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Storage Hints.
Carbon dioxide

Carbon dioxide - a residue-free treatment option for organic stored commodities

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Carbon dioxide is one of the few treatments available for insect control in dry commodities that are destined for organic and bio-dynamic markets. Carbon dioxide (CO_2) treatment involves displacement of air in a storage environment to a concentration of carbon dioxide that is toxic to insects.

The major requirements to achieve an effective carbon dioxide treatment are:
- Commodity is stored in a sealed or sealable silo, bulk bin or other container.
- Gas-tightness of the silo or container is checked using a standard pressure test.
- Supply of carbon dioxide gas during application is sufficient and continuous.
- Carbon dioxide concentration is accurately measured during and following application.

Carbon dioxide is generally well suited for treatment of all dry commodities that enter storage in good condition. To be completely effective against all insect species and developmental stages, carbon dioxide must be retained at a minimum concentration of 35 per cent (%) for 15 days.

Carbon dioxide is not likely to be completely effective in the following situations and therefore an alternative treatment should be considered:
- Where the sealed enclosure repeatedly fails a pressure test.
- When fumigation treatment needs to be completed in less than 15 days.
- When Trogoderma species are known to be infesting the commodity.

Supply of carbon dioxide

Carbon dioxide is a non-flammable, colourless, odourless gas, about 1.5 times as heavy as air. Carbon dioxide can be added from an external source to a sealed enclosure using either gas produced from a liquid supplied in pressurised cylinders or from solid "dry ice".

Food grade carbon dioxide is supplied as a liquid in pressurised cylinders containing between 20 and 32 kilograms. Liquid CO_2 changes to a gas when released from the cylinder. The rate of release of gas from the cylinder is controlled by a regulator designed specifically for carbon dioxide. One kilogram of liquid CO_2 produces 0.5 cubic metres of gas. High pressure tubing is used to pass the gas from the regulator to the entry port located at the base of the storage silo or enclosure.

Solid "dry ice" is also a useful source of gaseous CO_2. At sub-zero temperatures, carbon dioxide changes directly from a solid to a gas. Dry ice is supplied as blocks, crushed ice or pellets. Crushed ice or pellets rapidly change to a gas and are best for initial gas addition. Blocks are useful to make up gas loss during treatment due to their slower release. Dry ice is best suited for use in gastight containers or low volume sheeted stacks. Place the dry ice on the commodity surface prior to sealing or at the base of the container or stack.

Footnote: The warehouse beetle, *Trogoderma variabile*, is the only exotic *Trogoderma* species known to be established in Australia.

Carbon dioxide treatment

Carbon dioxide treatment is not difficult but is more demanding than conventional fumigation using phosphine. The most important requirement for an effective carbon dioxide treatment is a well-sealed silo or enclosure, which ensures that minimal gas leaks out.

The complete process consists of four stages:

- Sealing the storage silo or enclosure.
- Confirming the storage silo or enclosure is sealed.
- Adding the carbon dioxide.
- Waiting for the carbon dioxide to work.

