Navarro, S. and Donahaye, E. [Eds.](1993) Proc. Int. Conf. Controlled Atmosphere and Fumigation in Grain Storages, Winnipeg, Canada, June 1992, Caspit Press Ltd., Jerusalem, pp. 343-351.

DUCTING SYSTEMS FOR SILO FUMIGATIONS IN TIANJIN MUNICIPALITY*, CHINA

Rui SUN[1], Lianghua GUAN[2], Chengguang ZHANG[1], Chunhe LIU[1] and Jianhua LUI[1]

[1] Tianjin Grain Bureau, P.R. of China

[2] Tianjin Animal and Plant Quarantine Service, P.R. of China

ABSTRACT

The increased use of silos of different types and capacities for bulk grain storage in Tianjin, has required the development of various fumigation systems suitable for the specific types of silo in use. Five fumigation trials were carried out on the following types of storage facility. For brick silos of medium capacity using phosphine, six vertical distribution ducts were connected to a peripheral supply duct situated at the base, and connected via a supply duct to a phosphine generator outside the silo. For small silos of about 300 tonnes capacity, four vertical distribution ducts were positioned mid-way between the center and the periphery. The bottom of each duct was sealed and the top extended above the roof of the silo. Phosphine was applied by dropping the tablet or sachet formulations down the ducts. For small box-shaped brick grain tanks the four fumigation ducts were positioned diagonally and projected above the surface of the grain. Application was from within the tank, after which the fumigator exited the tank via a manhole. For large silos of 500 to 1000-tonnes capacity, circulation systems were installed for either methyl bromide application from cylinders using a heater, or phosphine from a generator. A peripheral supply duct at the rim of the cone fed six distribution ducts converging inwards and downwards to the base of the cone. A connecting duct linked the supply duct with the fumigant supply and the blower, and a closed duct leading outside the silo to the headspace. Fumigant application was upwards through the grain. Also, for large capacity silos, the ducting of a common aeration/fumigation system was used for circulation of methyl bromide applied in the headspace and distributed down through the grain bulk. All of the systems provided effective insect control.

---

* Tianjin Municipality is the third metropolis of China with a jurisdiction covering 5 counties and a population of about 9 million people.

INTRODUCTION

In recent years, many types of silos have been built in the Tianjin Municipality for storage of various grains under different conditions without fumigation facilities. This report describes the results of a selection of successful trials using different fumigation technologies. Fumigation facilities were installed in silos of different types and capacities, and different fumigation methods were adopted for each type of silo. The objectives were to find the most suitable fumigation method for each type of facility, thereby enabling the installation of suitable fumigation systems in old silos, and to propose scientifically-proven systems for the design of new silos. Fumigation in this report was limited to the use of methyl bromide and phosphine.

MATERIALS AND METHODS

Fumigation ducts

The fumigation duct is an essential part of the fumigation unit. It may serve either for fumigation only or for both fumigation and aeration. For the former use, it should have a relatively small diameter. It should suffice to handle 2 - 3 circulations of silo air volume per hour. The more commonly installed duct is larger and should be designed to meet the needs of the aeration system with an airflow rate of no greater than 12 m/sec in the main duct and no greater than 5 m/sec in branch ducts. Each silo should be equipped with a fan to supply air at a rate of 3 - 6 m^3/hour/tonne. The commonly used duct is placed peripherally. When used for fumigation, it should have a delivery rate of 1.5 m^3/hour/tonne. This necessitates careful choice of a suitable fan.

The fan

A centrifugal fan is used commonly for methyl bromide, while an explosion proof centrifugal fan should be used for phosphine application. Total pressure of the fan should be 10-20% greater than the resistance of grain to airflow and the friction loss in the ducts. Fan airflow rate should be 10-15% higher than at the exhaust duct.

Methyl bromide liquid heater

This is a unit required for low ambient temperature conditions. The heater should be sufficiently powerful to evaporate the liquid methyl bromide, and is adjustable for operation at temperatures between 30 and 80°C. At ambient temperatures above 16°C, the heater is not usually employed.

Phosphine generator or methyl bromide cylinder

The phosphine generator is a unit designed specifically for the production of phosphine to enable application of the gas through ducting into the grain mass. It consists of a reactor, vacuum pump, and ducting. The zinc phosphide and sodium carbonate is placed in the reactor together with some water. The pump is then activated to create a negative pressure inside the reactor, after which sulphuric acid is poured in slowly using a funnel. After the reaction, the vacuum pump is run to draw the phosphine from the reactor through the ducting into the silo.

Methyl bromide is supplied in liquid form in cylinders.

