THE ISSUE OF PHOSPHINE INSECTICIDE EFFICACY

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The very specific way phosphine works explains the great variety of issues raised that no other pesticide nor other fumigant encounters. For example, recommended dosages vary from 0.5 to 5 g/m3 and the exposure time from 3 to 30 days. What should we do?

1 - THE WAY PHOSPHINE WORKS

The way phosphine works is complex. Phosphine acts on two main enzymes, oxydase cytochrome and catalase. These two enzymes regulate the conditioning of oxygen to enter the mitochondrion. Blocking their action makes it impossible for oxygen to penetrate into the cell leading to the formation of super oxides which are the true biocidal agents. The mainspring of this system is iron, the change from ferrous iron to ferric iron ($Fe^{++} \rightarrow Fe^{+++}$). The inactivation of the enzymes occurs at low phosphine concentrations, but it proceeds according to the acquisition of resistance. For example, in Australia, the minimal concentration to block the enzymes went, for all species, from 25 ppm in 1990 to more than 100 ppm in 2004. In many countries, 200 ppm has been chosen, like in France, UK or Australia. We in France have not yet failed with this concentration. However, we should remain cautious, because phosphine resistance is not an empty word: presently, we find adult insects withstanding concentrations of 1000-2000 ppm, whereas a susceptible insect dies in a few hours at 30 ppm.
Besides the dosage factor, there is a time factor. Phosphine acts on the respiratory chain. Insects with a low respiratory rhythm such as in the case of low temperatures or for stages with low respiratory rates like eggs or pupae, need much longer exposure to gas than those with a high respiratory rhythm such as larvae or adults. The gas exposure length will thus depend on the temperature which determines the time for an insect to develop from a tolerant stage to a sensitive stage.

Under 10°C, this length is several weeks and phosphine fumigation is almost impossible. This is a huge limitation to its usage. Beyond that, the development speed will increase considerably with temperature and above 30°, we can have exposures of 3 to 5 days compared to 10 to 30 days at around 15°.

The dosage should allow one to maintain a higher concentration than the minimum necessary to inhibit the enzymes. Two factors could have an influence on the decrease in concentration over the course of a fumigation: leaks and sorption. Leaks are a circumstantial phenomenon and can be managed. Sorption depends on the product, the dosage, the temperature and the gas exposure length. The table1 gives an idea of the adsorption intensity for different groups of stored products. Sorption is accelerated for a given product through an increase in temperature and moisture content. The quantity of gas sorbed increases with the gas exposure length or the moisture content.

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2 –DOSAGE AND EXPOSURE TIME RECOMMENDATION.

In matters of fumigation, efficacy closely depends on the dosage and the exposure time. Phosphine concentrations depend on the amount applied, the amount sorbed by the commodity and the gastightness of the storage: The goal is to obtain 200 ppm at the end of fumigation, whatever it is. If gastightness is likely to be poor, the dosage should be increased by 0,5 g/m3. It is useless to go beyond that, because defective gastightness does not allow one to maintain enough gas throughout the fumigation and control will be poor, no matter what quantity is used.In practice, the standard dosages vary quite a bit between countries: 0.2 to 0.5 g/m^3 in Australia, 1 g/m^3 in Canada, France, UK, USA, 1.5 g/m^3 in Egypt, 2 g/m^3 in Tunisia and 3 to 5 g/m^3 in Germany or Syria.

The gas exposure length is a function of temperature of the product. An important point for fumigation is the hygrometry which surrounds phosphine formulations which plays a role in defining fumigation length. The table 3 gives an idea of the influence of relative humidity. The table 4 gives what we have proposed for a long time visors in France to kill all the stages, including the egg and pupal stages.

CONCLUSION

The good use of phosphine lies on two independent factors, dosage and exposure time. The dosage depends mainly of the opinion we have of the resistance of insects and for a little part of the commodity and of the quality of thegastightness. The exposure time depends mainly of the temperature which leads the insect development and sometimes of the relative humidity if it is too low.

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Table 1: Sorption scale for different groups of stored products.

Type of Stored Product	**Adsorption Level**
Dried fruit, tobacco	Low (10-30%)
Grains	Medium to high (>30-70%)
Oil-producing plants and high-fat dried fruit, pulses with pods, paddy rice.	High (>70%)

Table 2: Dosage of fumigant (g/m3) in relation to its sorption capacity

Stored product and presentation	Dosage in g/m3	
	Bulk	Bags (including 2 T bags)
Low adsorption	1	1
Medium adsorption	1,5	1
High adsorption	2	1,5

Table 3 :Hydrolysis speed in ppm/h (S) and time in hours (T) to obtain 90 % of the reaction of different phosphine formulations at different hygrometries (in g/m3 of water in air).

Water content		9.7 g/m^3		13 g/m^3		17.4 g/m^3		25.4 g/m^3	
Formulation		S	T	S	T	S	T	S	T
Tablets	Phostoxin	13	42	18	30.5	23	25	29	20
Pellets	Phostoxin	26.1	20.5	33.8	17	48	13	-	-

Table 4: Length of exposure time (days) for total efficacy of phosphine on all stages, including eggs and pupae (dosage of 1.5 g/m3).

Grain temperature Typical cases	Length (days)	5° to <10°	10° to <15°	15° to <20°	20° to <25°	25° to <30°	> 30°
Insects having tolerant stages (*Sitophilus* spp) or insects presenting hidden forms (*R.dominica*, ….	Optimum	-	30	20	15	10	7
	Minimum	-	20	15	10	7	5
Other insects		10	8	7	5	4	3