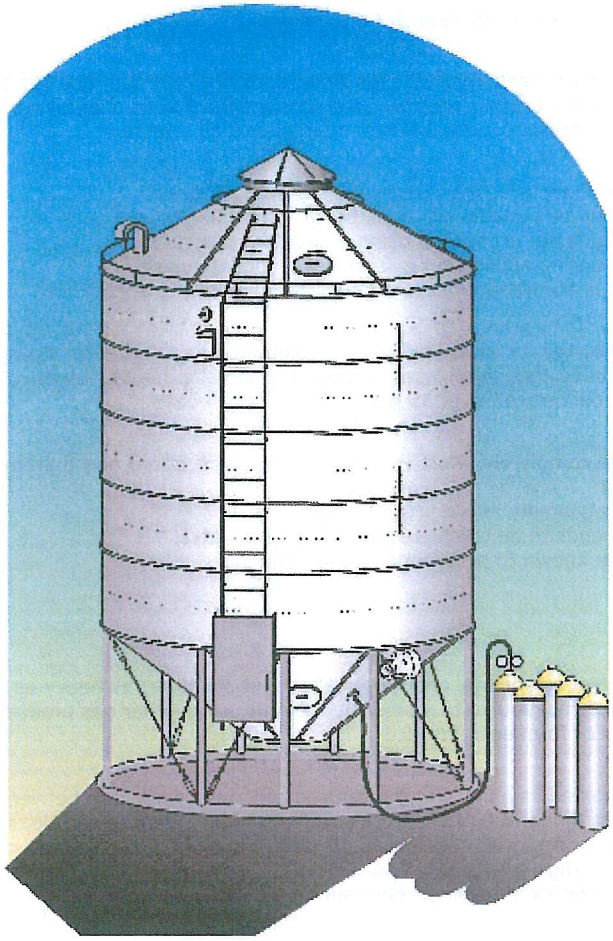

Diagram 1. Typical sealed farm silo, showing pressure relief valve and top gas sampling point

The following equipment is essential to carry out a successful treatment of a farm silo:

- A sealed silo or a silo able to be sealed to a high standard of gas-tightness. Gas inlets need to be fitted at top and bottom to deliver the gas and measure gas concentration (see Figure 1). A point, preferably at the top of the silo, is required to sample gas concentration in the headspace.
- An oil-trap pressure relief valve (see Figure 2). Apart from the initial pressure test, a pressure and vacuum relief valve balances gas pressure during environmental heating and cooling of gases in the storage silo. Light hydraulic or paraffin oil should only be used in the relief valve. Do not use vegetable oil.

Diagram 2. Oil-trap pressure relief valve

- If the silo is not fitted with an oil-trap pressure relief valve, a U-tube manometer is needed (see Figure 3) to check the standard of gas-tightness.
- Silicone sealant or butyl mastic and an application gun to seal hatch, chute and inspection port closures. Silicone sealants are preferred because they set relatively hard while retaining elastic properties. Butyl mastic is more difficult to apply and retains a soft finish which can be accidentally removed through abrasion.
- Self-adhesive plastic tapes to seal around duct and chute access points. 18-millimetre (mm) electrical and 50 mm duct tape are the most useful. Woven tapes, fibreglass bandages and thick acrylic paints may be required to repair and seal large gaps.
- A source of high-pressure compressed air for pressure testing the storage silo.
- At least one 30-kilogram (size G) cylinder of food-grade carbon dioxide per 15 tonnes of storage capacity, plus one extra cylinder. For example, two cylinders for 15t, three for 30t and four cylinders for 45t. In partially-filled silos, one 30-kilogram cylinder of carbon dioxide will be required per 10 tonnes of storage capacity.
- A carbon dioxide pressure regulator with a fitting to connect to flexible plastic tubing rated by the manufacturer for use under high-pressure.
- Several lengths of plastic tubing to extend from the ground to the top of the silo and back. The diameter of the tubing needs to fit the gas inlets on the silo.
- An electronic instrument or gas detector tube kit to accurately measure carbon dioxide concentration.

