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Application Analysis on Alternative Technologies for Methyl Bromide Phase-out in Chinese Grain Storage Industries

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Abstract: According to the *Copenhagen Amendment* in the *Montreal Protocol on the ozone depleting substances (ODS)*, putting the Chinese government's promise actually into practice and ensuring Chinese grain storage safety, a permanent guarantee mechanism for methyl bromide phase-out has been established. From a technical point of view, Chinese grain storage industry has taken *recirculation fumigation under film with phosphine* and *fumigation technologies by combination of phosphine with carbon dioxide* as alternative technologies for methyl bromide fumigation. Fumigation experiments to control pests in 32 demonstration depots of 9 provinces and cities in China have been carried out for more validation and later evaluation of application effects of alternative technologies. It has been shown that the lethal effects towards pest insects reached 100% in 31 cases and 90% in one case. Therefore, the application of the investigated alternative technologies for methyl bromide fumigation in grain storage seemed to be scientifically reasonable and sufficiently effective. Beside economical, social and environmental benefits, there was also technical support for the establishment of permanent mechanisms for phase-out of methyl bromide.

Key words: grain storage industries, methyl bromide alternatives, phosphine, application effect

Preface

It has been taken three years (2005 – 2007) to nearly phase out methyl bromide in Chinese grain storage industries. After making great efforts, lots of prominent achievements have been gained, and the project on phase-out of methyl bromide will be totally finished till the end of 2008. Meanwhile, as the described project was the first one of internationally appointed projects for Chinese grain storage industries, it was related to the international reputation, political attitude and social duties of Chinese grain storage industries. Beside of the significant influence, it was also an important Chinese contribution for protecting mankind's living environments. To consolidate the pro-phase achievement on methyl bromide phase-out, a permanent mechanism should be established with technical support to that methyl bromide will never be reused again. From May to October 2007, in elaborate organization and arrangement by the State Administration of Grain, the experiment on alternative technologies, such as *recirculation fumigation technologies with phosphine under film* and *fumigation technologies by combination of phosphine with carbon dioxide*, have been carried out for controlling pests in 32 demonstration depots. In another two depots that had been selected for demonstration as well, no pests were present

and therefore no fumigation was applied. As a sub-project undertaker unit, Chengdu Grain Storage Research Institute sent professional engineers to the demonstration depots for trial inspection and to give guidance on fumigation technologies and on technical application. By inspection and later evaluation of the alternative technologies, the quick replacement of methyl bromide in China has been enhanced and technical support for the establishment of permanent alternatives for methyl bromide fumigation in grain storage provided.

Introduction of Alternative Technologies for Methyl Bromide

Main Technologies for Phasing out Methyl Bromide

According to the actual condition of grain storage industries and argumentation by professional experts, such technologies as *recirculation fumigation technologies with phosphine under film* and *fumigation technologies by combination of phosphine with carbon dioxide* have been chosen as the main alternative technologies for phasing out methyl bromide in grain storage industries.

Demonstration Depots that Applied alternative Technologies for Methyl Bromide

The specific demonstration depots are described in Table 1.

Devices and Applied Chemicals

International assistance devices were taken for application as fumigation equipments. The supply with equipments was organized following public bidding. It comprised phosphine recirculation fans, phosphine generators, phosphine measuring devices, phosphine alarm devices, centrifugal fans, aluminum phosphide product, carbon dioxide in steel cylinders, equipment for worker safety, recirculation pipes, plastic liners, etc.

Main Survey on Fumigation

i) Fumigation modes

According to different types of granaries, different techniques of fumigation have been applied, such as recirculation fumigation under film in house granaries or large house granaries and recirculation fumigation in whole granaries in silos.

ii) Actual fumigation situation

By making great efforts for several months, according strictly to *LS/T1201 - 2002 (Fumigation regulation of phosphine recirculation, LS/*

T1201 - 2002)^[1], fumigation experiments have been carried out under local guidance of technical engineers in 32 demonstration depots including tests on pest control. The total fumigated volume was 131 281m and the total amount of fumigated grain was 97 419t, including 67 642t of wheat, 17 489t of maize and 12 288t of paddy.

Out of 32 demonstration depots, 31 depots (96.9%) passed the gas tightness test (LS/T1201, the tightness is at least 40s pressure from 250 Pa to 250 Pa in house granaries, and at least 40s in silos) as excellent. According to the test, a house granary should have a half life of pressure decay of not less than 40s after stored grains, and silos and squat silos not less than 60s. There was only one depot with worse gas tightness performance (grain supply center, Handan grain administration). The specific fumigation situation is given in (Table 1).

