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NEW DEVELOPMENTS IN THE FUMIGATION OF BULK AND BAGGED GOODS IN-TRANSIT

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ABSTRACT

The concept of using the time that goods are in-transit while travelling from port of origin to port of destination has for many years been recognised as both an opportunity for insect infestation to develop and an opportunity for insect extermination to be carried out.

Both phosphine and methyl bromide have both been widely used for many years but with methyl bromide due to be phased out shortly under the United Nations Montreal Protocol Agreement, phosphine is becoming even more widely used. However standards in respect of safety and efficacy currently vary very greatly throughout the world.

This paper describes how the members of a group of companies directly involved in these treatments have developed new technologies and application methodology to provide greater safety and greater efficacy of treatment. The paper describes work that has evolved from that described in earlier papers from the group, and in particular the development of the use of cylinderised phosphine and very deep probing.

INTRODUCTION

With increasing demands throughout the world for improved standards of food safety the requirement to deliver food free of infestation has also increased. However the extent of the demands have also increased, and now the requirement is not only for freedom from infestation, but also for zero or very low residues, no health risks, and no increase in costs.

For many years the treatment of bagged and bulk grain cargoes transported between countries has been carried out in a traditional manner that evolved to meet the requirements of the seller. There is now a need to change this concept in order to meet the increased demands of the buyer and end-user.

Another issue that has arisen, is that in addition to these increased demands, methyl bromide (MB) is to be phased out over the next few years and it will be necessary to replace current MB fumigations with effective alternatives. Phosphine (PH_3) can replace most uses of MB for ship and in-transit fumigation provided the procedure for the PH_3 fumigation is specified correctly, and the specification strictly adhered to by the fumigator (Watson *et al.* 1999).

Conventional treatments

When loading grain, the seller or shipper normally carries out a treatment to try to ensure that any insects found during loading will be killed, and also that live insects will not be found when the vessel arrives at the discharge port. These treatments may be carried out with a residual insecticide, by MB fumigation, or by PH_3 fumigation.

The disadvantages of residual insecticides are that they are only effective when the stored-product insects emerge from the grain and come into contact with residues of the insecticide that have been sprayed on to the grain. This means that some immature stages may still be alive on arrival at the discharge port because they have not yet emerged from within the grain.

Both MB and PH_3 are fumigants, which act in a gaseous state and can provide a quick kill of adult insects. However to kill all developmental stages it is essential to achieve an even distribution of gas throughout the cargo and to maintain a lethal concentration for a long enough period, once this has been achieved. The concentrations and exposure periods of PH_3 required to control different insect species at different temperatures are well documented (Hole *et al.,* 1976), as are those necessary to kill all stages of mite infestations (Wilkin *et al.* 1998).

Failure to comply with the above requisites is the reason why most in-ship fumigations fail to kill all stages of the insects present. They fail either because gas distribution is poor, or where it is satisfactory, the gas is not retained in all areas for a sufficient duration (Leesch, *et al* 1986). This information has been available for many years but was largely ignored by exporters because to carry out a fully effective fumigation is perceived to be more expensive. Therefore because the exporters only require that the cargo be accepted at the discharge port, the fumigation is often arranged with this key objective in mind. For example aluminium phosphide applied to the surface or only to the top few meters of a bulk of grain will result in a very thorough fumigation of grain near the surface but very little fumigation of grain in the lower part of the bulk (Leesch *et al.* 1986, and Tables 1 and 2). Much other evidence has been produced to demonstrate the unevenness of gas distribution (Redlinger *et al.* 1986), and this is shown in Fig. 1. However, in terms of achieving the exporters' limited objectives of no live insects being visible on grain at the discharge port, this type of fumigation is generally acceptable, and is usual practice.

