

**Penetration of Methyl Isocyanate
Through Organic Vapor and Acid
Gas Respirator Cartridges**

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Abstract

Methyl isocyanate (MIC) is a very volatile liquid which is highly toxic (TLV 0.02 ppm) and possesses inadequate warning properties. Because of the high toxicity and lack of adequate warning properties, organic vapor (OV) cartridges are contra-indicated for use against MIC. Nevertheless, a study was undertaken to evaluate the MIC breakthrough of OV and acid gas cartridges in order to assess their effectiveness. Two different manufacturers' OV and acid gas cartridges were tested against MIC at three different relative humidities and at different concentrations of MIC in air. Breakthrough times were generally very short. Relative humidity had a large effect on the breakthrough characteristics. The test apparatus and results will be presented.

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Methyl isocyanate (MIC) is a volatile, toxic chemical (TLV = 0.02 PPM) used to manufacture carbamate pesticides. The principal manufacturer of MIC is Union Carbide and the site of production is Institute, West Virginia. In light of the Bhopal disaster and possible safety problems at the Institute facility, NIOSH conducted this research as a basis upon which to recommend protective equipment which might be used in an emergency. Both protective clothing and respirators were evaluated. In particular, NIOSH studied air-purifying respirators in order to assess their effectiveness against MIC vapor penetration. NIOSH does not recommend any air purifying respirator for MIC because of its high toxicity, lack of warning properties and because no effective end of service life indicator is currently available for MIC.

This report only addresses MIC penetration through air-purifying cartridges. Another report addresses the protective clothing issue. The results presented are for two different manufacturers' organic vapor (OV) and acid gas cartridges. Penetration tests were conducted at three or four MIC challenge concentrations and at three different humidity conditions. In general, breakthrough times (1% of challenge concentration) were very short. Also, high relative humidity was found to significantly decrease the breakthrough time of MIC.

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Background

Methyl isocyanate is an extremely hazardous compound due to its toxicity (TLV = 0.02 ppm), volatility, and flammability. The NIOSH/OSHA Occupational Health Guidelines for Chemical Hazards¹ contains a monograph on MIC that summarizes information on permissible exposure limits, chemical and physical properties and potential health hazards. Recommendations for medical surveillance, respiratory protection, and sanitation practices are given. These recommendations are in accordance with good industrial hygiene and medical surveillance practices. Also, the NIOSH/OSHA Standards Completion Program contains a "Draft Technical Standard and Supporting Documentation for Methyl Isocyanate". The chemical and physical properties^{2,3,4} and toxic effects⁵ of MIC have also been reported.

Experimental Procedures

A. Materials

Methyl Isocyanate (17,022-4) was obtained from the Aldrich Chemical Company, Inc.⁶, and was from lot # 3317A6.

Hexane (HPLC Grade with a UV Cutoff 195nm) was obtained from Fisher Scientific.

Air was house air which was passed through a dryer, sorbent and high efficiency filter to remove any residual contaminants.

B. Detectors

The H-Nu, PI-101, Miran 1A, and Century OVA 108 direct reading instruments were all initially evaluated for MIC detectability. The Miran 1A General Purpose Infrared Gas Analyzer was used for the analytical monitoring of MIC because it was the most sensitive analytical technique immediately available. The Miran 1A is a single-beam, variable filter spectrometer, capable of scanning the infrared spectral range between 2.5 and 14.5 μ m. The instrument is equipped with a gas cell having variable pathlength between 0.75 and 20.25 metres. Metal Bellows Corporation pumps Model MB-41 were used as the sampling pump. They have a flowrate of approximately 8 liters per minute.

C. Experimental Design

The laboratory set-up employed is shown in Figure I. House air was passed through an in line dryer to remove residual moisture. The inlet air flow was controlled by means of a central valve (A). This flowrate can be varied from 60 - 120 Lpm but is always maintained at a flowrate that exceeds the flowrate pulled by the downstream vacuum source (G). A syringe pump was used to inject MIC into the airstream at a predetermined rate. By adjusting the syringe pump feed rate and the inlet air flowrate, a known upstream concentration can be generated. However, the upstream MIC concentration was found to vary somewhat over the duration of any particular run. To reduce these fluctuations in the upstream concentration, a buffer tank was added to the system. The upstream MIC vapor concentration (C_0) was continually monitored by means of an infrared detector (IR). When humidified conditions were necessary a Miller-Nelson Research Inc. Model HCS-201 Flow-Temperature-Humidity Control System was placed in line.

