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NITROGEN FUMIGATION

The organic way for safe long-term storage of grain, pulses, and vegetables

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Food is lost or wasted every year during storage, which harms the environment, the economy, farmers, and the people who need food the most.

FAO (the Food and Agriculture Organization of the UN) says that one out of every three food items in the world is either lost (14 percent after harvesting) or wasted (17 percent at retailers or consumers). This is equal to 8-10 percent of the greenhouse gases that warm up the planet.

To put it into further perspective, a one percent reduction in grain loss means saving approximately 27 million tonnes of grain, enough to feed about 70 million people for a year.

Nitrogen fumigation is a technology that can be applied to effectively terminate biological activity in grain storage silos. This secures a long and safe storage time and prevents losses.

Improved technologies have enabled a larger production of nitrogen at grain storage sites with capacities of up to 600 m3/hour in one 40' container or equivalent space. The cost of nitrogen generation is reduced compared to earlier technologies.

Below, is an overview of how nitrogen fumigation can be implemented using the CROP-PROTECTOR Nitrogen Generator. This technology has already been implemented in more than 100 silos holding from 2 - 9,000 tonnes of grain.

Grain losses during storage

The causes for grain losses during storage are many and includes pest infestation (insects, birds, and rodents) and microbial infection (fungus, bacteria, mites, etc.). Other factors are changes in moisture content, poor handling, poor sanitation, and incorrect grain aeration. These losses occur throughout the post-harvest period, which spans from harvest to milling. Unlike crop losses during growth, which can be compensated by further plant growth, post-harvest losses cannot be recovered.

Many losses are due to technical inefficiencies and grain storage procedures that are not adequate relative to the environment/climate of the storage silos. Since crops are harvested in specific seasons and stored until consumption, measures must be taken to preserve the stored grain. Three technologies in particular can be used to minimise losses in a sustainable way and without the use of pesticides; they are:

- Automatic aeration control of the grain silos.
- Use of chilling machines to cool the grain down.
- Application of a modified atmosphere to store the grain, such as nitrogen.

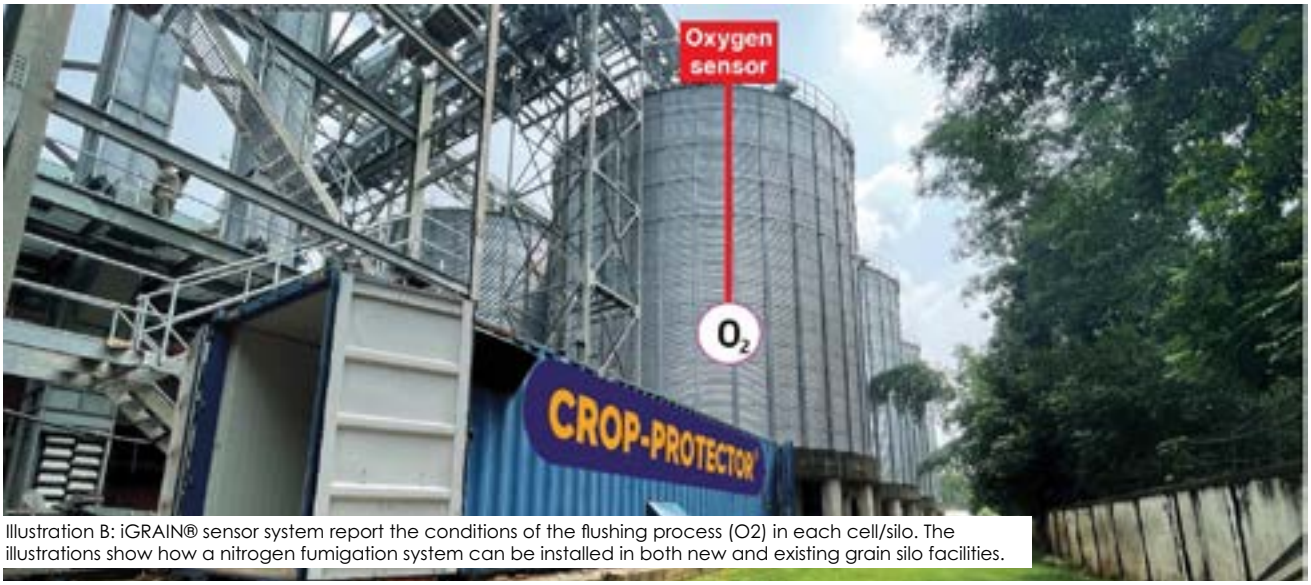


Illustration B: iGRAIN® sensor system report the conditions of the flushing process (O2) in each cell/silo. The illustrations show how a nitrogen fumigation system can be installed in both new and existing grain silo facilities.

