *CLF* Principles

1. Combined individual storage volumes vary widely with excellent efficacy; 2. Circulate PH_3 gas 1-2 days (3-5 volume changes) until at uniform peak; 3. Stop blower - continuous recirculation increases gas leakage; 4. Monitor headspace gas; when gas drops to marginal kill level (~ 200 ppm), operate blower 'a few minutes' to raise headspace gas to target level (~ 400-700 ppm); 5. Grain bulk in each storage provides PH_3 gas reserves.

In the 1990s many Oklahoma elevators implemented these CLF Principles manifolding all steel bins and concrete silos forming 10,000 to 50,000 t fumigation units. Design and economic data developed from these CLF systems were used in annual Oklahoma Elevator Management Workshops (Noyes et al. 1995).

In 2000, several grain companies requested *CLF* systems for flat storages. The best sealed warehouse was at Mid-Oklahoma Coop, in Kingfisher, Oklahoma. Two men worked 7 d to seal their 20,000-t warehouse and install 2 *CLF* blowers. In 2000, their peak gas concentration was 2050 ppm 24 h after dosage. Seven days later, their headspace gas level was 850 ppm. In 2001, Mid-OK Coop reduced dosage 50%. Their 24 h gas reading was 1050 ppm; after 7 d, their concentration was 450 ppm.

Closed loop fumigation systems typically use one recirculation blower for 2 to 10 steel tanks and 2 to 40 concrete silos as a unit. Thus, steel bin, concrete silo and warehouse storage facilities of 5,000-100,000 t are fumigated *as one unit* with *CLF*. Multiple fans are used on large warehouses. The largest *CLF* system in Oklahoma was a 90,000 t (45 m × 150 m) warehouse at Tulsa Port of Catoosa. This structure, with 18 aeration fans and ducts per side, used three pipe manifolds per side and had a 2.25 kW blower connected to six aeration fans / ducts per 50 m section.

After my *CLF* presentations at the 1998 *International Working Conference for Stored Product Protection* (*IWCSPP*) in Beijing, China (Noyes et al., 1998), the *China Oil and Seeds Committee* adopted *CLF* into the design of all concrete silos (*Squats*) and warehouses built in 19 new State Grain Depots across China between 1998-2000. In November 1999, Dr. Navarro and I lectured at two 2-day workshops in Nanjing and Beijing on the topic, *Aeration and CLF*, using photos of China's new *CLF* and aeration systems (Noyes and Navarro, 1999). We also presented a 5-h summary of *Aeration and CLF* to the 600 delegates of the *National Conference of Grain Depot Directors, Managers and Scientists* in Beijing.

Sealing storage structures for *CLF*

Sealing leaky bins, silos and warehouses is vital to successful *CLF* operation. Figure 2A illustrates available 'off-the-shelf' materials used for affordable grain storage sealing. These materials include expanding impervious adhesive foams, medium to strong tackiness adhesive sprays (red topped cans), elastomeric concrete foundation paint and nylon mesh (*Kool Seal*, Fig. 2A), heavy plastic contractor bags, high quality duct tape, exterior grade silicone caulk, and 6 mil polyethylene plastic sheeting. Please note that adhesive foam products like *Great Stuff* have an expansion ratio of 3 to 5 times their original volume. Practice using it slowly until you determine how fast and how much it expands before it becomes firm. Most expansion occurs in the first 10 to 15 min. Apply it in shallow layers; wait 10 to 15 min between layers to allow gradual filling of large spaces.

Primary Affordable Sealing Areas: (In priority sequence of major gas loss sealing importance)

Steel Bins: Roof-wall gaps; Roof Vents; Fill points; Discharge conveyors; Roof/Side Doors; Concrete base - sidewall seam.

Concrete Silos: Under-roof wall vents; Fill points; Unload conveyors; Roof deck - wall gap; Manhole doors.

Warehouses: Drive and walk-in doors; Windows; Roof vents; Fill points; Discharge conveyors; Roof leaks; Concrete Base - sidewall seam.