Table 1. Description of the specifics of the 32 demonstration fumigation depots

Province	No	Name of depot	Gas tightness (pressure half life in s)	Grain	Amount off grain (t)	Recirculation mode	Mortality (%)	Inhibition ratios of F1 generation (%)
Liaoning	1	Youyi State grain reserve and intermediate depot in Dalian	80	maize	8209	Fumigation in whole granary	100	100
	2	Jinzhou state grain reserve depot in Dalian	42	maize	3100	Fumigation under film	100	100
	3	Zhuanghe state grain reserve depot	40	wheat	2411	Fumigation-under film	100	100
Gansu	4	Grain depot in Wuwei city	42	maize	3500	Fumigation under film	100	100
Shanxi	5	802 Unit in Shanxi Province	40	wheat	4500	Fumigation under film	100	100
Hebei	6	Hanshan state grain reserve depot in Handan	42	wheat	4110	Fumigation under film	100	88
	7	ChengGuan grain supply center, Jize grain administration	40	wheat	5272	Fumigation under film	100	100
	8	State grain reserves depot in Ci county	40	wheat	1691	Fumigation under film	100	100
	9	purchase and sale reserve depot in Yongnian county	40	wheat	2202	Fumigation under film	100	100
	10	Daning state grain reserve depot	60	wheat	3311	Fumigation under film	100	100
	11	Hucun grain supply center, Handan grain administration	35	wheat	721	Fumigation under film	90	90

Province	No	Name of depot	Gas tightness (pressure half life in s)	Grain	Amountoff grain(t)	Recirculation mode	Mortality (%)	Inhibition ratios of F1 generation (%)
Hebei	12	Handan depot, Chi- na grain reserve Co.	45	wheat	6109	Fumigation un- der film	100	100
	13	grain depot, Feix- iang county grain administration	40	wheat	620	Fumigation un- der film	100	100
	14	the second grain depot Guangping grain administration	40	wheat	840	Fumigation un- der film	100	100
Shandong	15	state grain reserve depot in Heze city	60	wheat	5814	Fumigation un- der film	100	100
	16	state grain reserve depot in Guang county, Liaocheng	52	maize	2680	Fumigation un- der film	100	100
	17	first depot of state grain reserve depot in Lingqing	50	wheat	1337	Fumigation un- der film	100	100
	18	state grain reserve depot in Zhengcheng	40	wheat	3008	Fumigation un- der film	100	100
	19	Dingtao state grain reserve depot	45	wheat	2562	Fumigation un- der film	100	100
	20	Juye state grain re- serve depot	60	wheat	3447	Fumigation un- der film	100	100
	21	Dongjiao state grain reserve depot in Zi- bo city	45	wheat	3318	Fumigation un- der film	100	100
	22	Bingzhou state grain reserve depot	42	wheat	3500	Fumigation un- der film	100	100
	23	Donga state grain reserve depot	45	wheat	1907	Fumigation un- der film	100	100
Tianjing	24	Chengdong state grain reserve depot in Jinghai	43	wheat	2514	Fumigation un- der film	100	100
	25	JunLiangcheng state grain reserve depot	60	wheat	830	Fumigation in whole granary	100	100
	26	PuJidao state grain reserve depot	60	wheat	853	Fumigation in whole granary	100	100
	27	Binghai state grain reserve depot	60	wheat	1379	Fumigation in whole granary	100	100
Anhui	28	mechanization grain depot in Anhui	49	paddy	4065	Fumigation un- der film	100	100
	29	state grain reserve depot in Mengcheng	60	wheat	1000	Fumigation un- der film	100	100
	30	Anhui state grain reserve depot, China Grains&OilsGroup Science&Technology Corp.	56	paddy	8223	Fumigation un- der film	100	91
Guang dong	31	Haizhu grain depot in Guangzhou city	90	wheat	2463	Fumigation in whole granary	100	100

Province	No	Name of depot	Gas tightness (pressure half life in s)	Grain	Amount of grain (t)	Recirculation mode	Mortality (%)	Inhibition ratios of F1 generation (%)
Guang dong	32	Maozhou state grain reserve depot in Guangxi	60	wheat	1923	Fumigation un- der film	100	100

Evaluation of Alternative Application Technologies for Phasing out Methyl bromide

Efficacy of the Alternative Technologies

According to the lethal effects against the pest insects, the fumigations in 31 depots showed excellent results (100% mortality of adult test insects). Due to 10% surviving insects in depot No. 11, where the pressure test had failed, total mortality rate of adults amounted to 96.9% of all tested depots. In depot No. 6, No. 11 and No. 30 some progeny (12%, 10% and 9%, respectively) developed.

Implementation of Alternative Technologies

During construction, each demonstration depot in the project of methyl bromide phase out mastered training of people, field guidance. Experts answered questions of storemen and carried out practical operations. However, as it was the first time to encounter and apply this technology in some depots, application of the technique was still weak and more effort will be needed.