These technologies have different advantages under different circumstances. Table 1 below compares three technologies often used to preserve stored grain.

The demand for nitrogen fumigation is increasing for several reasons. First it is a gentle 'natural–green' and environmentally friendly type of fumigation and can be used to preserve all types of grain including organic products. It also solves two major challenges for the safe storage of grain because it works without the use of pesticides, and it copes with the increasing problem of resistance against the most used pesticide phosphine (PH3).

What is nitrogen, and what is it used for?

Nitrogen (N2) forms about 78 percent of the Earth's atmosphere, it is odourless, tasteless, and colourless. Nitrogen is widely used in the food and beverage industry to create a Modified Atmosphere and replace the air (Oxygen) to keep products fresh and safe for a longer time. Nitrogen is also used in many other industrial applications. In the below, the focus is on nitrogen fumigation as an alternative way to safely store grain in big silos.

What is nitrogen fumigation of stored grain?

Nitrogen fumigation works as follows:

The nitrogen is flushed into a silo. The nitrogen flows through the grain in the silo and modifies the ambient air (21 percent oxygen and 79 percent nitrogen) in the interstitial space between the grain kernels.

Gradually, the nitrogen concentration increases. The concentration of nitrogen should be as high as possible. The oxygen concentration should be reduced to maximum 2.5 percent, and preferably down to 1.0 percent. The lower the oxygen, the more efficient the 'killing' of insects and reduction of other biology like fungus etc.

Once the oxygen concentration has reached a low level, it must be maintained for a certain 'reaction time'. This time is dependent on many factors, especially the grain temperature. Higher temperature is better because the biology requires more oxygen when the metabolism is increased at higher temperatures.

How is nitrogen produced?

For large scale application, nitrogen must be produced on site. The most economical way to produce it, is via a process called pressure swing adsorption (PSA). Basically, the process has the following steps: first compressed air is generated, then the air is dried in a freeze drier, and then nitrogen (78 percent) and oxygen (21 percent) are separated in an adsorption process. In principle, this is a simple process, but reaching a high throughput with a high nitrogen purity (above 99 percent) requires sophisticated technology.

Nitrogen production has also changed considerably over the years. Pressure-Swing-Adsorption systems (PSA) have improved in energy efficiency. Cases with 10.000m3 silos has been purged to below 1.0 percent O_2 in a few days, reaching a lethal low concentration of oxygen to terminate unwanted biology. The time it takes to flush a silo and reach a low Oxygen concentration depends on how well the silo is sealed.

Example - The CROP-PROTECTOR® Nitrogen Generator

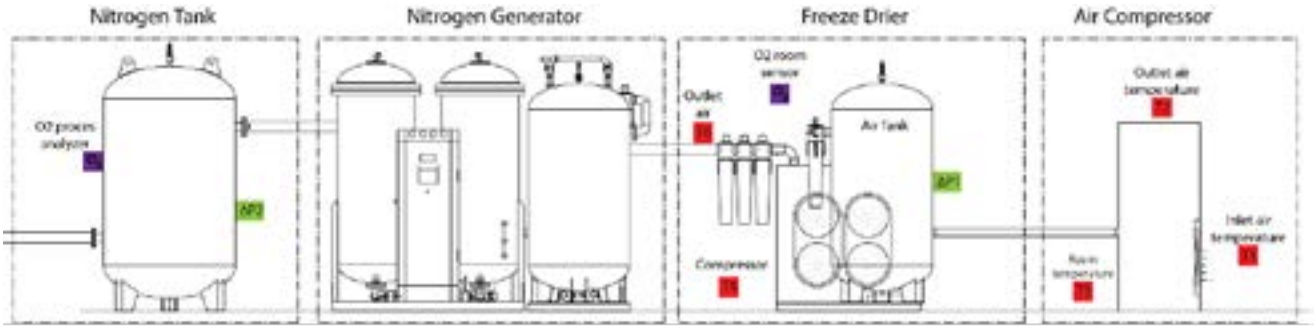
The CROP-PROTECTOR Nitrogen Generator is a new generation Pressure-Swing-Adsorption systems (PSA) with high energy efficiency and efficient generation of Nitrogen. The generator allows nitrogen purities of 98.0 percent - 99.95 percent. Capacities range from 50 - 600 Nm3/h.