Insect control

To monitor insect mortality in the trials described below, cages containing 20 adult *Sitophilus oryzae*, 20 adult *Rhyzopertha dominica*, and 20 adult *Tribolium castaneum* were placed in the grain mass before fumigation, and removed 48 hr after fumigant application. Cages of unexposed insects served as control.

RESULTS

Trial 1 - Fumigation from peripheral ducts

This trial was carried out to exemplify the treatment of small silos of 7 m or less in diameter. Six vertical, perforated, plastic distribution ducts (having 224 perforations per duct), were positioned equidistant from one another, and branched off from the peripheral supply duct that circumscribed the inner vertical wall at the base of the silo at the junction with the cone. Both the supply duct and distribution ducts were 3 cm in diameter. The grain bulk was approximately 10 m high, whereas the distribution ducts were 8 to 9 m high, set close to the walls, and capped at their ends. The supply duct was joined by a connecting duct to the phosphine generator situated outside the silo (Fig. 1). Phosphine concentrations were measured using Dräger tubes. Results of the trial are given in Table 1.

Table 1: Phosphine concentrations (mg/m^3) after fumigation of a brick silo containing 150 tonnes of wheat (Zn_3P_2 dosage was 3g/m^3 in headspace and 5g/m^3 in grain mass).

	Time after application (hr)									
Depth (m)	5		29		51		102		150	
from surface	center	side	center	side	center	side	center	side	center	side
0.5	1500	2000	90	200	50	50	20	10	10	10
2.5	2000	2000	1000	100	50	70	50	50	10	0
4.5	2000	2000	1000	200	50	50	10	10	10	0
6.5	2000	2000	1000	500	50	20	10	20	10	10

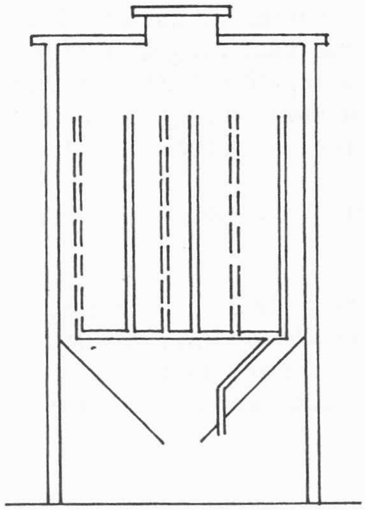

Fig. 1: Vertical view of peripheral perforated plastic distribution ducts and the supply duct for connection to the phosphine generator.

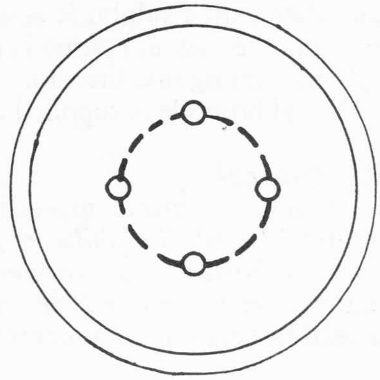

Fig. 2: Non-peripheral fumigation duct composed of four 10-cm diameter ducts spaced mid-way between the perimeter and the center of the silo

Table 1 shows that in the small silo, due to natural diffusion, the phosphine gas became uniformly dispersed within the bulk after 5 hr. Because the duct system was close to the inside walls of the silo and was less than 5 cm in diameter, it was not easily damaged by grain movement during loading and unloading. Furthermore, the system was easy to install and because the applicator was outside the silo and did not involve the use of a fan, the system gave good results with the advantages of safety and economy.

Trial 2 - Non-peripheral fumigation duct system

This system is suitable for small silos with a capacity of about 300 tonnes. In these silos, four ducts 10 cm in diameter were spaced equally mid-way between the perimeter and the center of the silo (Fig. 2). The bottom end of each duct was sealed, while the upper outlets projected above the roof and were equipped with a sealed cap that could be opened when needed. In this system, the dosage was administered either by dropping sachets of aluminium phosphide (AlP) down the ducts or by using a phosphine generator. Because the distance between the ducts was shorter, uniformity of gas distribution was greater. The larger diameter of ducting enabled slow release from the generator of low concentrations of phosphine through the duct perforations and retention of phosphine within the grain bulk for a longer time. Alternatively the application could be carried out by the usual method with sachets dropped into the ducts.

Table 2: Variations in phosphine concentration (mg/m^3) in brick silo containing 300 tonnes of wheat (AlP dosage was $3g/m^3$ in headspace and $7g/m^3$ in grain mass).