Permanent Application Mechanism of Alternative Technologies

In the fumigation experiments, it was the first time for many demonstration depots to apply recirculation fumigation technologies. The local training and guidance by professional experts resulted in effective technology transfer at every depot. Meanwhile, comparing alternative technologies with old techniques, the alternative technologies succeeded in better pest control and revealed economical benefits towards conventional fumigation and fumigation with methyl bromide. It was also aim of the project to enable to lead these technologies into application in other granaries by self-financing investment. It is worth to mention that most depots with good facilities indicated that they would play a leading role in spreading the new techniques and also improve their own grain storage technologies. Therefore, from the point of development, alternative technologies will be more and more accepted and welcomed which is very useful for the quick phase out of methyl bromide.

Technical Support and the Union of Re-

search institutes and Grain Storage

By practicing the sub-project on technical support for phasing out methyl bromide, some difficulties of applying alternative technologies have been solved. Especially for the handling of pesticide resistance, a system for inspection of resistance has been built up by collecting grain storage pests and by carrying out resistance inspection in regular depots and in those for demonstration. Meanwhile, by these experiments for validation and inspection of resistance, the union of the research institute with grain storage enterprises was formed. The union met and solved some difficulties to apply the alternative technologies for methyl bromide fumigation; the phenomenon of pests that could not be controlled with regular treatments and how to control them when they showed to be resistant. The union provided most grain storage enterprises with technical support.

Analyses on Benefit

Economical Benefit

Costs for recirculation fumigation with phosphine under film and fumigation by combination of phosphine with carbon dioxide

The main costs involved with the application of alternative technologies include costs for chemicals, fees for carbon dioxide steel cylinders, equipment depreciation charge, power fees and costs for plastic films. According to the specific condition and the pest infestation in every depot. carbon dioxide

a) Chemicals: applied at the dosage of $1.5 - 3\text{g}/\text{m}^3$. The actual aluminium phosphide consumption was 414.7kg, which was equivalent to about 10 000 Yuan RMB (aluminium phosphide at a recommended price of 26 000 Yuan for each ton).

b) carbon dioxide: 276 bottles of cylinderised were used, which was equivalent to about 8 000 Yuan RMB (carbon dioxide at a recommended price of 30 Yuan for each bottle and 25kg of each bottle).

c) Equipment depreciation charge: including recirculation devices, generators, pipes and others ancillary equipments. The total assistance costs were about 4 millions Yuan RMB in 32

demonstration depots. According to the content of ten granaries in every depot and depreciation for 10 years, and every depot have 10 warehouses, the depreciation charge for each granary was about 40 000 Yuan RMB.

d) Supply with plastic film; according to 100 Yuan RMB for each granary (exception: five silos or squat silos), the total costs were 2 700 Yuan RMB.

e) Power fees were the last factor. The total power consumption during fumigation could reach 3456 degrees (two 750W power of each recirculation fan, intermittent recirculation for 3 days in 32 depots). At 0.8 Yuan RMB for each degree with industrial consumption, the total charges were about 2 700 Yuan RMB.

Therefore, during fumigation with alternative technologies in 32 demonstration depots, the total costs summed up to 63 400 Yuan RMB every year, of which the main part was used for equipments. Basically, all fumigations were fully effective and achieved mostly 100% control. Therefore, only one fumigation was necessary per year.

Costs for application of conventional fumigation with phosphine

The main costs involved with application of conventional phosphine fumigation include the cost for the aluminium phosphide product and labor costs. If conventional fumigation with phosphine was taken in 32 demonstration depots, the total fumigation volume would reach 206 629m³. According to conventional fumigations two times every year at least with dosage of 6g/m³ as the least, 2 279kg of aluminium phosphide would be required, equivalent to 59 000 Yuan RMB (recommended price of 26 000 Yuan per ton). Corresponding to 50 Yuan per person per granary for a single fumigation, 19 200 Yuan in 32 depots would be necessary for 6 persons.

The total costs would reach 78 200 Yuan. If two fumigations would be necessary per year, increased labor and much more phosphide product would be required without the guarantee of complete control of pests with possible side effects towards man and environment.

Cost for application of methyl bromide

Most of the money for this type of cylinder based fumigation with methyl bromide has to be spent for the chemical itself. If fumigation with this gas was carried out in 32 demonstration depots, the total fumigated volume would reach 206 629m³. On the base of one yearly fumigation with methyl bromide with 25g/m³, 5 165kg

of gas had to be used. While the recommended price of this gas is 28 000 Yuan each ton, the fumigation would totally cost 145 000 Yuan RMB. Though it could help to control grain storage pests, it would bring the risk to cause destruction of the ozone layer.

It was shown that the application of alternative technologies did not only control pests completely, but also reduced costs clarified by actual fumigation validation experiments in 32 demonstration depots. The costs were 80% of conventional fumigation with phosphine and 44% of fumigation with methyl bromide.

