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EVALUATION OF LARGE, MODERN WAREHOUSE STORAGES DESIGNED AND CONSTRUCTED FOR APPLICATION OF CARBON DIOXIDE

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ABSTRACT

Warehouses for controlled CO_2 storage with a total capacity of 45,000 tonnes were constructed at Mianyang, where field experiments were successfully carried out. This paper describes the construction techniques, CO_2 supply and distribution system, auto-monitoring system, security and safety facilities, sealing materials, gastightness test techniques and field experiments. The results showed that design and construction techniques were reasonable. The pressure decay half-life from 500 Pa to 250 Pa, reached 12 minutes and thus effectively ensured maintenance of the concentration of CO_2. Automatic supply and distribution of CO_2 as well as monitoring were carried out during the whole process. The field experiment proved that both phosphine susceptible and resistant strains of *Sitophilus zeamais*, *Rhyzopertha dominica* and *Tribolium castaneum* had been effectively controlled to achieve complete kill with an exposure for more than 14d to CO_2 at concentrations within the range of 35%~75%. After incubating the mixed samples under different culture-conditions for 42d, no live adults appeared. There were also no significant changes in the level of microorganisms in the grain stored under CO_2. After 10 months storage, under CO_2, grain quality of the newly harvested grain with safe moisture content and good quality, was compared with grain of similar qualities but under conventional storage. The grain quality under CO_2 was better than the conventional storage and remained stable after unsealing.

INTRODUCTION

With the continuous progress of technology and advances in the quality of life, people care more about the protection of the environment, and consequently the demand for "green food", which is of high quality and without chemical contamination, is increasing rapidly. The current grain storage technologies are developing towards an integrated way to reduce the use of chemical pesticides, including the use of low-temperature storage, controlled atmosphere (CA) techniques and biological control. The controlled CO_2 technique involves flushing CO_2 into well-sealed warehouses so as to change the storage atmosphere, to control pests, to inhibit mold activity, and delay grain aging.

The first modern warehouses with controlled CO_2 were constructed at Mianyang, China in 2000, for a total storage capacity of 45,000 tonnes and consist of several bins with a capacity of more than 5,000 tonnes for each. After the first-period construction, experiments were carried out to compare them with conventional storage.

CONSTRUCTION OF THE CA WAREHOUSES

Construction Techniques

Condition of the warehouses

Warehouses with controlled CO_2: There are 5 horizontal warehouses consisting of 2 bins each, with dimensions: 24m width_96m length_7.8m height. (6 m height of grain bulk). Total capacity is 45,000 tonnes, with 5,000 tonnes capacity of each bin.

Control Warehouse: consists of one horizontal bin with the same dimensions as the above, but in which conventional storage was carried out as control.

Sealing Material

Based on the requirements of controlled CO_2 warehouse, several materials were tested and compared, with regard to flexibility, texture, resistance to extreme temperature and deterioration, resistance to ultraviolet radiation, non-contaminant or non-toxic content, durability, easy of use, low air-permeability, good adhesive ability, and with reasonable price.

Locations and Methods for Sealing

- According to the original design, the following steps were carried out:
- the windows and venting pipes were equipped with air-tight and heat-preservation facilities as well as axial fans to the windows
- the interior walls of the warehouse were brushed with Coating A
- sealing of the walls, top, and floor of the warehouses, was made, with each bonding point into camber of 150 mm
- highly elastic materials were filled into the gaps of the chambers
- all the openings of the warehouses were sealed, including the inlet holes, outlet holes, vent openings, axial fan openings, the CO_2 supply openings were checked, as well as the bonding point of lines and other openings.

Air-tightness of the Warehouses under CO_2

The pressure decay half-life of the warehouses with CO_2 reached more than 12 minutes with a decline from 500Pa to 250Pa, while the control only lasted about 40 seconds for the same pressure decay. Tests indicated that CO_2 concentration could effectively be ensured by a one-time introduction of CO_2.

Assembly of Equipment for Warehouses with CO_2

The key point in the CO_2 storage technique was the assembly of various equipment. In the construction phase, a large-scale central CO_2 supply and distribution system was initially set up. At the same time automatic gas monitoring, safety and security systems for use with the CO_2 were developed and applied (Fig. 1).

