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# Phosphine Dosimeter Tubes A Alternate Approach for Fumigation Monitoring

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**Abstract**: To ascertain the adequacy of fumigation as well as to comply with the regulatory norms one has to monitor the phosphine concentration from the beginning to the end of fumigation which can last five to seven days. When aluminium phosphide tablets are used in an enclosure to generate phosphine the phosphine concentration starts building up from zero and reaches a maximum and starts declining from the peak value with time. To calculate the total phosphine dose (which is the most important parameter) received by the food grains, it is necessary to make several measurements during the entire period of fumigation. The phosphine dose is then determined by by calculating the area under the curve phosphine concentration v/s time.

As an alternative to making several measurements for measuring the total dose, we have developed a phosphine dosimeter tube, which does the same job with a single measurement. For this purpose, a calibrated freshly opened phosphine dosimeter tube is kept at a suitable place inside the enclosure at the beginning and the phosphine dosage in ppm h is read at the end of fumigation on the dosimeter scale.

The total phosphine dosage received by the food commodities is governed by the phosphine loss due to leaky enclosures, the amount of aluminium phosphide used, its quality, and the total time of exposure. Hence the total dosage measured on the dosimeter tells about the adequacy or other dosage related factors of fumigation and can throw light on the underlying cause for the eventual failure of a fumigation like substandard amount of aluminium phosphide tablets, leaky enclosure, or inadequate time of exposure etc.

The paper will describe the method of calibration of dosimeter tubes and their various uses in fumigation experiments.

**Key words**: phosphine dosimeters, fumigation monitoring

## Introduction

Phosphine is one of the most widely used fumigant for disinfestation of cereals, tobacco, spices and other stored products. Fumigation is carried out generally by producing Phosphine ($PH_3$) in situ by dosing the fumigation enclosure with calculated amounts of aluminium phosphide. The aluminium phosphide reacts with the atmospheric and grain moisture to produce $PH_3$. When this method is followed the $PH_3$ concentration starts building from zero and attains a maximum in about 24 hours and then starts falling as the $PH_3$ generation stops while the leaks from the enclosure and the absorption of $PH_3$ in the grain and on other sources of losses continue to bring down slowly the $PH_3$ concentration. The concentration profile of $PH_3$ starting from zero and going through a peak and its subsequent continuous fall is governed by several factors like total aluminium phosphide used, the total volume of the enclosure, amount and nature of the commodity inside, the moisture content in the stored products, the leak rate from the enclosure, the absorption characteristics of the commodities etc.

Fumigation procedure requires a certain concentration profile to be maintained during the entire period of fumigation to ensure that the fumigation is adequate to effect total insect mortality. The insect mortality is governed by an entity called the fumigation dose' or $PH_3$ dose which is defined as the concentration time product expressed in ppm hrs or ppm days. It is not the $PH_3$ concentration only at any time or the time of exposure alone which determines the adequacy of the fumigation but it is the total dose expressed in ppm hrs which determines the insect mortality or the effectiveness of the fumigation. Hence in order to determine the adequacy of the fumigation, it is necessary to measure the total

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$PH_3$ dose received by the food products.

The concentration time product, by its very definition turns out to be the area under the curve obtained by plotting the concentration Vs time. If this quantity is to be measured when the concentration is not constant but varies over a wide range starting from zero, it is necessary to make several, on-the-spot measurement of concentration at regular intervals over the entire period of fumigation to generate the concentration Vs time curve to find out the area under that. This involves several measurements and it is time consuming. Hence an alternate method which can directly measure the total dose received by the food grains by a single measurement if available is ideal for this application.

The dosimeter tube described in this paper does that job and measures the total dose received by the stored products during the entire course of fumigation with a single measurement. This paper describes this dosimeter tube including its working principle, calibration method and its uses for fumigation.

## Experimental Method

The dosimeter tube consists of a narrow glass tubing of about 4mm OD and 3mm ID with a length of about 15cm filled with $PH_3$ sensing chemical. Both ends of the tube are sealed with round tips. The sensing chemical occupies 8 to 10cm of the tube beginning from one end. At the other end of the sensing chemical, a plug is placed to hold it in position. There is a scratch mark immediately after the plug for facilitating the breaking of the tube before using.

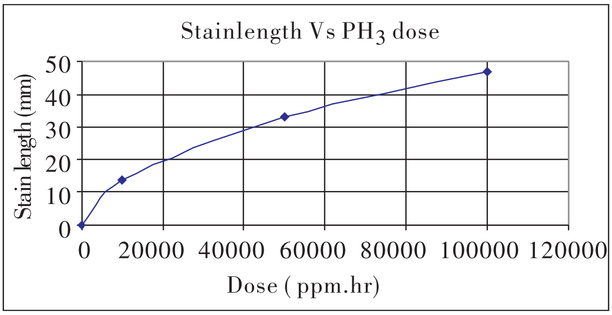
## Working Principle

The dosimeter tube works on the diffusion of $PH_3$ gas into the sensing chemical in the tube and on the reaction with it producing a colored stain when the tube is placed in the environment containing $PH_3$. The tube has to be broken at the scratch mark before it is placed in the $PH_3$ environment for measurement. The diffusion through the tube follows the Fick's law of diffusion and the stain length produced depends on the concentration and time of the fumigation, which can be expressed as the concentration time product or the dosage.