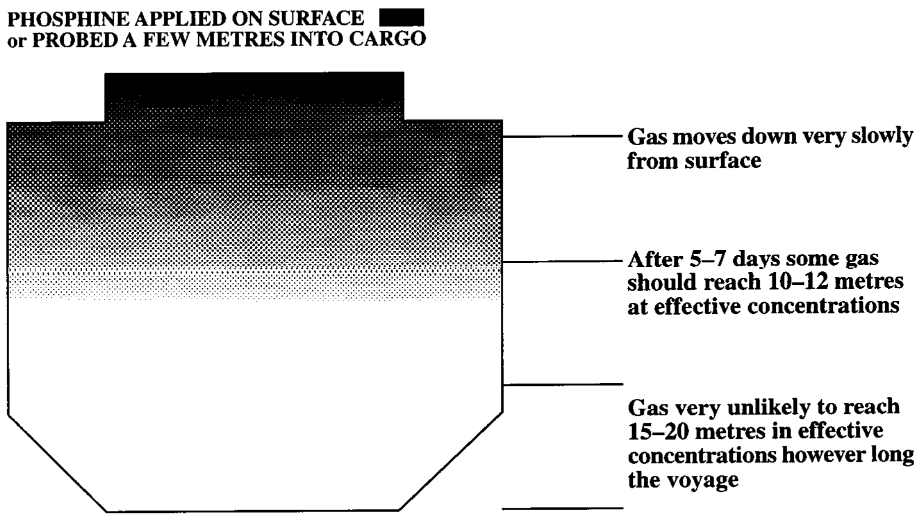

Fig. 1. Traditional fumigation of cargo in ships hold using phosphine.

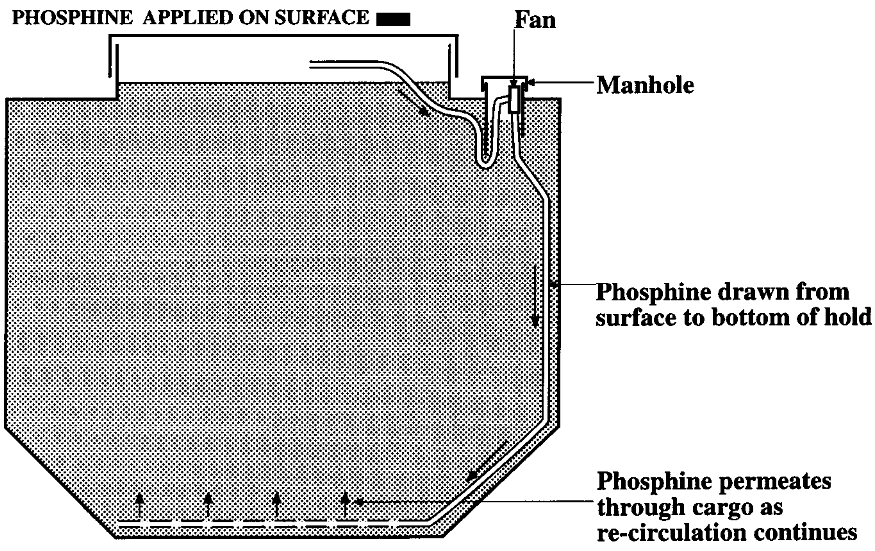

Fig. 2. Fumigation of cargo in ships hold using phosphine and the J. system.

Is it possible to achieve a fully effective in-transit fumigation of goods?

In 1994 a group of independent fumigation companies located in different parts of the world drew up a protocol to work together as the International Maritime Fumigation Organisation (IMFO) to address these issues. The objective was also to take into account the many variables, which existed world-wide, though the factors in common were:

(i) A ship's hold can be an excellent fumigation chamber if it can be made gastight.

(ii) A lot of research had been carried out by well-respected government laboratories throughout the world, on the movement and distribution of fumigants, and on the concentrations necessary to eradicate a wide range of pests at different temperatures, though most of this research is ignored by exporters when specifying fumigation.

(iii) In some countries, systems which provided an excellent distribution of fumigant were already available (e.g. Degesch re-circulation J System in Europe and USA) while in other countries they were not available.

(iv) Control of the fumigation once it leaves the load port is largely ignored. Responsibility for satisfactory completion of the fumigation during the voyage and ventilation at the discharge port is generally left to the master of the vessel.

(v) Safety: In some countries (e.g. Canada) the safety recommendations and regulations set out by the United Nations International Maritime Organisation (Latest recommendations published 1996) are strictly adhered to. In many others, they are often ignored.

What does the receiver or end user of the cargo want?

