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Application and development of controlled atmosphere with nitrogen in Chinese grain storage

YANG JIAN, FU PENGCHENG, LI HAOJIE, YAN XIAOPING, LI YUE*, DING JIANWU, SHENG QIANG

Sinograin Chengdu Grain Storage Research Institute, Chengdu, P. R. China

ABSTRACT

The technology of controlled atmosphere (CA) using Nitrogen (N_2) to change the composition of the atmosphere around grain stacked in an air-tight warehouse creates an environment adverse to the growth and reproduction of insect pests and offers a significant alternative to chemical control of insect pests. Five years of research shows that: (i) N_2 concentration higher than 95% is effective to inhibit the development of pest populations; (ii) N_2 concentrations higher than 98% is an effective for the control of adults, larvae, pupae and eggs; (iii) the quality (fatty acid value, taste score, color, odor) of paddy and corn after 18 months storage and within one year after storage, had better quality than conventional storage. Using N_2-CA at concentrations greater than 90%, the storage period can be prolonged to an additional 12-24 months. Small-scale, operational granary tests, showed: (i) the prevention effect of insect pests is significant; (ii) aerobic microorganisms are inhibited; (iii) the rate of grain quality change is slowed; (iv) heating of corn in the store is prevented.

At the beginning of 2007, China began to promote N_2 controlled atmosphere (CA) technology on a large=scale. By the end of 2015, over 15 million tonnes of stored grain in more than 150 depots of 21 provinces has completed the construction of N_2-CA projects. This has helped China reach an advanced level in grain storage. The operational costs of the technology due to research and innovation are reducing and the gas injection process is increasingly effective so as a result, a complete N_2-CA technology system has been established.

Key words: Application, Controlled atmosphere, Development, Grain storage, N_2

China is a major grain producing and consuming country and central grain reserves are essential for economic growth and social stability. To guarantee the quality grain supply, China Grain Reserves Corporation (Sinograin) has promoted research, development and application of environmentally friendly grain storage, transport technologies and implementing low temperature (15°C) and quasi-low temperature (20°C) grain storage in the north-west, north and northeast regions of China and temperature control and controlled atmosphere (CA) grain storage in the southern region. However, creating and maintaining, low temperature grain storage is difficult and expensive to achieve in the subtropics and tropics within China.

*Corresponding author e-mail: *liyl_112@163.com*

Since 2007, Sinograin has supported the research, development and practice of grain storage under controlled atmosphere with nitrogen (N_2-CA) to reduce operating costs and enhance application by improving warehouse air tightness. A large number of scientific tests have been carried out, verifying CA advantage by preventing and killing insect pests, inhibiting bacteria and delaying grain deterioration under the environmental conditions of southern China.

For a long time, Fumigants, such as phosphine (PH_3), methyl bromide, and contact chemicals such as malathion, and fenitrothion, have been the most common methods to prevent and control insect pests in stored grain in China. However, the use of chemicals does not meet the national food standards and some of them have been prohibited. Without effective

substitutes, phosphine remains in infrequent- use but a national investigation into PH_3 resistance of stored grain insect pests carried out by Sinograin Chengdu Grain Storage Research Institute (Chengdu Institute) over several years, showed the number of species of stored grain insect pest with high resistance to PH_3 has risen gradually. There has been an increase in the proportion of high-resistance ($R/S \geq 40$) species with lesser grain borers having a PH_3 resistance factor of over 900 in some regions of China.

By changing the composition of atmosphere around grain stacked in air-tight warehouses, controlled atmosphere grain storage technology creates an environment to restrict the growth and reproduction of insect pests and offers a significant alternative to chemical prevention and control of insect pests.

MATERIALS AND METHODS

N_2-CA grain storage techniques and application

Pressure swing adsorption (PSA) N_2 generators are used with an automatic control system which regulates the flow of N_2 according to the concentration in the warehouse. N_2 is pumped into a warehouse in which a gas tight enclosure had been formed by sealing the five sides of grain bulk or surface with plastic film made of polyvinyl chloride film or lamination film to improve airtightness. The flow rate of the PSA ranges from 156 m^3h^{-1} to 310 m^3h^{-1} according to the power of the generator.

Automatic control system can identify turning on or off of N_2 generator, opening or close the valve by automatically measuring the N_2 concentration. The concentration of nitrogen was calculated by deducting the oxygen concentration from 100%. The nitrogen monitor equipment was made by Chengdu Chang-ai Electric Technology Co. Ltd. The whole process was controlled by computer.

Chengdu Institute and construction companies have developed a series of gas charging techniques for different types of warehouse. And choose the extraction and forced exhaust method as a satisfactory one.

