0506

Experiment on Grain Storage by Controlled Atmosphere with Carbon Dioxide

Zheng Wei[1], Zhou Yungen[1], Rao Mingquan[2], Gao Zhidan[2] and Wang Jingcai[3]

Abstract: Controlled atmosphere technologies with carbon dioxide for grain storage, which were safe, simple, effective and hygienical, could not only effectively control grain storage pests, but also keep chemicals from harming person, polluting grain, corroding grain storage devices and destroying environment compared to chemicals such as phosphine. "No chemicals emission" has been coming true and is required for green food and protecting environment for the mankind, meanwhile, it has provided a new way for inhibiting pests' pesticide resistance growth.

Key words: carbon dioxide, controlled atmosphere, fumigation

With the social development and progress, making such achievements as excellent qualities, fresh, environmental protection and pollution – free, minimizing the loss of quality and quantity of stored grain, would be inevitable for grain industries joining in competition and improving benefits. It should be developing grain storage technologies gradually which are pollution-free such as controlled atmosphere, low temperature, controlling by combination of physical and biological methods.

With technical guidance from superior technical administration office and ChengDu grain storage research institute, the experiment on controlling pests by controlled atmosphere with carbon dioxide firstly was carried on by JiuJiang National Grain Depot, China Grain & Oil Group Science & Technology Corp. in 2005, and lots of success achieved. Since 2005, comparing with the control granary with conventional grain storage technologies, the research about grain storage with carbon dioxide controlled atmosphere influence on grain qualities has been carried out.

1 Fumigation Principles of Controlled Atmosphere with Carbon Dioxide

Using large gas supplying system outside, matching with automatic system for inspection carbon dioxide in granaries, steering system for recirculation ventilation and devices for regulating pressure of granaries, carbon dioxide would be concentrated to input CA granaries with excellent sealing performance, and meanwhile, the concentration of carbon dioxide would be well-distributed because of forced recirculation system, and the continuous monitoring of the concentration. By altering gas composition in granaries, the ecological environment of pests and mould is destroyed, respiration of grain inhibited, deterioration of grain quality postponed and grain pests controlled.

2 Main Technologies Indexes of Experiments on Fumigation by Controlled Atmosphere with Carbon Dioxide in Filled Granaries

2.1 Indexes of gas tightness: the half time, in which pressure of 500 Pa decreased to 250 Pa, should over 240 s.

2.2 In normal condition, the consumption of carbon dioxide should be below 3 kg for one tonne of grain every year.

2.3 Insect mortality with carbon dioxide should reach 100%.

2.4 The cost should be below 4 Yuan for one tonne of grain every year.

3 System Configuration for Controlled Atmosphere with Carbon Dioxide

3.1 Gas Distribution System Outsides

It consisted of such devices as liquid carbon dioxide storage tank, evaporator, decompressor, gas balancing tank and airfeeding pipe. The gas distribution devices and craft flow-sheet was as follows. (Figure 1)

3.2 Automatic Monitoring System for Carbon Dioxide Concentration

Carbon dioxide automatic monitoring system consisted of many devices to achieve auto-

1. *Storage Office of JiangXi Branch, State Grain Reserves* 332000
2. *JiuJiang National Grain Depot, China Grain & Oil Group Science & Technology Corp.*
3. *GongQing Grain Depot, State Grain Reserves* 330300

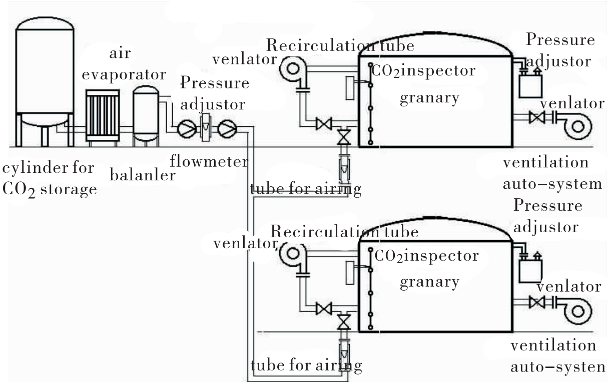

Fig. 1 **Photograph of CA system with carbon dioxide**

matic transportation and management of carbon dioxide, such as carbon dioxide gathering nets, administration system of gas pipe, metering equipment for carbon dioxide concentration, data communication system, computer and software for monitoring.