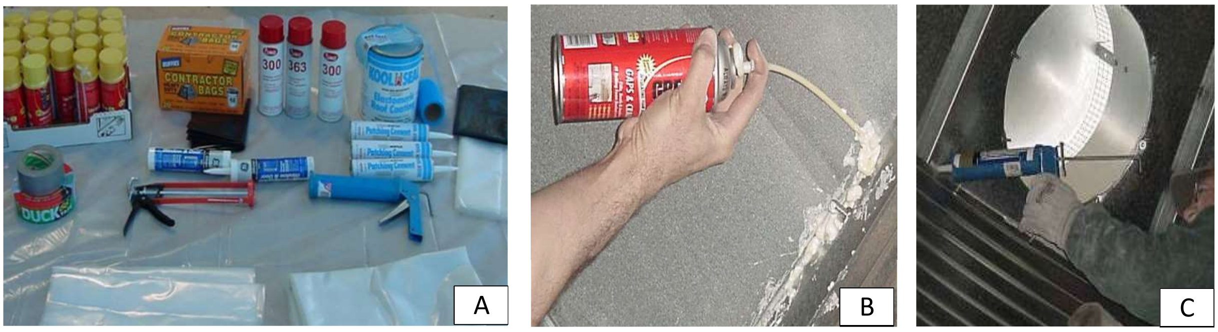

Fig. 2. Economical sealing materials (A), foam wide roof gaps (B), silicone caulk narrow roof gaps (C).

Sealing steel bin roof to sidewall air gaps

Roof sidewall air gaps are the largest gas leak areas in bolted steel bins which must be sealed (Figs. 2B and 2C). Roof panel ridge stiffeners at sidewalls (Fig. 3A) and fill cap flashing rings require critical sealing. Roof panel ridge ends under fill ring flashing collect dust, fines, and other airborne debris which must be cleaned out and sealed with expanding foam sealers like “Great Stuff” (Figs. 2A and 2B). Roof stiffener ridges at the sidewall need to be filled with adhesive spray foam (Fig. 2B). Steel (or wooden) plates that profile roof rib openings (Fig. 3A) can be caulked around edges for a tight seal, or openings can be foam sealed using a temporary blocking material until the foam hardens.

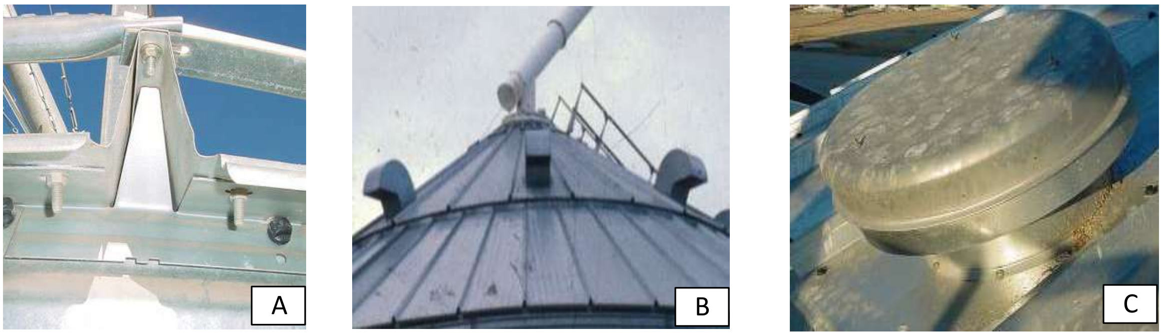

Fig. 3. Caulk edge of steel roof ridge plate (A), double bag roof vents (B), fill cap and down spout sealing (C).

Fill-cap openings and roof doors (Figs. 3B and 4A) are sealed using 6 mil plastic sheeting attached to raised flange openings and sides with adhesive spray. Plastic 6 mil sheets should be oversized by 20-30 cm so sheet edges can overlap below door and fill ring lips. Wrap excess plastic down sides and bind with duct tape, sealing plastic to steel surfaces. Seal roof vents (Figs. 3B and 3C) using doubled industrial plastic bags, duct tape around vent bases, and cross-tape tops of bags to provide wind resistance. Seal concrete foundation to steel wall base junction (Fig. 4B) with an exterior elastomeric paint for a durable flexible seal. Reseal concrete bin bases annually.