The airstream containing the challenge MIC vapor was pulled through the cartridge cell housing that contained either a single cartridge or a pair of cartridges depending on the manufacturer's respirator cartridge design. Immediately downstream from the cartridges was another IR detector which monitored the breakthrough concentration as a function of exposure time. The downstream flow was then passed through a sorbent scrubber to remove residual vapors before reaching the vacuum source.

Both the upstream and downstream IR detectors were calibrated each day before experiments were conducted. The IR instrumental conditions were adjusted for the concentration range of interest. The upstream concentration varied from 280 to 1100 PPM whereas the downstream concentration range of interest was between 0 and 50 PPM. Both IRs were calibrated by injecting known quantities of MIC into a closed loop calibration setup. The IR absorbance was monitored as a function of the MIC concentration. A typical set of calibration curves are shown in Figures II and III. The upstream calibration was done using neat MIC. The downstream calibration required the use of a 10% MIC/90% hexane solution and the IR absorption due to hexane was subtracted from the total.

The lower limit of detection was determined by two different methods. A known amount of liquid MIC was injected into a large carboy (50 liters), allowed to vaporize, and then an aliquot injected into the closed loop. In the other method, a head space sample of MIC vapor at 20°C (vapor in contact with liquid MIC) was injected into the closed loop. The lower limit of detection was 0.20 ppm by the former method and 0.32 ppm by the latter. The minimum detectable concentration claimed by the manufacturer is 0.6 ppm. During these experiments the following IR conditions were used:

0 - 0.100	absorbance scale
11.6	wavelength
20.25m	path length
1	response
1	slit width

This lower limit of detection is approximately 20 times the TLV for MIC (.02 ppm).

The cartridges tested were all "as received" from the manufacturer with no preconditioning. Two manufacturers' products were evaluated; one having a single cartridge arrangement and the other a dual cartridge. The cartridges were weighed and placed in the cell holder. The cell holder was connected to the downstream vacuum source and the flowrate through the system adjusted to 64 Lpm by means of a standard dry test meter. When all the adjustments had been made, the inlet gas stream containing the MIC was placed on line and the upstream and downstream absorbance values were monitored as a function of time.

After the breakthrough test was completed, the cell holder was removed from the system and disassembled. Final cartridge weights were determined. Next, the cartridges were dismantled and the sorbent removed. The empty cartridge was then weighed; thus permitting the calculation of the sorbent weight.

Results

A. Organic Vapor Cartridges

Breakthrough data obtained for OV cartridges of Manufacturer A at dry conditions for challenge concentrations of 1004 PPM, 742 PPM, 556 PPM and 300 PPM along with the average breakthrough times for the three separate determinations are presented in Tables I, II, III and IV, respectively. Plots of the average breakthrough time curves for these challenge concentrations are illustrated in Figures IV, V, VI and VII. Similar data for OV cartridges from Manufacturer B are given in Tables V through VII and corresponding plots in Figures VIII through X. This data clearly shows that at high MIC challenge concentrations, which might be encountered in an emergency situation, MIC is poorly adsorbed on OV cartridges. This point is reinforced by the observation that at the lowest challenge concentration studied (\approx 300 PPM), a breakthrough time of only about 30 minutes was observed and this breakthrough concentration was approximately 20 times the TLV for MIC.

The cartridge weight data for the dry runs of Manufacturer A and B are presented in Tables VIII and IX respectively. Included in these tables are the delta weight gain for each run and the calculated capacity of the sorbent $\frac{\text{gms. adsorbent}}{\text{gms. of sorbent}}$. Both these values reflect the low adsorption capacity of charcoal for MIC. Also, as expected when the challenge concentration decreases so did the adsorption capacity decrease. The breakthrough time variation as a function of challenge concentration was

investigated. The average 1% breakthrough time as a function of challenge concentration was determined for the cartridges of manufacturers A and B at dry conditions (Table X). This data is then plotted on log-log axes (log 1% breakthrough time vs. log challenge concentration) as shown in Figure XI. From this plot an estimate of breakthrough time can be obtained for a given challenge concentration over a limited range. Extrapolation outside this range can be extremely dangerous.

