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DEVELOPMENT OF TECHNIQUES TO INCREASE THE EFFICENCY OF METHYL BROMIDE FUMIGATIONS

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DEVELOPMENT OF TECHNIQUES TO INCREASE THE EFFICIENCY OF METHYL BROMIDE FUMIGATIONS

by

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CONTENTS

SUMMARY

A new microprocessor-controlled dosing system to fumigate flour mills with methyl bromide against insect pests has been developed and tested at the Central Science Laboratory. Subsequently two flour mills were fumigated. The first mill was treated in the traditional way, using an initial dose with manual topping up whenever the concentration of fumigant fell too low to achieve the required concentration-time product (CTP). This was done to obtain comparative data. The second mill, following a smaller initial dose was placed under the control of the new dosing system.

The microprocessor-controlled automated dosing system showed promise as a more efficient means of fumigating flour mills by enabling CTPs sufficient to control pest species to be achieved more reliably and at the same time using less methyl bromide than was previously possible.

OBJECTIVES

a) To investigate a method of reducing emissions of methyl bromide from flour mill fumigations.

b) To examine the potential of a new microprocessor-controlled dosing system to reduce the amount of methyl bromide applied for the control of flour mill pests.

INTRODUCTION

Flour mills are fumigated with methyl bromide when they become infested with insect pests. For control of such pests a dose sufficient to achieve a concentration-time product (CTP) of at least 200 g h m^{-3} throughout the mill is recommended (Anon, 1974). To ensure adequate CTPs are obtained over-dosing of some areas is common.

Leaks from structures such as mills are often localised and unpredictable and depend on variable factors such as rain and wind speed and direction. They can cause areas of low CTP making effective fumigation difficult and it is usually necessary to monitor the concentration of gas during the fumigation. When the concentration falls below the level necessary to achieve the required CTP in a given area "top-up" gas needs to be introduced. Even when these precautions are taken some mills need to be fumigated as often as once a year.

The ozone layer in the upper atmosphere prevents harmful ultra-violet radiation from reaching the earth's surface. A hole has been discovered in the ozone layer over the South Pole causing concern about the effect of man-made chemicals (notably CFCs) on the upper atmosphere (SORG, 1988). Recently it has been suggested that methyl bromide has an adverse effect on the ozone layer (SORG, 1990) and there is a need, therefore, to reduce the amount of methyl bromide that is released to the atmosphere.

To reduce the amount of methyl bromide used in fumigations an automated dosing system has been developed at the Central Science Laboratory (CSL), capable of monitoring the concentration of gas in up to sixteen areas and when necessary to re-dose to ensure that adequate CTPs are obtained using the minimum dose.

MATERIALS AND METHODS

Development of an automated dosing system for methyl bromide

The automated dosing system (Fig. 1) can serve up to sixteen separate areas. Dosing lines going to each area are opened and closed by a series of rack-mounted solenoid valves. These valves are supplied by a gas manifold connected to a cylinder-based supply of methyl bromide. The valves are controlled by a microprocessor in the main cabinet of the system to which they are connected via cables.

A sample of gas is drawn from each area in sequence via "nylon-6" gas sampling lines (2mm bore) to the main cabinet of the system where the concentration of methyl bromide is measured by a thermal conductivity detector. The sample lines are selected by a set of solenoid valves and drawn by a pump via individual metering valves and a common flow meter. The metering valves and the flow meter allow the flow rate to be set for each sampling line. The flows are set within the optimum range of the detector so that concentrations of fumigant in each part of the fumigation enclosure are measured accurately.

A microprocessor compares the gas concentration level from every area with a level pre-set by the user. If a particular area is below the set level then it will receive additional gas for a programmed period via the relevant dosing line. The cycle is repeated for a predetermined period after which the microprocessor terminates the sampling and dosing process.

All functions of the sampling and dosing valves are controlled by a hand held microcomputer (Psion Organiser). The software programme (written at CSL) allows the setting of the dosing valve opening times, the sampling time, the interval between cycles and the number of cycles. The programme also allows the selection of the number of sampling points to be monitored. The only factor remaining outside the control of the Psion Organiser is the concentration threshold for redosing, currently set using a potentiometer. Further refinements are in progress to bring this under software control. The microcomputer is connected to the main cabinet via a ribbon cable. The system is powered from a 240v AC mains supply.

Trials in flour mills

Two trials were undertaken at separate mills (A and B). Both mills had become infested with the Mediterranean flour moth *Ephestia kuehniella* (Zeller), the confused flour beetle *Tribolium confusum* (J du Val) and, in the case of mill B, with the varied carpet beetle *Anthrenus verbasci* (L.). The Turkish grain beetle *Cryptolestes turcicus* (Grouvelle) and the rust-red flour beetle *Tribolium castaneum* (Herbst) are other common pests of flour mills.

In both trials the concentration of fumigant was monitored automatically from a mobile laboratory equipped with a 5880 Hewlett Packard gas chromatograph (GC) fitted with a flame ionisation detector, two 16-port stream selection valves and a 1 m x 3.1 mm OD glass-lined stainless steel column packed with Porapak QS. Samples of gas were drawn from the atmosphere in the fumigated area to the GC via "nylon-6" gas sampling lines (2 mm bore) using a Capex pump at a constant rate controlled by a mass flow controller.

Mill A

The fumigation was carried out by Igrox Ltd and was monitored by CSL staff. Fig. 2 shows the layout of the mill and the areas that were fumigated. Gas sampling lines and eight reinforced PVC dosing lines were fixed in various positions throughout the mill. The positions of the dosing lines are given in Table 1 and the positions of the sampling lines are given in Table 2.

The outlets of the dosing lines were split using plastic piping to which were joined lengths of perforated polythene lay-flat tubing to provide good gas distribution. The windows and doors were then closed and obvious sources of leakage were sealed using gas-proof sheeting and adhesive tape.

Methyl bromide was introduced as vapour from a vapouriser to each dosing line in turn (Fig. 3). At various times "top-up" gas was added using the same method in an attempt to ensure that CTPs of 200 g h m^{-3} or more were attained at all positions. The packing area did not receive an initial dose as it was expected that gas would spread from the flour bins. Table 1 shows the volumes of the fumigated areas and the dosage applied.

As the fumigation was conducted according to a commercial protocol using standard dosing techniques, a bioassay was not included and the trial was assessed using gas concentration data alone.

Mill B

The bin area and the mill itself were fumigated. These were in the same 5-storey building. The sampling lines used to monitor the treatment were positioned on each floor as shown in Fig. 4, except on the ground floor bin side where the low position was in a small ante-room to the right of the stairway and on the fifth floor mill side where the highest position was in the far corner with respect to the main stairway. There were no sampling lines on the bin side on the fifth floor. An additional sampling line was fixed next to each lower sampling position for the automated dosing system.

Two sets of dosing lines, one set for the initial dose and one set for top-up dosing, were positioned in the building. The initial dose was to be applied by Igrox Limited using the same method that was used at mill A. Dosing lines similar to the ones used at mill A were positioned on each floor on the bin side and on the mill side except floors 2 and 3 on the bin side which were to be dosed from the same line. Altogether nine lines were used. Table 3 shows the volumes of the fumigated areas and the initial dose to each area.

The extra gas required to ensure CTPs greater than 200 g h m^{-3} was to be applied by CSL staff using the automated microprocessor-controlled dosing system. The second set of dosing lines and additional gas sampling lines were positioned on each floor and on each side of the building, except on the fifth floor bin side. In this case the dosing lines were 9.5mm OD nylon lines with ceramic jets in the outlets. To avoid liquid methyl bromide dripping on to the machinery and to provide good distribution, perforated lay-flat tubing of 3 to 5m lengths were taped to the end of each dosing line. The other end of each length of tubing was secured at a point diagonally across the room at a similar height to the jet. Lengths of polythene sheeting were placed over the machinery to provide extra protection against liquid methyl bromide. The inlet of each dosing line was connected to one of the rack-mounted solenoid valves of the automated dosing system. The valves were connected to a cylinder of 100% methyl bromide via a manifold.

