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Evaluation of large modern warehouse designed and constructed for application of carbon dioxide

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Abstract

The updated warehouses of controlled CO_2 storage with total capacity of 45,000 tons were constructed at Mianyang, in which field experiments were successfully carried out. This paper definitely introduced the construction techniques, CO_2 supply and distribute system, auto-monitor system, security and guarantee facilities, sealing materials, airtight techniques and field experiments. The results showed that design and construction techniques were reasonable. The pressure decay half-life reached 12 minutes from 500 pa declined to 250 pa, and thus effectively ensured the concentration of CO_2. Auto supply and distribution for CO_2 as well as monitoring were realized during the whole process. The field experiment proved that both susceptible strains and resistant strains of *Sitophilus zeamais*, *Rhizopertha dominica* and *Tribolium castanuem* have been 100 % controlled with exposure for more than 14 d to CO_2 which concentration ranged from 35 % ~ 75 %. After incubating the mixed samples at different culture-conditions for 42 d, no alive adults appeared. There were also no significant changes in the quantity of carried microorganism in the grain stored with CO_2. Compared with conventional storage, after 10 months storage with CA for the new-harvest grain with safe moisture content and good quality, the grain quality was better and could be steady after unsealing.

Key words: CO_2 controlled atmosphere, CA grain depot, construction and application.

Introduction

The controlled CO_2 techniques means inflating CO_2 into well-sealed warehouse so as to change the ecological storage environment, inhibit molds and respiration of grain, control pests, and delay grain aging.

Since, 2000, the first modern warehouses with controlled CO_2 were constructed at Mianyang city in China, which get a total capacity of 45,000 tons and consist of several chambers with a capacity of more than 5,000 tons for each (Banks and Annis, 1980; Ripp, 1983; Banks, 1984; Banks and Ripp, 1984; Annis and Van Someren-Greve, 1984; Banks et al., 1980). After the first-period construction, experiments were carried out compared with conventional storage.

Construction of the CA warehouses

Construction techniques

Condition of the warehouses

Warehouses with Controlled CO_2: 5

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horizontal warehouses consist of 2 chambers, 24 m width x 96 m length x 7.8 m height, 6 m height of grain bulk, 45,000 tons of total capacity, 5,000 tons capacity of each chamber.

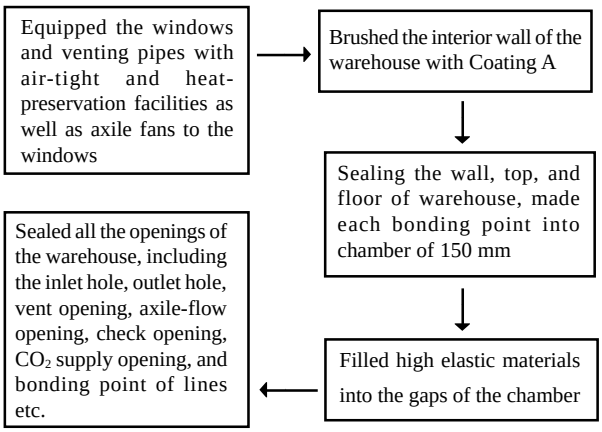
Control Warehouses: 1 horizontal warehouse with the same condition of the above, which adopts conventional storage as control.

Sealing material

Several materials were screened out by comparison, which were flexible, tractile, resistant to extreme temperature and corruption, ultra-radiation-proof, non-contaminant or non-toxic, durable, easy to use, of low air-permeability, good adhesive ability, and with reasonable price.

The position and methods for sealing

According to the original design, the following steps were conducted:



Air-tightness of the warehouses with CO_2

The pressure decay half-life of the warehouse with CO_2 reached more than 12 minutes from 500pa declined to 250 Pa . Through inspection, it was proved that the concentration of CO_2 could be effectively ensured by one-time introduction of CO_2.