Next, OV cartridges of Manufacturers A and B were run at elevated relative humidities. Both 50% and 73% RH were used in these studies with the challenge concentration being between 750 and 800 PPM. The data for Manufacturer A cartridges at 50% and 73% RH are presented in Tables XI and XII. The corresponding average breakthrough curves are illustrated in Figures XII and XIII. The 50% RH data is not significantly different from the dry condition data. However, at 73% RH the onset of breakthrough is faster but the rate of increase of the breakthrough concentration with time is significantly suppressed. Likewise, the data for Manufacturer B cartridges at 50 and 73% RH are given in Tables XIII and XIV with the corresponding breakthrough time curves presented in Figures XIV and XV. Exactly the same trend was seen with Manufacturer B cartridges as with Manufacturer A cartridges. Weight data for Manufacturers A and B cartridges when run at the humidified conditions are presented in Tables XV and XVI.

Given these results, a set of cartridges was run at 73% RH to see if an increase in absorbance occurred at 3.4 λ which could probably be associated with mono methyl amine, a decomposition product of methyl isocyanate. This experiment verified an increase in absorbance at 3.4 λ . This suggests that the suppression of the MIC breakthrough concentration curve at 73% RH was probably due to the formation of methyl amine at or near the charcoal surface. Thus, additional experiments were performed in order to determine the breakthrough characteristics of methyl amine with OV cartridges. These experiments were done using the methyl amine certification test with OV cartridges. Results for "as received" and "preconditioned" cartridges are found in Table XVII. As expected, the OV cartridges are ineffective in adsorbing mono methyl amine. However, cartridges which had been pretreated at high relative humidity conditions showed increased methyl amine adsorption due to the presence of adsorbed water on the charcoal sorbent. This is the same effect that is probably occurring during the MIC runs at 73% RH. In fact, when acid gas (AG) and OV/AG cartridges were studied against a MIC challenge vapor the same phenomenon was observed for the 3.4 λ absorption.

B. Acid Gas and Organic Vapor/Acid Gas Cartridges

It was thought that due to the high reactivity of MIC that acid gas cartridges which might act as a catalyst might be effective. Duplicate runs for Manufacturer A's acid gas cartridges at dry and 73% RH are shown in Table XVIII with the corresponding breakthrough curves illustrated in Figures XVI through XIX. The results at dry conditions gave breakthrough

times greater than 60 minutes but when these same acid gas cartridges were tested at a high humidity (73%), instantaneous MIC breakthrough was observed. This instantaneous breakthrough concentration persisted at a steady level (< 4 PPM) for approximately 30 minutes before any further increase in the level of MIC breakthrough resulted. Similar results were obtained for Manufacturer B OV/AG cartridges as displayed in Table XIX and Figures XX through XXIII. The cartridge weight data for both these sets of data is listed in Table XX. It is interesting to note that Manufacturer A's AG cartridges actually lost weight when run at dry conditions. Also, note the rather large weight gains observed at 73% RH which is mostly due to water uptake.

C. Jonas Model Results on Organic Vapor Cartridges

Since NIOSH has been conducting research on the evaluation of the Jonas Model for predicting organic vapors breakthrough characteristics, one final experiment was conducted with Manufacturer B cartridges at dry conditions. Four cartridges were stacked in series and challenged with MIC to see if the Jonas (7, 8, 9, 10, 11, 12, 13, 14) breakthrough model applied. This model states that the breakthrough characteristics are directly proportional to sorbent weight. The data obtained for the respective four cartridges in series are presented in Table XXI with the weight and calculated capacity data in Table XXII. The four breakthrough curves are presented in Figure XXIV.

The 1% breakthrough times and the corresponding sorbent weights are:

<u>Time to 1% Breakthrough (min.)</u>	<u>Cumulative Sorbent Weight (gms.)</u>
11.9	46.6996
30.8	92.4586
50.0	140.3193
69.9	188.7943

The above 1% breakthrough times were all corrected to a concentration value of 950 PPM. This was done by assuming linear behavior of the challenge concentration with breakthrough time $\left(\frac{1\% \text{ BT} \times \text{CC}}{950}\right)$. A plot of these 1% breakthrough times versus the sorbent weight gave a straight line (Figure XXV) in accordance with the modified Wheeler equation. Results from a least squares analysis are as follows:

$$\begin{aligned} \text{slope} &= .4076 \\ \text{Y intercept} &= -7.0998 \\ R^2 &= .9999 \end{aligned}$$

The equilibrium adsorption capacity (W_e) was calculated from the slope as follows:

$$\begin{aligned} \text{slope} &= W_e / C_0 Q \\ .4076 &= W_e / 2.239 \times 10^{-6} \text{ (64000)} \\ W_e &= .0584 \text{ gm./gm.} \end{aligned}$$

where

$$C_0 = \frac{950 \text{ PPM (57.05)}}{10^9 \text{ (24.205)}} = 2.239 \times 10^{-6}$$