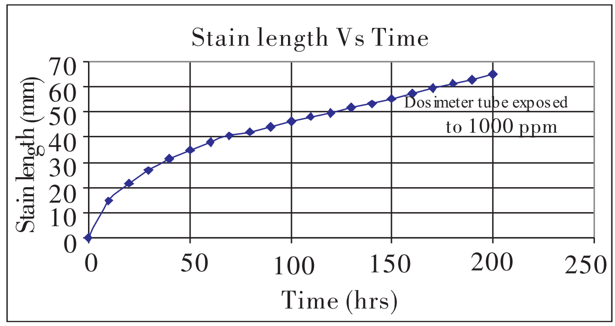
It should be noted, a $PH_3$ dosage of any magnitude can be produced by several combinations of concentration and time, and for all the combinations of time and concentrations for the same dosage, the same stain length is obtained within experimental errors. This is illustrated in Table 1 and Graph 1.

**Table 1. Stain length Vs Phosphine Dose**

| Conc. [ppm] | Time [h] | Dosage [ppm h] | Stain length on dosimeter tube [mm] | Average stain length [mm] | Average standard deviation |
|---|---|---|---|---|---|
| 50 | 200 | 10000 | 14.2 | | |
| 100 | 100 | 10000 | 14.0 | 13.7 | 4.3% |
| 200 | 50 | 10000 | 12.5 | | |
| 1000 | 10 | 10000 | 14.0 | | |
| 250 | 200 | 50000 | 33.0 | | |
| 500 | 100 | 50000 | 34.5 | 32.9 | 2.7% |
| 1000 | 50 | 50000 | 32.0 | | |
| 5000 | 10 | 50000 | 32.0 | | |
| 500 | 200 | 100000 | 42.0 | | |
| 1000 | 100 | 100000 | 48.0 | 46.9 | 5.4% |
| 2000 | 50 | 100000 | 49.0 | | |
| 10000 | 10 | 100000 | 48.5 | | |




**Graph 1 Stain length Vs $PH_3$ Dosage**




**Graph 2. Stain length Vs time**

## Calibration

The dosimeter tube can be calibrated by using the stain length for different dosages and marking them on the tube for different doses. Refer Graph 1.

Alternatively, dosimeter tube can be exposed to a constant concentration of 1 000 ppm (or any other suitable concentration) and the stain length obtained ploted for different time intervals (refer graph 2). The dosimeter tube is marked with time t = 0 to t = 200 hours. Reading the dosimeter tube (i. e. time) and multiplied by 1 000 when it was exposed to this gas content gives the dosage. This method can be used for calibration.

**Table 2. Stain length vs time for 1 000 ppm exposure**

| Time h | Stain length on dosimeter tube (mm) | Time h | Stain length on dosimeter tube (mm) |
|---|---|---|---|
| 0 | 0 | 110 | 48 |
| 10 | 14.5 | 120 | 49.5 |
| 20 | 22 | 130 | 51.5 |
| 30 | 27 | 140 | 53.5 |
| 40 | 31.5 | 150 | 55.5 |
| 50 | 35 | 160 | 57.5 |
| 60 | 38 | 170 | 59.5 |
| 70 | 40.5 | 180 | 61.5 |
| 80 | 42 | 190 | 63 |
| 90 | 44 | 200 | 65 |
| 100 | 46 | | |

## Application

### Determination of the Adequacy of Fumigation

The dosimeter tube can be used to determine the adequacy or other important factorts of the fumigation. If the fumigators know the $PH_3$ dosage to be applied for the fumigation experiment, they can measure the actual dosage received by the commodity and compare it with the expected dosage. This can be carried out by placing the dosimeter tube at the beginning of the fumigation at a suitable location within the fumigation cover and taking it out after the fumigation and aeration and read the total $PH_3$ dosage received. The tube-before placing it inside-should be broken at the scratch mark and placed either horizontally or vertically.

In a silo of a fixed volume and for a fixed volume of stored products and a fixed dosage, one can expect the same stain length for repeated fumigations. If in any experiment the stain length obtained is much smaller than the average stain length which one used to get, it is a sure indication that the fumigation had failed. The failure could have happened because of leaks or inadequate amount of fumigant or substandard fumigant material used. This becomes a handy method for fumigators to ascertain the adequacy of fumigation and provide a proof of fumigation to their clients.

### $PH_3$ Concentration Distribution

Many a time though, the AlP dosing is adequate $PH_3$ concentration distribution is not uniform for various reasons. At many places, the $PH_3$ concentration can be very very low, which is not adequate to kill the insects. The dosimeter tube can be used to find this non-uniform distribution by keeping several dosimeter tubes at different locations and measure the $PH_3$ dosage on the tubes placed at different locations. Non-uniform distribution will lead to widely varying stain lengths (dosages) on the dosimeter tubes placed at different locations.

### To Provide the Proof of the Fumigation

The dosimeter tube which measures the $PH_3$ dosage can be used as a proof of fumigation and also to ascertain that it is carried out properly. The stain length on the tube remains the same after it is taken out of the silo after the fumigation and can be produced as a proof.

## Conclusion

This novel device should prove to be a very useful device for the applications already described in the paper.