Gas samples were drawn sequentially from each dosing position via the gas sampling lines to the sensor in the dosing system. The threshold value was set at 25 g m^{-3}. When the concentration of methyl bromide fell below this value the dosing system was set to open the appropriate valve for 3 minutes to deliver liquid methyl bromide to the dosing position. Opening a valve for 3 minutes delivered approximately 0.6 kg of methyl bromide.

The temperature in different parts of the mill was monitored by four copper-constantan thermocouples connected to a chart recorder. In addition, the wind velocity and direction was monitored during the fumigation by a weather station mounted on the silo roof and connected to the same chart recorder.

Insect bioassay at mill B

The bioassay consisted of 36 plastic escape-proof jars containing flour infested with late stage larvae and pupae of a laboratory strain of the rust-red flour beetle, *Tribolium castaneum*. The pupae are the most tolerant stage to methyl bromide. The jars were prepared by adding 50 unsexed adults to each jar containing approximately 30 g whole wheat flour. The samples were then incubated at 30°C, 60% rh for 10 days after which time the laying adults were removed. The jars were then incubated at 25°C, 60% rh for a further 10 days.

Of the 36 jars, 34 were conveyed to the mill. Two were placed in the free space in the mill at each of sixteen locations near gas sampling positions and two jars (site controls) were returned to the laboratory for incubation at 20°C, which was approximately the same temperature as that recorded in the mill. Immediately after the fumigation, all jars were returned to the laboratory and incubated at 25°C. They were examined four weeks later for the presence of emerged adults and compared with the two control jars held throughout the fumigation trial period at 25°C, 60% rh at the laboratory.

RESULTS AND DISCUSSION

Table 1 shows the dosage applied at mill A and Table 2 shows the CTPs obtained. Figures 5 to 8 show the variation of concentration with time in different parts of the complex. The theoretical CTP is the CTP that would have been obtained over 22 hours if the total dose (initial dose + final dose) had been applied at the beginning and there had been no leakage. The large difference between theoretical and actual CTPs shows areas of leakage especially in the screens, and the mill and stoneground areas.

At four sampling positions at mill A, all of which were outside the mill and stoneground unit, the CTPs were lower than the recommended value of 200 g h m^{-3} (Table 2). The low CTPs may have been improved by using the automated dosing system but more gas would have been used. However, within the mill and stoneground unit CTPs were much higher than required and here a considerable dosage reduction could have been achieved.

Table 3 shows the initial dosage applied at mill B and Table 4 shows the CTPs obtained and the positions of the bioassays. Figures 9 to 13 show the variation of concentration against time on each floor of the mill.

The average CTP at mill B was 395 g h m^{-3}. Because of the present limitations of the automated dosing system it is not possible to determine exactly how much top-up gas went to each area. Therefore a theoretical CTP cannot be calculated for each area. The software is in the process of being up-graded to overcome this problem. However, an additional 87kg of methyl bromide was applied to the mill using the microprocessor-controlled dosing system, bringing the total dosage applied to 199kg. Using this figure, the overall theoretical CTP was 940 g h m^{-3}.

The theoretical CTP obtained at mill B is similar to the overall theoretical CTP of 970 g h m^{-3} obtained at mill A indicating that a similar total dose per unit area was used. However, only the mill and stoneground unit at mill A was similar in structure, area and function to the fumigated area at mill B. Here the theoretical CTP was 1070 g h m^{-3} (Table 1), 14% higher than at mill B.

The average actual CTP at the mill and stoneground unit at mill A was much higher than necessary at 512 g h m^{-3}, indicating that an excess of methyl bromide was used. The more even and lower CTPs at mill B show a more efficient use of methyl bromide. Therefore, an effective treatment using less methyl bromide would have been possible in the mill and stoneground unit at mill A if the initial dose was lower and top-up dosing had been under the control of the automated system as was the case at mill B.

At mill B the average CTP was 42% of the theoretical and at the mill and stoneground unit of mill A the average CTP was 47% of the theoretical. This indicates an essentially similar degree of leakage at the two sites.

Temperature, wind velocity and direction monitoring at mill B

The overall mean temperature in the mill was 19.7°C. Table 4 gives the average temperature and range recorded from each thermocouple. The minimum and maximum temperatures recorded were 16.7°C and 21.8°C respectively. The wind direction was mostly W to WNW with a mean velocity of about 3.3 m s^{-1} ranging from zero to 9 m s^{-1}. These figures are only representative of the top of the mill building since the lower part was somewhat sheltered.

Bioassay at mill B

The 25°C controls produced a mean of 1497 adults and the 20°C controls produced a mean of 1265 adults. From the timing of the control emergence, the number of pupae treated in the mill at approximately 20°C was estimated to be at least 800 at each location. No stages survived the fumigation. This was to be expected since the minimum CTP obtained was 235 g h m^{-3}. A CTP of 180 g h m^{-3} is sufficient to control all stages of the common mill pests at 15°C (Anon., 1974), a lower temperature than in the mill. Less than 180 g h m^{-3} would be required for control at an average temperature of 20°C. The recommended minimum free-space CTP of 200 g h m^{-3} takes into account the need for penetration of gas into flour residues within machinery.

The work of Hill, Border and Armstrong

It is of interest to compare the results obtained at mills A and B with some early, well-documented reports of mill fumigations with methyl bromide. Hill and Border (1953) described two 24-hour fumigations carried out in 1952 and 1953 of a six-floored mill of 17018 m^3 volume i.e. of similar volume to mill A. The mill was dosed at 20.23 and 19.97 g m^{-3} in 1952 and 1953 respectively. These two fumigations achieved mean CTPs of 344 and 290 g h m^{-3} against overall theoretical CTPs of 485 and 480 g h m^{-3} i.e. 71% and 60% respectively. They reported a marked difference in concentration levels between the ground and upper floors due to layering, especially in the 1952 fumigation, and this instigated the conventional practice of overdosing the upper floors at the expense of the lower floors, which was done in the 1953 fumigation.

Hill and Armstrong (1956) repeated the monitoring exercise in 1954 by fumigating the same mill at 20.2 g m^{-3} for a 49-hour fumigation. They noted less leakage, even during the longer exposure, due to very mild weather conditions with practically no wind. Another feature of this treatment was that the layering of the methyl bromide was more pronounced than in either of the previous two fumigations despite very considerable overdosing of the top two floors and underdosing of the ground floor. This could not be explained by a temperature effect since the mean temperatures were only slightly less than in previous years. This apparent unpredictability of the degree of layering is a major argument for the use of an automated dosing system. In the 1954 fumigation the free space CTPs after 24 hours were sufficient to control insect pests but this could not be predicted at the outset of the treatment. Hence there was a planned increase in exposure period to utilise any gas remaining at the end of the first day. Again automated dosing would always result in satisfactory CTPs and could prevent the need for extended exposure time. The introduction of the microprocessor-controlled dosing system would represent the first significant advance in 40 years of dosing operations for flour mill fumigations.

CONCLUSION

The free-space CTPs obtained at some locations in the conventionally dosed mill A may not have been adequate for complete control of the pests present. The microprocessor-controlled automated dosing system offers the prospect of a more efficient means of fumigating flour mills by achieving the concentration-time products needed for complete kill of pests using less methyl bromide than was previously possible, and hence reducing methyl bromide emissions to the atmosphere.

FUTURE WORK

To upgrade the new dosing system to record the amount of methyl bromide dosed from each line and to make the re-dosing threshold more simple to set.

To assess the performance of the system at different field sites and under different conditions.