Using 47.198 grams as the average weight of sorbent per cartridge and a fill volume of 119 cc, the resulting bed packing density is .3966

gms./cm³. The first order rate constant (kv) at a concentration ratio $\frac{C_0}{C_x}$ (C_0 = challenge concentration & C_x = breakthrough concentration) of 1% can then be determined as follows:

$$\text{intercept} = \frac{-W_e \rho \ln C_0/C_x}{k_v C_0}$$

$$-7.0998 = \frac{-.0584 (.3966)(4.6052)}{k_v (2.239 \times 10^6)}$$

$$k_v = 6710 \text{ min}^{-1}$$

The critical bed weight was found to be 17.42 gms. This means that a bed of 17.42 gms. of charcoal in this configuration would give instantaneous MIC breakthrough.

The adsorption space available in the carbon sorbent to adsorb the vapor is calculated from the adsorption capacity (W_e) as follows:

$$W_v d_e = W_e$$

where d_e is the density for MIC ($.967 \text{ gm/cm}^3$).

This calculation employs the concept of volume pore filling of Bering, et al.¹⁵. The adsorption space (W_v) was found to be $.056 \text{ gm/cm}^3$.

Cartridges from the same manufacturer but from a different lot gave W_v values of $\approx .15 \text{ g/cm}^3$ for acetone at 1060 PPM and $\approx .20 \text{ g/cm}^3$ for chloroform at 1000 PPM. The W_v value for MIC is significantly lower and reflects the fact that MIC is weakly adsorbed on charcoal sorbent.

Conclusions

This study showed that none of the commercially available air-purifying cartridges tested provided protection against MIC breakthrough at high MIC

challenge concentrations which might be expected during an emergency situation. Organic vapor cartridges tested at dry conditions against a 300 ppm MIC challenge concentration gave a breakthrough time of approximately 30 minutes but the breakthrough concentration was 20 times the TLV for MIC. OV cartridge results at 50% RH were not significantly different from the dry condition data. However, at 73% RH the onset of breakthrough for the OV cartridges was earlier but the rate of increase in the breakthrough concentration was slower. Organic vapor/acid gas and acid gas cartridges gave breakthrough times greater than 60 minutes at dry conditions against the high MIC challenge concentrations. These same cartridges showed instantaneous MIC breakthrough when tested at 73% RH.

Sorbent capacity data for the OV cartridges confirmed that MIC was weakly adsorbed on charcoal. All the results obtained support and emphasize the importance of NIOSH's recommendation that any air purifying respirator should not be used for MIC because of its high toxicity, lack of warning properties and because no effective end of service life indicator is currently available for MIC.

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TABLE I

MIC Breakthrough of OV Cartridges at
Dry Conditions for Manufacturer A at 1004 PPM

<u>Breakthrough Concentration (PPM)</u>	<u>Time to Breakthrough Run # 1 (mins.)</u>	<u>Time to Breakthrough Run # 2 (mins.)</u>	<u>Time to Breakthrough Run # 3 (mins.)</u>	<u>AVG. Time to Breakthrough (mins.)</u>
1.0	13.7	13.3	-	-
1.2	14.1	14.2	12.4	13.6
2.4	14.4	14.9	12.8	14.0
3.2	14.7	15.4	13.1	14.4
3.9	-	15.8	13.5	-
4.5	15.1	16.0	13.6	14.9
5.2	-	16.3	13.8	-
6.6	15.7	16.6	14.1	15.5
8.0	-	-	14.4	-
8.7	-	17.1	-	-
10.1	16.3	17.3	14.7	16.1
13.6	16.7	17.7	15.1	16.5
17.0	17.1	18.1	15.5	16.9
20.6	17.4	18.4	15.7	17.2
24.0	17.7	18.7	16.0	17.5
27.4	18.0	19.0	16.2	17.7
30.9	18.2	-	16.4	-
34.4	18.4	-	16.6	-
37.8	-	-	16.8	-

TABLE II

MIC Breakthrough of OV Cartridges at
Dry Conditions for Manufacturer A at 742 PPM