Assembly of assorted facilities for warehouses with CO_2

Figure 1 shows the technical flow chart:

CO_2 supply and distributing system

The CO_2 supply and distributing system is used to store liquid CO_2 safely, vaporize and send gas CO_2 when necessary.

Auto-monitor system for CO_2 concentration

The system consist of gas sampling pipe network, gas control pipeline, infrared CO_2 detect facility, data traffic device, CO_2 supply control device, inspection computer, inspection software, which was shown in Figure 2.

The system could determine and report the CO_2 concentration of several points in the warehouse automatically, and is friend for user to operate and update. The CO_2 concentration could be detected on-line well and truly, thus also lead to utilizing the CO_2 resource reasonably effectively and economically.

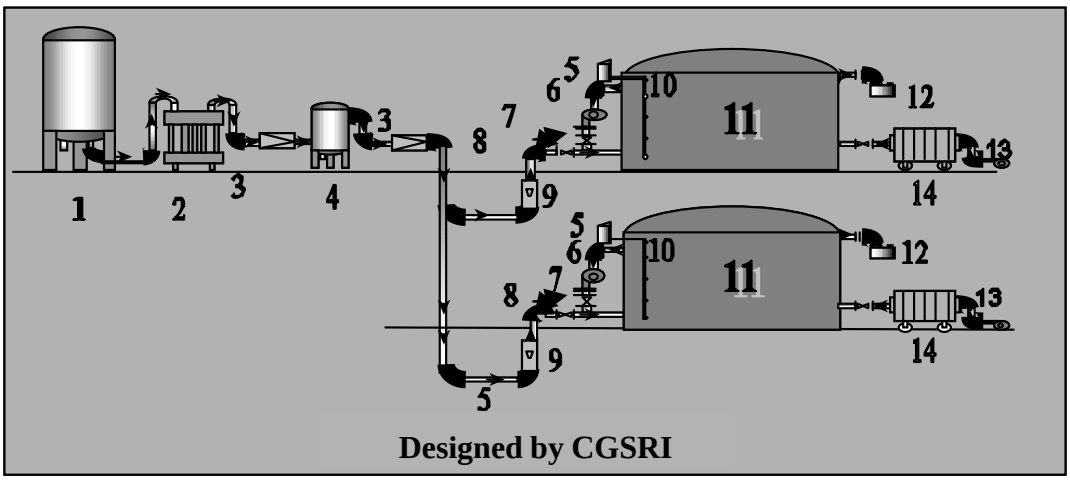


Figure 1. Technical flow chart of CO_2 storage of grain designed by Chengdu Grain Storage Research Institute (CGSRI).

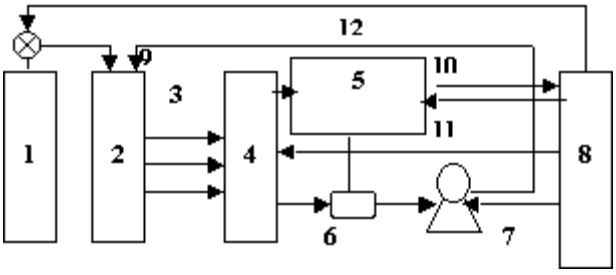


Figure 2. The principle of auto-monitor system for CO_2 concentration.

The application of grain storage with CO_2

After accomplished the first-period construction, 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 more than 14day, while during the second period, effective concentration of CO_2 was maintained.

Effect against the insect pests

Materials and methods

Test Insects: Susceptible and resistant strains to phosphine of two weeks adult insects of *S. zeamais, R. dominica* and *T. castanuem* were tested respectively. The resistant factors were 196,204 and 8. Each test contains 20 adults and mixed-stage insects (eggs, larvae, pupas) of each above test insects. Control test was prepared the same way except adopt 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 kept in incubator of 25 ± 1 °C, 70 ± 5 %; 30 ± 1 °C, 70 ± 5 % respectively to count the number of the next progeny. The emergence of progenies was observed 56 d later after treatment.