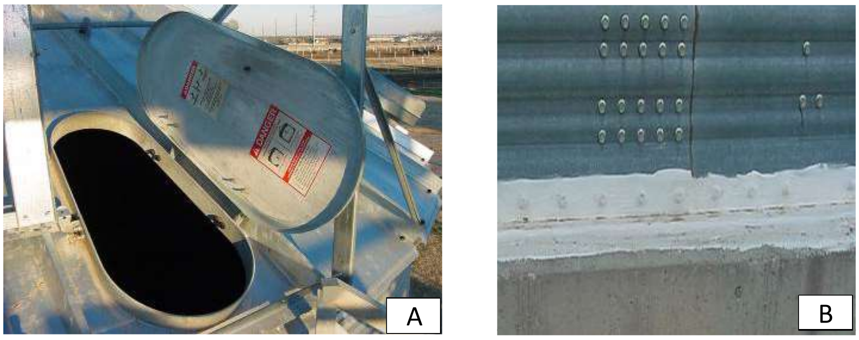

Fig. 4. Seal door flanges with adhesive spray and plastic sheeting (A), elastomeric paint base seal (B).

Many steel bins have fill spouts or auger discharge spouts installed through bin fill caps (Fig. 3B). Some downspouts have an extended "Y" with removable cleanout plates, so the spout can be 'stuffed' or 'foamed' to block gas flow up spouts but remove blockage after fumigation. Spouts with flange ring connectors above fill caps (which can be loosened) allow thin plates to be inserted between flange rings to block spout gas loss. If spouts cannot be sealed above the bin, spouts must be sealed inside bins using adhesive spray, 6 mil poly sheeting, or industrial plastic bags and duct tape.

Sealing roof and sidewall doors, and fan inlets

Bin roof doors and bin side doors are large openings where large volumes of gas can escape if not well sealed. These openings have flanges that can be sealed using adhesive spray, 6 mil plastic sheeting, and duct tape. Cut the plastic sheeting at least 20-30 cm wider than the outer dimensions of the roof and sidewall door flanges (Fig. 4A). Spray the flange surfaces with a medium to strong tackiness industrial adhesive (the 300 and 303 labelled cans in Fig. 2A), then lay the plastic sheet over the opening with the oversized plastic sheet centered on the door flanges. Lightly press the plastic sheet against flanges so the adhesive bonds. Read the label on how quickly tackiness sets up. As soon as the plastic sheet bonds, tuck excess plastic edges under the flange, and wrap duct tape tightly around the plastic so the plastic sheeting is held tightly across the flanges. Close and latch doors to protect the plastic sheeting from windblown debris that might penetrate the plastic, causing gas leaks.

Fig. 5. Sealed fan inlet with plastic and X-braced (A), fan motor shaft foam sealed (B), caulk auger push rods and foam inside tube (C).

The primary sealing area of aeration fans is the fan inlet (Fig. 5A). Measure the diameter of the fan inlet orifice outer edges, then increase the diameter of the 6-mil polyethylene sheet material by 20-30 cm to allow material to wrap behind or under the orifice ring. Aeration fan guards are bolted near the outer edges of the fan inlet orifice. Silicon-caulk the bolts and holes before applying plastic sheeting over the inlet orifice. Apply duct tape in a cross (X) pattern across the fan guard plastic covering to keep it from flapping and being perforated during strong winds or fumigations.

Foam the motor shaft holes through fan housings to prevent gas leaks (Fig. 5B). Inspect aeration fan housings for holes, wiring conduit entry points, cracks, gaps at the mounting face to the bin or aeration ducts, or flange connections from fan outlet to aeration ducts, and then seal these leak points with caulk, adhesive foam, plastic sheeting and adhesive spray, or other suitable methods. Centrifugal fans mounted on concrete pads collect moisture and trash, and can rust through. Apply expanding foam under fan housings or caulk around housing base on concrete to seal fan housings.

Discharge conveyor sealing

Steel bin, concrete silo annex or warehouse discharge conveyors (Fig. 5C) are hard to seal. Remove U-trough conveyor cover close to wall, then add about 20-30 cm of expanding foam to the U-trough under the bin or warehouse wall. While the foam is still expanding, replace the cover panel so the foam pushes up against the cover. After fumigation, cut out most of the foam; remaining foam will be removed as grain discharges.