<u>Breakthrough Concentration (PPM)</u>	<u>Time to Breakthrough Run # 7 (mins.)</u>	<u>Time to Breakthrough Run # 8 (mins.)</u>	<u>Time to Breakthrough Run # 9 (mins.)</u>	<u>AVG. Time to Breakthrough (mins.)</u>
.8	15.5	16.3	15.9	15.9
1.4	17.0	17.1	17.3	17.1
2.1	17.6	17.6	17.9	17.7
2.8	18.3	18.2	18.3	18.3
3.4	18.6	18.6	18.8	18.7
4.8	19.2	19.1	-	-
5.4	-	-	19.6	-
6.8	19.9	19.7	20.1	19.9
8.0	20.4	20.1	20.6	20.4
10.0	20.8	20.4	20.9	20.7
12.0	21.1	20.8	21.3	21.1
13.3	21.4	21.0	21.6	21.3
15.4	-	-	21.8	-
16.7	21.8	21.5	22.0	21.8
20.0	22.2	21.9	22.4	22.2
23.3	22.5	22.2	22.7	22.5
26.6	22.9	22.5	23.0	22.8
30.0	23.1	22.7	23.3	23.0
33.2	23.4	23.0	23.6	23.3
36.7	23.6	23.2	23.8	23.5

TABLE III

MIC Breakthrough of OV Cartridges at
Dry Conditions for Manufacturer A at 556 PPM

<u>Breakthrough Concentration (PPM)</u>	<u>Time to Breakthrough Run # 4 (mins.)</u>	<u>Time to Breakthrough Run # 5 (mins.)</u>	<u>Time to Breakthrough Run # 6 (mins.)</u>	<u>AVG. Time to Breakthrough (mins.)</u>
0.8	-	18.8	20.3	-
1.4	19.9	19.8	21.5	20.4
2.1	20.6	20.4	22.7	21.2
2.8	21.1	21.0	23.5	21.9
3.4	21.8	21.3	23.9	22.3
4.1	-	-	24.4	-
4.8	22.4	22.0	-	-
5.4	-	-	25.1	-
6.8	23.2	22.6	25.6	23.8
8.0	23.5	22.9	26.2	24.2
10.0	24.1	23.4	26.7	24.7
11.4	-	23.7	-	-
12.0	24.5	-	27.1	-
13.3	24.8	24.0	27.4	25.4
14.8	-	-	27.7	-
16.7	25.3	24.6	28.1	26.0
20.0	25.8	24.9	28.6	26.4
23.3	26.1	25.3	29.0	26.8
26.6	26.5	25.5	29.4	27.1
30.0	26.8	25.8	29.7	27.4
33.2	27.1	26.1	30.1	27.8
36.7	27.4	26.3	30.4	28.0
40.0	27.7	-	-	-

TABLE IV

MIC Breakthrough of OV Cartridges at Dry Conditions for
 Manufacturer A at 300 PPM.

Breakthrough Concentration PPM	Time to Breakthrough Run # 38 (min.)	Time to Breakthrough Run # 39 (min.)	AVG Time to Breakthrough (min.)
.4	28.3	37.2	32.8
1.0	32.1	39.9	36.0
1.7	33.7	41.4	37.6
2.4	34.5	42.6	38.6
3.0	35.3	43.4	39.4
3.6	36.0	44.3	40.2
5.0	36.9	45.5	41.2
6.4	37.8	46.3	42.1
7.7	38.5	-	-
9.0	39.1	-	-
9.6	-	48.0	-
10.3	39.7	-	-
12.9	40.7	49.4	45.1
16.2	41.6	50.4	46.0
19.5	42.5	51.4	47.0
22.8	43.2	52.4	47.8
26.1	43.9	53.0	48.5
29.3	44.6	53.8	49.2
32.8	45.2	54.4	49.8

TABLE V

MIC Breakthrough of OV Cartridges at
Dry Conditions for Manufacturer B at 964 PPM

<u>Breakthrough Concentration (PPM)</u>	<u>Time to Breakthrough Run # 16 (mins.)</u>	<u>Time to Breakthrough Run # 17 (mins.)</u>	<u>Time to Breakthrough Run # 18 (mins.)</u>	<u>AVG. Time to Breakthrough (mins.)</u>
.8	4.1	4.5	6.4	5.0
1.6	5.8	6.2	7.4	6.5
2.3	-	-	9.0	-
2.9	8.5	9.0	10.9	9.5
3.6	9.4	10.6	12.0	10.7
4.3	-	12.2	-	-
5.0	11.2	13.3	13.4	12.6
6.4	13.2	15.8	15.1	14.7
7.0	14.1	17.4	16.1	15.9
8.4	15.9	19.5	17.8	17.7
9.6	18.2	22.0	-	20.1
9.8	-	-	19.8	-
10.4	-	23.4	-	-
11.1	20.0	-	21.7	20.9
11.7	-	24.6	-	-
12.4	22.7	-	-	-
13.2	23.5	-	24.0	23.8
13.8	24.3	26.4	-	25.4
14.4	25.7	-	25.4	25.6
15.8	-	27.1	-	-
15.9	26.7	-	-	-
16.6	-	-	26.6	-
17.2	27.8	27.7	-	27.8
19.2	28.5	-	27.7	28.1
20.0	-	28.4	-	-
22.0	29.4	28.9	-	29.2
22.7	-	-	28.8	-
23.4	29.8	-	-	-
24.8	30.1	29.4	29.2	29.6
26.1	30.4	-	-	-
27.4	30.6	29.9	29.8	30.1