1+30kg cyl per 15-tonne silo capacity

8.
For a 120tonne silo
9 cylinders
8×15 = 120 tonnes
+1

9

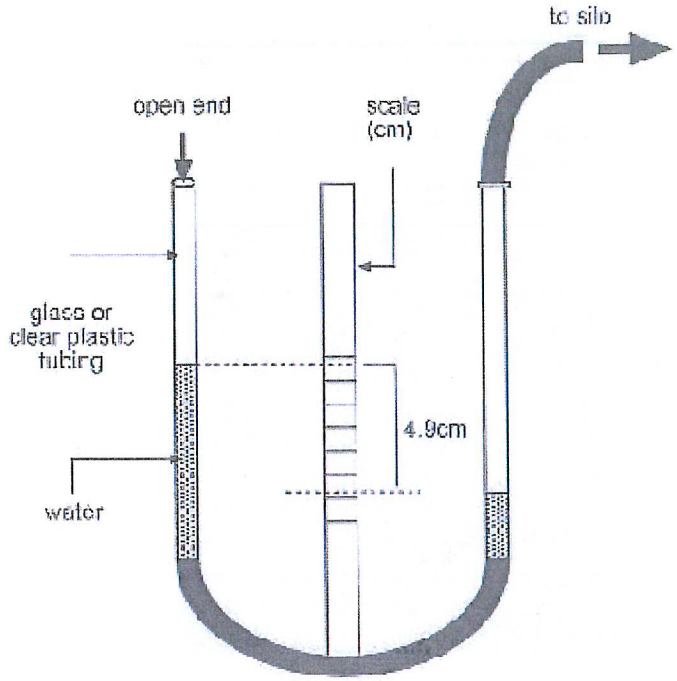

Diagram 3. Manometer, showing displacement of fluid due to pressure from silo

Sealing farm silos

For a carbon dioxide treatment to be successful it is essential the silo is properly sealed. A well-sealed silo ensures that minimal gas leaks out and air does not leak in. New sealed silos purchased from a reputable manufacturer should be sealed to an adequate standard of gas-tightness at the time of purchase. Regular maintenance to seals of hatches, chutes and sampling points will maintain the required level of gas-tightness, and provide a barrier to insect invasion into the grain.

Storage silos not manufactured as sealed have to be sealed. To seal a silo to a high level of gas-tightness, it is necessary to ensure that the fabric, hatches and chutes are well-sealed or sealable. It can be expensive to adequately seal an existing silo made of steel sheeting bolted or riveted together, with open eaves at the junction of the roof and sides, and purchasing a new sealed bin should be considered. Silos that have been retro-sealed are also more likely to fail than factory-sealed units. Common failure points on a retro-sealed silo are roof panel joints, roof/wall junctions, filling hatches and grain outlets.

Sealed silos must be fitted with relief valves to protect the structure from damage due to excessive positive or negative pressure which can build up in response to changes in environmental conditions during treatment. The better sealed a silo is, the more prone it will be to such problems. The most likely source of pressure related damage in a sealed silo is caused by implosion due to low pressure levels within the storage.

Pressure testing a farm silo

✓ Simple test
water manometer

Time take from 1" apart to ½" apart.

The level of sealing is checked by carrying out a pressure test. In a silo, a pressure test consists of blowing air into the enclosure using an air compressor, hand-held blower or vacuum cleaner until a small positive pressure is created, then turning off the airflow and recording how long it takes for the pressure to halve. A full, well-sealed farm silo is considered sufficiently sealed if the time exceeds three minutes. In an empty silo, a five minute halving-time is recommended. As the pressure halving-time shortens below these time limits, the likelihood of failure increases greatly.

Should be 3 mins for good seal.

To seal and assess the level of sealing of a farm silo, follow these steps:

- Inspect and test the storage for obvious leaks.
- Inspect all rubber seals and replace any that are damaged.
- Close and seal all hatches, doors and chutes.
- Check oil in pressure relief valves if fitted.
- Repair any leaks with silicone sealants or mastic. Use woven tapes, Poly Vinyl Chloride (PVC) tapes, fibreglass bandages and thick acrylic paints to seal repairs to large gaps.

Carry out a pressure test when all visible or detectable leaks are sealed. Pressure testing is best conducted on metal farm silos in the cool of the morning when there is minimal wind and ambient temperature is relatively stable.

When pressure testing follow these steps:
- Connect the airline and slowly open the valve to add air, which increases the pressure in the silo.
- When the pressure indicator shows about five centimetres (two inches) of pressure (as shown by the displacement in cm or inches) of oil in the pressure relief valve or U-tube manometer, turn off the air.
- Time the pressure fall.

If the test fails, re-examine any potential leak points such as the wall-to-floor, roof-to-wall, hatches, chutes and lap joints, and repair using a suitable sealant. Add air to increase the pressure in the silo, and while the silo is still under pressure spray or paint soapy water on all the joints and silo openings. Bubbles will appear where there are leaks. Large gaps and holes (greater than 1 cm) may not be detected using this method. If visual inspection or the soap bubble test fails to detect large holes, then smoke generated from a flare may be required.

OH & S warning
It is easy to slip on wet metal surfaces, so care should be taken when using detergent solution to check for leaks at heights and on the silo roof. Wear a safety harness and do not perform the work alone.