CO_2 supply and distribution system

The CO_2 supply and distribution system is used to store the liquid CO_2 safely, vaporize and supply the CO_2 when necessary.

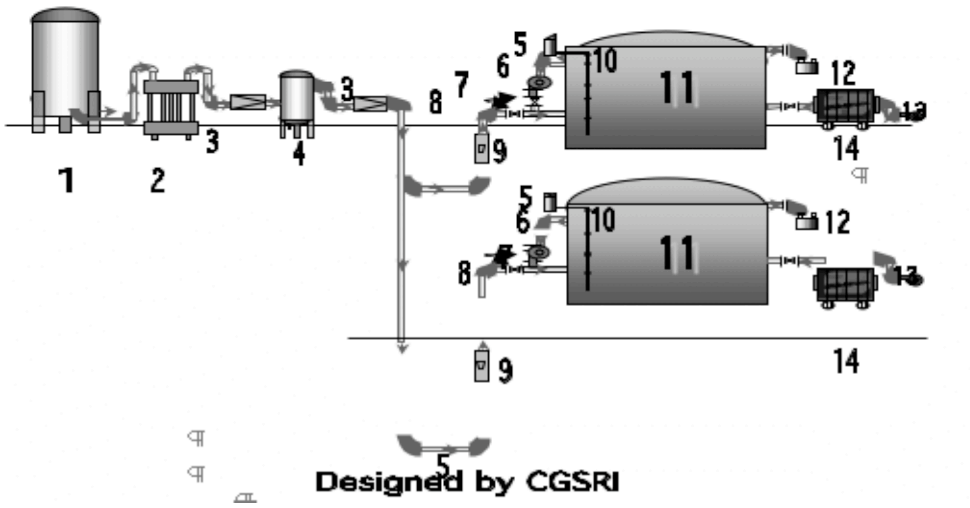

Figure 1. Technical flow chart of CO_2 storage of grain designed by Chengdu Grain Storage Research Institute (CGSRI).

1. CO_2 cylinder, 2. evaporator, 3. decompression facility, 4. gas balance cylinder, 5. CO_2 supply pipeline, 6. circulation pipeline, 7. circulation fan, 8. switch valve, 9. flow meter, 10. auto-monitor system for CO2 concentration, 11. warehouse storage with CO_2, 12. pressure balance facility, 13. fan, 14. intelligent control system

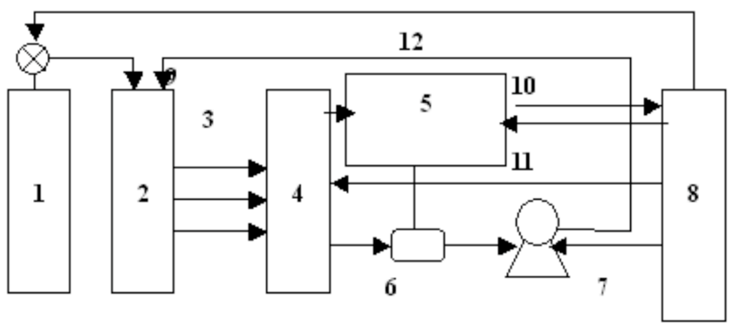

Figure 2 - The principle of automatic system for monitoring CO_2 concentration.

1. CO_2 supply source, 2. warehouse storage with CO_2, 3. sampling from multiple lines, 4. multicenter control device, 5. infrared CO_2 detect facility, 6. buffer, 7. pump, 8. inspection computer for telecontrol, 9.CO_2 supply control device, 10.data output, 11.on-off control 12 signal return

Auto-monitor system for CO_2 concentration

The system consists of a gas sampling pipe network, gas control pipeline, infrared CO_2 detector facility, data traffic device, CO_2 supply control device, inspection computer, inspection software, that are shown in Fig. 2.

The system can determine and report the CO_2 concentration of several points in the warehouse automatically, and can be run on MS Windows as well as being user friendly to operate and update. Due to its excellent performance, the CO_2 concentration could be reliably recorded on-line, thus also lead to utilizing the CO_2 resource reasonably effectively and economically. The system was based on the detection standard of China Measurement Technology Institute. The detection limit was 0-100%, basic error ≤1.0%, F·S,, repeatability ≤0.5%F·S, drift of zero and span<1.0% F·S/48h).