Environmental Benefit

Grain storage industries brought pollution into environment, which accounted for yearly chemical consumption for grain storage and the risk of destroying the ozone layer with methyl bromide. The less chemicals are used, the less pollution to the environment will occur. When alternative technologies were taken in 32 demonstration depots, the consumption of aluminium phosphide added up to 414.7kg. During fumigation with phosphine the consumption of Aluminium phosphide got to 2 279 kilogram. If the fumigation was carried out with methyl bromide, the consumption would be 5 156kg and the ozone layer would be damaged too. Obviously, there were significant environmental benefits linked to the application of alternative technologies in grain storage industries.

Social Benefit

There were three aspects to reflect social benefits when applying alternative technologies in grain storage industries. The first one was the reduction of consumption of chemicals and decrease of pollution into the environment. Therefore, Chinese industry protected man and environment from application of ozone depleting methyl bromide for protection of grain against insect pests. The second one was to avoid storemen from entering into granaries to open gas bottles or distribute phosphides and come into direct contact with fumigants. A side effect was the decrease of labor and an improved healthy situation for storemen. The last one was that the application of alternative technologies increased the scientific level in the grain storage industries, improved the application of toxic chemicals and ensures the sustainability of use of phosphine in grain storage industries by decreasing the risk of development of phosphine resistance. The described approach has ensured sustainable developments for pests control in Chinese grain storage industries and ensured

Chinese grain storage safety.

Factors Influencing the Use of Alternative Technologies

Four factors influenced the application of alternative technologies, such as the difference of application alternative technologies, such as the hardware condition (granaries and equipments), resistance of some grain storage pests, and the cost for investment.

Huge Difference of Application Alternative Technologies

All 32 demonstration depots improved their technique of applying alternative technologies for pest control in grain storage. However comparing all depots, there were differences concerning the application of alternative technologies.

The first difference was that many depots were very familiar with fumigation technologies with phosphine under film and fumigation technologies by combination of phosphine with carbon dioxide. The second one was that it was the first time for many depots to learn about and apply alternative technologies. Despite training by experts that had been sent to the local demonstration depots by the State Grain Administration, still some application techniques remained weak.

Constraints for Good Gumption Practice in Granaries and Equipments

Due to different conditions in each depot, especially concerning the age of some buildings, difficulties could be observed to keep up with maintenance. There were leakages in windows, doors and equipments leading to weak gas tightness performance and resulting in effects typical for bad fumigation. As examples there was leakage between films, windows and doors in the HuCun grain supply center of HanDan county and between centrifugal fans with silo in JunLiangCheng State grain reserve depot in TianJing.

Phosphine Resistance

During these validation experiments, some pests could not be controlled in few depots. There were two kinds of conditions, such as bad gas tightness performance leading to surviving adults and F_1 progeny. When only the F_1 generation was found alive, there could have been two main reasons, such as grain reinfestation after fumigation, accidental errors or others factors. For proper application of chemicals, several ways were recommended, such as the use of sleeves with phosphide products, increasing the daily efforts to prevent pest infestation by inten-

sified inspection and using traps and other devices, paying attention on pesticide resistance and strengthening inspection, especially to such grain storage pests with risk of high resistance as the rusty grain beetle.

Cost, such as Start-up Investment

There were many advantages for alternative technologies, such as decreasing labor intensity, improved pest control and preventing storemen from inhaling poisonous gas. However, it would take more start-up investment to apply these technologies by distributing lots of pipes, devices and apply other modifications. Meanwhile, during application of alternative technologies, it would be necessary that phosphine generators outside buildings should be equipped with carbon dioxide cylinders to decrease temperature during chemical reaction of the phosphide and prevent ignition before application chemicals. But in practice, many depots could not buy carbon dioxide cylinder in the local market, and it would have increased the application investment if they were bought in other places. All these constraints restricted the promotion and application of alternative technologies to some extent.

Prospects

By validation of the application technique and later evaluation of alternative technologies for phase out of methyl bromide in grain storage industries, it was shown that the alternative technologies was more appropriate, reasonable and competitive. Beside of economical, social and environmental benefits, there was technical support for the establishment of permanent mechanisms to phase out methyl bromide. However, in many depots the application of technologies was still weak, some strains of pests were resistant to pesticides, weak gas tightness granaries was observed, rules for the application of fumigants were missing or too simple. Therefore, the assistance project of phase-out of methyl bromide could be consolidated in many places. This could be enhanced by carrying out inspection on resistance and on technical support services. The relevant rules for good fumigation should be enacted as soon as possible and advanced pesticides and new technologies should be developed and promoted.

Reference

- 1 Fumigation regulation of phosphine recirculation, LS/T1201 - 2002, State Administration of Grain, China.