ACKNOWLEDGEMENTS

The authors are grateful to Igrox Ltd for all their help and to Mrs A L Clifton and Mr G Barnett for their assistance in the mill trials work.

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Table 1. Details of dosing: Fumigation at Mill A

Position of dosing line	Volume (m^3) Treated	Methyl bromide initial dose (kg)	Methyl bromide top-up dose (kg)	Theoretical* CTP ($g\ h\ m^{-3}$)
Conditioning bin	850	27	9	930
Tweens	700	23	0	720
Screens	1400	45	45	1410
Mill and Stoneground	4200	114	90	1070
Drying plant	1400	45	9	850
Packing area	2300	0	23	890
Old flour bin	2800	93	113	
New flour bin	2800	91	0	
Total	16450	438	289	970

*CTP obtained if all fumigant had been applied at the start of the treatment and there was no leakage throughout the fumigation period.

Table 2. **Concentration-Time Products (CTPs) of methyl bromide obtained at Mill A**

Area	Theoretical* CTP (g h m^{-3})	Sampling line position	Line number	ACTUAL CTP (g h m^{-3})
Conditioning bin	930	Top	1	309
		Bottom	2	104
Screens	1410	Top screen room	3	99
Mill and Stoneground	830	Ground floor, mill	4	723
		First floor, mill	5	614
		Second floor, mill	6	411
		Third floor, mill	7	388
		Fourth floor, mill, screen by railing	8	442
		Fourth floor, mill, head high	9	496
Packing area	1020	Centre	10	583
		By sealed door	11	74
Old flour bin		Top	12	37
New flour bin		Top	13	336
		Bottom	14	135
Average (for mill section):				512

*See Table 1

Table 3. **Initial dosage of methyl bromide applied at Mill B**

Floor	Side of building	Volume Treated (m^{-3})	Methyl Bromide initial dose (kg)
5	Mill	538	13.0
	Bin	56.6	1.2
4	Mill	651	15.5
	Bin	368	9.1
3	Mill	651	15.7
	Bin	368	8.7*
2	Mill	651	15.3
	Bin	368	8.7*
1 (Ground)	Mill	651	15.5
	Bin	368	9.3
Total		4670	112

* A total of 17.4 kg was delivered to floors 2 and 3 from one dosing line.

Table 4. **Concentration-Time Products (CTPs) of methyl bromide obtained at Mill B**

Floor	Side of building	Height (m) and presence of bioassay (✓)	Line number	CTP (g h m^{-3})	Temp (°C)	
					Mean	Range
5	Mill	3 ✓	15	235	-	-
	Mill	1 ✓	16	302	-	-
	Bin	3 ✓	-	-	18.9	17.5 - 19.8
4	Mill	3 ✓	17	321	-	-
	Mill	1 ✓	18	330	20.2	18.8 - 21.8
	Bin	3 ✓	19	345	-	-
	Bin	1	20	343	-	-
3	Mill	3 ✓	21	308	-	-
	Mill	1 ✓	22	305	-	-
	Bin	3 ✓	23	379	-	-
	Bin	1	24	376	-	-
2	Mill	3 ✓	25	358	-	-
	Mill	1 ✓	26	367	20.1	16.7 - 21.6
	Bin	3 ✓	27	440	-	-
	Bin	1	28	437	-	-
1 Ground	Mill	3 ✓	29	441	19.7	17.6 - 20.6
	Mill	1 ✓	30	533	-	-
	Bin	3 ✓	31	514	-	-
	Bin	0.5 ✓	32	781	-	-
Average				395		

Fig. 1 MICROPROCESSOR - CONTROLLED DOSING SYSTEM

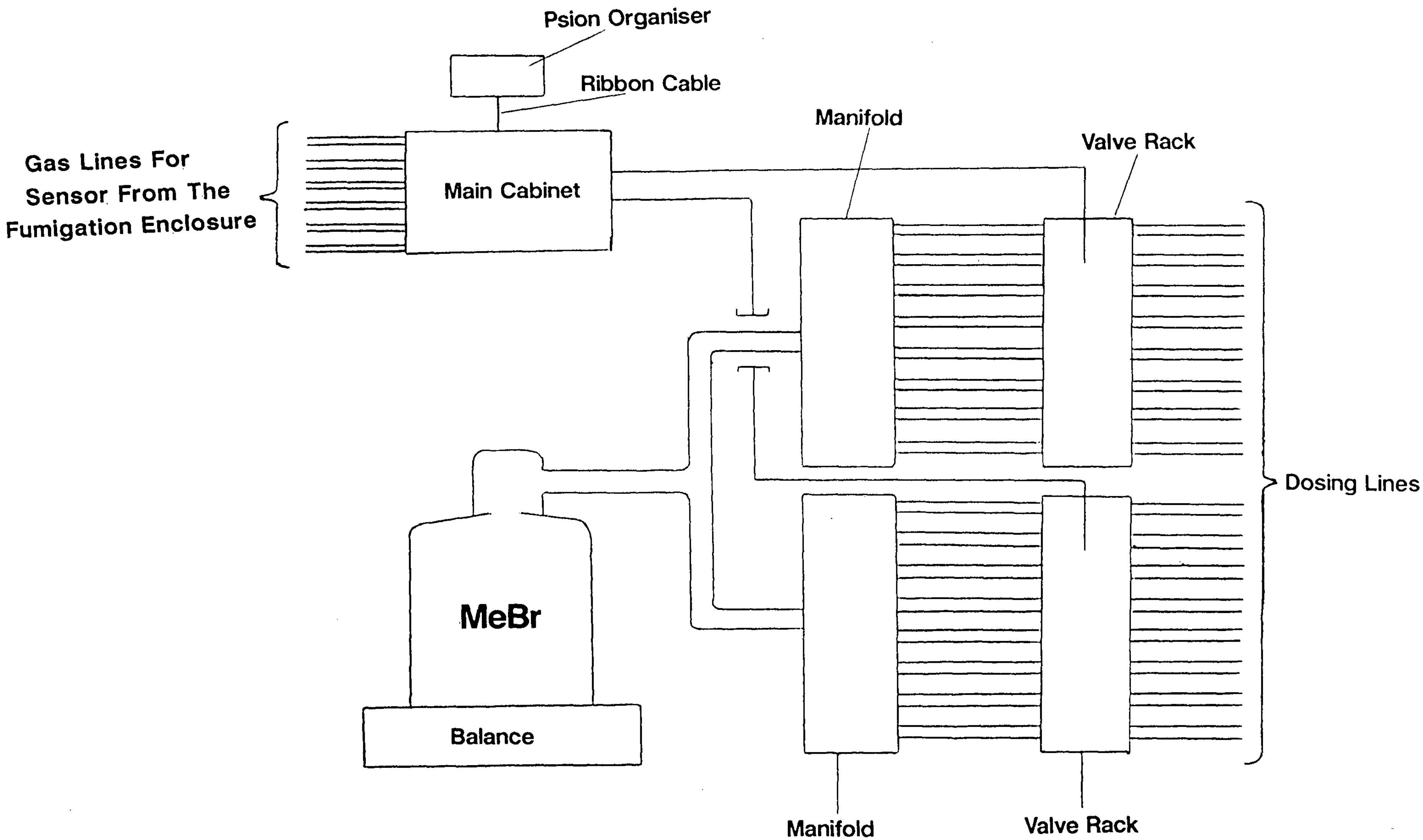
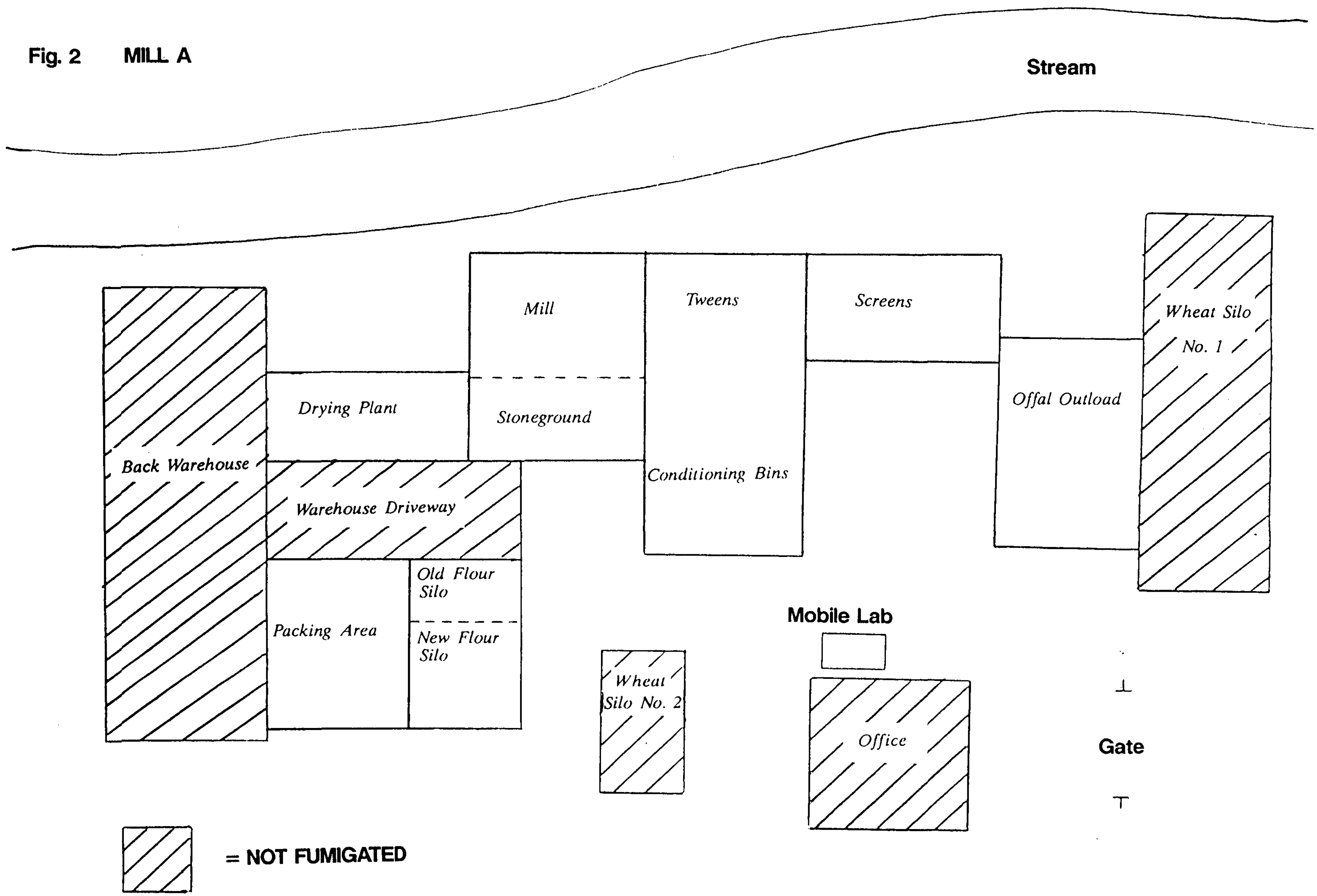


