A REVIEW OF THE FUMIGATION OF RAILTRUCKS DURING TRANSIT IN EAST AFRICA

by

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Introduction

Problems associated with the occurrence of insect infestation on grain and grain products within rail trucks have been recognised for some time. The cross-infestation of commodities transported in infested railtrucks and the rapid dissemination of stored products insects are perhaps the most important of these. As a result of this, considerable work has been carried out, principally by workers in the USA and Canada. A variety of procedures for disinfesting the empty truck have been reported: by means of insecticidal sprays, single fumigants and fumigant mixtures (Schesser, 1967, 1967a, 1971; Cotton, 1960), sometimes assisted by specialised machinery to ensure the satisfactory penetration of insecticide to all sites of infestation (Dawson, 1962).

The practice of utilising the railtruck as a fumigation chamber, disinfesting both the commodity and the truck simultaneously, was reported as early as the 1940's. Phillips (1952) and Phillips and Latta (1953) conducted the first detailed studies on the method, using methyl bromide, for the destruction of pink bollworms in cottonseed. He encountered considerable difficulties concerning the satisfactory distribution of the fumigant, but overcame this by using forced recirculation equipment. Redlinger (1957) also used methyl bromide, together with recirculation blowers and tubing, for the successful fumigation of bulk rice, as shown by the complete mortality of certain stages of *Triobolium, Sitophilus* and a moth species, which he included as caged test insects within the truck.

Although sound in theory, the use of methyl bromide was beset by problems when considered in the context of use in African countries. The method is complicated, hazardous, subject to considerable human error, and entails operational delay when trucks remain static.

Rutledge (1968), describes the practical significance of phosphine, derived from 'Phostoxin', a commercial tabletted preparation of aluminium phosphide, as an alternative fumigant. Due basically to the simplicity of fumigations with this product, the use of phosphine has become widespread for both static and in-transit railtrucks, especially in America. Schesser (1967b) describes a series of trials with processed cereal products in which he compared the fumigation of different types of trucks. His tests showed that concentrations of gas lethal to *Tribolium castaneum* could be maintained in static and moving freight and hopper wagons, providing adequate precautions were taken to prevent the escape of the gas. In most rail-trucks, the application of masking tape around the doors was sufficient. A faster evolution of gas and consequently shorter exposure periods were also possible if the aluminium phosphide pellets or tablets were ground into a powder and the particles blown into the truck.

The first detailed trials with phosphine carried out in Africa were by Lochner (1964) on maize railed over a long distance to Durban in South Africa. After extensive preliminary trial work on the distribution, dosage and effectiveness of the gas against the more common storage pests, ie *Sitophilus oryzae, Rhizopertha dominica, Tribolium castaneum, Oryzaephilus surinamensis* and *Ephestia cautella*, his in-transit trials showed considerable promise and provided suitable background information for the institution of trial work in East Africa.

It is the purpose of this paper to briefly describe the trials carried out in East Africa and to summarise the results concerning the disinfestation of the more common stored products insects. Based upon this practical trial work, the use of different commercial preparations evolving phosphine is compared to the alternative use of methyl bromide. The effective sealing of the railtrucks is discussed and some mention is made of the relative costs of the methods tried. In most trials, test insects were included within trial consignments in an attempt to assess the efficiency of fumigations and where possible, gas concentrations were measured and temperatures taken during transit. It should, however, be pointed out that firm conclusions were often difficult to draw due to the variation in age, type and state of the railtrucks used in East Africa.

The Development of the Method

Trials were initiated in East Africa in the first instance due to the constant appearance of heavily infested produce at the port of Mombasa after railment from inland locations. The trials reported here were carried out during the period 1965-1970 by various members of staff of the Tropical Stored Products Centre (P H Giles, J A McFarlane, A A Baker, R W D Taylor and A H Harris) seconded to the Kenya Ministry of Agriculture. In 1965, Giles (personal communication) fumigated two stationary trucks, one with four doors and the other with only two doors, both being fairly typical of those found in the country (Fig. 1). These were filled with bagged yellow maize and 'Phostoxin'* tablets were broadcast over the surface of the bags at 2.7 and 5 tablets per ton of grain. The doors and any holes in the truck bodies were sealed with self-adhesive PVC tape from the outside and the trucks were opened five days later.

Results showed that the maximum gas concentration probably occurred at about 15-16 hours after the introduction of the tablets. Total Concentration x Time (CT) products (Monro, 1971) of 2.6 mg/h per litre (from 2.7 tablets per ton grain) and 10.5 mg/h per litre (from 5 tablets per ton grain) were found, but no gas could be detected after 3 and 4 days respectively. These low values were probably due to excessive leakage of fumigant from the trucks. The partial survival of a few *S. oryzae* in bioassay tubes and some *T. castaneum* in the maize itself verified the above conclusions. Further investigation with higher dosages of phosphine was therefore justified together with an improved method of preventing the loss of fumigant.

Giles carried out a further trial with two trucks containing freshly prepared cotton seed cake. Tablets were applied as before but at the rate of 4.9 and 9.9 tablets per ton of cake and the doors were sealed with self-adhesive brown paper tape from the outside. Alternatively, on some doors, eight foot square pieces of 500 gauge polythene sheet were attached to the inside surface of the door frame with one inch wide PVC tape, the last door again being sealed from the outside as previously described. Shortly after sealing, the trucks were railed approximately 750 miles from Jinja to Mombasa.

Again, the fumigant leaked rapidly, virtually no gas being present just under 3 days later. Loss of fumigant was in this case probably aggravated by the constant movement of the doors during the journey with the result that even lower CT products were obtained; 1.2 mg/h per litre from 4.9 tablets per ton and 2.5 mg/h per litre from 9.9 tablets per ton. Nevertheless, no survivors of *T. castaneum* emerged from the test containers. It appeared that very low concentrations of phosphine over quite short exposure periods were sufficient to control this species, a major pest of oil cakes, grain, cereal products and many other commodities. This conclusion agrees with laboratory toxicity tests (Burns Brown et al. 1968). Survivors of *S. oryzae* were, however, observed even at the higher dosage rate of phosphine. Although not an important pest of cotton seed cake, this apparent survival was highly significant if cereal grains or grain products infested with *S. oryzae* were to be fumigated in transit.