Safety and Security Facilities

To prevent pressure differences from occurring between inside the warehouse and the ambient, two sets of pressure balance facilities were assembled in each bin. The pressure could be detected up to a level of ±2,000 Pa with a precision of ±20 Pa. In addition four sets of oxygen-breathing devices were provided as a standard safety regulation during operation.

APPLICATION OF CO_2

After the first-period construction had been accomplished, field experiments were carried out for one year. During the first period of CO_2 storage, the CO_2 concentration ranged from 70% to 35% maintained for more than 14days, while during the second period, a continuous effective concentration of CO_2 was maintained.

Effect on Insects

Materials and Methods

Test Insects: Two weeks old, adult insects of strains of *Sitophilus zeamais*, *Rhyzopertha. dominica* and *Tribolium castaneum* resistant and susceptible to phosphine of were tested. The resistance factors were 196, 204 and 8 respectively. Each test contained 20 adults and mixed-stage insects (eggs, larvae, pupae) of each of the above test insects. A control test was prepared in the same way but was placed in the conventional storage. Each test was done in 10 replicates. After 1 month exposure, the mortality rate was recorded, and all the insects were sieved out and the grain samples were kept in an incubator at 25±1°C, 70±5% r.h.; and at 30±1°C, 70±5% r.h. to count the number of the next progeny. The emergence of the progeny was observed 56d after treatment.

Treatment of the test insects: The test groups numbered 1~6 were laid at the four corners of the warehouse at different heights. The test groups numbered 7~10 were laid at the vent openings and check doors.

Results

Tests in the wheat warehouse storage under CO_2. All test adults of the of two strains of the three insects species were totally controlled. No next progenies of the mixed-stage cultured insects emerged after 56 days treatment.

Tests in the paddy warehouse storage under CO_2*:* All test adults of the of two strains of the three insects species were totally controlled. No next progenies of the mixed-stage cultured insects emerged after 56 days treatment.

The insects that originally existed in the warehouse before treatment: It was found that the insect density of samples from No. 13 wheat warehouse underCO_2, was about 15 insects/kg wheat, consisting mainly of *S. zeamais* and *Sitotroga. cerealella*. After the treatment with controlled CO_2, no insects emerged over the next half year. The same situation was found in samples from No. 14 wheat warehouse under CO_2, which were infested with Psocidae (booklice) before treatment, while after treatment no live booklice were found in the warehouse.

Conclusions

The results clearly demonstrated that the treatment of 70% - 35% CO_2 for 14 days was very effective against each stage of the tested insects (susceptible and resistant), and no residual live insect populations remained in the grain.

These trials showed also that the application of controlled CO_2 was effective against psocids, which could be an alternative control method for this insect family.

Effect of CO_2 on Molds

Materials and Methods

Warehouses: Bins Nos. 12, 13, 14 and 15 were chosen as test for CO_2 storage, each bin contained 3,000 - 5,000 tonnes of grain;

Test Grain: Newly-harvested paddy and wheat from Sichuan and Hunan, with moisture content of 11.6% -12.3%;

Sampling: Grains were sampled every 3 or 4 months over a one year period for analysis of mycoflora in the grain. The preparation of samples was conducted by the Chinese standard method GB4789-1-94.

Results

Through the 370 days of CO_2 grain storage in the field trials, the results of grain fungal colonies can be seen in Table 1. Test results of bacterial counts were omitted from this table.

TABLE 1

Result of colonies of fungi recorded on grain stored under CO_2 and on grain stored under normal atmospheric conditions (unit: colony formation units (CFU) per gram grain).