Fig. 2 MILL A



Stream
Mill
Tweens
Screens
Wheat Silo
No. 1
Drying Plant
Stoneground
Offal Outload
Back Warehouse
Conditioning Bins
Warehouse Driveway
Old Flour
Silo
Packing Area
New Flour
Silo
Mobile Lab
Wheat
Silo No. 2
Office
Gate
= NOT FUMIGATED

Fig. 3 DOSING SYSTEM USED AT MILL A AND THE INITIAL DOSE AT MILL B

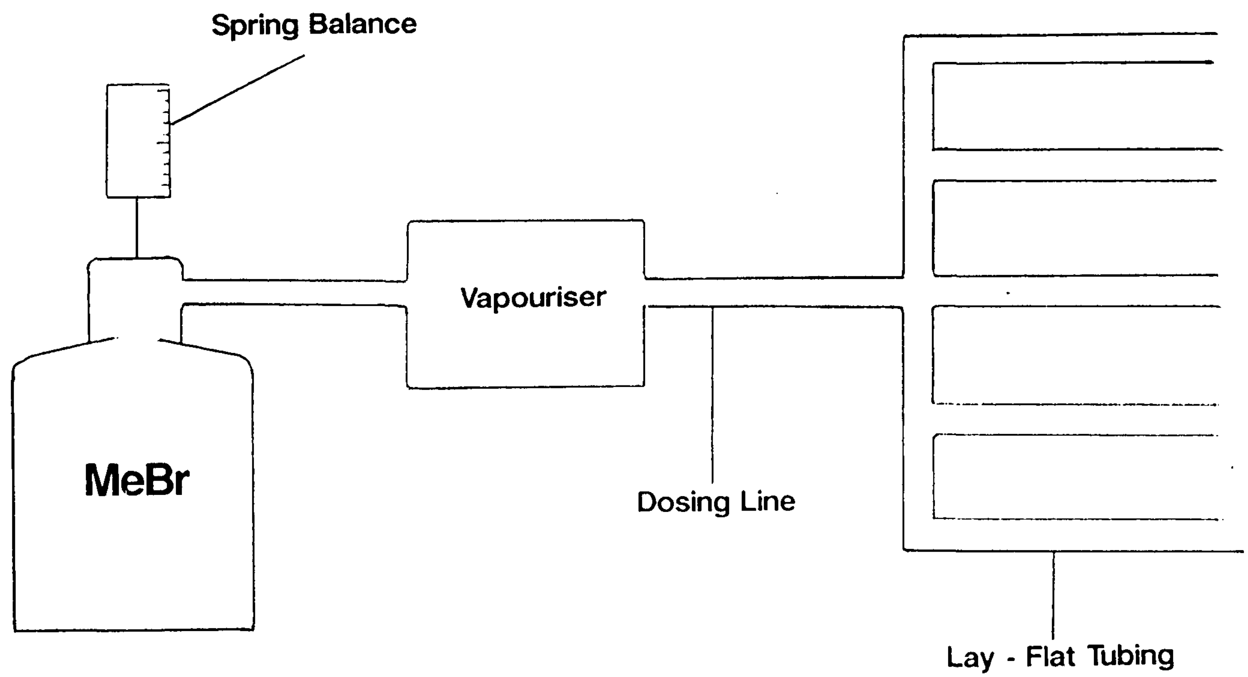


Fig. 4 MILL B (Plan View)