The receiver does not want to receive live infestation at any time but especially from imported cargoes. This is because imported cargoes may contain species or strains that are not present in the receiving country. For example, as insect tolerance and resistance to PH_3 becomes more widespread in some Asian and African countries, it is especially important that these insect strains are not allowed to enter countries where resistance is not present. In addition, in many countries the food processing companies will not accept commodities that show any sign of live infestation. In the UK for example most food production companies including flour millers, have a zero insect tolerance policy.

Therefore, the objective of the group (IMFO) was to provide the receiver or end-user with the opportunity to specify in which way the cargo is to be treated so that all live infestation be eradicated, with little or no detectable insecticidal residues remaining, and that procedures would be used to ensure safety to the crew and to all those involved in discharging the vessel

DEVELOPMENT WORK

It was decided that various methods of fumigation were needed to address various situations, and some of this work has been reported in previous papers. This paper reports on the following subjects:

1. Comparison of re-circulation method with two passive fumigation systems
2. Use of cylinderised phosphine
3. Deep probing technology

1. Comparison of powered re-circulation fumigation system with two passive systems for the phosphine fumigation of a bulk grain cargo

Objective

An in-transit PH_3 fumigation trial was carried out jointly by Igrox Ltd. of the UK and the Cyprus Grain Commission in March–April 1999. The objective was to assess the relatively efficacy of the Degesch powered re-circulation (J System) for PH_3 fumigation compared to a normal passive PH_3 fumigation, and also to make an assessment of the relative ease of ventilation of the systems.

Methods

A five hold vessel (The M.V. Maganda) that had been chartered to carry 24,000 tonnes of feed barley from UK to Cyprus was selected. The grain was characterised by the following parameters: moisture content 14.0%, test weight 66.8 kg/hL, foreign matter 1.9%, and temperature 17ºC.

The five holds were treated as set out in Table 1, and as follows:

Hold 1 – Aluminium phosphide applied as Detia ExB sachet strips to the surface of the grain at an application rate of $1.0 g/m^3$.

Hold 2 – Aluminium phosphide applied as Detia ExT tablets to the surface of the grain at an application rate of $1.5 g/m^3$.

Hold 3 – slack – ExB sachets to the surface of the grain at $1.0 g/m^3$ + J System

Hold 4 – Detia ExT tablets to the surface of the grain at $1.5 g/m^3$ + J System

Hold 5 – Detia ExB sachets to the surface of the grain at $1.0 g/m^3$+ J System

All holds except hold 2 were in fact fitted with the J System (see Fig. 2) but it was only used in holds 3, 4 and 5 to assist the fumigation during the voyage. It was also used to assist ventilation prior to discharge in holds 1, 3, 4 and 5, in Cyprus.

All holds except hold 3 were subjected to bioassay in which adult insects only were placed in the grain bulk. Bioassays with *Trogoderma granarium* also contained some larvae. Gas concentrations in the holds were recorded during the voyage by the Chief Officer using an Agridox Phosphine Monitor (electro chemical cell method) as set out in Table 2.

TABLE 1
Application of J-System* technology for fumigation of a cargo in transit M.V. Maganda, Cardiff – Limassol March – April 1999

Parameter	Hold 1	Hold 2	Hold 3	Hold 4	Hold 5
Kind of fumigant	Aluminium phosphide	Aluminium phosphide **	Aluminium phosphide	Aluminium phosphide	Aluminium phosphide
Form of fumigant	Sachets strips	Tablets	Sachets strips	Tablets	Sachets strips
Rate of insecticide. (g of a.i./m^3)	1,0	1,5	1,0	1,5	1,0
Quantity of insecticide (kg)	21	34	23	34	22
Hold capacity (m^3)	7205	7604	7604	7604	7529
Grain quantity in holds, (tonnes)	5304 Fill	5597 Fill	1960 Slack	5597 Fill	5542 Fill
Installation of Fan & Pipes in the hold	Yes	No	Yes	Yes	Yes
Running of fan during transit (re-circulation)	No	No	Yes	Yes	Yes
Installation of air drawing pipes for monitoring Phosphine	Yes	Yes	Yes	Yes	Yes
Depth of air drawing below the grain surface in holds (m)	2 - 12	2 - 12	2 5 -	2 5 12	2 5 12

* The J-System technology is a Detia-Degesch (Germany) patent and includes an application of Phosphine in tablet or sachet strips on grain surface in combination with re-circulation of phosphine-air mixture inside a sealed hold during transit.