Warehouse number and type	Grain storage category	Initial CFU	After 185 days CFU	After 370 days CFU
No.10 normal warehouse	Paddy	5.4×10^3		2.5×10^3
No.11 normal warehouse	Wheat	5.6×10^2	8.95×10^3	1.5×10^3
No.12 CA warehouse	Paddy	2.7×10^4		2.5×10^3
No.13 CA warehouse	Wheat	3.7×10^2	8.5×10^2	4.7×10^3
No.14 CA warehouse	Wheat	7.8×10^2	8.2×10^2	1.9×10^3
No.15 CA warehouse	Wheat	6.1×10^2		5.7×10^2

Discussion

Examination of data on the number of fungal colonies of the wheat and paddy stored under CO_2 revealed that a slight change occurred over the one year of storage period. But when we examine and analyze the bacterial population, the results did not differ between the initial counts and after one year of storage under CO_2. Because of limited access to sampling ports of the storage under CA, only small samples could be taken. But the field fungi which can reflect grain freshness degree hypnocyst and Fusarium avenaceum were reduced gradually. Though the test-out rate which is represented by the Aspergillus glaucus, Aspergillus flavus, Aspergillus candidus is high, it was stable on the whole. The tested fungal categories, at suitable moisture content and with the extension of storage time are capable of reducing the grain quality. However, by applying the CO_2 storage, development of fungi at the tested moistures was not apparent.

Effects of CO_2 treatment on grain quality

Materials and methods

Experimental: Warehouses No. 12 containing paddy, No. 13 and No. 14 containing wheat were chosen for CO_2 treatment and two untreated warehouses No. 10 containing paddy and # 11 containing wheat were selected as controls. In contrast to the CO_2 treated grain, the controls were fumigated using PH_3 by recirculation to control the insect pests. Samples were taken for testing grain quality before the trial, in October and in April and May of the following year.

Test for quality parameters: Test methods for long-grain non-glutinous rice and wheat quality were according to the international standards. For moisture content, fatty acid, and degree of conglutination, the samples were tested at 105°C constant weight method of GB5497-85, the cereal fatty acid measurement method of GB/T15684-1995 and the capillary movement conglutination degree measurement method of GB5516-85 respectively.

Quality index: The quality index used in this trial was based on long-grain non-glutinous rice and wheat storage of "The quality judgment standards of grain and oil storage " used by the National Grain Reservation Bureau and the National Quality Technology Supervision Bureau in 1999, as well as according to the grain classing standards of "Paddy" of the international standards GB1350-1999 and "Wheat" of the GB1351-1999 to classify grains.

Results

Effects on quality of long-grain non-glutinous rice: The experimental results are shown in Table 2.

Table 2 shows that after 10 months storage the regress scoring value of CO_2 treated storage and normal storage decreaseD by 8.8 fen and 11.4 fen, respectively .The acid value of CO_2 CA storage and normal storage increased by 2.1 KOH mg/100g dry-sample and 4.8 KOH mg/100g dry-sample, respectively.

The acidity of CO2 CA storage and normal storage rises to 0.3 KOH mg/10g, dry-sample and 0.4 KOH mg/10g dry-sample, respectively. The conglutination degrees of CO2 CA storage and normal storage were reduced by 3.7mm2/s and 4.2mm2/s, respectively. Germination rate of CO2 CA storage and normal storage decreased by 28% and 43%, respectively. These results indicate that CO2 CA storage significantly slows quality changes compared to normal storage. For extended storage time, it is assessed that the advantage of CO2 CA storage will be further revealed especially under hot and wet adverse climatic conditions.

TABLE 2

Effects of CO_2 treatment on long-grain non-glutinous rice quality compared to untreated grain; tests were based on samples taken from the experimental facilities.

	Date	Storage quality controlling index of long-grain non-glutinous rice						Acidit y Hml/1 0g ample	Quality index							
		Fatty acid alue KOH g/100g dry sample	Degree of cosity m2/s)	Germin tion centage %	Regres s value	Tastin g uation fen)	Color scent		Broken ice eld%	vholer ases%	mpur y%	moist re%	Unsou nd nel%	Dutsid e addy %	Yello ice %	Compreh nsive valuation
No.12 CA rehous e	2002.5.20	19.7	14.6	80	96.2	81	normal	1.0	76.9	54.0	0.7	12.7	5.6	1.4	0	Third class
	2002.10.25	20.9	12.3	63	90.8	79	normal	1.2	76.7	54.3	0.8	12.7	5.9	1.3	0	Third class
	2003.4.8	21.8	10.9	52	87.4	78	normal	1.3	77.0	54.0	0.8	12.7	7.1	1.0	0.3	Third class
No.10 ormal rehous e	2002.5.20	19.1	14.8	77	96.5	81	normal	1.1	76.8	53.6	0.7	12.3	6.8	1.1	0.6	Third class
	2002.10.25	22.4	12.3	41	88.9	79	normal	1.3	76.2	55.4	0.4	12.5	8.1	0.3	0.2	Third class
	2003.3.15	23.9	10.6	34	85.1	78	normal	1.5	76.1	53.0	0.6	12.6	8.3	0.6	0.3	Third class

Effects on wheat quality: The experimental results are shown in Table 3.