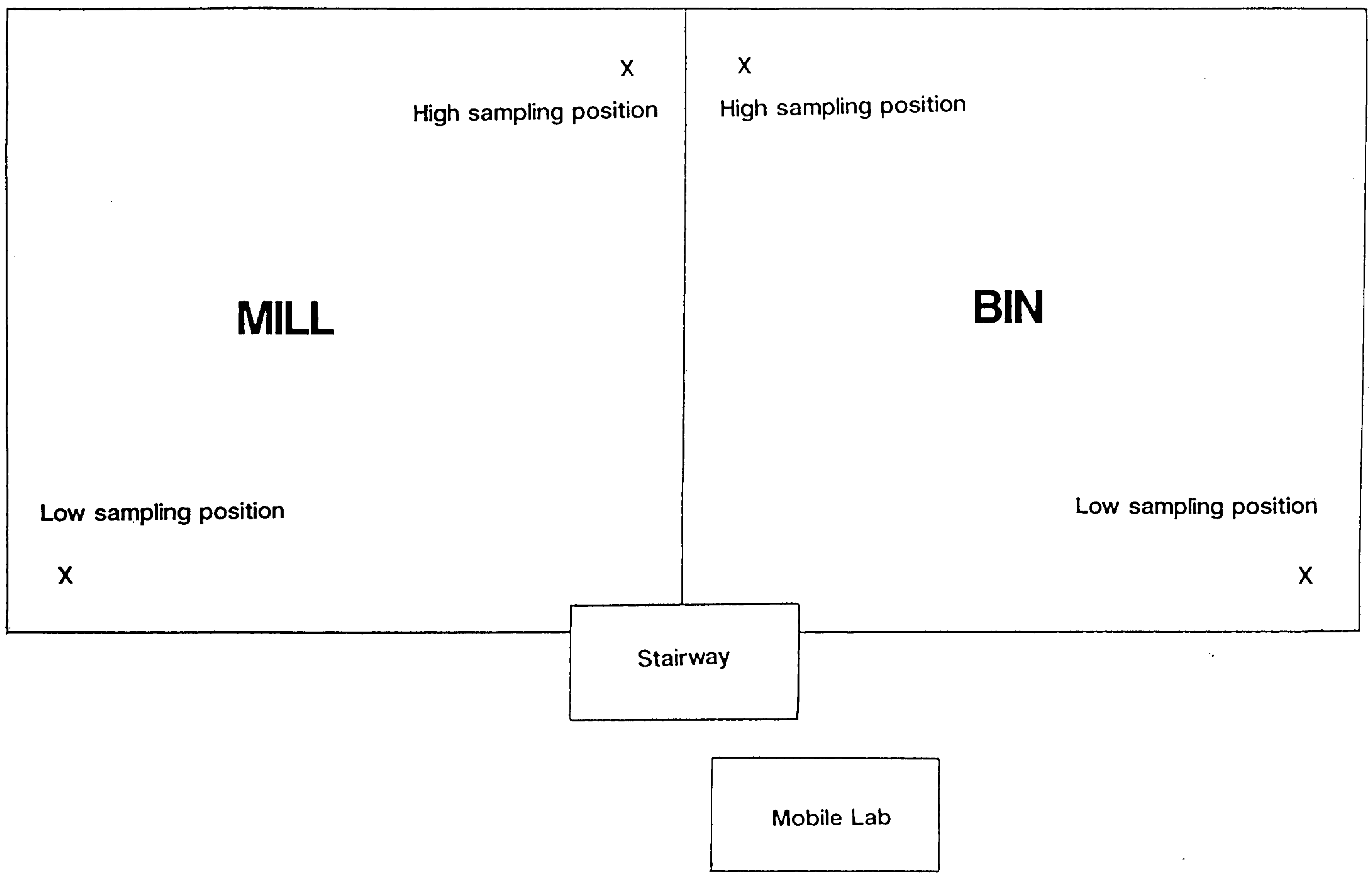


Fig. 5 Concentration of Fumigant Against Time In The Conditioning Bin And Screens At Mill A.

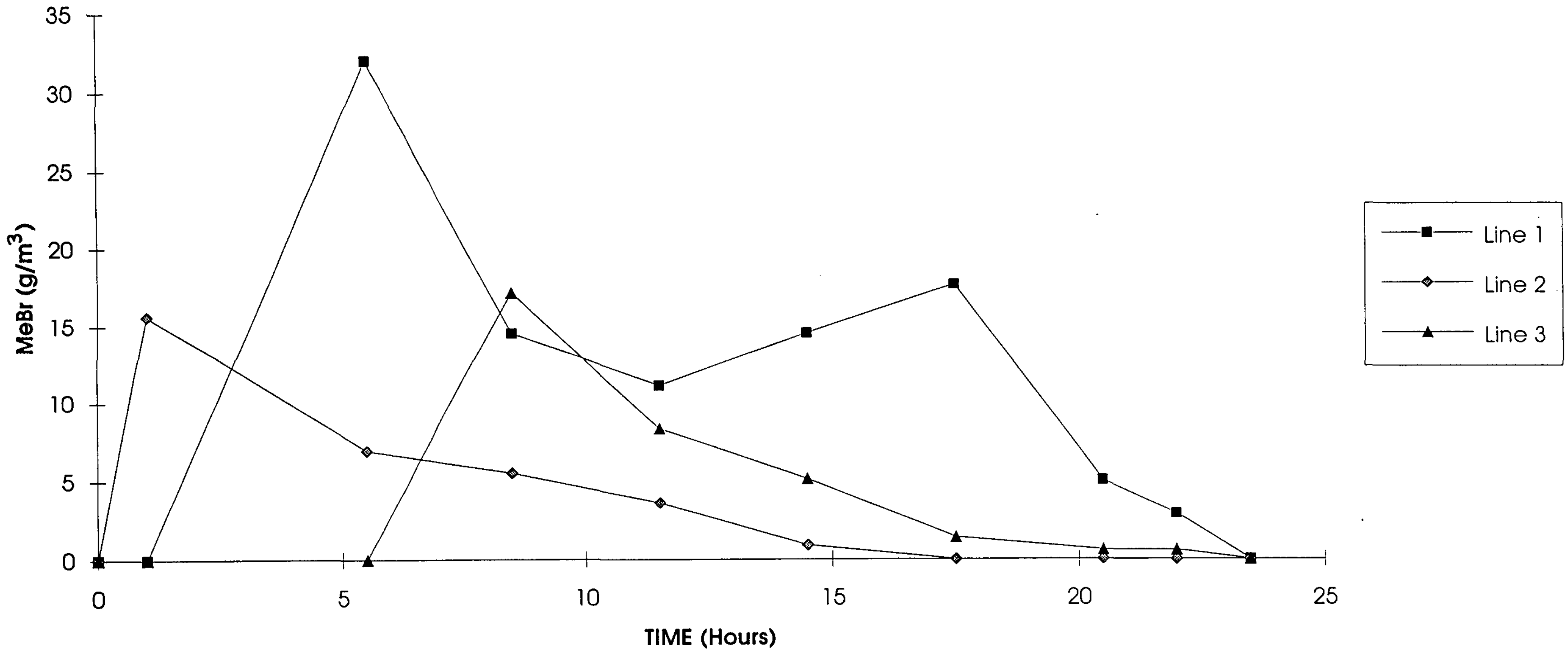


Fig. 6 Concentration of Fumigant Against Time In The Mill At Mill A.