(i) Dilution method

Upward gas charging – until gas bag is swollen – turn off N_2 generator – turn on circulation fan – exhaust air through vent – until gas bag is shrunk – turn on N_2 generator – repeat the above-mentioned procedures – until the target concentration is reached.

(ii) Substitution method operating procedures

Upward gas charging – until gas bag is swollen – open vent – intake and exhaust at the same time – until the gas bag's pressure is excessive – turn off N_2 generator – until partial gas bag is shrunk – repeat the above-mentioned procedures – until the target concentration is reached.

(iii) Extraction and forced exhaust method operating procedures

Upward gas charging – until gas bag is swollen – forced exhaust and extraction through several vents – N_2 generator is turned on during extraction – until gas bag is nearly shrunk – stop forced exhaust and extraction – repeat the above-mentioned procedures – until the target concentration is reached (N_2 generator is turned on from start to finish).

The Chengdu Institute worked with N_2 generator manufacturers in 2009, designing a PSA N_2 generator for grain storage with one button start up, high gas flow and low operating cost. Compared with the N_2 generator at the start of the project the energy consumption per unit was decreased by about 30%, improving competitiveness and since 2010 widely introduced to all of the CA warehouses in China.

The Chengdu Institute carried out a series of field tests on various gas charging techniques at the Sinograin's depots in Mianyang, Haikou, Qingdao, Anlu, Lujiang, Foshan, for establishing several gas application techniques for different conditions. Standards for the vent positions and vent sizes of different N_2 generators were specified depending on their individual applications to prevent gas bags causing accidents. As for the original groove tube, the installation and disassembly is inconvenient, not

Table 1 Lethal times of N_2 concentration ranges to different life stages of insect (Unit: Day)

Insects pests	Control of adults ($LT_{99.9}$)		Inhibition of eggs, pupae and larvae ($LT_{99.9}$)	
	98%~100% (N_2)	96%~98% (N_2)	98%~100% (N_2)	96%~98% (N_2)
*Sitophilus zeamai*s (Motschulsky)	5.57	6.55	18.95	14.22
Rhyzopertha dominica (F.)	10.94	68.40	19.04	37.97
*Tribolium castane*um (Herbst)	4.48	21.16	4.33	15.03
Oryzaephilus surinamensis (L.)	4.48	16.51	4.15	10.34

Fig. 1. The gas bag with airtight film-covered system.

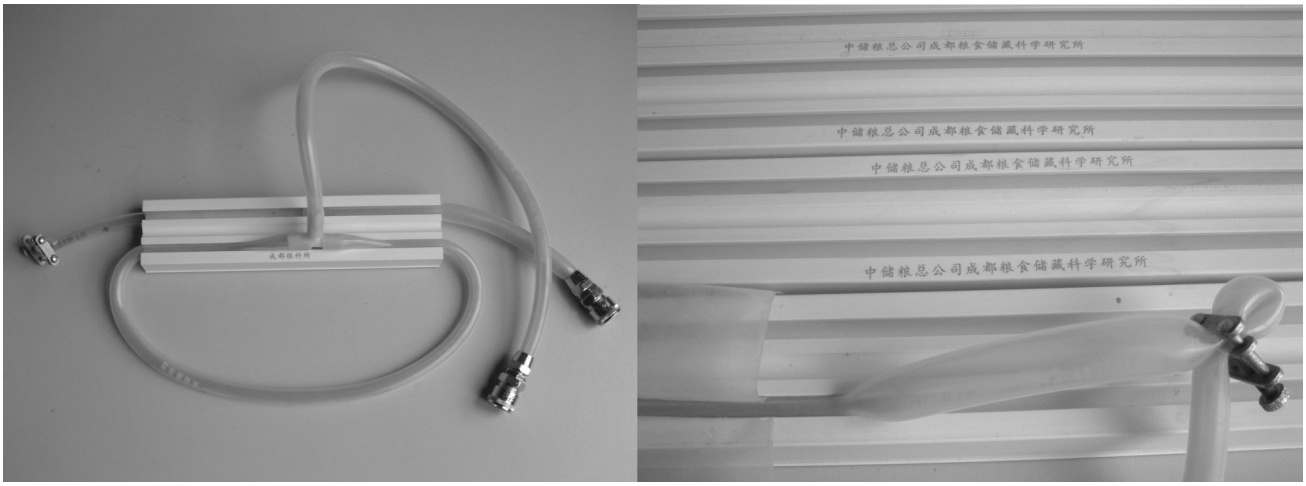

Fig. 2. PVC airtight double-groove tube with inflatable rubber hose.