TABLE 3

Effects of CO_2 treatment on wheat quality compared to untreated grain; tests were based on samples taken from the experimental facilities.

Numbe r of Wareh ouse	Sampling time	Storage quality controlling index of wheat				Quality index of wheat				
		Degree of viscosity (mm2/s)	Flour water absorption (%)	Taste value (fen)	Color scent	Bulk density _ g/L_	Unso und kerne l %	Imp urity %	moist ure_ %_	Compre hensive value
No.13 CA wareho use	2002.5.21	7.0	197	75	normal	775	6.4	0.6	11.9	Second class
	2002.10.18	8.2	197	77	normal	778	8.0	0.5	12.0	Second class
	2003.4.7	8.1	201	77	normal	778	6.4	0.7	12.1	Second class
No.14 CA wareho use	2002.5.22	7.4	196	75	normal	769	5.8	0.7	11.6	Third class
	2002.10.18	7.6	200	77	normal	769	9.7	0.7	11.9	Third class
	2003.3.17	7.7	212	77	normal	772	8.7	0.7	12.1	Second class
No.11 CA wareho use	2002.5.21	8.2	187	75	normal	770	10.4	0.8	11.8	Second class
	2002.10.21	9.3	194	77	normal	775	9.8	0.7	12.2	Second class
	2003.3.16	8.3	206	77	normal	781	10.8	0.7	12.1	Second class

Table 3 shows that after 10 months, wheat quality had some improvement under CO_2 storage. This quality improvement may be associated with the physiological late maturity of wheat. Because of the improved wheat storage conditions, an additional advantage of CO_2 storage over normal storage could be in its capacity to enable long term storage.

Effect of CO_2 treatment on grain quality after unsealing

Experimental method

After 50 days of unsealing, tests were carried out on long-grain non-glutinous rice samples taken from No.12 CA facility. Samples were taken every 10 days for determination of moisture content, fatty acid, acidity, conglutination degree, germination rate, taste value, color and aroma. During the same period tests were also carried out for broken rice yield and wholesomeness.

Results

The experimental results are shown in Table 4.

TABLE 4

Effects of CO_2 treatment on long-grain non-glutinous rice quality of samples taken from storage in No.12 facility after unsealing.

Days after unsealing	Storage quality controlling index of rice						Acidity KOHml/ 10g sample	Quality index of rice							Comprehensive value
	Fatty acid value KOHmg/ 100g dry-sample	Degree of viscosity (mm2/s)	Germination percentage %	Regress value	Taste value (fen)	Color scent		Broken rice yield %	Wholesomeness %	Unsound kernel%	Moisture content %	Unsound kernel%	Outside of paddy%	Yellow rice %	
0	21.8	10.9	52	87.4	78	normal	1.3	77.0	54.0	0.8	12.7	7.1	1.0	0.3	Third class
10	22.3	11.1	51	87.6	78	normal	1.3				12.7				
20	22.6	10.4	50	86.3	78	normal	1.3				12.7				
30	22.6	10.3	52	86.2	78	normal	1.3				12.7				
40	22.6	10.3	52	86.2	78	normal	1.4				12.7				
50	22.6	10.3	52	86.2	78	normal	1.3	76.9	53.6	0.8	12.7	6.6	0.9	0.3	Third class

Table 4 shows that after unsealing, the quality controlling index and quality index had not markedly changed. This suggests that safe moisture, good-quality grain stored under CO_2 will not be adversely changed after unsealing.