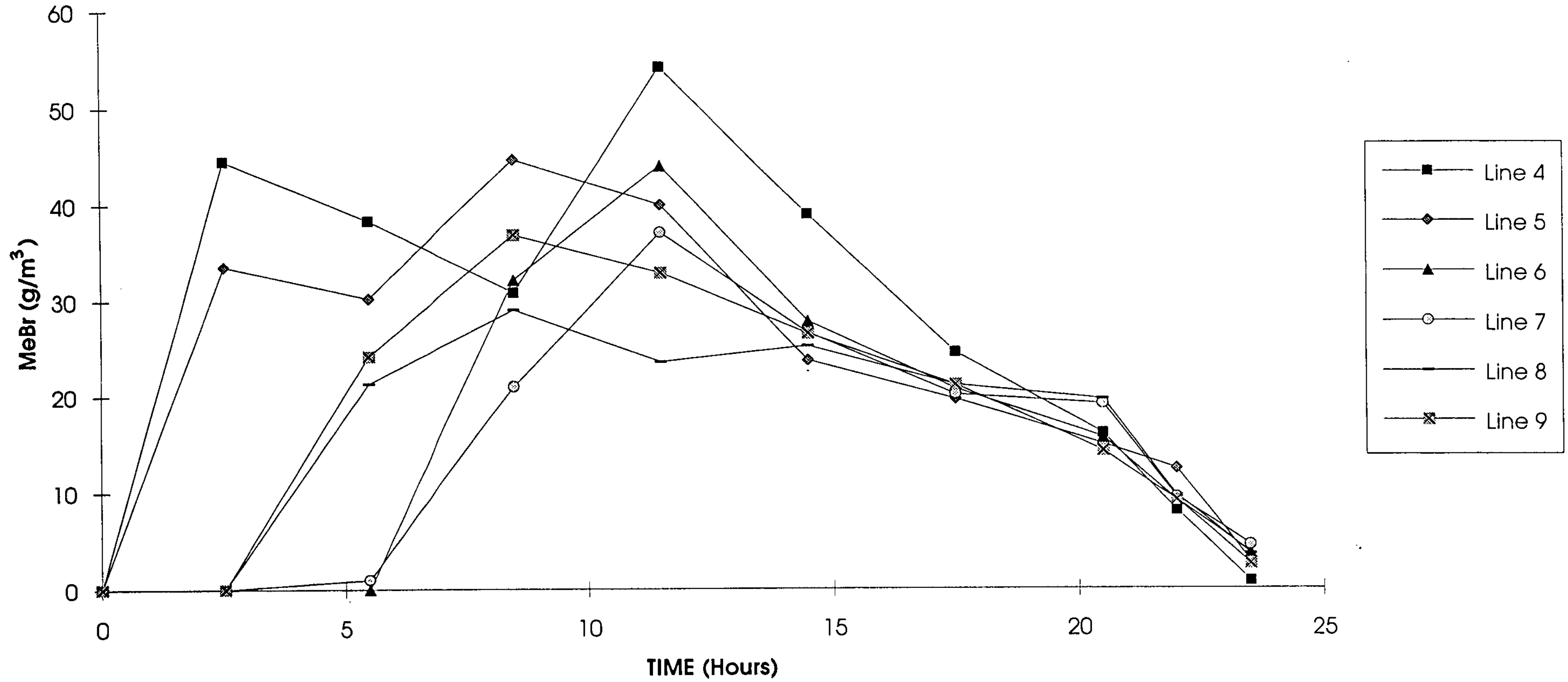


Fig. 7 Concentration of Fumigant Against Time In The Packing Area of Mill A.

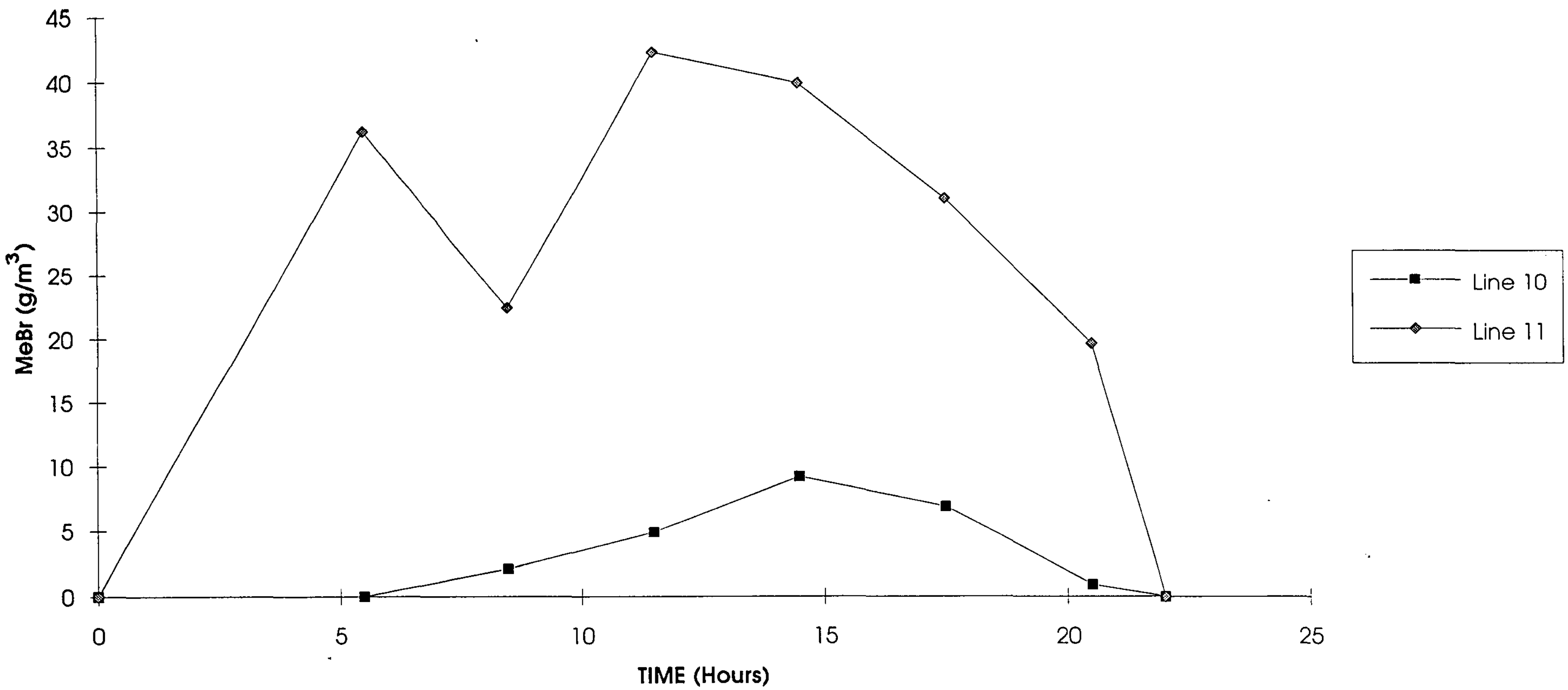


Fig. 8 Concentration of Fumigant Against Time In The Flour Bins At Mill A.

