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

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Abstract

The updated warehouses of controlled CO₂ 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, CO₂ 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 CO₂. Auto supply and distribution for CO₂ 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 castaneum* have been 100% controlled with exposure for more than 14 d to CO₂ 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 CO₂. 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: CO₂ controlled atmosphere, CA grain depot, construction and application.

Introduction

The controlled CO₂ techniques means inflating CO₂ 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 CO₂ 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 CO₂: 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 CO₂
The pressure decay half-life of the warehouse with CO₂ reached more than 12 minutes from 500pa declined to 250 Pa. Through inspection, it was proved that the concentration of CO₂ could be effectively ensured by one-time introduction of CO₂.

Assembly of assorted facilities for warehouses with CO₂

Figure 1 shows the technical flow chart:

CO₂ supply and distributing system
The CO₂ supply and distributing system is used to store liquid CO₂ safely, vaporize and send gas CO₂ when necessary.

Auto-monitor system for CO₂ concentration
The system consist of gas sampling pipe network, gas control pipeline, infrared CO₂ detect facility, data traffic device, CO₂ supply control device, inspection computer, inspection software, which was shown in Figure 2.

The system could determine and report the CO₂ concentration of several points in the warehouse automatically, and is friend for user to operate and update. The CO₂ concentration could be detected on-line well and truly, thus also lead to utilizing the CO₂ resource reasonably effectively and economically.

Figure 1. Technical flow chart of CO₂ storage of grain designed by Chengdu Grain Storage Research Institute (CGSRI).
The application of grain storage with CO₂

After accomplished the first-period construction, field experiments were carried out for one year. During the first period of CO₂ storage, the CO₂ concentration ranged from 70% to 35% maintained more than 14 days, while during the second period, effective concentration of CO₂ 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 CO₂: 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 CO₂: 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 CO₂, was about 15 insects/kg wheat, which mainly consist of S. zeamais and S. cerealella. While after treatment with controlled CO₂, there were no insects emerging in the next half year. The same condition was with the NO.14 wheat warehouse with CO₂, 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% CO₂ 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 CO₂ 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 CO₂ 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’ CO₂ 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 CO₂ 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 flavus 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 CO₂ 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 CO₂ CA and normal storage (mostly points PH₃ 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°C 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.

Table 1. Examination result of grain fungi’s germ quantity of CO₂ CA grain storage and the normal grain storage of the exemplary facility (unit: entry per gram).

<table>
<thead>
<tr>
<th>Warehouse number and type</th>
<th>Species for storage</th>
<th>First 185 days</th>
<th>370 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.10 normal warehouse</td>
<td>Paddy</td>
<td>5.4 x 10³</td>
<td>2.5 x 10³</td>
</tr>
<tr>
<td>No.11 normal warehouse</td>
<td>Wheat</td>
<td>5.6 x 10²</td>
<td>8.95 x 10¹</td>
</tr>
<tr>
<td>No.12 CA warehouse</td>
<td>Paddy</td>
<td>2.7 x 10⁴</td>
<td>2.5 x 10³</td>
</tr>
<tr>
<td>No.13 CA warehouse</td>
<td>Wheat</td>
<td>3.7 x 10²</td>
<td>8.5 x 10²</td>
</tr>
<tr>
<td>No.14 CA warehouse</td>
<td>Wheat</td>
<td>7.8 x 10²</td>
<td>8.2 x 10²</td>
</tr>
<tr>
<td>No.15 CA warehouse</td>
<td>Wheat</td>
<td>6.1 x 10²</td>
<td>5.7 x 10²</td>
</tr>
</tbody>
</table>
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 CO2 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 CO2 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 CO2 CA storage after unsealing

Experimental method
Take samples of long nonglutinous rice grains after first CO2 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 CO2 CA grain storage and the normal grain storage of the exemplary facility.