Economic benefit analysis

Experimental conditions and approaches

The economic analysis was carried out on warehouse No.12 for paddy stored under CA, and warehouse No.13 for wheat stored under CA. Warehouse No.10 for paddy and No.11 for wheat were stored under normal conditions, served for comparison and were synchronously constructed, to record the storage expenses. Comparative analysis of expense of direct materials (CO_2 and PH_3), auxiliary materials, water and electricity consumed, maintenance, and the character of environment protection, and expected benefit was carried out after one year.

Results

Results of economic analysis are shown in Table 5.

TABLE 5

Economic analysis that compares CA treatment compared to normal storage in warehouse (unit: yuan)

Number of warehouse	No.10 normal warehouse	No.11 normal warehouse	No.12 CA warehouse	No.13 CA warehouse
Grain storage variety	Paddy	Wheat	Paddy	Wheat
Direct material cost in press-house period	0.79	0.58	2.49	1.94
Direct material cost in normal storage period	0.54	0.36	1.70	1.30
Usage cost in normal storage period per ton	1.87	1.31	2.95	2.25
Newly increased benefits beforehand per ton in a year	0	0	47.05	47.75

Notes: 1.Statistics compare expenses of the two grain-storages without administrative expenses.
2. Expected benefit is based on normal grain storage criteria. If CA grain storage is extended to two years, storage per half a kilogram evaluate 0.05 yuan , then the income will rise to 50 yuan per year: 50 yuan/t*year

Analysis

Expenses of CO_2 grain storage per tonne in a year for paddy and wheat are less than 3.0 yuan, 2.5 yuan respectively. If we adopt atmosphere source which are in line with the food-class liquid CO_2 standards (GB10621-89) of China, then the price will be reduced from 960 yuan per tonne at present, to 600 yuan, and the usage expense of paddy and wheat will be under 2.3 yuan ,1.8 yuan per tonne/year respectively. Direct materials costs will also be under 1.0 yuan per tonne/year.

CA grain storage under CO_2 is characteristically termed as “green-grain” storage. The grain having been stored for two years with CA storage, after being offered into the market, prices are expected to increase above 40 yuan per tonne in a year according to the principle that superior quality should have higher price.

CA grain storage can kill pests effectively, prohibit bacterial development, prolong the storage period, and avoid chemical toxicity to humans, contamination of the grain and the environment. Furthermore, it can avoid rapid build-up resistance to pesticides which is a factor whose benefit is difficult to estimate . It answers the demand for "green-food" and the current demand of the foodstuff market. These hidden social and economic benefits can not be directly translated into monetary gain, so their comprehensive economic benefit is higher than the normal grain storage practice.

Demonstration effect and prospect

The success in the construction of the model facility under CO_2 CA grain storage and the results achieved in the field suggest the following:

* To rebuild properly the tall bungalow warehouses which are commonly constructed at present in the P..R.China, and then ensure that the gas tightness can hold a 500Pa pressure half life of 12 minutes. Such levels of gas tightness should fulfill the requirement for the application of the CA storage technology.
* The technology and the equipment used in the P.R.China can completely provide the centralized gas supply system used presently, and automatically monitor CO_2 concentrations inside the warehouse.
* CA techniques can effectively prevent and control grain storage pests and completely avoid using pesticides thereby preventing pollution of the environment and enabling green-storage of commodities.
* The use of CA storage under CO_2 inhibits the development of saprophytic microflora on foodstuffs without change in quality.
* By storage under CO_2 for 10 months, long-grain non glutinous rice quality is superior to that under the normal storage. Because of the delayed ripeness and endurance of wheat, this effect on wheat is not significant. Removal of the seal will not adversely affect the quality of grain stored under CO_2.
* Storage under CO_2 has economic and social benefits that exceed normal storage and is in line with the trend for the demand of "green food" in the grain market.

Prospects

The CO_2 storage technology is feasible for construction and application as an advanced technology of green storage under P.R.China conditions.

- The successful realization of the five large CA experimental grain facilities in the P.R.China in 2002 further suggests that the time is ripe for the popularity and potential application of this technology in the country.
- This technology is appropriate for diversification efforts aimed at achieving high quality, high benefit, high nutrition value, low loss rates, low pollution and reduction in cost of operations. The technology is likely to further expand and popularize with the economic development and expanding grain marketing system.

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