4 Granaries and Pests for Testing

4.1 Elementary Information of Experimental Granaries

4.1.1 NO. 6 CA granary was large granary (30 meters long, 21 meters wide and 7.8 meters high). Grain was filled to 6.3 meters high. The index of gas tightness was about 7.3 min for empty granary, about 6.3 min for full granary. Granary was filled with 2170 t of late long-grain nonglutinous rice, which was produced in 2004 and stored in July, 2005. Furthermore, the average moisture was 13.5%, the surface, upper, middle and lower grain temperatures were 27℃, 25℃, 25℃, 24℃ respectively, and the average temperature was 25℃.

4.1.2 NO. 3 ordinary granary, was 30 meters long, 21 meters wide, 7.8 meters high filled to 6.5 meters high. The index of gas tightness was about 0.7 min for empty granary, about 0.7 min for full granary. Granary was filled with 2291 t of late long-grain nonglutinous rice, which produced in 2004 and stored in July, 2005. Furthermore, the average moisture was 13.5%, the surface, upper, middle and lower grain temperature were 28℃, 26℃, 24℃, 24℃ respectively, and the average temperature was 25℃.

4.2 Pests Tested

There were three kinds of main grain storage pests species in No. 6 CA granary (*Sitophilus zeamais*, *Rhizopertha dominica*, long-horned flour beetle), at a density of 17 insects per kilogram of grain. Same three insect species were also present in No. 3 granary at s density of 9 insects per kilogram of grain.

4.2.1 Species of pests tested

There were three kinds of main grain storage pests with phosphine sensitivity (*Sitophilus zeamais*, *Rhizopertha dominica* and *Tribolium castaneum*). There were three kinds of main grain storage pests with phosphine resistance (*Sitophilus zeamais*, *Rhizopertha dominica* and *Tribolium castaneum*). Their phosphine resistance indexes were 196 times, 204 times and 8 times, respectively.

Six kinds of grain storage pests with all life stage (egg, larva, pupa and adult), were divided into 10 groups, each of which had 20 adult and other life stage.

Moreover, one control group was set up, each of which had 20 adults and other life stage. Their mortality was determined after 1 month.

4.2.2 Experimental method: Figure 2 shows the location of insect placement in the granary and depth, for the six groups of pests tested. The insects were placed into experimental granary by sampler. Four corner location were 2 m from walls. The seventh and eighth group of pests tested were put near the ventilation ports, the ninth and tenth were hanged 1 meter over the surface of grain bulks. All insects were located before sealing granaries. After expiration of experiment and exhausting gas, and mortality was assessed.

* No. 2 (1m deep)　　　　No. 3 (3m) *

* No. 5 (2m)

* No. 6 (middle)

* No. 1 (3m)　　　　(1m) No. 4 *

Fig. 2 **Burying points of all pests tested and their depth**

5 Experimental Inspection Objects

5.1 Carbon Dioxide Concentration Inspection in No. 6 CA Granary

5.1.1 Figure 3 and 4 show the locations of CO_2 sampling.

5.1.2 Inspection methods

Carbon dioxide concentration was recorded automatically by carbon dioxide automatic monitoring system every day for 15 days. Meanwhile, to assure carbon dioxide distribution well, recirculation fans were started after aerating for 12 h, and were 24 h for recirculation upper.