** The first 2000 tonnes of grain in hold 2 were treated with 12mL/tonne Actellic in addition to Phosphine.

Date of phosphine application: 28.3.99
Date of opening and ventilation of holds: 9.4.99
Date of count the survival of insects in bioassay tubes: 15.4.99
Duration of treatment of insects with phosphine during transit: min 12 days (326 hours)
Trogoderma granarium was in the larval stage

TABLE 2
Phosphine concentrations in ppm at different depths in the holds during transit

Date of measurement	Time of monitoring Phosphine (hours after application)	Depth of measure ment below surface m	Hold 1 Phosphine Strips No re-circ 1.0 g m^3	Hold 2 Phosphine Tablets No re-circ 1.5 g m^3	Hold 3 Phosphine Strips Re-circ 1.0 g m^3	Hold 4 Phosphine Tablets Re-circ 1.5 g m^3	Hold 5 Phosphine Re-circ 1.0 g m^3
		2	39	94	88	2000	336
28.3.99	36	5			0	198	145
		12	0	0		8	165
		2	29	152	104	1552	158
30.3.99	84	5			92	1564	173
		12	0	0		188	96
		2	10	698	141	645	118
1.4.99	132	5			122	653	104
		12	5	8		688	92
		2	28	612	121	588	94
3.4.99	180	5			135	614	91
		12	8	14		641	96
		2	138	468	113	509	89
5.4.99	228	5			126	520	93
		12	14	39		542	92
		2	185	114	86	525	118
9.4.99	326	5			91	522	120
		12	58	56		522	127

Results

1. All insects in all holds (except some *Trogoderma* granarium in hold 1) were dead, (Table 3).
2. The PH_3 concentrations in Holds 3, 4, and 5 were very uniform after a few days and remained so throughout the voyage, (Table 2).
3. The PH_3 concentrations in holds 1 and 2 remained very non-uniform throughout the voyage, (Table 2).
4. After 3.5 days there was still no PH_3 at 12 m in holds 1 and 2. Eventually some low levels of gas (max 57 ppm) did reach 12 m and bioassay showed that this was sufficient to kill the adult insect-pests, (Table 2).

Ventilation

Unfortunately the measurements that were planned to be taken during the ventilation process could not be carried out for operational reasons. However it was observed that ventilation was completed more quickly, easily and safely where the ExB sachets and J System were used, compared to where the ExT tablets were used. Nevertheless a satisfactory method of safe removal and disposal of the residues whether from sachets or tablets, remains a requirement for the Cyprus Grain Commission.

TABLE 3
Survival of adult-stage insects at different depths in the holds at the end of transit (Bioassay)

Location below grain surface (m)	Origin of insect strains	Insect species	Hold 1 Phosphine Strips No-Recirculation		H old 2 Phosphine Tablets No-Recirculation		Hold 4 Phosphine Tablets Recirculation		Hold 5 Phosphine Strips Recirculation	
			Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead
2	Cyprus	*Sitophilus* spp	0	147	0	84	0	209	0	63
		R. dominica	0	22	-	-	0	5	0	4
		Tribolium spp.	0	185	0	191	0	151	0	74
		O. surinamensis	0	59	0	179	0	42	0	77
		*T. granarium**	4	23	0	36	0	51	0	50
	UK	*Sitophilus* spp	0	174	0	321	0	93	0	302
		R. dominica	0	60	-	-	0	33	0	8
12	Cyprus	*Sitophilus* spp	0	144	0	113	0	233	0	90
		R. dominica	-	-	-	-	-	-	-	-
		Tribolium spp.	0	148	0	400	0	318	0	254
		O. surinamensis	0	75	0	58	0	21	0	86
		*T. granarium**	-	-	-	-	0	86	0	118
	UK	*Sitophilus* spp	0	249	0	169	0	242	0	254
		R. dominica	0	50	-	-	0	69	0	81

**Trogoderma granarium* was in the larval stage

Conclusions

The Degesch powered re-circulation method (J System) clearly provides a much more efficient method of distributing PH_3 gas evenly through a cargo in a ship hold then a passive system. The results of this test confirm earlier work by others (Leesch, *et al.,* 1986; Redlinger *et al.* 1982). The concentrations achieved at 12 m in Holds 1 and 2 were not sufficient to kill eggs and juvenile stages of most stored-product insect species.