Dosage rate and exposure time

A carbon dioxide concentration of 35% or higher, maintained at or above 20 degrees Celsius (°C) for 15 days or more, can kill all stages of all insect species (except *Trogoderma* species) that are pests of stored commodities. At temperatures below 20°C, carbon dioxide is less effective and a longer exposure time may be required to obtain complete insect control. Discharge of gaseous CO_2 from pressurised cylinders is also slower at low temperatures, and its use is not recommended when temperatures fall below 15°C.

An initial concentration of 80% or greater is required in an adequately sealed silo to retain an atmosphere of 35% CO_2 following 15 days treatment. The recommended exposure time is based on an initial high concentration, degrading down to 35% CO_2 after 15 days.

If the pressure halving-time is less than three minutes for a full silo, carbon dioxide may need to be added daily to stop the concentration falling below 35%. Adding carbon dioxide every day is complicated, consuming and expensive since the concentration needs to be measured regularly using a suitable electronic instrument or gas tube detector kit and large quantities of gas are used.

If the silo failed the pressure test by a considerable margin, the level of sealing is poor and continual addition of carbon dioxide will not guarantee the required concentration is maintained.

Removing excess carbon dioxide from a farm silo following treatment should be possible through natural ventilation. Aeration fans, if fitted, can be used to vent the gas more rapidly.

Adding carbon dioxide

Carbon dioxide is heavier than air and during application of gas from the bottom of a silo, air is gradually forced up through an open hatch or vents at the top. The amount of gas being purged into the bin will generate substantial pressure and small vents and/or pressure relief value fitted may not be sufficient to vent the air being purged from the bin. The top access hatch or vent should therefore be opened during gas application. The vent is then closed and sealed when a target concentration of 80 to 90% CO_2 is reached.

After the pressure test has been performed successfully, carry out the following steps to add carbon dioxide:
- Disconnect the U-tube manometer (where used).
- Fit the CO_2 regulator to the cylinder.
- Connect the carbon dioxide cylinder to the bottom of the silo using suitable high-pressure hosing from the regulator to the inlet port. It is important to keep the length of hosing between the regulator and inlet port to a minimum; a maximum 1 m hosing length is recommended; 2 m will slow the rate of delivery due to expansion of carbon dioxide as it moves along the hosing.
- Ensure there is sufficient opening at the top of the silo to allow the air displaced by the carbon dioxide to escape. One kilogram of liquid CO_2 will produce approximately 0.5 cubic metres of gas.

- Turn on the carbon dioxide cylinder valve and then open the pressure regulator. The flow of carbon dioxide should result in the inlet tube becoming frosty over a number of minutes (Diagram 4).
- Add carbon dioxide until the concentration at the top of the silo reaches 80-90% or until the cylinder freezes and the gas flow is reduced.
- If the cylinder freezes disconnect it and connect another cylinder. The frozen cylinder will slowly thaw and can be used later if needed.
- When the concentration of carbon dioxide at the top of the silo reaches 80 to 90% or the full contents of the cylinders are used, stop adding gas. Turn off the tap on (i) the cylinder, then (ii) the regulator before closing the top hatch of the silo.
- Close and seal the top of the silo.

Diagram 4. Frosting of regulator and inlet tubing during application

A concentration of 80% carbon dioxide approximates two kilograms of gas applied per tonne of grain in a full silo. In a partially-filled silo, three kilograms per tonne of gas will be required. These target concentrations can be used to estimate the amount of cylindered gas required for a complete fumigation. It is worthwhile having at least one additional cylinder available for use during application.

Each cylinder could take about three hours to dispense. If the cylinder freezes, set it aside and re-use it when thawed. At 25°C, it should be possible to dispense about three-quarters of a cylinder before it freezes and solidifies. Liquid carbon dioxide may also freeze in the delivery line during application and time will be required for it to thaw before gas addition can continue.

Installation of a shedder plate immediately adjacent to the gas discharge port into the silo is recommended to minimise problems with carbon dioxide solidifying around the port and reducing gas flow. A shedder plate can be formed from a finely perforated, convex-shaped metal panel or moulding.

CO2 application hint

A manifold system using high pressure tubing to connect two to four cylinders can be used to decrease the time required to apply the gas. A regulator must be fitted to the manifold system. A sufficient number of spare cylinders need to be available to maintain a high deliver rate using a manifold system.