McFarlane (personal communication) continued trial work with a higher dosage of phosphine and with attempts to improve the sealing of the truck doors. Three trials were carried out in covered rail trucks, both of welded and riveted construction (Fig 2) and with both sliding and hinged doors.

The sealing procedure used in these trials merits special mention since this was later adopted as a routine. Strips of polyurethane foam, of suitable dimensions (factory off cuts) were inserted into all door joints as they were closed (Figs 3a, b and c). It was suggested that any movement of the doors within the truck frame would be compensated by the spongy nature of the foam thus limiting the excessive loss of fumigant experienced in earlier trials. The last junction to be sealed, that of the leading edge of the doors, frequently required the assistance of a crowbar and G-clamp in order to compress the foam sufficiently to enable the doors to be locked. A disadvantage of this method was that much of the sealing procedure had to be carried out from inside the truck before loading could commence, resulting in possible delays. More than one person was required during this operation. However, these practical difficulties were outweighed by the success of trial fumigations.

In the first two trials, bagged wheat bran was treated with 10 and 20 tablets per ton and railed to Mombasa from Nairobi, a distance of approximately 300 miles, the total fumigation period being 40 and 50 hours respectively. An untreated control truck was sent with those under test. Apart from a very low survival of *Acanthoscelides obtectus* larvae in bioassay tubes at both dosage levels, results showed a complete kill of *T.castaneum* (pupae and adults), *S. oryzae* (eggs, larvae and pupae) and *A.obtectus* (pupae and adults).

*'Phostoxin' is manufactured by Degesch, Frankfurt, W Germany and is hereafter referred to as 'tablets'.

Fig. 1. Types of railtrucks common to East Africa; note the variation in truck size, types of construction and doors.

Photo: A A Baker

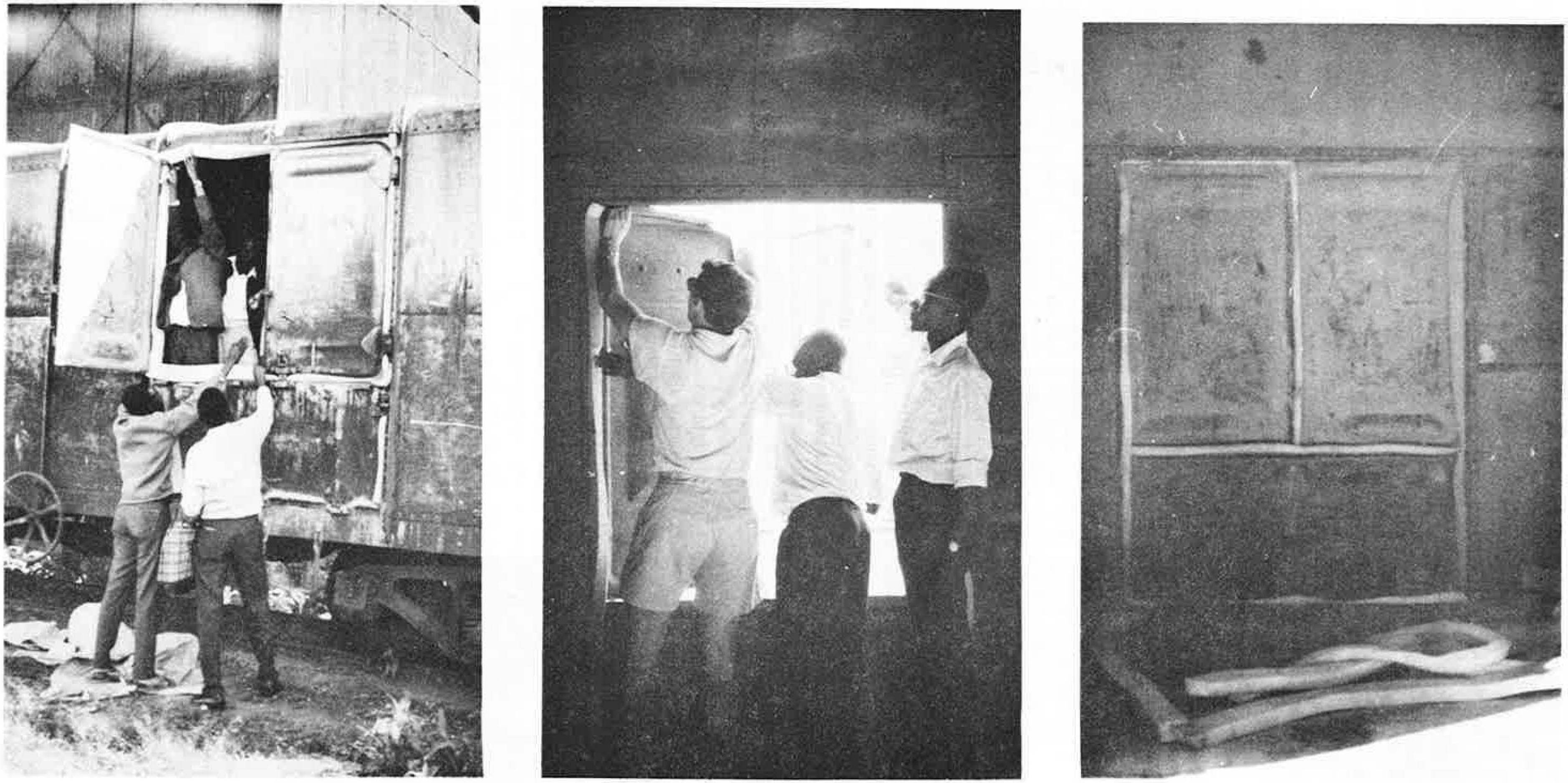
Fig. 2. Railtrucks of more recent design which can be sealed effectively and which retain fumigant reasonably well.

Photo: A A Baker

The third trial, using only one truck containing animal feeds, fumigated with 10 tablets per ton over a longer period of about 110 hours, resulted, however, in the complete mortality of *A.obtectus* pupae and pre-pupae. Results also showed that there was no difference in the effectiveness of the fumigation between trucks of welded or of riveted construction; nor between trucks fitted with hinged or sliding doors, provided the sealing procedure outlined was carefully employed. A minimum exposure period of 40 hours was recommended and checks on residual phosphine in trucks at the time of unloading confirmed that no operational hazard existed after this period with this method.