The concentrations achieved at all depths in holds 3, 4 and 5 were sufficient to control all stages of all stored-product insects (Hole *et al.* 1976).

Further work needs to be carried out to verify the efficacy of ventilation prior to discharge to ensure the safety of workers handling the cargo. Clearly a system (J System), which distributes the gas efficiently in the hold is likely also to assist in the rapid removal of gas from the hold by re-circulating fresh air through the cargo. The removal of PH_3 residues by re-circulating fresh air through the cargo is easier when PH_3 strips have been used instead of tablets because the strips can be completely removed and taken away from the hold. Safe handling and disposal of aluminium phosphide residues remains a problem for receivers of fumigated cargoes. The shorter the voyage, and the lower the grain temperature, the larger is the problem with the handling and disposal of aluminium phosphide residues from both types of phosphine formulations (either tablets or retrievable strips). In this situation serious problems may occur with grain handling during and after discharge, particularly if metal phosphide tablets have been inserted directly into the grain.

Acknowledgements
We thank the Master, Chief Officer and crew of the M V MAGANDA, and the Charterers Glencore UK, for their cooperation and help, and we recognise the assistance provided by The Cyprus Grain Commission staff in Limassol, and the Igrox staff in UK. (A. Varnava - Cyprus, C.R. Watson - UK)

2. Fumigation of cargo in ship holds using cylinderised phosphine

Phosphine in a ready to use gas mixture in cylinders for fumigation of food commodities is now available in some parts of the world. In Australia and the USA a mixture of PH_3 and CO_2 (ECO_2FUME) has been developed and marketed. In Germany a gas mixture of PH_3 and N_2 (FRISIN) has been developed by IMFO members S & A GmbH of Hamburg, who are currently using the product widely in Germany. At the present time Frisin is the only cylinderised phosphine product approved for use on commodities and other foodstuffs anywhere within the EU, although it is only currently approved in Germany. Each cylinder of Frisin holds 10 m^3 of gas mixture, containing 250 g of active PH_3.

The key benefits of Frisin for general commodity use are as follows. The active agent PH_3 is directly available. The specific weight of Frisin provides a 1:1 proportion with air and tests have shown that the gas mixture is distributed rapidly and homogeneously through any bulk commodity if application pipes are inserted correctly. Effective dosage levels can be much lower than with conventional aluminium phosphide or magnesium phosphide methods of fumigation. Additional PH_3 can be added easily and safely during the fumigation if monitoring shows it to be necessary. The use of Frisin makes the development of resistance to PH_3 far less likely because accurate dosing of all the commodity is possible. This contrasts with conventional methods where often gas distribution is very uneven resulting in frequent survival of juvenile stages of insects in pockets of low gas concentration. This survival of more tolerant individuals to PH_3 can lead to resistance. There are no solid carriers involving the need to dispose of powdery residues on completion of fumigation as is the case with conventional methods. Ventilation can be rapid and efficient because the gas is evenly distributed in the goods. The process enables only the minimum requisite amount of fumigant to be used because dosing can be accurately controlled.

When the use of Frisin for fumigating commodities in ships holds was considered by "S & A", a number of potential areas in which Frisin would be advantageous over conventional phosphine in-transit methods were addressed:

(i) The PH_3 could be released into the hold in such a way that an even and homogeneous distribution of the gas could be achieved within a few minutes. This would allow checks for leakage to be carried out immediately and with confidence that if any leakage might occur it would be immediately detectable. This procedure contrasts with conventional methods (unless a powered re-circulation system is used) where it may take at least several days for the PH_3 to penetrate to some parts of the hold and therefore the initial leakage checks carried out before sailing may be misleading.