	Time after application (hr)					
Depth (m)	25		67		142	
from surface	center	side	center	side	center	side
0.5	40	60	1500	2000	30	30
2.5	40	50	2000	2000	1500	2000
4.5	2000	50	2000	2000	2000	2000
6.5	2000	50	2000	2000	2000	30

A further advantage of this system is that the application of the fumigant is from above the silo roof. However, because the ducting is distant from the silo wall, it is more easily damaged during unloading and suitable measures must be taken to strengthen the ducts.

Trial 3 - Non-peripheral fumigation ducts for grain tanks.

The same method as in Trial 2 was adopted for use with small box-shaped grain tanks constructed of brick with cement lining and of an approximate 200 tonne capacity. The four fumigation ducts were positioned diagonally (top view, Fig. 3) and projected above the surface of the grain bulk. A manhole positioned at the top of the side-wall enabled the operator to drop the sachets inside the ducts, place the covering cap and then exit the tank via the manhole.

Trial 4 - Circumferential fumigation duct system

This system is suitable for medium to large silos of a 500 to 1,000-tonnes capacity. It consists of fumigation ducts, blower, methyl bromide liquid heater, or phosphine generator. The ducting was composed of three elements: 1) The supply duct: a peripheral duct installed at the base of the silo at the junction between the vertical wall and delivery cone. Six distribution ducts converging inwards and downwards from the peripheral duct with their ends surrounding the unloading chute at the base of the cone. 2) Circular connection duct, connecting the peripheral duct with the silo exterior where it branched into two arms, one leading to the circulation fan (blower), the other to the MB cylinder or phosphine generator (Fig. 4). 3) Vertical closed duct leading from the inlet side of the blower up the outer wall of the silo, and into the headspace of the silo where it was suspended from the roof, terminating in a "shower" nozzle above the grain.

The fumigant was released into the peripheral duct and via the radial ducts into the grain, where it diffused upwards and was sucked through the upper nozzle back to the blower in a closed circulation system. Flow rate of the fumigant was 350 m^3/hr.

This system for use with large silos is effective, economical, and safe. However, if circulation is used insufficiently, then it takes a longer time for the fumigant to disperse throughout the grain mass and concentrations are higher at the base of the silos (as shown in Table 3). The duct system must be reinforced to protect it from damage during unloading.

Table 3: Methyl bromide concentrations (g/m^3) due to insufficient recirculation after fumigation of a concrete silo containing 1,000 tonnes of wheat (MB dosage was 25g/m^3 in headspace and 50g/m^3 in grain mass).

Depth (m) from surface	Time after application (hr)							
	25		52		70		85	
	center	side	center	side	center	side	center	side
1	4.5	4.8	8.8	7.8	4.6	4.5	3.7	4.8
13 - 14*	6.8	4.6	13.0	7.3	4.4	3.7	5.3	4.5
27 - 29*	35.2	7.3	18.2	6.8	7.8	4.0	6.8	5.4

* 14 and 27 m depth at center; 13 and 29 m depth at side

Trial 5 - Fumigation and aeration system with common supply duct

This system is also based on a circumferential arrangement and is suitable for all kinds of silos. The circular supply duct is installed outside the lower cone with a diameter 60% that of the inner diameter of the silo. Six small connecting ducts, positioned equidistantly around the supply duct, penetrate the silo and connect with distribution ducts installed radially on the inside of the cone. (Fig. 5). A vertical recirculation pipe is installed as in Trial 4 (Fig. 4). MB is forced up the vertical duct and released into the head-space via the nozzle. It then distributes down through the grain bulk and recirculates via the distribution ducts at the base of the silo. This enables rapid dispersal of the fumigant and uniform distribution of the fumigant after approximately one hour (Table 4). The common fumigation/aeration system can be converted rapidly to aeration purposes. Since the supply pipe is positioned outside the silo, it is not susceptible to damage during unloading and is also easily installed and convenient to repair. Flow rates for fumigation are 1.5 m^3/hr/tonne, and for aeration, 6 m^3/hr/tonne.

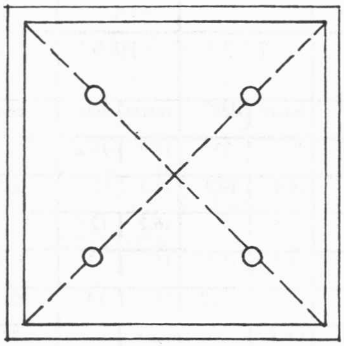

Fig. 3: Top view of non-peripheral fumigation ducts for grain tanks. Four fumigation ducts positioned along diagonal lines.