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

Results and analysis

The Results of Test in Wheat Warehouse Storage with CO_2: All test adults of 3 insects of 2 strains were 100 % killed. No next progenies of the mixed-stage cultured insects emerged after 56 days treatment.

The Results of Test in Paddy Warehouse Storage with CO_2: All test adults of 3 insects of 2 strains were 100 % killed. No next progenies of the mixed-stage cultured insects emerged after 56 days treatment.

The Original Insects Existed in the Warehouse Before Treatment: It was found that the insect density of NO.13 wheat warehouse with CO_2, was about 15 insects/kg wheat, which mainly consist of S. *zeamais* and *S. cerealella.* While after treatment with controlled CO_2, there were no insects emerging in the next half year. The same condition was with the NO.14 wheat warehouse with CO_2, which had found booklice before while after treatment no booklice alive in the warehouse.

Conclusion

From the result, it was clear 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 residue will be lead to at the same time.

The field experiment also showed that the techniques of controlled CO_2 was effective against booklice, which could be an alternative for control of booklice.

Inhibition effect against molds

Materials and methods

Warehouses: The new warehouse No.12,13,14 and 15 were chosen as the test warehouses for CO_2 storage, each test warehouse contained with 3,000 ~ 5,000 tons of grain;

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

Sampling: Sampled every 3 or 4 months to analysis mycoflora in the grain, which had been stored for 1 year. The preparation of samples was conducted by the Chinese standard method GB4789-1-94.

Experimental result and analysis

Result

Through 370 days' CO_2 CA grain storage in the field, the examination result of grain fungi's germ quantity can be seen from the Table 1, the examination of bacteriallogzaph is omitted.

Analysis

We can see from the examination datum in the field germ quantity and bacteriallogzaph: grain fungi's germ quantity of the wheat and paddy which are stored by CO_2 CA in one year changes a little during the whole storage period. But when we examine and analyze the grain mildew bacteriallogzaph, the result has no obvious variety. Because of being limited by CA sampling, we take little specimen .But general speaking being handled by CO2, the field fungi representative which can reflect grain's freshness degree ¨D¨D*hypnocyst* and *Fusarium avenaceum* are reducing gradually. Though the test-out rate which is represented by the *Aspergillus glaucus link Aspergillus flavous link Aspergillus candidus link* and so on is high, it was stable on the whole. The test-out fungi categories reduce gradually with the extension of storage time. Therefore adopting the CO_2 CA storage grain fungi are regardless on the quantity and the category for the complete moisture grain.

Quality influent effect

Experimental material and method

Experimental method

Choose CA warehouses (No.12 paddy, No.13 wheat and No.14 wheat) which are newly set up by exemplary facility and two normal warehouses which are set up synchronically (No.10 paddy warehouse and No. 11 wheat warehouse) as experimental warehouses. Conduct grain storage contrastive experiment of CO_2 CA and normal storage (mostly points PH_3 recirculation fumigation to kill pests). Measure grain's quality before this experiment, in October continuously and in May, April of the second year.

The method of quality judgment

The method of long-grain nonglutinous rice and wheat 's quality judgment is in line with the international standards. Thereinto the moisture, the value of fatty acid and the conglutination degree are respectively judged by the 105? constant weight method of GB5497-85, the cereal fatty acid measurement method of GB/T15684-1995 and capillary movement conglutination degree measurement method of GB5516-85.

The method of quality judgment

The quality index measured by this experiment is on the basis of the long-grain nonglutinous rice and wheat's storage quality controlling index of "The quality judgment standards of grain and oil storage "(try out), distributed 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 class grain.

Table 1. Examination result of grain fungi 's germ quantity of CO_2 CA grain storage and the normal grain storage of the exemplary facility (unit: entry per gram).

Warehouse number and type	Species for storage	First	185 days	370 days
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

Experimental result and analysis

The quality effect of long-grain nonglutinous rice

The experimental result can be seen from tables 2 and 3;

From these two tables, under storage with CO_2 CA , the changes of the main qualities of the long-grain nonglutinous rice is smaller than that by normal method .And If reserved continuously the difference between them will enlarge.