(ii) As the PH_3 will be homogeneously mixed throughout the hold and provided that the concentration is sufficient and leakage does not occur, an efficient kill of all insects in all parts of the hold can be expected. This contrasts with traditional in-transit fumigation methods (unless a powered re-circulation system is used) when often in deep holds little if any PH_3 ever reaches the lower parts of the hold (Leesch *et al*. 1987).

(iii) The PH_3 can be applied on completion of loading without having to reopen the ship holds; consequently there will be no delay to the ship sailing due to wet weather delaying the fumigation.

(iv) Before or on arrival at the discharge port, ventilation of the cargo can be carried out safely and efficiently because there are no solid carriers (powdery residues of tablets or blankets etc) to dispose of, and the gaseous mixture (N_2 and PH_3) that is spread evenly through the ship's cargo can be easily and rapidly dispersed *via* the ship's own ventilation system.

Because of these perceived benefits "S & A" have developed a methodology for applying Frisin to cargoes in ships holds by placing flexible tubing in the hold prior to loading and they are currently treating cargoes being loaded in Germany using this method. To date eleven vessels destined for Middle East and Baltic ports have been treated and no problems with insects, residues, ventilation, safety or environmental concerns have been reported. Efficacy tests are continuing and will be reported on at a later date. (W. Szemjonneck - Germany, C.R. Watson - UK)

3. Development of the deep probe

Description of the method

The technique that has been designed and developed by Adalia Preventive Services Ltd., Canada and involves a technology that makes it possible to fumigate high volumes of grain from 1,000 to 100,000 tonnes or more without moving the grain. This efficient and safe technique allows for rapid distribution of the aluminium phosphide (ALP) fumigant in solid or gaseous form, through the mass of grain.

System Components

The system is composed of 3 elements (Fig. 3).

1. The Platform, constructed of aluminium with hydraulic or mechanical propulsion which reduces the physical effort and increases probe penetration.

2. The Probe. Two types of probe have been designed. The first is made of aluminium, ~ 2 inches (50 mm) in diameter, for very deep fumigant application. It can also be connected to a re-circulation system. The second is made of plastic, ~ 3

inches (75 mm) in diameter, and is used for silos and ship fumigation with re-circulation. Both probes have a special head design to maximize performance.

3. The Vacuum system. This enables the probe to penetrate very deeply without too much stress, and when combined with the hydraulic system of the platform enhances the system's performance.

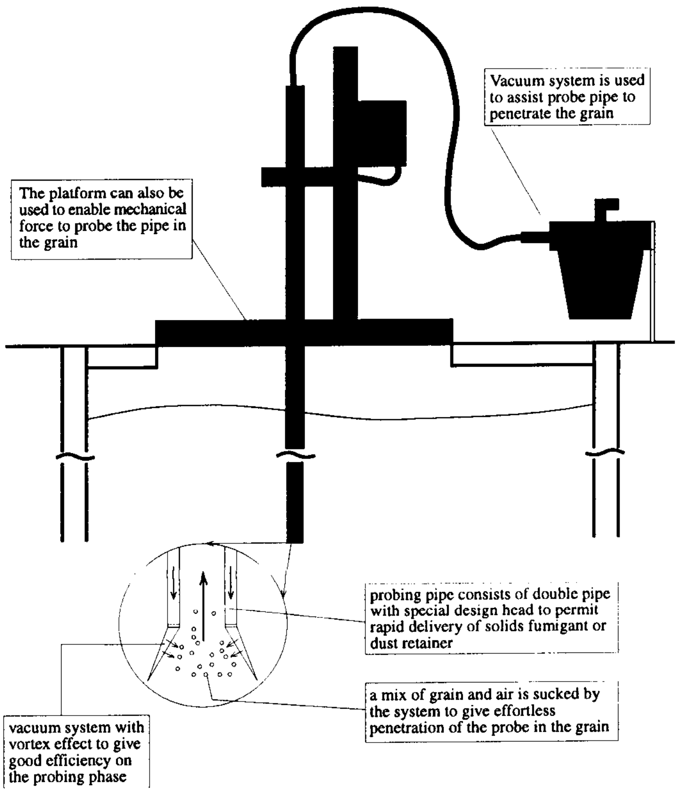

Fig. 3. Fumigation using deep probing system.