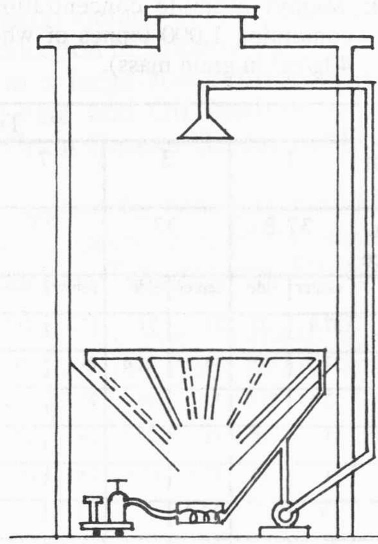

Fig. 4: Vertical view of circumferential fumigation duct system showing the MB generator and circulation system.

DISCUSSION

1. The five fumigation systems described above are suitable for silos of different types and capacities. All of the trials produced 100% mortality of the stored-product insects tested. Based on criteria of durability, ease of operation, efficiency and low cost, the most effective system was the "fumigation and aeration system with common supply duct".

2. For small silos, if the only problem is fumigation, then the fumigation system with peripheral ducts of Trial 1 is the most efficient due to its ease of installation and low risk of damage during unloading.

3. The choice of flow rate is most important. If the flow rate is too low, it will take too long for the fumigant to distribute through the bulk, whereas excessive flow rates are uneconomical. Key points to consider are the flow rate that should be 1.5 m^3/hr/tonne and a silo volume replacement rate of 2-3 times per hour.

4. Common fumigation/aeration systems should be designed according to the aeration requirements. In particular, care should be taken when selecting the fan capacity. For fumigation, a centrifugal fan (Model CQ 18) was used with a flow rate of 600m^3/hr. For aeration a centrifugal fan (Model 4-72-12 3.6A) was used with a flow rate of 1,930 - 5,480 m^3/hr.

Table 4: Methyl bromide concentrations (g/m^3) after fumigation of a concrete silo containing 1,000 tonnes of wheat (MB dosage was $15g/m^3$ in headspace and $40g/m^3$ in grain mass).

Depth (m) from surface	Time after application (hr)													
	1		3		7		12		24		48		48 hr Ct product	
1 m in headspace	37.8		33		31		24		27.3		19.9		1176.9	
	center	side	center	side	center	side	center	side	center	side	center	side	center	side
1	37.8	33	33	31	27.3	27.3	21.9	22.5	21	22.5	19.9	16.2	1098.4	1072.5
3	33	33	30	32.6	29	29	18.8	18.8	19.9	19.9	16.2	15	1052.1	1005.5
5	32.6	32.6	30	29	25.2	25.2	19.9	23	15.5	17	16.2	12.5	927.95	917.1
7	31	29	32	27.3	24	21	18.8	23	16.2	15.5	15	13	899.4	874.9
9	31	30	27.3	27.3	23.5	23	20	17	17	16.2	15	14	905.65	849.5
10.5	29		27.3		24		17.2		15.5		12.5		775.1	
average	32.48		30.82		25.79		20.41		18.53		15.45		962.92	

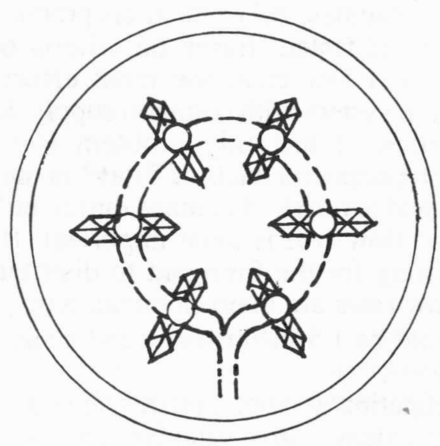

Fig. 5: Top view of a fumigation and aeration system with a common supply duct, showing 6 perforated metal ducts connected to a distribution duct.

REFERENCES

Anon (1983) A test on phosphine fumigation method in brick silos. Dazhigue Pujidao Grain Storage (Local publication in Chinese).

Anon (1986) A methyl bromide test in a large-size reinforced bar silo. Junliangchen Mill of Tianjin, Grain and Oil Institute of Tianjin, Experimental center of Tianjin Grain Bureau (Local publication in Chinese).

Anon (1991) A report on common-duct system for fumigation and aeration for cooling grain and controlling insects in medium sized silos. Tanggu District Grain bureau of Tianjin, Tanggu Grain Storage (Local publication in Chinese).

USDA (1984) Plant protection and quarantine treatment manual. Hyattsville, Md., U. S. Dept. Agriculture, Animal and Plant Health Inspection Services.