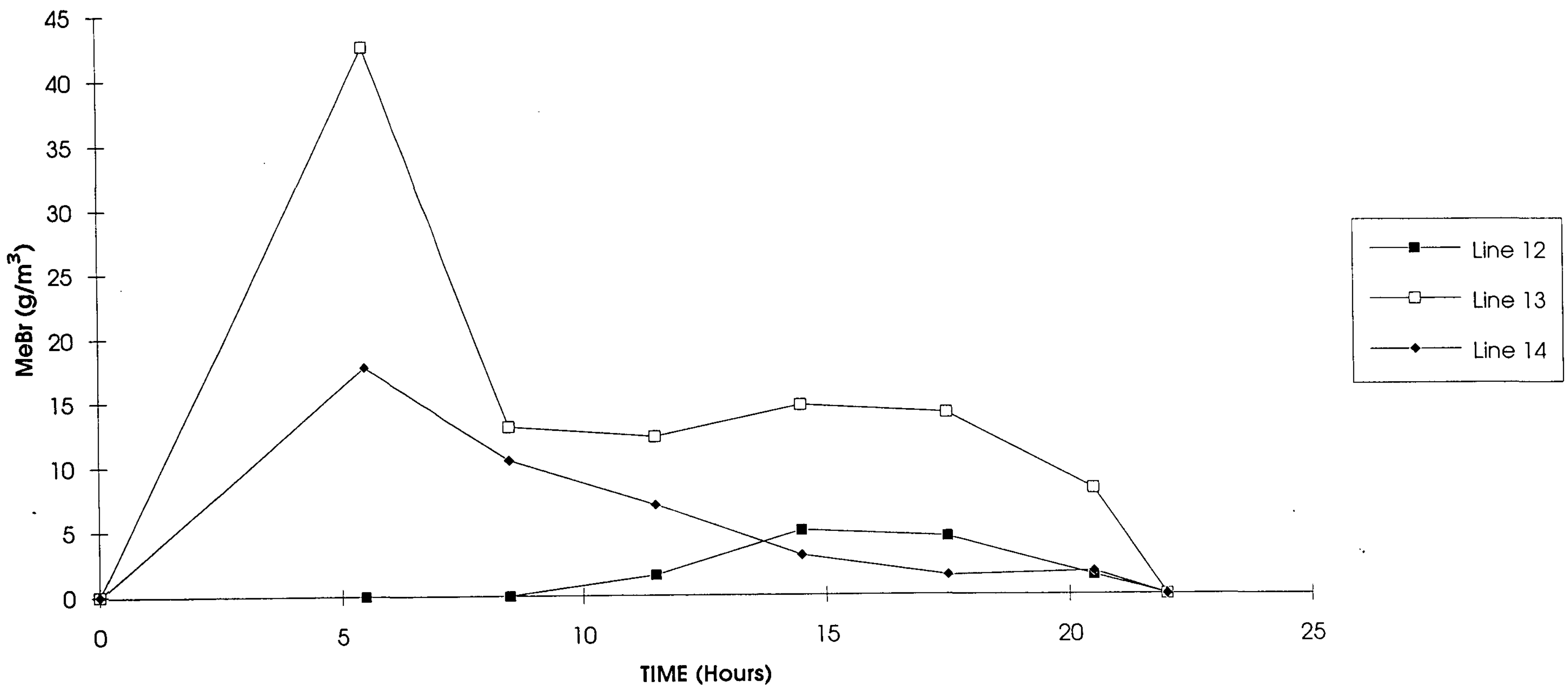


Fig. 9 Concentration of Fumigant Against Time On The Fifth (Top) Floor of Mill B.

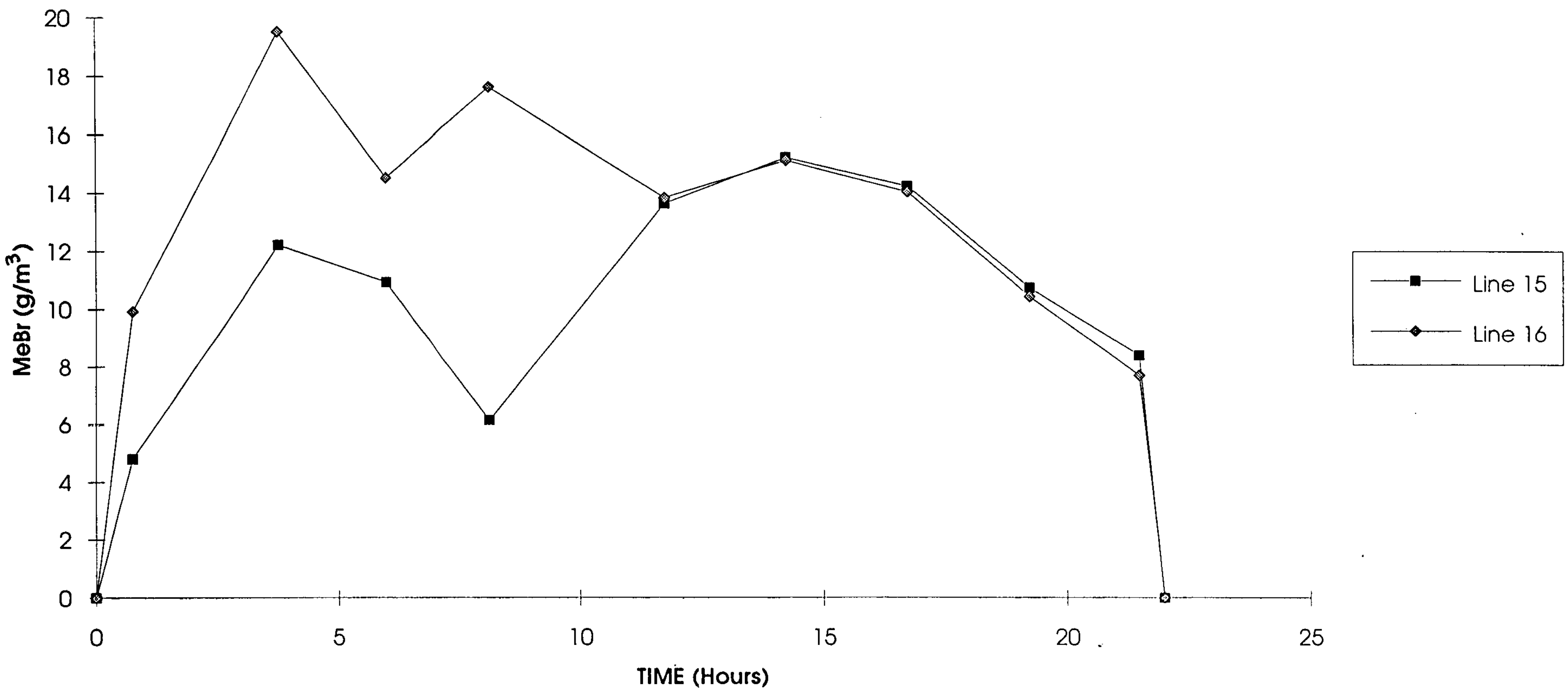


Fig. 10 Concentration of Fumigant Against Time on The Fourth Floor of Mill B.

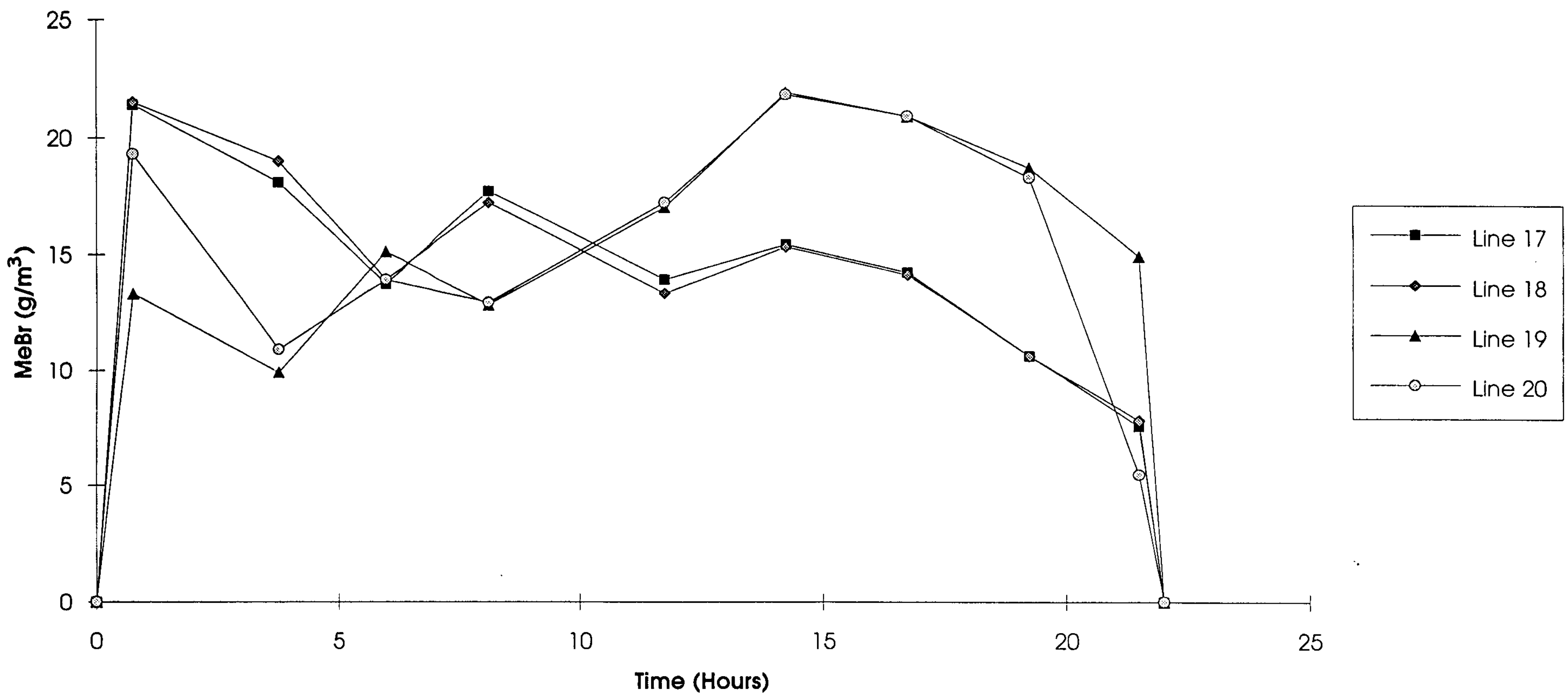


Fig. 11 Concentration of Fumigant Against Time on The Third Floor of Mill B.