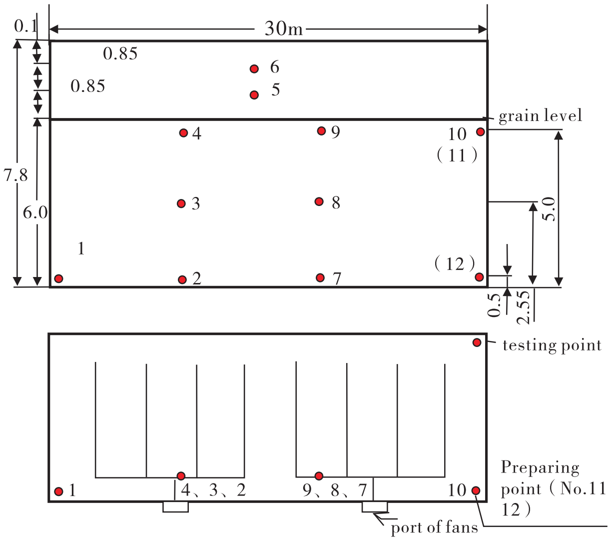

Fig. 3 **and** 4 **Ichnography of locations of CO_2 sampling**

5.2 Inspection Pests

After fumigation for 15 days by CA with carbon dioxide in No. 6, 18 days in No. 3 ordinary granary, tested pests in grain bulks were checked respectively and the mortality of pests were determined. In addition, the tested pests were kept at 25℃ and 75% RH for 30 days. We assured whether living pests occurring or not after inspection.

5.3 Analyses on Quantities Alteration

Quantities of paddy were sampled for inspection in No. 6 CA granary and No. 3 ordinary granary, periodic inspection and comparing analysis was taken during grain storage.

6 Results

6.1 Test Procedures

Starting at 17:00 p. m. on Sept. 22, 2005, carbon dioxide was filled in No. 6 CA granary, until 23:00 p. m. It took 6 h. According to the predicted proposal, such conditions were desired as temperature of carbon dioxide keeping about 22℃, 50 – 150Pa of pressure, flow at rate of 500 cubic meters each hour, 5.6 tons of carbon dioxide consumption and 2.58 kilograms of each ton grain gas consumption. Recirculation fumigation with AIP carried on in No. 5 ordinary granary on Sep. 2nd, 2005, which was at 13.5 kilograms of Aluminum phosphate consumption and 300 mL/m^3 of setting concentration.

Table 1. **Concentration altering – time on CA experiment with CO_2 in No.** 6

Date	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Sep. 22	88.95	81.75	73.02	68.07	31.24	64.48	85.83	75.86	67.62	65.19
Sep. 23	78.86	68.68	69.68	65.07	47.10	63.33	78.28	70.94	66.33	64.74
Sep. 24	60.79	61.32	62.67	62.34	53.40	59.34	63.17	63.13	62.55	59.35
Sep. 25	60.34	59.01	58.61	59.01	54.61	58.03	59.00	60.19	59.13	58.15
Sep. 26	55.49	55.44	55.15	55.78	52.07	55.02	55.15	57.06	56.51	56.08
Sep. 27	54.50	56.35	57.54	57.25	49.86	54.87	58.42	59.08	59.18	58.16
Sep. 28	52.97	53.66	55.47	55.50	48.63	53.27	55.18	54.66	54.43	54.41
Sep. 29	51.51	52.41	54.17	54.24	47.87	52.28	53.86	53.19	52.86	52.68
Sep. 30	50.48	51.40	53.10	53.07	47.27	51.31	54.16	51.57	51.33	51.16
Oct. 1	51.00	51.22	52.75	52.95	47.04	51.07	52.66	51.69	51.29	51.53
Oct. 2	50.64	50.78	52.34	52.43	46.64	50.56	52.29	53.94	54.89	54.74
Oct. 3	48.05	49.26	50.02	50.10	45.05	48.70	50.32	48.15	48.35	47.27
Oct. 4	46.74	48.20	49.71	49.61	44.34	47.92	49.59	45.13	43.10	44.88
Oct. 5	46.30	45.39	44.98	45.93	43.37	45.62	45.83	47.76	46.64	46.83
Oct. 6	46.83	45.08	44.19	44.78	42.41	44.51	44.82	46.59	45.53	46.12
Oct .7	45.38	43.97	43.29	44.09	41.60	43.61	43.97	45.81	44.77	45.34
Oct. 8	44.78	43.25	42.24	43.09	40.44	42.96	43.27	45.22	44.24	44.54
Oct. 10	37.06	38.60	36.94	38.23	36.97	38.41	37.39	40.14	38.55	39.68
Oct. 12	34.49	36.80	35.26	36.56	36.13	36.88	35.73	38.05	36.36	37.42

6.2 Carbon Dioxide Concentration Altering during CA Fumigation in Grain Bulks (see fig. 1 and table 1 in details)

Carbon dioxide concentration altering during CA fumigation in No. 6 figure 1.