Both of the wheat's qualities storaged by CO_2 CA and normal method have a little improvement. And the difference between them is not obvious. Maybe it is due to wheat's physiological late maturity and technologic late maturity.

Quality variety of CO_2 CA storage after unsealing

Experimental method

Take samples of long nonglutinous rice grains after first CO_2 storage in No.12 CA depot. During the 50 days since unsealed, sample every 10 day and measure samples' moisture content, fatty acid, viscosity, acidity, sprouting rate, tasting value, color and scent. During the same period, measure broken rice yield and whole kernels and analyze speed of the quality variety.

Table 2. The long-grain nonglutinous rice's quality measurement result of CO_2 CA grain storage and the normal grain storage of the exemplary facility.

Date	Fatty acid value (KOH mg/100g dry sample)		Degree of viscosity (mm^2/s)		Germination percentage (%)		Tasting valuation (mark)		Color scent	
	12#	10#	12#	10#	12#	10#	12#	10#	12#	10#
2002.04	21.9	21.1	13.5	16.0	77%	70%	81	82	Normal	Normal
2002.09	20.2	21.6	13.5	16.0	65%	68%	Not test	80	Normal	Normal
2003.03	21.6	22.7	9.0	9.4	52%	16%	77	73	Normal	Normal
2003.09	22.4	26.1	8.8	8.8	41%	17%	77	73	Normal	Normal
2004.03	24.5	27.0	8.6	9.1	41%	3%	77	73	Normal	Normal
2004.09	26.4	32.0	8.6	-	24%	-	Not test	77	Normal	Normal
2005.03	27.8	Convey out	-	Convey out	-	Convey out	75	Convey out	Normal	Convey out
2005.09	27.3	Convey out	-	Convey out	- -	Convey out	75	Convey out	Normal	Convey out

Table 3. The wheat's quality measurement result of CO_2 CA grain storage and the normal grain storage of the exemplary facility.

Date	Degree of viscosity			Flour muscle absorption			Tasting valuation		
	mm^2/s			%			mark		
	11#	13#	14#	11#	13#	14#	11#	13#	14#
2002,05	8,2	7	7,4	187	197	196	75	75	75
2002,10	9,3	8,2	7,6	194	197	200	77	77	77
2003,04	8,3	8,1	7,7	206	201	212	77	77	77
2004,04	8,1	8,1	-	202	204	-	74	74	-

Experimental result and analysis

Experimental result can be seen from Table 4.

From Table 4, after unsealing, quality index has no obvious change, and storage quality controlling index changes slowly. It suggests that safe-moisture, good-quality grain which is dealt with rational CO_2 CA storage technology will not badly change after unsealing.

Economic benefit analysis

Through the CA facility construction and the applied experiments which pack grain and press warehouse, we contrastively analyze and predict the statistics of storage expenses, the economic benefit concerning CO_2 CA grain storage and normal grain storage in one year.

Experimental conditions and approaches

Choose No.12 paddy CA warehouse, No.13 wheat CA warehouse and No.10 paddy normal warehouse, No.11 wheat normal warehouse which are synchronously constructed and the type to numerate the grain storage expense. Conduct comprehensively contrastive analysis of expense of direct materials (CO_2 gas and PH_3), auxiliary materials, water and electricity consumed, maintenance, and the character of environment protection, expected benefit etc. for the press-warehouse experiment in a year.

Experimental result and analysis

Experimental result

We numerate exemplary facility's expense in the period of pressing warehouse and analyze the operating cost and contrastive benefit in normal grain storage period as Table 5:

Analysis

We can make conclusion from the above datum analysis:

The usage expense of CO_2 CA grain storage per ton in a year is that 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 our country, then the price will reduce from 960 yuan per ton at present to 600 yuan, the usage expense of paddy and wheat will be under 2.3 yuan ,1.8 yuan per ton in a year respectively, direct materials cost also will be under 1.0 yuan per ton in a year.