The system is integrating a series of components to separate the Nitrogen from air. These are: an intake filter unit, screw compressor, purification system, air freeze dryer, molecular sieve with adsorption towers, and nitrogen buffer tank where the nitrogen is stored. From there a distribution system of valves and

Table 1: Comparison of three technologies often used to preserve stored grain

Technology	Applicable in which climates	Main advantages	Main disadvantages	Effect on insects	Effect on fungi and bacteria	Price per tonne (incl. Investment depreciation*)
Nitrogen (MA)	All	Terminates a wide variety of biology		Complete termination possible	Significant reduction	USD 0.25/tonne
Cooling / chilling	Mostly in hot climates	Puts a wide variety of biology to sleep	Repeated treatment needed as grain warms up	Sleep	If grain is wetted fungus will start to grow if only shortly	USD 0.35/tonne (per treatment)
Automatic aeration control	All	In most climates it is inexpensive if started immediately after storage	Only very few suppliers. Not always adequate in hot climates	Sleep	Sleep	USD 0.5/tonne

Illustration B: iGRAIN® sensor system report the conditions of the flushing process (O2) in each cell/silo. The illustrations show how a nitrogen fumigation system can be installed in both new and existing grain silo facilities.



hoses secure the nitrogen distribution to the silos/storage tanks. The system includes a Siemens HMI with an easy-to-use menu driven automatic control system.

The CROP-PROTECTOR Nitrogen Generator is used together with an iGRAIN® sensor system, which monitors the flushing process and the condition of the stored grain. All the measurement data from the iGRAIN sensor system and the oxygen/nitrogen concentrations are available to the operator via the iGRAIN Dashboard Manager and in the iGRAIN Smart App. This makes it easy to control the fumigation process.

The CROP-PROTECTOR® is permanently installed either in a 20' or 40' HQ container or delivered on a skid-frame system for local installation. Normally, the generator is placed near the storage silos for easy application. The nitrogen is distributed from the buffer tank by the generator via connection hoses and a valve/manifold system to the relevant silos.

Which commodities and applications are suitable for nitrogen fumigation?

Table 2 gives a small overview of the many applications where nitrogen is already applied.

Nitrogen has been used for preservation of high value commodities for many years. New technology now makes it feasible to store larger amounts of grain with nitrogen.

Table 2: Overview of the many applications where nitrogen is already applied

Grain commodities	Pulses and oil seed	High-value crops	Other applications
Wheat	Beans	Nuts	Fruit
Barley	Lentils	Coffee beans	Vegetables
Maize	Rapeseed	Cocoa	Pasta
Rice	Sunflower	Pistachio	Edible oil silos
Sorgum	Soybean	Almonds	Spices

Scientific validation of nitrogen fumigation efficiency

Researchers have studied the use of pure nitrogen and other modified atmospheres to control infestation of stored crops. The application for pest control has been studied for more than 50 years. Research has been carried out in different industrial silo structures targeting populations of many species such as the rice weevil (*Sitophilus O.*), the saw-toothed grain beetle (*Oryzaephilus S.*), the red flour beetle (Tribolium C.), and many more. Most trials resulted in complete or partially complete mortality of insect-based pests.

The findings can be summarized that to be effective for control of all stages of grain insects an atmosphere should reach an oxygen concentration of 1 – 2 percent and be applied for a minimum of 5 - 14 days. The research has shown that several parameters influence the efficiency of nitrogen fumigation; these parameters include temperature, relative humidity, and exposure time. It has been shown that the higher the temperature the more efficient the treatment is due to the increased metabolism and the associated oxygen demand; and further that the increase of temperature remarkably shortened the treatment time to 2–5 days.

Several studies have confirmed that nitrogen has no effect on the basic qualitative parameters of the treated grain, while at the same time, the nitrogen enriched atmosphere caused a considerable reduction of the microbiological load of these commodities, such as yeast and moulds. Further scientific research has confirmed that Nitrogen also preserves the stored commodity in fresh condition.

Conclusion and advantages of nitrogen fumigation

Nitrogen Fumigation has been used for more than 50 years. It has been widely used in some high value commodity infestation control applications but rarely in big silos for common grain infestation control. However, due to improved technology and lower cost the application of Nitrogen is now increasingly used in stored grain applications to control infestation as an alternative to conventional methods such as phosphine fumigation, heat treatment, cooling, and aeration control.

The features and possible advantages could be listed as:

- More cost-efficient compared to alternatives.
- It is a green technology and suitable for organic products.
- The nitrogen atmosphere maintains the natural quality of the grain, including its colour, texture and odour while preserving freshness.
- Suitable for all types of crops, with only one universal technology.
- Secure extended long-term storage, some reports many years.
- Oil seed is protected against oxidation.
- It is non-toxic and safe for the environment unlike pesticides.

Any applications should always be evaluated under the specific conditions to secure the best and most economical solution.