It has been shown from table 1 that the original average concentration was 58.2% on Sep 23rd after gasing and the whole average concentration still reached 37.8% 18 days later. It proved by gasing experiments that the required 35% of carbon dioxide concentration was maintained for over 15 days.

6.3 The Effect on Controlling Pests

According to this experimental proposal, the effect of controlling pests in No 6 CA granary and No. 3 ordinary granary was 100%. After taking 10 groups of sample pests tested buried in No 6 granary, no pests alive were found. The control group of pests tested were put into conditions with certain temperature and humidity after taking out, and then observed for one month, no living pests were found, the morality ratios reached 100%. Till Sep. 2006, there were 5 heads each kilogram of grain storage pests in No 3 ordinary granary, the main pests spices of which were *Sitophilus zeamais* and *Cryptolestes ferrugineus*. Recirculation fumigation with 10 kilograms of AlP was carried on again on 20th Sep..

However, since fumigation with carbon dioxide controlled atmosphere on Sep. 2005, there were no grain storage pests so far in No 6 CA granary. It showed that fumigation with carbon dioxide controlled atmosphere had the same effect as conventional fumigation with AlP in short term, however, here could keep longer term for no pests by fumigation with carbon dioxide controlled atmosphere, and there was more excellent fumigation effect than conventional fumigation with AlP.

6.4 Inspection and Analysis on Grain Qualities

The condition of qualities altering during paddy storage in No. 6 CA granary and No. 3 conventional granary were as follows. See table 2 and table 3 in details.

Table 2. Results on paddy qualities inspection in No. 6

Data (a – m)	moisture (%)	impurity (%)	Roughness rate (%)	Head rice (%)	Fatty acid value (mgKOH/100g)	Taste panel (scores)	Smell and color	Whether fit for storage or not
2005 – 7 – 31	13.5	0.9	76.3	50.5	19.7	87	normal	yes
2005 – 9 – 6	13.5	0.8	77.0	51.3	21.5	85	normal	yes
2006 – 3 – 7	13.8	1.0	77.0	55.5	22.8	84	normal	yes
2006 – 9 – 6	13.5	1.0	77.2	54.7	22.9	84	normal	yes
2007 – 3 – 7	13.5	1.0	77.1	54.5	24.5	82	normal	yes

Table 2. Results on paddy qualities inspection in No. 3

Data (a – m)	moisture (%)	impurity (%)	Roughness rate (%)	Head rice (%)	Fatty acid value (mgKOH/100g)	Taste panel (scores)	Smell and color	Whether fit for storage or not
2005 – 7 – 31	13.5	0.9	76.6	53.6	20.3	88	normal	yes
2005 – 9 – 6	13.5	0.8	77.0	52.2	20.4	85	normal	yes
2006 – 3 – 7	13.0	0.9	77.2	54.8	22.4	84	normal	yes
2006 – 9 – 6	13.2	0.9	77.1	54.8	24.2	83	normal	yes
2007 – 3 – 7	13.3	1.0	77.5	54.5	25.6	82	normal	yes

From table 2 and table 3, the qualities of late long – grain nonglutinous rice in No. 6 CA granary had the same as No. 3. There were rather little alteration in such indexes as moisture, impureness and roughness ratios etc. during grain storage. The fatty acid value of pay in No. 6 CA granary has become 24.5 mgKOH/100g till March 2006, here raising about 4.8 mgKOH/100g, and the taste panel went to 82 scores, decreasing about 5 scores. The fatty acid value of pay in No 3 ordinary granary has become 25.6 mgKOH/100g till March 2006, here raising about 5.3 mgKOH/100g, and the taste panel went to 82 scores, decreasing about 6 scores. It showed from analyses that the altering of the fatty acid value and taste panel scores in both No. 6 CA granary had the same as No. 3 ordinary granary. By comprehensive judgment, paddy qualities in both granaries were fit for storage.

7 Analyses on Economic Benefits

There were analyses between running fees for grain storage in No. 6 CA granary with No. 3 ordinary granary during the period of from July 2005 to March 2007. Except of such common fees as administration costs and staff salaries, the analyses costs only included objects between both storage ways during experiment.