Following this work, the fumigation of commodities in railtrucks during transit became fairly common in Kenya. A further advantage was quickly realised in that considerable time could be saved not only because the produce was fumigated whilst in transit but also because immediate disinfestation measures were not necessary when the produce was unloaded. In addition to this, consignments could be 'nominated' or railed direct to the dockside provided less than one live insect per 200 lb bag of produce could be guaranteed. A consequent saving of about K.Sh.20 per ton was estimated as a result of savings in handling and storage charges on nominated cargoes. This type of operation,was therefore considered an important step towards the future efficiency of an export maize movement especially with reference to the rapid loading of shipping.

One of the present authors (Baker) conducted a trial during 1968 to investigate the feasibility of this procedure. Nine trucks containing bagged white maize were sealed and treated with 10 tablets per ton of grain. This 'nominated' consignment was than railed to the Port of Mombasa, the total exposure period being about 50 hours.



a

b

c

Fig. 3. The sealing of a hinged/flap-type railtruck door by the insertion of polyurethane foam strips or factory offcuts:

a:- exterior view

b:- interior view

c:- the sealed door; note also the unused offcuts on the truck floor

Photos: R W D Taylor

Sampling by sieving showed that although the maize was invariably heavily infested at the start, on arrival in Mombasa there was less than an average of one live insect per 200 lb bag. Insect numbers were therefore considered low enough for the consignment to be immediately exported without further treatment.

At about this time 'Detia'*, another proprietary form of aluminium phosphide, became available in East Africa. This product, in powder form, is contained in gas-permeable packets, each being equivalent to eleven 3 gm tablets of 'Phostoxin'.

Baker undertook a further trial to compare the efficiency of fumigation with these products. The alternative use of methyl bromide was also considered since this fumigant is introduced as a gas enabling high CT products to be obtained in the first few hours of the fumigation.

Tablets and packets were scattered over the surface of the bags as in previous trials but at 5, 7.5 and 10 tablets per ton and equivalent rates of packets per ton of grain. In trucks fumigated with methyl bromide, all doors were sealed, the fumigant then being introduced at 1, 2 and 3 lbs per 1,000 cu ft of total truck space, through piping either sandwiched between the foam at door junctions or placed through ventilators where these were present (Fig. 4.). After the correct weight of methyl bromide had been applied, the piping was withdrawn, the foam sealing any gaps. Where ventilators were used for dosing, these were sealed with adhesive tape after the removal of piping.

Examination of bio-assay tubes showed complete mortality of adult *S.oryzae, T.castaneum* and *A.obtectus* at all rates of all fumigants tested, apart from the lowest dose of methyl bromide. However, after incubation of the tube sievings, small numbers of live *S.oryzae* appeared from all except the highest dosage of each fumigant. It was again apparent that the late larval or pupal stages of *S.oryzae* and *A.obtectus* were more difficult to kill and it is safe to conclude that the higher doses of both methyl bromide and phosphine were necessary to obtain complete mortality.

McFarlane however commented further (personal communication) on the low survival of *A.obtectus* larvae in his trials where subsequent emergence data revealed that survival of later larval or pre-pupal stages occurred. Tests on these survivors showed that they were at least 95% non-viable. A low survival therefore does not necessarily lead to the persistence of an insect population after treatment with these fumigants.

Fig. 4. The introduction of methyl bromide through tubing which has been temporarily placed through the ventilators at the end of the truck. Note also the gas cylinder upon weighing scales.

Photo: R W D Taylor

*'Detia' is manufactured by Chemische Fabrik Weinhem, W Germany and is hereafter referred to as 'packets'.

A Note on the Temperatures within railtrucks

Both Giles and Baker incorporated temperature recording equipment within the railtrucks during their trials and the results are summarised here. Although temperatures under the roof and near the walls fluctuated enormously with ambient conditions (15-43°C), as expected, the temperature within the commodity varied little (23-26°C), with a mean value of about 24°C. There was greater fluctuation of temperature in the outermost bags of the stacks nearest to the truck sides and top.

The persistence of phosphine in railtrucks

Of the trials described so far, detailed chemical analyses of phosphine concentrations were only undertaken by Harris in the trials organised by Giles in 1965. Experimental work was carried out during 1968 and 1969 by one of the present authors (Taylor), on the behaviour of phosphine in truck fumigations, which supported and clarified conclusions arising from the bioassay data.

The evolution and loss of phosphine from a stationary truck containing bagged maize was compared to that obtainable under ideal conditions (data provided from work on a sealed laboratory container.) The truck was sealed as before and treated with 7.5 tablets per ton of grain. Detailed analysis of phosphine concentrations were made inside the bags of maize and within the truck free space during the entire 69 hour exposure period, using the 'bubbler apparatus' described by Taylor (1968).

Gas sampling at eleven points showed an enormous loss of fumigant at the start. Nevertheless, the gas readily penetrated the bags of maize, maximum concentrations being obtained at most points after about 16 hours (Fig 5A.). After this time, leakage resulted in a rapid fall in fumigant concentration, especially around the doors as illustrated by the very low concentrations at 'C', a location near to the base of one door. It is important to bear this sort of atypical result in mind when observations show that a few insects have survived from an otherwise successful fumigation. The main point that is demonstrated by Fig. 5A is that phosphine concentrations are not maintained as in a sealed laboratory chamber; the railtruck merely restricts the leakage of gas sufficiently to obtain reasonable CT products as outlined in Table 1.

Table 1. Phosphine CT products obtained after 48 hours from phostoxin tablets at an average temperature of 25°C and a relative humidity of 70% in a stationary railtruck and in a sealed laboratory container receiving an equivalent dosage.

Treatment	mg hours per litre
Sealed laboratory container	195.5
Stationary truck - free space	44.5
Stationary truck - average in-bag recording	46.0
Stationary truck - minimum in-bag recording	10.0

Taylor and Harris carried out a trial similar to that undertaken earlier by Baker, bagged maize being treated during transit with three dosage rates each of tablets, packets and methyl bromide. The fumigation period was about 90 hours. Fig 5B illustrates the results obtained from each phosphine treatment over the first 60 hours after the introduction of the packets or tablets; the results obtained with methyl bromide will be discussed later.

Maximum concentrations were achieved after about 24 hours, whilst the trucks awaited movement. Thereafter, in-truck concentrations rapidly decreased when the journey commenced, movement probably being an important cause of increased leakage. Little or no fumigant could be detected after 52 hours.