Fig. 3. The grain bulk covered by air tight liner for maintaining N_2 atmosphere.

only increasing labor intensity, but also being liable to damage film, so the Chengdu Institute developed an inflatable seal stripe to improve the air tightness of warehouses and applied a patent (No. 2010105499978, Name: an Airtight System of Film-covered Grain Warehouse) on the PVC airtight double-groove tube with inflatable rubber hose. With the advantages of improving the air tightness of warehouse, simplifying operation, saving materials and reducing labor intensity, this invention has been applied to nearly 100 controlled atmosphere warehouses with remarkable effects. The air tightness of warehouse with grain is that decay time (min) -300Pa to -150 Pa is 5min in N_2-CA grain storage.

The Chengdu Institute developed a N_2-CA grain storage control and management system for real-time monitoring of the change in N_2 concentration in the grain mass, and the automatic control of gas charging, recirculation and gas supplement. This facilitated the improvement of N_2-CA grain storage in China, decreasing the operating costs

RESULTS AND DISCUSSION

According to some Australian researchers (Banks et al., 1980), the lethal effect of N_2 on insect pests

Table 2 Insecticidal effects of N_2-CA technology at some Sinograin's depots

Depot No.	Depot Type	Covered Film	Air Tightness	Grain Type	Ave. Grain Temp. (Min.-Max.)	N_2 Conc.	Ex-posure Time	Main Insect Pests	Insecticidal Effect
1	Flat Warehouse	Five Sides	-300pa 270s	Wheat	25 ºC	≥97%	25d	*Sitophilus zeamais*, *Rhyzopertha dominica,Cryptolestes ferrugineus, Liposcelis bostrychophilus*	100%
2	Flat Warehouse	None	500Pa 355s	Paddy	24ºC (Max. 33.0 ºC)	≥98%	30d	All Life Stages of *Sitophilus oryzae*, *Rhyzopertha dominica and Tribolium castaneum* Sensitive and Resistant to PH_3	100%
3	Flat Warehouse	None	-300Pa 150s	Paddy	20ºC (Max. 29.4 ºC)	≥95%	30d	All Life Stages of *Sitophilus oryzae*, *Rhyzopertha dominica and Tribolium castaneum* Sensitive and Resistant to PH3	*Sitophilus oryzae* (100%), *Rhyzopertha dominica* and *Tribolium castaneum* (60%)
4	Squat Silo	None	500Pa 323s	Corn	20ºC (Max. 30.0 ºC)	≥98%	15d	*Sitophilus zeamais*, *Rhyzopertha dominica, Cryptolestes ferrugineus, Tribolium castaneum,Liposcelis bostrychophilus*	Adults (100%) 79 *Rhyzopertha dominica* Eggs, Pupae and Larvae Found
							90d		Adults (100%) 2 *Rhyzopertha dominica* Eggs, Pupae and Larvae Found
							120d		100%
5	Flat Warehouse	Five Sides	-300Pa 300s	Paddy	20ºC	95~ 98%	45d	*Sitophilus zeamais*, *Rhyzopertha dominica,Cryptolestes ferrugineus,Tribolium ca*staneum, *Liposcelis bostrychophilus*	100%
6	Flat Warehouse	Surface cover	-300Pa 127s	Paddy	<20ºC (Max. 28.4 ºC)	≥ 95%	28d	*Sitophilus zeamais,Cryptolestes ferrugineus,*	100%
7	Flat Warehouse	Surface cover	-300Pa 113s	Paddy	20 ºC	≥96%	36d	10 Insect Pests/kg	100%
8	Flat Warehouse	Surface cover	-300Pa 107s	Wheat	20 ºC	≥97%	28d	*Sitophilus zeamais*, *Tribolium castaneum, Tribolium confusum*	100%
9	Flat Warehouse	Surface cover	-300Pa 286s	Paddy	19 ºC	≥98ºC	30d	*Sitophilus zeamais*, *Rhyzopertha dominica*, *Cryptolestes pusillus Oliver*	100%
10	Flat Warehouse	Surface cover	-300Pa 240s	Corn	18.8 ºC (Max. 24.3 ºC)	≥98ºC	8d	*Sitophilus zeamais*, *Plodia interpunctella*	100%
							18d	*Cryptolestes ferrugineus,*	100%
							60d	Tribolium castaneum,	100%
11	Flat Warehouse	Surface cover	-300Pa 125s	Paddy	18 ºC (Max. 28.3 ºC)	≥97%	40d	*Sitophilus zeamais*, *Rhyzopertha dominica,Cryptolestes pusillus* (Schonherr), *Tribolium castaneum*	100%

in stored grain is closely related to temperature. In grain at less than 12% moisture contentand 23°C with 98-100% N_2 concentration, it will take 28 days to kill all of the insect pests to reach the same insecticidal effect at 18°C it will take 105 days to achieve the same result.