Table 4. Comparative analyses economical benefits between CA grain storage with conventional fumigation

No.	Capability (t)	Quantity of grain (t)	Height of grain bulks (m)	Fumigation times	Fumigation costs (Yuan)			Coating film	Nutrition support	Consumption of power	Repairing fee for gas tightness	The total cost
					The main cost		Assistant cost					
					CO_2	AIP	CO_2					
6	2722	2140	6.3	1	4480			35		120	440	5075
3	2722	2291	6.5	2	630	850	800	400	60	240	2980	

From the comparative analyses in table 4, it showed that 2.37 Yuan each ton grain of preserving fees in No 6 CA granary was higher than 1.3 Yuan in No 3 ordinary granary, however, it only leaded small proportion in the whole preserving fees.

8 Analyses and Discussion

8.1 Analyses on Comprehensive Benefits

8.1.1 Though there was lower cost during conventional paddy storage, for the application of fumigation with phosphine, it would be inevitable to lead residual accumulation of grain increasingly after phosphine fumigation for a long term, there was much pollution on grain and environment to some extent. In addition, it would lead corrosion to such ancillary equipments as grain condition monitoring system, and raise pesticide resistance increasingly for grain storage. However, CA with carbon dioxide could not only be effective to control pests for grain storage safely, but also protect human, grain and environment from harming, contaminating and destroying by chemicals. It was consistent with requirement of people for green food and had excellent social benefits, meanwhile, it also applied a new way to inhibit pests resistance growth.

8.1.2 CA technology for grain storage is currently one of the most advanced technologies in the world. With the condition of grain storage industries in China, the approach for grain storage with carbon dioxide is one of most simple and effective technology among such three CA grain storage technologies as carbon dioxide filling. CA grain storage could make breakthrough from the situation which Chinese grain storage industries relied on phosphine to control pests in the past. If the achievement of "no emission of chemicals" in grain storage industries, it would be favor of prevention chemicals from human and animals pollution, ecologic destroy and making pollution-free green grain storage coming true.

At the same time, to decrease the use of chemicals to control pests, and then reduce pollution on grain, it would be favor of enterprises breaking green barriers to establish green and ecological imagine and competitive strength the domestic and international markets.

8.2 Gas tightness of Granary Was the Key to Application with CA Technologies with Carbon Dioxide

To achieve all technical indexes requirement of CA granary, the gas tightness performance of granary was essential. The concentration can be maintained during fumigation with carbon dioxide in excellent gas tightness granary. With gas consumption decreasing and costs lowering, the superiority of CA grain storage could be reflected.

Gas tightness inspection should be focus on the sealing effect of walls inside in CA granary, connecting between walls with grounds and so on. Airtight plastic joints, polyurethane and acrylic 885, 991, and other materials could be chosen to fill up cracks among boards and seal granaries at the top of granary (after filling with plastic joints at wider gapes, the treatment of "3 coating and 2 clothing" would take with fiberglass cloth and acrylic again).

To assure the sealing and insulation effect, gas tightness insulating windows and doors, windows axial fans, gas-tight insulation ventilation tube would be chosen, high weathering airtight plastic sealing would be applied. Leakage checking and mending was taken into practice by such methods as observation, listening and so on. After checking gas tightness performance carefully before fumigation, according to the proposal of gas tightness inspection by PT positive pressure, the test on gas tightness was carried on to ensure requires of gas tightness performance.

9 Prospect of Application

To ensuring grain storage in safe and no pollution, controlled atmosphere with carbon dioxide could effectively control grain storage pests and keep grain with safe moisture storage with no chemicals usage. It showed that application of these technologies have gone mature. Their successful application in JiuJiang National Grain Depot, China Grain & Oil Group Science & Technology Corp. and others districts approved that modern grain storage administration has centered on such goals as food quality, high-nutrition, high efficiency and low pollution and low-cost, and developed along the direction of intensive development. With the development and promotion of national economy furthermore, there would be broad application prospect.

10 Acknowledgements

We thank Dr Digvir Jayas for editorial comments in this manuscript.