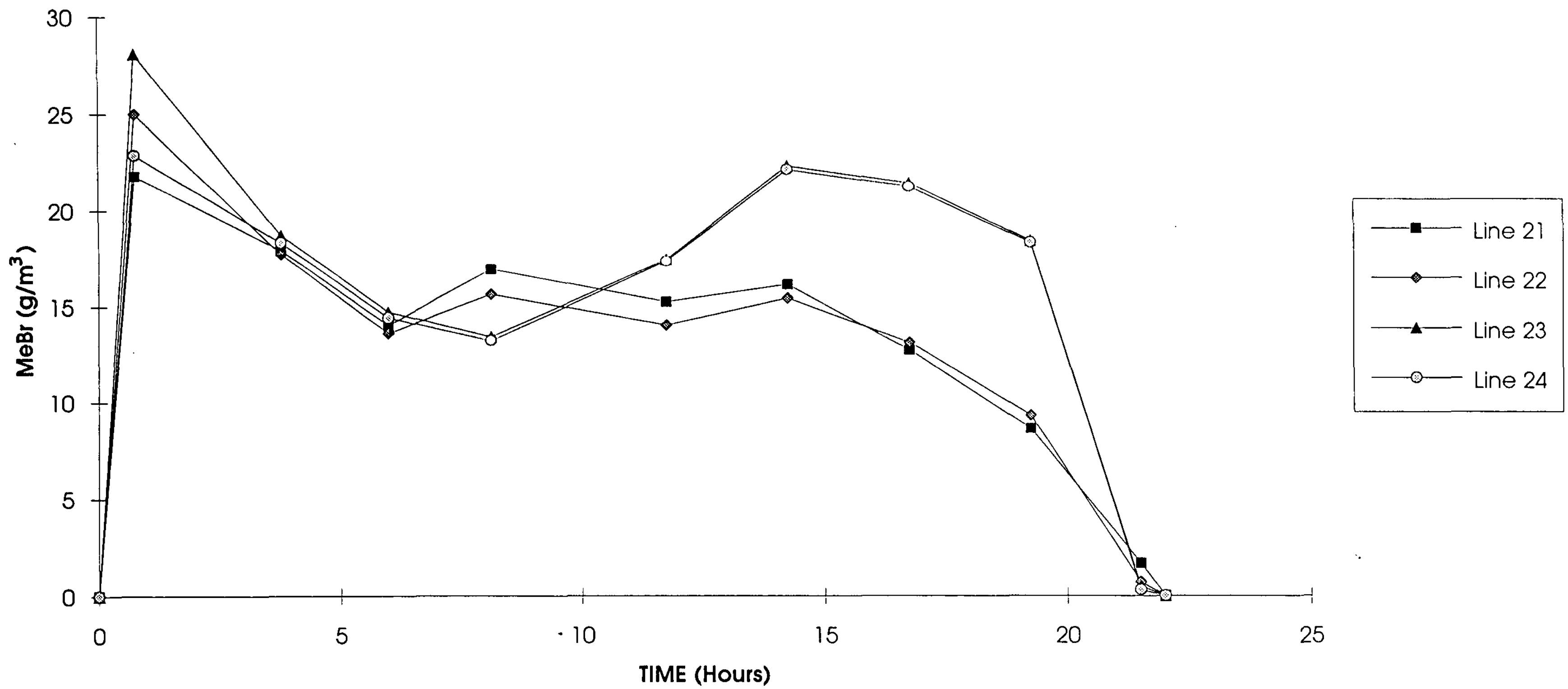


Fig. 12 Concentration of Fumigant Against Time on The Second Floor of Mill B.

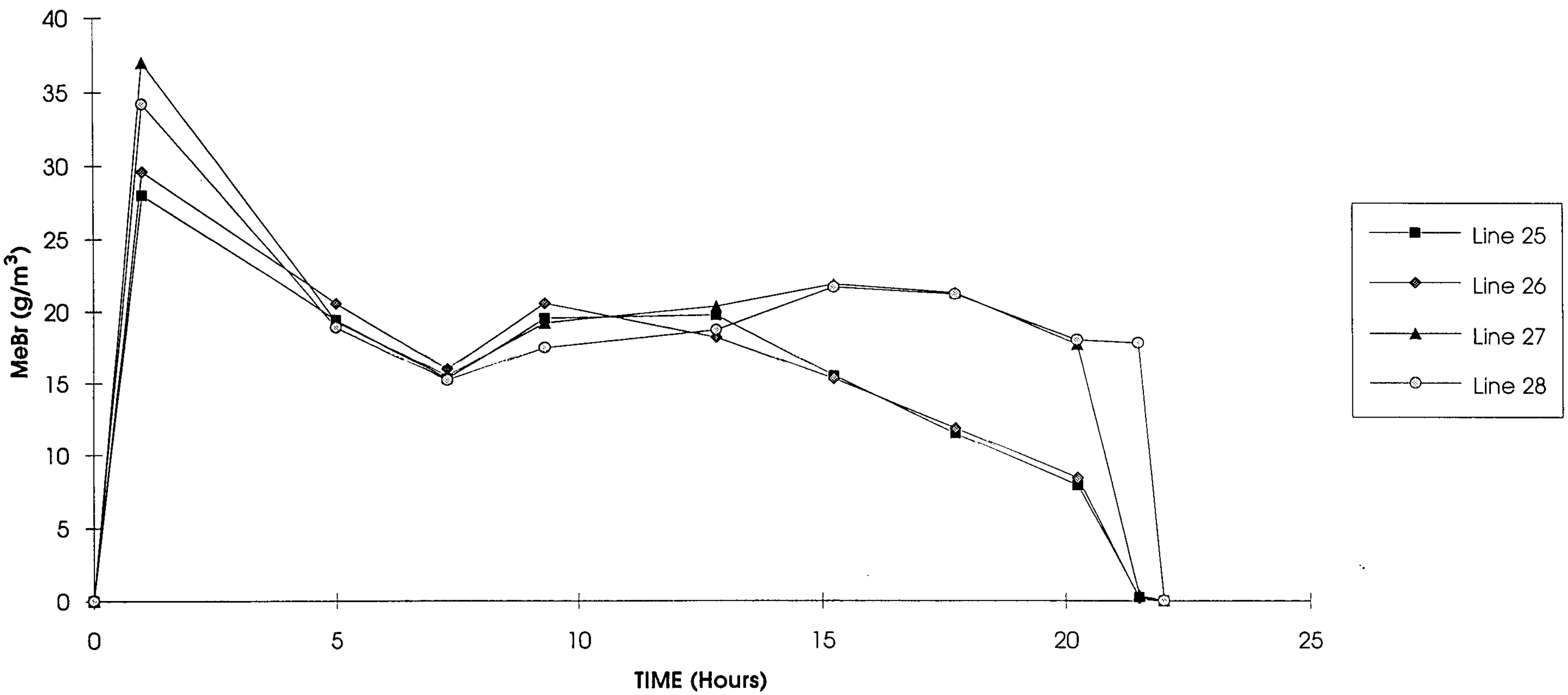


Fig. 13 Concentration of Fumigant Against Time on The First (Ground) Floor of Mill B.