Important points to remember

- Cylinders of carbon dioxide are under considerable pressure and should be stored, handled, and used with care.
- Stand cylinders in full sun to heat up the gas during delivery. This increases the rate of gas flow and minimises the problem of freezing during application.
- Cylinders should not be inverted at any time during application.
- Avoid possible dilution of the gas during application. The addition of carbon dioxide into the enclosure should be a continuous process. Careful planning of the treatment can ensure a continuous supply of gas is delivered.
- All gas delivery lines used must comply with the high-pressure requirements specified by the manufacturer or agent.
- All cylinders must be fitted with a regulator specifically for use with carbon dioxide.

Measurement of carbon dioxide

The concentration of carbon dioxide forming in the head-space during gas addition is monitored using gas detector tubes or a suitable electronic device. Completely seal the top hatch and vents when the target concentration is reached.

Carbon dioxide concentration in the headspace or top of the silo also needs to be monitored during treatment to ensure a minimum level of 35% is maintained for 15 days. Carbon dioxide is heavier than air and the gas tends to layer down to the lowest leakage point in a silo. Grain held in the upper part of the silo is therefore most vulnerable to low carbon dioxide levels, and is the portion monitored during treatment.

Gas detector pump and tubes are the cheaper option for measuring carbon dioxide concentration, but have an associated long-term cost of purchasing multiple dispensable detector tubes. Gas detector tubes can measure carbon dioxide concentration in the range of 20 to 60%. Higher concentrations can be measured using a suitable vessel to dilute the concentration by 50%.

A suitable diluter vessel can be made from brass piping and tubing, and the volume of the sample chamber should be twice the volume delivered from a single pump action. It is important to purge the sampling line prior to measurement or when diluting a gas sample. Use five pumps to purge a sampling line of 2 -3 mm ID, or 15 -20 pumps to purge sampling line 5 - 8 mm ID.

A range of electronic devices are available for measuring carbon dioxide concentration. The Riken® interferometer, Miran® infrared spectrometer and Gow-Mac® binary gas analyser, are examples of electronic devices which are used in environmental and work-space monitoring where accurate measurement of low gas levels is required. The oxygen concentration can also be measured using a suitable electronic device and the build-up of carbon dioxide calculated using a conversion chart. The Fyrite® range of gas analysers includes models that measure both carbon dioxide and oxygen. Electronic devices which accurately measure carbon dioxide or oxygen are expensive, ranging upwards from $5,000.

Safe use of carbon dioxide

Never enter a farm silo or an enclosed space which contains a commodity that has been under carbon dioxide treatment. Carbon dioxide is highly toxic to humans at concentrations above 10% even when sufficient levels of oxygen are present, and concentrations as low as 2% can cause respiratory distress. If a person a suffering from symptoms of exposure to high carbon dioxide atmospheres is removed quickly into fresh air, recovery should occur without ill effects.

During treatment, ensure all access points into the farm silo are locked and warning notices posted advising of the treatment in progress. At the completion of the treatment, ensure the commodity is well ventilated to reduce carbon dioxide to low levels. Remove all warning notices only after the store has been well vented. .

Safety equipment required for carbon dioxide fumigation includes safety shoes, sturdy gloves and a hand-trolley designed to secure and move cylinders.

When not in use, cylinders should be stored in a cool, dry, well-ventilated area and protected from physical damage. Cylinders should be stored upright and firmly secured, during storage and when being used.

Never attempt to repair a leaking or damaged cylinder valve. If the cylinder is leaking, try to shut the valve off. Take care since carbon dioxide dispensed as a liquid is very cold and contact can cause "cold burns" or skin damage.

Gloves should be worn when handling cylinders or pressure tubing/hosing during application of carbon dioxide.

Treatment costs

Carbon dioxide treatments do not have a set cost as the price of some components such as compressed gases, cylinder rental, and transport can vary. Costs can range from $1.00 to $2.50 per treated tonne in a full storage. This cost is based on prices quoted in New South Wales in 2001.Compared with conventional phosphine fumigations ($0.15-$0.25 per treated tonne in a full storage) carbon dioxide treatments are more expensive.