Most round tube auger conveyors have flange rings close to the foundation of storage structures. Disconnect flange rings and loosen shaft bearings to allow the auger tube to slide forward a 10-15 cm. Fill the auger tube cavity around the auger flighting at the flange ring opening toward the bin or warehouse foundation with a few centimeters of expanding foam, then reconnect the flange ring and tighten shaft bearing. The 10-15 cm of foam thickness will block gas flow, and the foam will shear away when the auger is started after the fumigation is completed. It may be possible to fill the end of the auger housing with foam to form an air-tight ‘plug’ of foam just ahead of the auger discharge if foam can be sprayed into the final 20-30 cm of the auger just ahead of the discharge outlet. The discharge auger (Fig. 5C) has a silver connecting band that can be loosened and slid forward enough to allow a short section of auger tube to be filled with expanding foam. If foam plugging of discharge conveyors is not feasible, the outlet of the conveyor including motor and drive must be ‘bagged’ with two to three industrial trash bags layered and sealed tightly with duct tape so there is plastic to steel tubing seal under the duct tape.

Sealing flat storage warehouses

Flat storage warehouses vary more in gas leakage than steel bins or silos. The best warehouses for sealing are those with long vertical wall sheets attached to horizontal steel stringers between sidewall and roof frames. Walking inside warehouses on sunny days will indicate leakiness from number and size of visible light spots. If there are a lot of light spots, the best option may be to coat and seal the inside walls with a thin tough exterior elastomeric spray or roller paint. Large roof eave, roof deck, conveyor inlet and discharge openings should be sealed like steel bins.

Sealing concrete silos

Most concrete silo leaks are at the top and bottom. Solid reinforced concrete sidewalls generally have few leaks, except for openings built for specific purposes, such as access doors, grain discharge chutes or spout outlets. Seal those with adhesive sprays, plastic sheeting or bags and duct tape.

Roof to sidewall air gaps are primary problems on concrete silos where roof decks were precast, then set on top of concrete silo walls without a filler material between roof and walls. Usually, these junctions are not caulked or sealed. Sealing the silo roof / wall cracks and external vent openings is best done when the silo is filled to within 1.5-2 m of the roof so boards or tarps on the grain surface make work platforms. If roof deck wall gaps are extremely close (0.5-1.0 cm), caulking may work. For larger gaps (1-2 cm), use foam spray to reduce material and labor.

Use expanding foam spray on exterior vents (Fig. 6A) building up shallow layers. An alternative is to cut plywood, cardboard (Fig. 6B) or steel plates anchored with "J" bolt hooks attached to vertical bars, and then silicone or adhesive foam spray around the edges, building up a thick layer of foam or caulk between concrete and plate materials. Another option is to cut a close-fitting plate and use a silicone bead or adhesive spray around the edges to push and secure it in place when the adhesive dries or the caulk sets. Discharge conveyors will be sealed like conveyors from steel bins or warehouses. Figures 6C and 7A illustrate methods of filling external vent openings. Figure 7B shows silo annex basement grain chute sealing points.

Fig. 6. Foam filling roof deck vents (A), roof vent sealing tools (B), roof vent foam sealing (C).

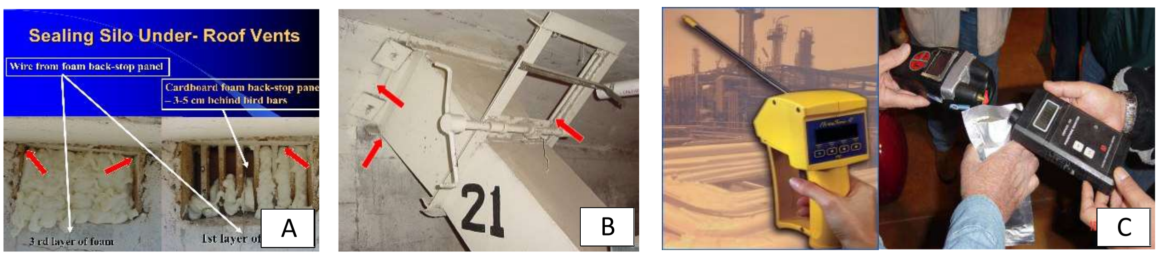

Fig. 7. Foam against cardboard (A), caulking silo spouts (B), PH_3 Gas meters are needed for sealing (C).

Storage leakage monitoring and inspections

Regardless of the type of storage, continued surveillance for leaks to improve storage seals improves fumigation. Finding gas leaks pays dividends in gas savings and higher fumigation efficacy. Your best sealing investment is a high quality PH_3 electronic tester (Fig. 7C) which allows for hundreds of quick samples. 'Sniffing' around discharge conveyors, aeration fans and ducts, the base of storages, around sidewall and roof openings after they are sealed, around fill and discharge conveyors, bin sidewall corrugated sheet junctions, fill rings and roof overhangs, bin base to concrete junctions during fumigations is vital to improving storage sealing. Enter empty storage units on sunny days and look for light points, and then seal them.