When the probe has reached the desired depth, the fumigant tablets or pellets are then gradually discharged as the probe reverses upward and out of the grain (Fig 4).

Silo fumigation using the deep probe and solid aluminium phosphide

Table 4 and Fig 5 present the results of the fumigation of silo No. 423 in the port of Montreal. Capacity of this silo is about 800 MT or 1,390 m^3, and with a depth of 30.5 m. The dosage applied was ~ 1.44 g/m^3, of PH_3 and the grain temperature was ~ 18°C.

The Aluminium phosphide formulation, (pellets), was applied to the grain between depths of 2 m to ~ 18 m below the surface. The experimental results reveal the movement of PH_3 in the silo and demonstrate that lethal concentrations were achieved throughout the full depth of the bulk.

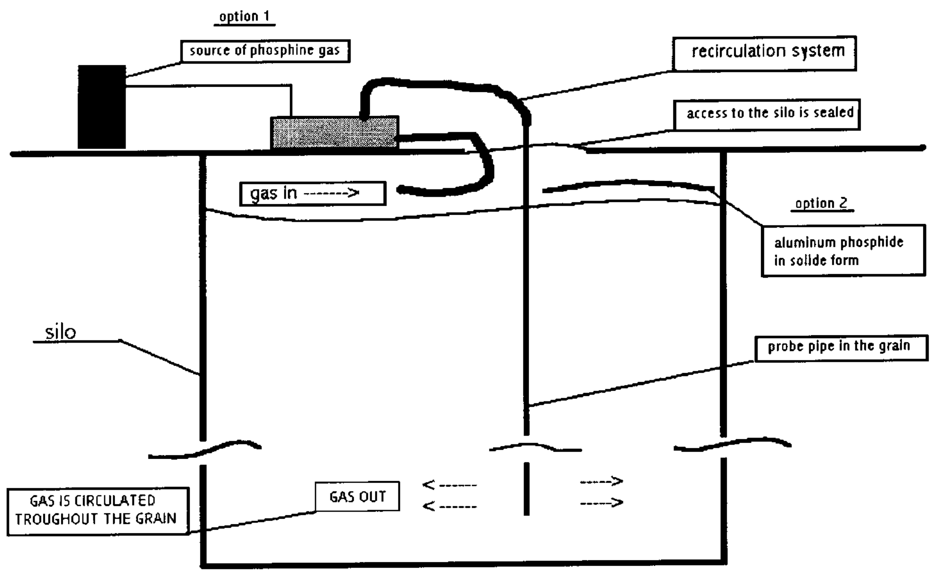

Fig. 4. Fumigation of silo or hold using deep probing and recirculation.

Application using re-circulation

The probe can also be connected to a re-circulation system for faster and residue-free fumigation; in this case the fumigant will be applied on top of the grain either as aluminium phosphide in a solid formulation, or possibly in the future with PH_3 from a generator, or cylinders such as ECO$_2$FUME. ECO$_2$FUME is a cylinderised mixture of 2% PH_3 and 98% CO_2 that has been developed and marketed in Australia and the USA. The mixture is used in Siroflo® and Sirocirc® systems for fumigation of grain in silos and flat stores in Australia, Cyprus, USA, China, New Zealand and in some other countries. Trials with ECO$_2$FUME for fumigation of grain in-transit have been carried out in Canada (Fields and Jones 1999).

TABLE 4
Phosphine fumigation at 1.44 g/m^3 of Canadian red spring wheat in a 800 tonne capacity silo in the port of Montreal

Time in days	Concentration in ppm / Depth				
	surface	6 m	12 m	18 m	27 m
1	100	500	500	500	180
2	485	1500	2400	1500	500
3	650	3000	2400	1800	380
4	1000	3000	2000	400	500
5	1000	2700	1500	500	500
6	1000	1800	1200	800	500
7	900	1500	1200	700	500
8	800	1500	1200	450	450