The CT products calculated for each treatment after 48 hours are listed in Table 2. A comparable CT product was obtained from 7.5 tablets per ton as with the stationary truck (Table 1) and an expected higher value was achieved from a higher dosage of 10 tablets per ton of grain.

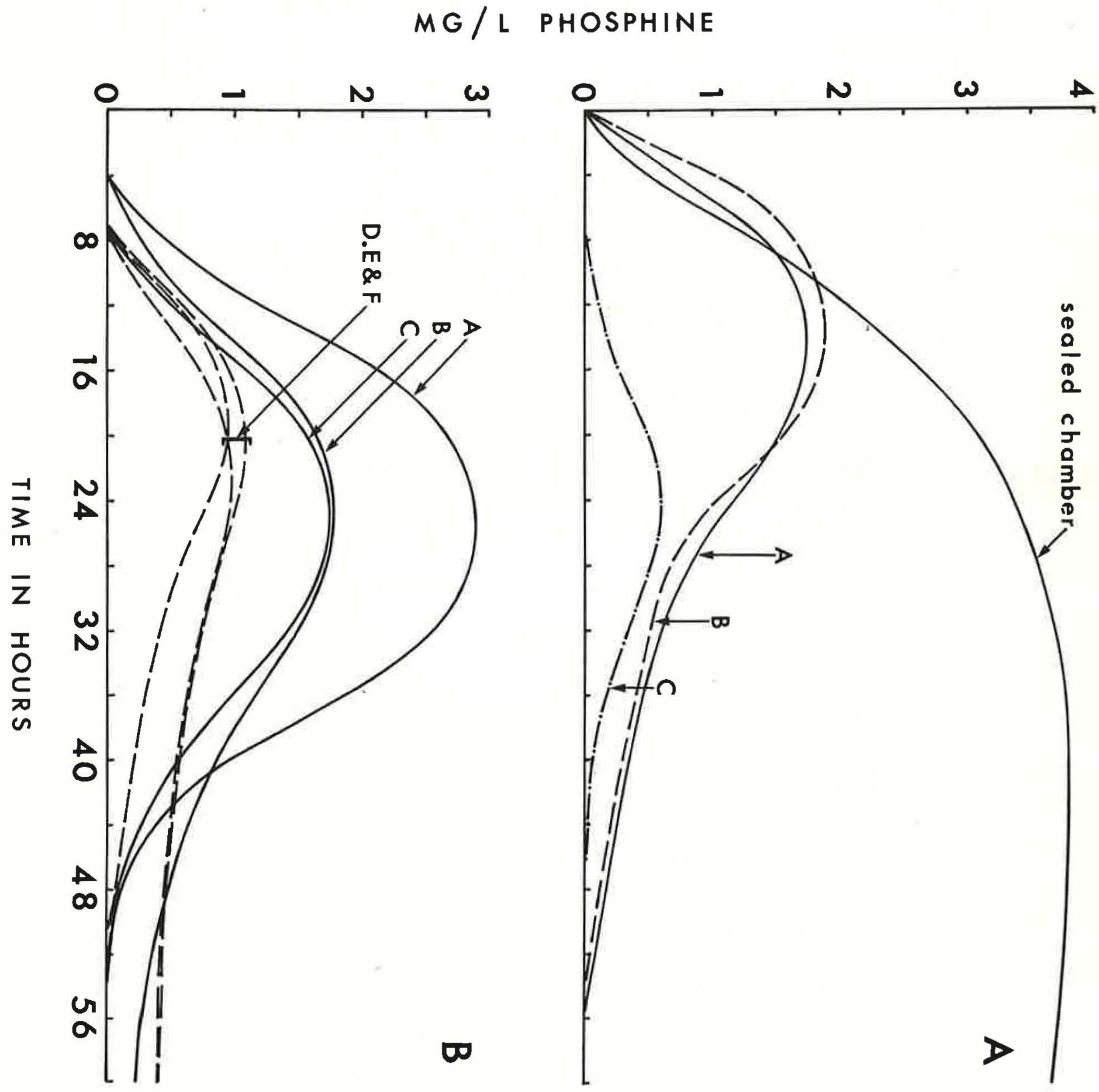


Fig. 5B. Concentration of phosphine in a railtruck from different rates of 'Phostoxin' tablets (continuous lines) and 'Detia' packets (broken lines). Lines A, B and C represent 10, 7.5 and 5 'Phostoxin' tablets per ton grain, and lines D, E and F represent equivalent rates of 'Detia' packets per ton grain. The truck started moving after 24 hrs. See Table 2 for CT products obtained at 48 hrs and text for explanation of difference between formulations used.

Fig. 5A. Comparison of concentration of phosphine evolved at 25°C and 70% R.H. in a sealed laboratory container and a stationary railtruck.

A:- the free space above the commodity
B:- the average in-bag recording
C: -the lowest in-bag recording

See Table 1 for CT products obtained at 48 hrs.

Table 2. Phosphine CT products obtained after 48 hours from different dosages of phostoxin tablets or detia packets in railtrucks during transit. Mean in-bag temperatures were approx 20°C.

Treatment	mg hours per litre at 48 hours
Phostoxin tablets	
@ 10 per ton grain	66.5
@ 7.5 per ton grain	50.0
@ 5 per ton grain	40.0
Detia packets at equivalent rates	
to 10 tablets per ton grain	17.5
to 7.5 tablets per ton grain	27.5
to 5 tablets per ton grain	30.5

Further reference to Fig. 5B. shows the 'Detia' treatments (lines D, E and F). At the two higher dosage rates used, inexplicably low CT products were obtained (Table 2.). This may in part be due to variation in the degree of sealing obtained in the different trucks, permitting different rates of fumigant leakage. The railtrucks used in these trials varied in age and type of construction, and variable rates of leakage could be expected.

The toxicity of phosphine to certain stored products insects has been investigated by the Pest Infestation Control Laboratory (Burns Brown et al 1968). It has been shown that some stored product insects are more susceptible to phosphine than others. At 25°C a CT product of only 10 mg/h per litre is more than sufficient to kill all developmental stages of *T. castaneum* over a 48 hour exposure period. It is likely, therefore, that all dosages included in Table 2 resulted in the complete mortality of this insect.