Closed loop fumigation systems - *CLF*

Combining multiple grain storages of various sizes into one larger fumigation volume provides a major improvement to James Cook's *J-System* recirculation fumigation model. Connecting storage units, regardless of size, as one recirculation fumigation volume is what I named "Closed Loop Fumigation" - *CLF*. Sealing grain storage structures permanently so they are ready to fumigate with minimal labor improves overall grain system management. Closed loop fumigation systems have greatly improved fumigation efficacy for controlling grain storage insects.

Closed loop fumigation system benefits

Although initial installation costs of *CLF* systems may be substantial, especially using outside contractors, financial payback can be relatively short while worker satisfaction and safety is improved because *CLF* creates: much faster response and purge timing than probe-tarp fumigation; (2) reduced fumigation labor; (3) improved worker safety; (4) reduced housekeeping; (5) reduced grain shrinkage and operating expense from no "turning" in concrete facilities; (6) lower fumigant dosages; (7) less gas release to environment; (8) high efficacy which minimizes insect PH_3 resistance.

Closed loop fumigation plumbing systems

In *CLF* systems, combined storages are connected by pressure and suction manifolds, like the upper and lower pipes connected to the *CLF* blower on steel bins (Figs. 1A and 1B). Pressure manifold pipes distributes gas from the blower (Figs. 8A and 8B) into the base of each storage through small lateral pipes (Figs. 8C and 8D) which tee off from the pressure manifold connecting to bottoms of silos. Lateral pipe shut-off valves (Figs. 8C and 8D) allow empty storage bins to be bypassed. In concrete silos, pressure pipes connect to grain discharge spouts through perforated boxes (Fig. 8C), so gas flows from the silo base up to the headspace. Blower suction pulls gas from all silo headspaces back to the *CLF* blower inlet (white pipe, Fig. 8A).

Fig. 8. CLF blower in silo annex (A), pressure manifold (B), lateral pipe to side silos (C), lateral pipe to center silos (D).

Closed loop fumigation plumbing materials

Schedule 40 UV resistant PVC pipe is the typical piping material used for *CLF* plumbing. Black flexible corrugated drainage tubing is practical and economical as it comes in long sections and follows the contour of storage bins and tanks, minimizing fittings. Gas velocity in *CLF* systems is quite low, so friction losses from flex tubing corrugations are negligible. Adapting between PVC pipes and flexible drainage hoses is relatively simple.

Closed loop fumigation blowers

Cast aluminum blowers work best for *CLF* systems. Cincinnati Fan Co. PB series 3450 RPM cast aluminum blowers (Fig. 9A) were used for *CLF* systems in all Oklahoma elevators. Figure 9B illustrates an aluminum blower circulating gas through six concrete silos. These blowers provide stable gas flows through *CLF* systems, are weather and spark resistant, and not subject to chemical reaction with phosphine gas. Closed loop fumigation blower performance data for the range of recirculation blowers are listed by Navarro and Noyes (2001). Degesch America and Chicago Blower Company market comparable cast aluminum blowers.

Fig. 9. Cast aluminum *CLF* blowers (A), *CLF* blower recirculating to 6 silos (B).

Venting fumigants with *CLF* fans

Once fumigation is complete, tanks or silos must be adequately vented before workers can re-enter storage units or grain can be shipped. For storages with aeration systems, unseal roof doors and vents, and operate the aeration fans for 3-6 h. Aeration fans should always be resealed immediately after the storage is vented to block insect reinfestation in the storage base.

When using *CLF* blowers to purge silos or tanks, disconnect blower suction piping then operate the blower to circulate ambient air to purge the storages. Open all roof vents or hatches so exhaust gas is immediately diluted with air moving across the tops of storage units. Storages without aeration fans can be purged much faster and to much lower gas levels using *CLF* blowers than by conventional gravity draft venting.

When *CLF* blowers are used for venting, 3-5 d of continuous blower operation should be used with open roof doors and vents. Storage bin, warehouse or silo base openings should remain sealed after purging fumigant gas to minimize insect reinfestation (Noyes et al., 1989).