Temperature of grain: ~ 18°C

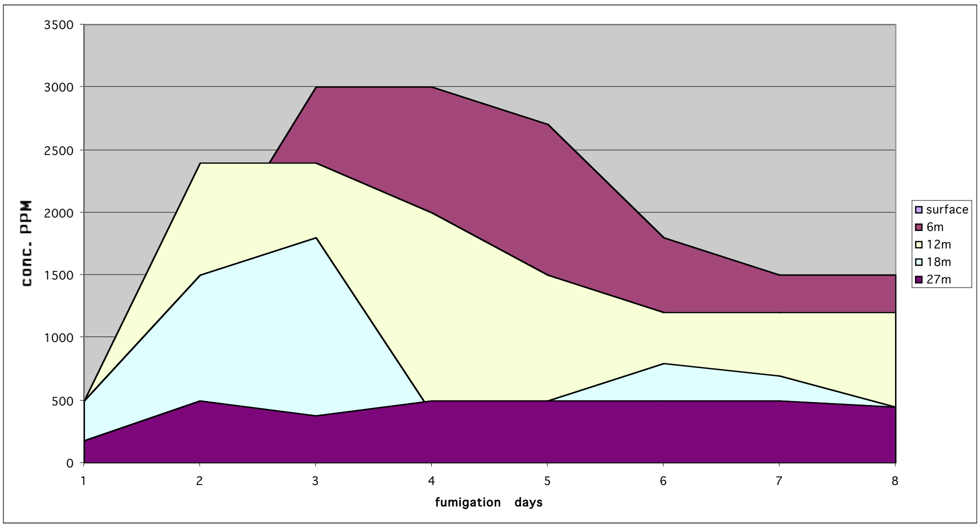

Fig. 5. PH_3 concentrations over time during fumigation of Canadian red spring wheat at 1.44 g/m^3 in a 800 tonne capacity silo in the port of Montreal.

Ship fumigation

Re-circulation has been developed and used for efficient fumigation of high volumes of grain for many years (Degesch J System). Normally this technique involves fitting the re-circulation system before the grain is loaded in to the silo or ship hold. The new 'Deep Probing' technology allows effective treatment to be carried out after loading has been completed either by inserting solid aluminium phosphide throughout the full depth of the cargo (as previously described) or by a variation of the re-circulation method which is in development. It consists of inserting probes after loading is completed and linking them to a re-circulation system (Fig. 5). The method is highly effective where extreme conditions are involved such as in short transit times or for quarantine fumigation. This new technology will be used in conjunction with one of the new PH_3 generators or with PH_3 from cylinders. The development of this technology is on-going. (D. Bureau - Canada)

New methodology – United Phosphorus / CSIRO generator

United Phosphorus Ltd (UPL) in conjunction with CSIRO (Australia) and Pest Control M. Walshe (PCMW) of India have developed a 'Phosphine Generator' enabling PH_3 to be produced instantaneously from aluminium phosphide tablets. The Generator is being patented by UPL. The first commercial trials were carried out in India in December 1999 and results were very encouraging. CSIRO have developed a formulation, which allows PH_3 to be generated at a controlled rate. Rates between 1 g/h for 16 d to 500 g/h for 8–10 h have been successfully generated in trials. Further work and detailed results will be reported in the future. (N. Pruthi - India)

CONCLUSIONS

Using a powered re-circulation system such as the Degesch J System provides a far more efficient fumigation method for fumigation of ships holds with PH_3 produced from aluminium phosphide than any other method. It also provides the opportunity for ventilation to be carried out more rapidly and effectively. Cylinderised PH_3 such as Frisin appears to have advantages over aluminium phosphide in respect speed of build up of lethal gas concentrations and the fact that no powdery residues remain to be disposed of. However, further work is needed to establish distribution patterns and ventilation requirements. The various forms of aluminium phosphide PH_3 generators appears likely to provide similar advantages to cylinderised PH_3 but their introduction also requires similar development work. Deep probing remains a useful option for effective use of aluminium phosphide and seems likely to have a part to play in the effective and economic use of PH_3 from cylinders or generators in ship fumigation.

The key to success is to specify precisely the method of fumigation, type of fumigant dosage, and length of fumigation. The person specifying the type of fumigation to be carried out on board a vessel can therefore choose whether to opt for partial eradication of insects, total eradication of all stages of all insects, or even total eradication of all mites in addition to all insects.

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