The most tolerant species tested by the Pest Infestation Control Laboratory was found to be *Sitophilus granarius*, closely followed by *S.zeamais* and *S.oryzae*. The pupal stage of this species can survive a CT product of 142 mg/h per litre over a 48 hour exposure period. From trial results it is evident that even the highest phosphine dosage would not give sufficiently high CT product values to achieve complete mortality, and this is verified by earlier trials where surviving *S. zeamais* were nearly always found.

It is well established (Table 3; Hole & Mills, personal communication) that in phosphine fumigation, the length of exposure period is of greater importance than C.T. product. Much lower CT products will give complete control of the resistant stages of *Sitophilus spp* over an extended fumigation period such as eight days.

Table 3. CT Products for Phosphine (mg. hrs/1) found to give a 100% kill of all developmental stages of the insects.

Exposure Period (days)		1	2	4	8
Sitophilus oryzae	25°C	NT	-	> 30.6	8.0
" "	30°C	-	> 17.5	4.5	X
Sitophilus zeamais	25°C	NT	-	30.6	8.0
" "	30°C	-	> 17.5	4.5	X
Sitophilus granarius	25°C	NT	-	> 30.6	8.0
" "	30°C	-	> 17.5	16.5	8.0
Tribolium castaneum	25°C	NT	2.1	X	X
" "	30°C	1.1	X	X	X
Acanthoscelides obtectus	25°C	NT	> 12.4	30.6	8.0
" "	30°C	NT	17.5	8.7	8.0

NB. Figures are for absolute 100% kill of cultures tested and no dose-mortality regression lines can be computed from the data.

NT = Not tested at this exposure period
\> = Survival occurred at this CT product and mortality was assessed as more than 95% of all stages
X = No figure given at this exposure period since 100% mortality was achieved at the next shorter exposure period at the lowest concentration tested.
\- = These exposure periods gave less than 95% mortality at the highest concentration tested and hence cannot be recommended

Compiled from data kindly supplied by B D Hole and K A Mills, Fumigant Section, Pest Infestation Control Laboratory, Slough.

The reason for this is that differences exist in the susceptibility of developmental stages of the insect to phosphine. Some preadult stages are more resistant than others, the adults being the least resistant (Howe, 1973). It has been shown that insect development continues during fumigation with phosphine (Reynolds *et al*, 1967). For control of all stages of *Sitophilus spp* a fumigation time sufficient to allow the more tolerant stages to develop into susceptible stages must be given, eg pupae to develop into adults.

Clearly, extended exposure periods such as 8 days are totally impracticable in nearly all cases of in-truck fumigation, and consideration must then return to possibilities of higher dosages. McFarlane, however, found that a dosage rate of 20 tablets per ton of grain did not give appreciably better results than 10 tablets per ton over a short fumigation period of about 45 hours and it is doubtful whether an extended exposure period at this higher rate would be advantageous, simply due to problems of excessive leakage, already illustrated.

In railtrucks fumigated during transit with phosphine it seems that an insufficient exposure period is most likely to be the cause of fumigation failure. Even at 10 tablets per ton, the highest recorded CT product over a 2-day exposure period was less than 70 mg/h per litre, which is not sufficient to kill the more tolerant stages of *S. zeamais*. However, if this insect is not an important pest in the commodity to be fumigated, this dosage might well be adequate to achieve commercial control and could be expected to kill all stages of *T. castăneum* and *A. obtectus,* two of the most common stored products pests in East Africa.

The possible use of methyl bromide

In view of the above reasoning, the results obtained with methyl bromide in the trial carried out by Taylor and Harris deserve further mention.

Initially, the use of methyl bromide seemed disappointing since most of the gas was lost after about 24 hrs, due to excessive leakage, even though the truck was stationary during this period (Fig. 6.). Nevertheless, high concentrations of fumigant were detected in the first few hours after dosing, methyl bromide being introduced in the gas phase. Higher average in-bag values were obtained relative to those in the truck free space. This was probably due to a later desorption of methyl bromide from the fumigated grain together with a slower leakage of fumigant from the bugged grain compared to a rapid loss from the truck free space.

The trial dosages were at 1, 2 and 5 lbs per 1,000 cu ft total space, and Fig. 6 graphically illustrates the loss of fumigant with time. The high initial concentrations resulted in relatively high CT products as shown in Table 4. An additional factor worth mentioning here is that there is no definite minimum period of exposure with methyl bromide, as is recommended for phosphine, and provided the required CT product is obtained, complete mortality of the common stored product insects can be expected even over a very short exposure period, eg twenty-four hours.

Table 4. CT Products for Methyl Bromide obtained at 20°C from in-truck fumigations from different initial dosages

Treatment lbs/1000 cu ft	CT Product after 24 hours (mg/h per litre) In free space	Mean in-bag
1	45	57
2	95	132
3	212*	242*
5	425	490

Reference to Burns-Brown (1959) indicates that, from the results of Table 4 the lowest dose would not achieve complete control at 25°C. A dose of 2 lbs/1000 cu ft would possibly be effective and 5 lbs/ 1000 cu ft could constitute considerable overdosing. An initial dose of 3 lbs/1000 cu ft could be expected to achieve complete control of all stored products pests and a theoretical curve extrapolated from this point, has been drawn in Fig. 6 and expected CT products included in Table 4.

The bio-assay results of Baker's trial verify the success of this dosage, no live insects being found at the end of the fumigation period or after subsequent incubation of the test insect material.