Model *CLF* elevator

The *CLF* Elevator (Fig. 10) installed *CLF* in all three types of storage. They recirculated gas through steel tanks, concrete silos, and their flat storage warehouse using a 3.7 kW PB-14A centralized blower, delivering about 2900 m^3/h to their 36,000-t steel bin storage at 0.08 $m^3h^{-1}t^{-1}$, to their 23,000-t flat storage at 0.13 $m^3h^{-1}t^{-1}$, and to all 20 of their concrete silos (17,000-t) at 0.17 $m^3h^{-1}t^{-1}$. This *CLF* Elevator can fumigate all three types of storages in sequence by starting fumigation of each storage type 1-2 d apart. After each storage system has reached peak uniform concentration (in 1.5-2 d), the *CLF* blower can be switched to alternate manifolds between storages to maintain desired headspace gas concentrations in each storage (Noyes et al., 1998).

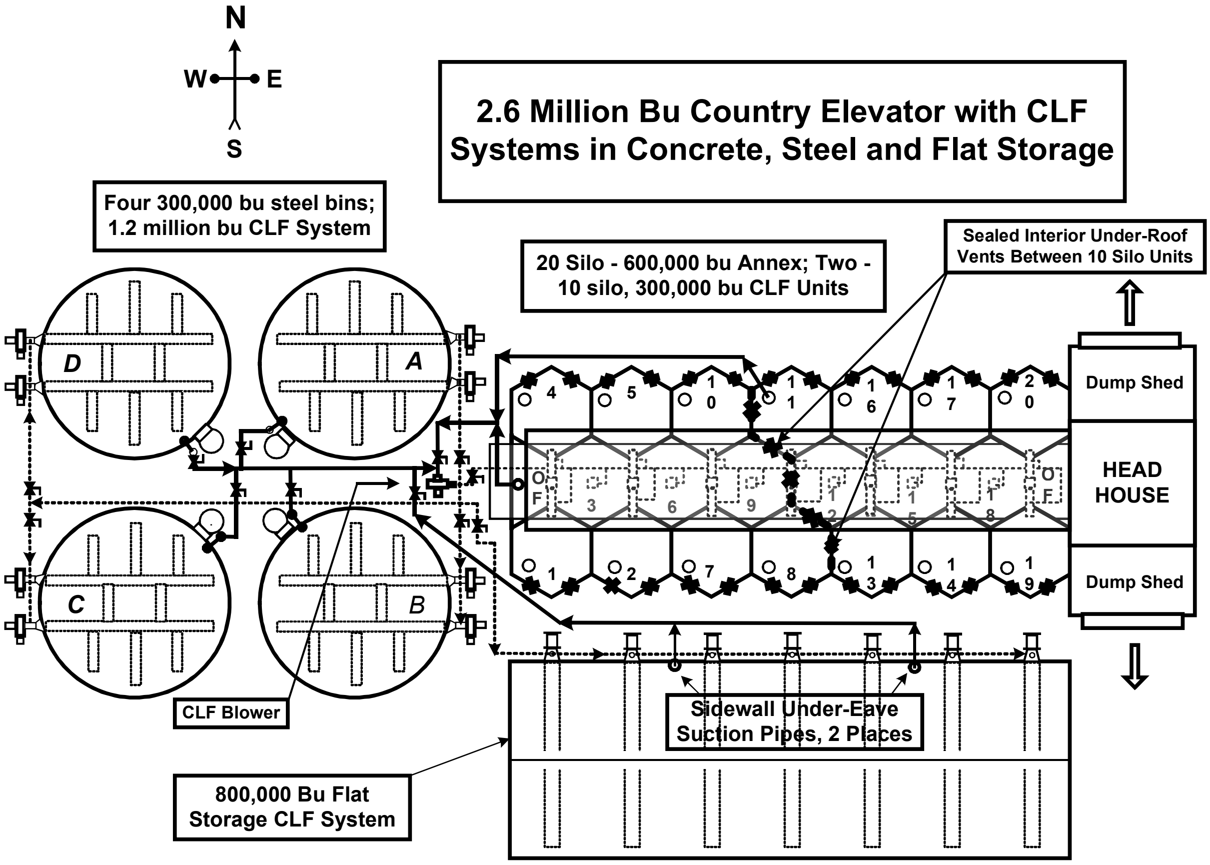

Fig. 10. Oklahoma elevator using central *CLF* blower for 4 steel bins, 20 concrete silos, and 1 flat Storage.

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