<table>
<thead>
<tr>
<th>Date</th>
<th>Fatty acid value (KOH mg/100g dry sample)</th>
<th>Degree of viscosity (mm²/s)</th>
<th>Germination percentage (%)</th>
<th>Tasting valuation (mark)</th>
<th>Color scent</th>
</tr>
</thead>
<tbody>
<tr>
<td>12#</td>
<td>21.9</td>
<td>13.5</td>
<td>77%</td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>10#</td>
<td>21.1</td>
<td>16.0</td>
<td>70%</td>
<td></td>
<td>Normal</td>
</tr>
<tr>
<td>2002.04</td>
<td>20.2</td>
<td>13.5</td>
<td>65%</td>
<td>81</td>
<td>Normal</td>
</tr>
<tr>
<td>2002.09</td>
<td>21.6</td>
<td>16.0</td>
<td>68%</td>
<td>82</td>
<td>Normal</td>
</tr>
<tr>
<td>2003.03</td>
<td>22.4</td>
<td>8.8</td>
<td>41%</td>
<td>65%</td>
<td>Normal</td>
</tr>
<tr>
<td>2003.09</td>
<td>24.5</td>
<td>8.6</td>
<td>3%</td>
<td>77</td>
<td>Normal</td>
</tr>
<tr>
<td>2004.03</td>
<td>26.4</td>
<td>8.6</td>
<td>3%</td>
<td>77</td>
<td>Normal</td>
</tr>
<tr>
<td>2004.09</td>
<td>27.8</td>
<td>Convey</td>
<td>75%</td>
<td>77</td>
<td>Normal</td>
</tr>
<tr>
<td>2005.03</td>
<td>27.3</td>
<td>Convey</td>
<td>77%</td>
<td>77</td>
<td>Normal</td>
</tr>
<tr>
<td>2005.09</td>
<td>27.3</td>
<td>Convey</td>
<td>77%</td>
<td>77</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Table 3. The wheat’s quality measurement result of CO2 CA grain storage and the normal grain storage of the exemplary facility.

<table>
<thead>
<tr>
<th>Date</th>
<th>Degree of viscosity mm²/s</th>
<th>Flour muscle absorption %</th>
<th>Tasting valuation mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002.05</td>
<td>8.2</td>
<td>7</td>
<td>187</td>
</tr>
<tr>
<td>2002.10</td>
<td>9.3</td>
<td>8</td>
<td>194</td>
</tr>
<tr>
<td>2003.04</td>
<td>8.3</td>
<td>8</td>
<td>206</td>
</tr>
<tr>
<td>2004.04</td>
<td>8.1</td>
<td>8</td>
<td>202</td>
</tr>
</tbody>
</table>
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 CO₂ 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 CO₂ 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 (CO₂ gas and PH₃), 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 CO₂ 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 CO₂ 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.

CO₂ 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,
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
PH₃ materials in PH₃ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ CA storage, then the foodstuff
epiphyte will have no evident change not only
quantity but also species for complete moisture
foodstuff.

With CO₂ 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 CO₂ CA techniques will not
become bad swiftly after unsealing.

If we use CO₂ 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**

CO₂.C.A storage technology is feasible for our
construction and application as a sort of advanced

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**Table 5. Analysis table of exemplary facility’s economic benefit (unit: yuan).**

<table>
<thead>
<tr>
<th>Number of Warehouse</th>
<th>No.10 normal warehouse</th>
<th>No.11 normal warehouse</th>
<th>No.12 CA warehouse</th>
<th>No.13 CA warehouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain storage variety</td>
<td>Paddy</td>
<td>Wheat</td>
<td>Paddy</td>
<td>Wheat</td>
</tr>
<tr>
<td>Direct material cost in press-house period</td>
<td>0.79</td>
<td>0.58</td>
<td>2.49</td>
<td>1.94</td>
</tr>
<tr>
<td>Direct material cost in normal storage period</td>
<td>0.54</td>
<td>0.36</td>
<td>1.70</td>
<td>1.30</td>
</tr>
<tr>
<td>Usage cost in normal storage period per ton</td>
<td>1.87</td>
<td>1.31</td>
<td>2.95</td>
<td>2.25</td>
</tr>
<tr>
<td>Newly increased benefits beforehand per ton in one year</td>
<td>0</td>
<td>0</td>
<td>47.05</td>
<td>47.75</td>
</tr>
</tbody>
</table>

**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
technology of green storage.

The success that five CO₂ 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 PH₃ 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 CO₂ gas treating machine etc., which will reduce greatly the capital and cost of technology application.

References