*These values calculated by interpolation

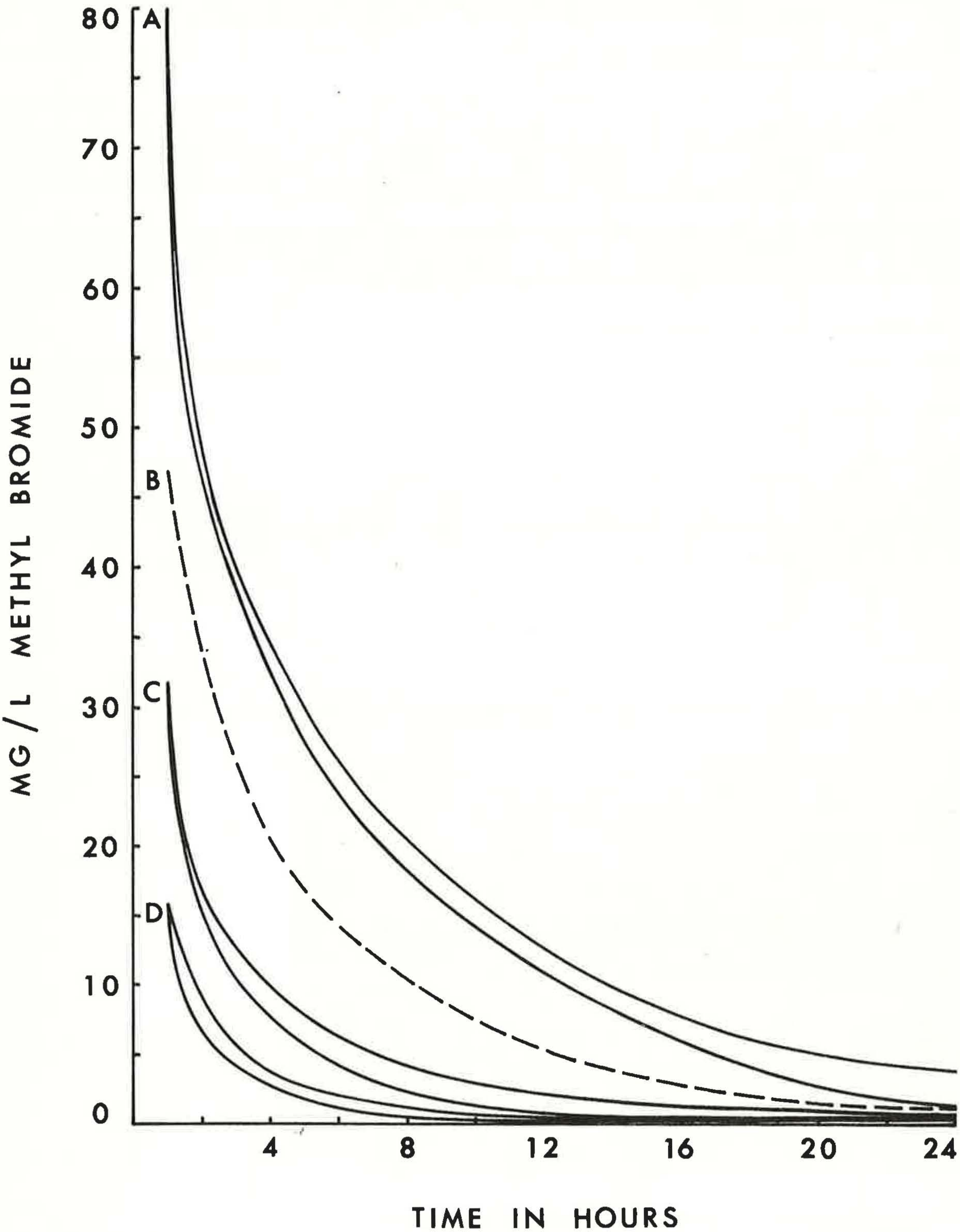


Fig. 6. Concentrations of methyl bromide in a stationary railtruck. Points A, C and D represent initial dosages of 5, 2 and 1 lb per 1,000 cu ft total space, the lower line in each case being the trial concentrations in the truck free space, the higher concentrations being mean in-bag values. The line extrapolated from point B represents a theoretical curve obtained from an initial dose of 3 lbs per 1,000 cu ft. See Table 4 for CT products obtained.

It would appear that provided a satisfactory procedure is used for introducing methyl bromide into the railtruck, this fumigant might well provide better disinfestation of bagged commodities than by using phosphine. The introduction of methyl bromide through tubing via ventilators or at door junctions, as explained earlier, is not difficult and this method does allow all doors of the truck to be sealed well in advance of the actual fumigation. The disadvantage of this method is that heavy cylinders containing liquid methyl bromide together with a weighing machine, must accompany the operator. This could be overcome by the use of a flat-backed vehicle or trolley and a long length of tubing that could readily be moved along a line of trucks awaiting fumigation.

To summarise the position with bagged cereals and grain products, it can be stated that phosphine can be used successfully to control the more susceptible insect pests found in East Africa, such as *T. castaneum*, at a rate of 10 tablets aluminium phosphide per ton of grain for a minimum period of 48 hours. The control of *Sitophilus* pre-adult stages may be difficult due to the relatively short exposure period frequently used, but a 72 hour exposure at the same dosage rate should give limited control.

Better insect control may be obtained by fumigating cereals with methyl bromide (at 3 lbs/1000 cu ft). Adequate CT products can be obtained over much shorter periods, ie 24 hours, a time that could easily be met whenever in-transit fumigations were necessary in East Africa.

The fumigation of bulk grain during transit

Although trials in America have indicated that methyl bromide does not appear to be a suitable fumigant for bulk commodities without recirculation equipment, which is unlikely to be available in East Africa, a useful alternative may well be phosphine in this case. A preliminary trial was carried out by Baker and Taylor during 1969 on the in-transit fumigation of bulk maize and wheat. Two trucks were sealed in the normal way, with the addition of 8' x 4' sheets of double-ply corrugated cardboard taped to the inside of the door frames. This enabled the doors used for loading to be almost completely closed but left sufficient space for the insertion of pneumatic conveyor tubing (Fig. 7). Two trucks were treated by applying aluminium phosphide tablets (contained in paper envelopes) to the surface of the grain at a rate of 10 per ton of grain. The doors were closed and sealed as previously described.