The experimental data acquired by the Chengdu Institute shows that, insect control at a N_2 concentration of less than 96% is poor. An experiment on N_2-CA's effect on controlling *Sitophilus zeamais* (Motschulsky), *Rhyzopertha dominica* (Fabricius), *Tribolium castaneum* (Herbst) and *Oryzaephilus surinamensis* (L.) adults, eggs, pupae and larvae, was conducted in a simulated warehouse, with temperature controlled at 25±1°C and N_2 concentration was set at two ranges, 96-98% and 98-100%.

Lethal times of these two N_2 concentration ranges for different life stages of insect pests are shown in Table 1.

The results of field application practice in existing warehouses in recent years showed that the effect of N_2-CA on controlling insect pests is closely related to the N_2 concentration and temperature in grain mass as well as the exposure time (Sufen 2009). To completely kill all of the insect pests at a lower temperature requires a longer exposure time (Baily and Banks, 1980). Compared with traditional grain storage, N_2-CA technology can control insect pests in stored grain, reducing the problem of dependence on PH_3.

Insecticidal effects of N_2-CA technology at some Sinograin's depots are shown in Table. 2.

The recommended exposure times at different temperatures and N_2 concentrations required by N_2-CA grain storage for control main insect pests in stored grain are shown in Table. 3.

The insecticidal effect of N_2-CA Technology relies on air tightness of grain mass, type of insect pests, moisture and N_2 concentrations and temperature and exposure time.

Nitrogen (N_2) storage to delay grain deterioration

The results of field applications in existing warehouses showed a combination of temperature control and N_2-CA technologies can perform well in maintaining paddy quality. The increase in fatty acid is comparatively slower, the grain color and smell remains normal, and deterioration is not accelerated after outloading. Experimental data collected by Sinograin's Guilin Depot in flat warehouses at an average temperature of 21° to 22°C showed that after summer, the average increase in fatty acid value of grain stored in three experimental warehouses is 0.4mg KOH/100g, and that of two comparative warehouses is 2.4mg KOH/100g. After CA storage the average value from three experimental storages is 0.6mg KOH/100g. Tests undertaken at Sinograin's Huzhou Depot on wheat, taste, fatty acid value, colour and smell, moistureshow grain quality and deterioration is not accelerated after outloading. The average fatty acid value of grain stored in eight flat warehouses under N_2-CA in Sinograin's Sanming Depot increased by 0.8mg KOH/100g after summer.

Table 3. Exposure times at different temperatures and N_2 concentrations for controlling main insect pests

N_2 concentration	Recommended exposure times at different temperatures		
	17ºC	25ºC	30ºC
≥95%	-	-	60d
96%~98%	-	70d	21d
≥98%	105d	28d	14d

Construction and operating costs of N_2-CA

The cost of N_2- controlled atmosphere (CA) grain storage is mainly depreciation of fixed asset investment and operating expenses. The economic analysis of existing warehouses adopting N_2-CA technology showed the total annual cost of N_2-CA grain storage can be controlled at 5.3-5.7 Yuan per tonne ($USD 0.795 – 0.855), in which 1.4 Yuan per tonne is spent on warehouse insulation and air tightness reconstruction (depreciated over three years), 1 Yuan per tonne on facility investment (depreciated over 10 years), 0.4-0.8 Yuan per tonne on CA grain storage operation and 2.5 Yuan per tonne on temperature control. Consumer demand for insecticide free grain results in a higher price and some investigations showed that the price of grain stored under CA is 20 Yuan per tonne higher than grain from standard storage.

CONCLUSION

Research and small-scale field experiments on low oxygen (O_2) grain storage was carried out at the end of the 1960s. There are two methods to create a low oxygen environment, one is natural de-oxygenation in grain storage (Grain Depot, 1974), consuming oxygen through grain respiration,the other is N_2 charging grain storage (Grain Depot, 1973), by extracting air from an airtight grain warehouse and filling it with N_2.

The promotion of N_2-CA technology was launched by Sinograin in 2007. At the end of 2015, N_2-CA grain storage reconstruction with a total capacity of over 15 million tonne at over 150 central depots has

been completed.

It is planned to extend the use of N_2 CA for the storage of processed grains and edible oils.

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