CO_2 CA grain storage is character of green grain storage. The grain being stored for two years with CA storage after being plunged into the market expects to increase above 40 yuan per ton in a year according to the principle that superior quality should has higher price.

CA grain storage can kill pests effectively,

Table 4. long-grain nonglutinous rice's quality variety of CO_2CA storage in No.12 facility after unsealing.

Days of unsealing	Storage quality controlling index of wheat						Acidity KOHml/10g sampler
	Fatty acid value (KOHmg/100 g dry-sample)	Degree of viscosity (mm^2/s)	Germination percentage (%)	Regress value	Tasting valuation (mark)	Color scent	
0	21.8	10.9	52	87.4	78	normal	1.3
10	22.3	11.1	51	87.6	78	normal	1.3
20	22.6	10.4	50	86.3	78	normal	1.3
30	22.6	10.3	52	86.2	78	normal	1.3
40	22.6	10.3	52	86.2	78	normal	1.4
50	22.6	10.3	52	86.2	78	normal	1.3

Table 5. Analysis table of exemplary facility's economic benefit (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 one year	0	0	47.05	47.75

Note: 1. Above expense statistics is contrastive expense of the two grain-storages approaches, which don't contain administrative expense mutually.

2. Expected benefit regards normal grain storage as benchmark. If CA grain storage for two years' green storage per half a kilogram evaluate 0.05 yuan , then the income will rise to 50 yuan per year: 50 yuan/t*year

prohibit bacteria, prolong grain storage's aging avoid chemical's danger for human, grain and environment. It can't erode the relevant establishment of grain warehouse and endanger PH_3 materials in PH_3 fumigation. Furthermore, it can avoid factor which can't be exactly numerated like the strength of grain storage pests' fastness. It answers for the demand of green food and current of foodstuff market. This latent social and economic benefit can't directly be accounted by money, so its comprehensive benefit, economic benefit is higher than that of normal grain storage pattern.

Demonstration effect and prospect

Demonstration effect

Succeeding in construction of exemplary facility with CO_2 CA grain storage and applying in the field suggest:

Rebuild properly the tall bungalow warehouses which is constructed in our country at present, then the warehouse's air-tightness can attain 500Pa pressure half life 12 minutes, which can entirely fulfill the demand of CO_2 CA grain storage technology for the warehouse's air-tightness.

Our country's technique and equipment can completely realize the mode of cosmically centralized air feed at present and automatic supervise function of CO_2 concentration inside of the warehouse.

Reasonable C.A techniques can effectively prevent and control grain storage pests and completely avoid using chemistry medicament. Therefore, no social effects of pollution and no pollution green-storage will come true.

If we use CO_2 CA storage, then the foodstuff epiphyte will have no evident change not only quantity but also species for complete moisture foodstuff.

With CO_2 CA storage in 3 years, long-grain no glutinous rice's quality is superior to that of the normal storage. The wheat's contrastive effect is not obvious, because of its late ripeness and endurance. The quality of grain which is reserved rationally with CO_2 CA techniques will not become bad swiftly after unsealing.

If we use CO_2 CA storage, the grain storage comprehensive economic benefit and social benefit will excel to normal storage and it's developing direction will accord with the trend of the demand of green food and grain market.

Prospect

CO_2 C.A storage technology is feasible for our construction and application as a sort of advanced

technology of green storage.

The success that five CO_2 CA enlargement experimental grain facilities have constructed in china in 2002 further suggests the popularity and appliance of this technology in our country have been mature.

This technology is suit for the direction of diversification, high quality, high benefit, high nutrition, low waste, low pollution and low cost. It will further enlarge and popularize with the consummation of our country's economic development and grain's market system.

From the present application effect, this CA style cost higher than PH_3 fumigation in aspects of capital and running. Our institute (CSR) focus on this problem to develop mobile carbon dioxide CA equipment, airproof materials and economics CO_2 gas treating machine etc., which will reduce greatly the capital and cost of technology application.

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