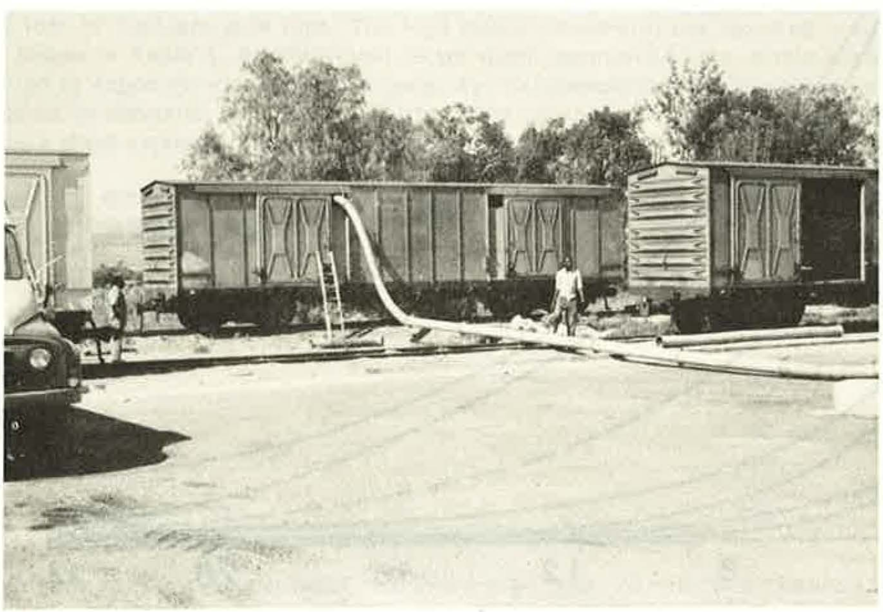


Fig. 7. Filling a railtruck with grain in bulk. Double-ply cardboard sheeting contains the grain during filling, allows the temporary insertion of pneumatic conveyor tubing, and facilitates the sealing and closure of the doors immediately after the introduction of fumigant.

Photo: A A Baker

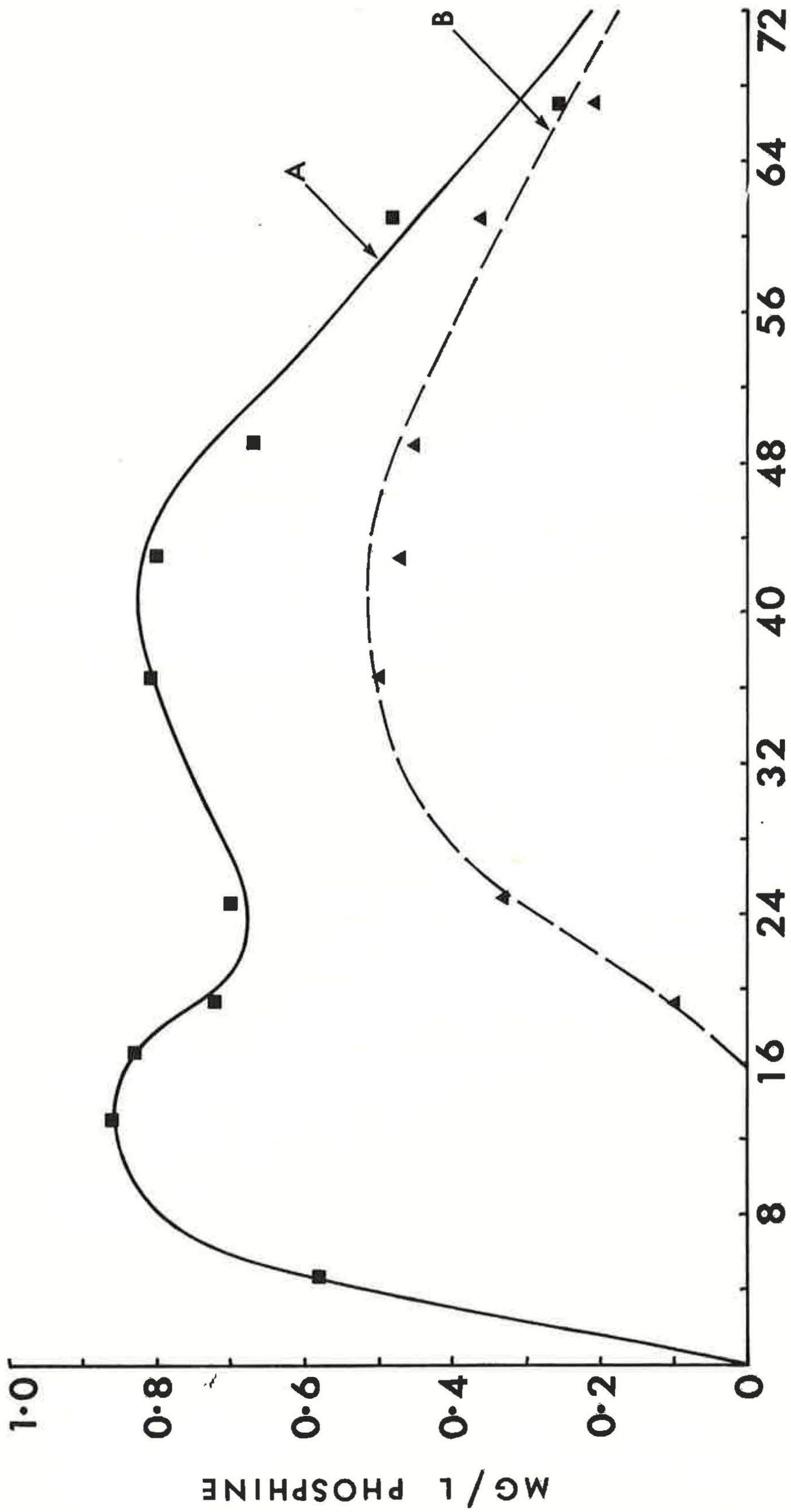


Fig. 8. Concentrations of phosphine obtained in a railtruck filled with maize in bulk. The truck started moving after 16 hours. Line A represents concentration in the free space of the truck and Line B the concentrations at the bottom of the load of maize. See text for CT products obtained at 48 and 72 hours.

The concentrations of phosphine obtained in this trial are illustrated in Fig. 8. About 18 hours elapsed before the fumigant was detected at the bottom of the load, but maximum concentrations were achieved after 80 hours. The slow penetration of this fumigant may therefore be a problem with bulk commodities in rail trucks. It is also interesting to note that the decrease in gas concentrations within the free space of the truck coincided with the periods of movement, the concentration increasing when the trucks remained stationary.

CT products achieved during the fumigation (72 hours) were calculated to be 46 mg/h per litre in the truck free space, and 21 mg/h per litre at the bottom of the grain. As with the bagged grain trials, these values are insufficient for the adequate control of species of *Sitophilus*, but *T. castaneum* and other more susceptible species would have been killed by this dosage rate. Adequate penetration of phosphine appears to be the problem in this instance, in addition to adequate exposure periods being impossible in practice. However, before discarding this method it might be worthwhile investigating bulk grain fumigation during transit by adding tablets to the grain stream as it is conveyed into the truck. Phosphine distribution might be improved with a consequent increase in CT product, although it is doubtful whether the tolerant stages of *Sitophilus* will even then be killed.

Indicator sachets

Indicator sachets for measuring CT products attained during methyl bromide fumigation were developed at the Pest Infestation Control Laboratory (Heseltine and Royce, 1960). Chemical analysis of the solution within the sachet was required at the end of the fumigation to determine the quantity of methyl bromide absorbed. This in turn gave some indication of the probable CT products achieved within the fumigated chamber. Heseltine later developed sachets for measuring CT products for phosphine (Burns Brown et al, 1969), the colour of the reagent changing at a pH of 3.2-3.4, equivalent to an exposure to phosphine of 85 ± 15 mg/h per litre at 25°C.

Besides the obvious use of such an indicator in normal stack fumigations, this development was also considered to be an invaluable inspection tool following the routine in-transit fumigation of railtrucks. A sachet introduced to a truck at the start of a fumigation would change colour at a certain minimum CT product. Observation of this change at the end of a journey, eg at the dockside, could allow release of the fumigated consignment for immediate shipment, without any delay due to normal inspection procedures such as bag sieving to determine whether live insects were present.

The sachets were used in a preliminary field test during the bulk fumigation trial described above. They were protected by perforated alkathene tubes and pushed into the grain about 2 ft from the surface near the loading door. The sachets were examined on opening the trucks. In most cases the sachets did not show a positive colour change, indicating that a CT product of 85 ± 15 mg/h per litre might not have been achieved. This was verified by chemical analysis of the intergranular atmosphere during the journey. In one case a satisfactory CT product was indicated by a complete and final change in sachet colour in a truck where chemical analysis showed very much lower CT products. The sachet colour change could have been due to its proximity to an envelope containing a number of tablets, resulting in a high local phosphine concentration. The siting of the sachets within produce fumigated in this way is thus of considerable importance. The sachet must be located in a position within the truck that will give an overall, average indication of the CT products achieved. Nevertheless, the results of this initial trial showed promise, making further investigation worthwhile. Later trials were carried out by McFarlane, Taylor and Baker on bagged wheat bran, maize germ meal and wheat flour. Indicator sachets were used together with bioassay tubes containing *S. zeamais* in all stages of development.

In most trucks where the sachet reagent colour change was complete, no adult *S.zeamais* emerged from the bio-assay tubes after subsequent incubation. Where the reagent failed to change to the final colour, live adults were often found when the trucks were opened, more emerging from the bio-assay tubes later. Recordings taken during the trials indicated that the temperature of the commodities fumigated was about 25 C and this is typical for produce railed from up-country Kenya. Although further trial work is necessary to verify the results so far obtained, the sachets used should give a reasonably true indication of CT products obtained.

A note on the costs of materials

Costs of fumigation in East Africa are approximately as follows:

Phostoxin	0.25 Kenya shillings (K.Sh.)	per tablet
Detia:	2.75 " " " "	per packet
Methyl bromide:	3.5 " " " "	per lb.

The average railtruck used for fumigation has a volume of 3000 cu ft and is usually loaded with 36 tons of produce. Comparing the recommended rates of each fumigant, ie 10 tablets per ton of grain (or equivalent) and 3 lbs methyl bromide per 1000 cu ft truck space, the latter treatment is undoubtedly far cheaper: K. Sh. 90.00 (phosphine treatments) and K.Sh. 10.50 (methyl bromide treatments).

The cost of materials required for sealing the truck doors is minimal, since they consist essentially of about 7 kg of foam offcuts per truck. There is general agreement by all those who have used this method on a trial basis in Kenya, that the cost per truck door is about K.Sh. 12.50 or about K.Sh. 50.00 per truck. Some of this foam is recoverable after unloading and can be re-used. A more realistic estimated cost per truck would therefore be about K. Sh. 25.00.

A certain amount of supplementary sealing of ventilators and other small holes, etc, might also be required, these being covered by adhesive paper tape at an assessed cost of K.Sh. 5.00 per truck sealed.

Overall costs, apart from labour charges which are almost impossible to estimate, would therefore be:

(a) Fumigation with phosphine:	Fumigant	K.Sh. 90.00	
	Sealing materials	30.00	
	Total cost per truck	120.00	K. Sh.
(b) Fumigation with methyl bromide:	Fumigant	K. Sh. 10.50	
	Sealing materials	30.00	
	Total cost per truck	40.50	K. Sh.

Note: Commercial servicing companies in East Africa make an overall charge of between K.Sh. 8-10 per ton of grain or grain product when fumigating railtrucks with phosphine (ie K.Sh. 288-360 per truck).

Summary of conclusions reached

a. It is clear that the method of sealing railtrucks using polyurethane foam strips has been adequately developed and that further investigations into truck sealing methods are not justified at the present time.

b. Insufficient exposure period is the most likely cause of fumigation failure in the case of phosphine treatments.

c. Treatments with aluminium phosphide at a dosage of 10 tablets (or equivalent) per ton of bagged grain are adequate for the control of the more susceptible stored product insects, eg *Tribolium* even over a 48 hour exposure period.

d. This treatment, however, will not achieve complete mortality of the more tolerant developmental stages of some insects, eg *Sitophilus,* and the exposure period should be extended to 5 days. An increase in dosage will only have a limited effect.

e. When trucks are opened, they should be well-aired before personnel are allowed to enter.

f. Treatment of bagged grain with methyl bromide at a dosage of 3 lbs per 1000 cu ft is an alternative control method to phosphine, and can be expected to achieve better results where *Sitophilus* spp are present.

g. Aluminium phosphide tablets applied to conveyed grain during loading of bulk consignments might be appropriate even though complete mortality of *Sitophilus* spp. may not be achieved. Methyl bromide fumigation in this case requires expensive recirculation equipment.

h. 'Indicator sachets' provide a useful inspection tool in the form of a fumigation check, especially on consignments designated for immediate export.

i. The costs of materials for in-truck fumigation are K. Sh. 40.50 per truck for methyl bromide and K.Sh.120/0 per truck using phosphine at the rates recommended.

Acknowledgement

Thanks are expressed to the Kenya Ministry of Agriculture for permission to publish the results of this work, carried out whilst on secondment to the National Agricultural Laboratories, Nairobi.

Special thanks are also due to P H Giles, J A McFarlane and A H Harris for releasing experimental data for study, enabling comments to be made upon relevant results in this paper.

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