TABLE VI

MIC Breakthrough of OV Cartridges at
Dry Conditions for Manufacturer B at 744 PPM

<u>Breakthrough Concentration (PPM)</u>	<u>Time to Breakthrough Run # 13 (mins.)</u>	<u>Time to Breakthrough Run # 14 (mins.)</u>	<u>Time to Breakthrough Run # 15 (mins.)</u>	<u>AVG. Time to Breakthrough (mins.)</u>
.8	8.7	5.5	6.5	6.9
1.6	9.9	6.5	8.7	8.4
2.3	10.9	7.7	10.6	9.7
2.9	12.7	8.6	12.6	11.3
3.6	13.5	-	13.8	-
4.3	14.6	10.1	15.1	13.3
5.0	15.2	-	16.6	-
5.6	16.2	11.7	18.0	15.3
6.4	17.5	12.6	19.6	16.6
7.0	18.4	13.3	21.8	17.8
7.6	-	13.6	-	-
8.4	20.5	14.6	23.8	19.6
9.7	-	16.0	26.7	-
10.4	24.0	16.8	-	-
11.2	-	18.2	28.6	-
11.7	27.0	-	-	-
12.4	-	19.4	29.8	-
13.8	29.3	21.0	30.9	27.1
15.2	30.8	22.8	-	-
16.0	-	-	31.9	-
17.2	-	25.0	-	-
18.0	32.3	-	32.7	-
18.6	-	26.6	-	-
19.3	33.0	-	-	-
20.1	33.5	-	-	-
20.7	-	28.8	33.6	-
22.0	-	30.2	-	-
22.8	34.1	-	-	-
23.4	-	31.3	34.3	-
24.0	-	32.1	-	-
24.8	34.7	-	-	-
26.1	-	33.7	-	-
	35.1	31.5	35.1	35.0

TABLE VII

MIC Breakthrough of OV Cartridges at
Dry Conditions for Manufacturer B at 536 PPM

<u>Breakthrough Concentration (PPM)</u>	<u>Time to Breakthrough Run # 10 (mins.)</u>	<u>Time to Breakthrough Run # 11 (mins.)</u>	<u>Time to Breakthrough Run # 12 (mins.)</u>	<u>AVG. Time to Breakthrough (mins.)</u>
.8	12.2	17.7	10.3	13.4
1.4	14.9	22.6	12.3	16.6
2.1	18.2	27.2	14.0	19.8
2.8	20.7	31.4	15.3	22.5
3.4	23.5	33.1	16.7	24.4
4.1	26.2	34.7	18.2	26.4
4.8	28.9	36.0	19.6	28.2
5.4	31.8	36.9	21.3	30.0
6.1	34.0	-	22.9	-
6.8	35.4	38.0	24.5	32.6
7.4	36.3	-	26.1	-
8.0	-	39.1	27.9	-
8.8	37.8	-	-	-
9.4	-	-	31.3	-
10.0	39.0	40.3	33.5	37.6
11.4	39.7	-	36.2	-
12.0	-	41.2	-	-
13.3	40.9	41.8	39.6	40.8
15.4	41.6	42.5	41.1	41.7
16.7	42.0	42.8	41.9	42.2
20.0	43.0	43.7	43.5	43.4
23.3	43.7	44.5	44.7	44.3
26.6	44.4	45.1	45.7	45.1
30.0	45.0	45.7	46.5	45.7
33.2	45.5	46.2	47.2	46.3

TABLE VIII

MIC Cartridge Weight Data for
 Manufacturer A When Run at Dry Conditions

Run Concentration PPM	Initial Cartridge Weight gms.	Cartridge Case Weight gms.	Final Cartridge Weight gms.	Initial Charcoal Weight gms.	Δ Wt. gms.	Capacity* gms./gms.
1004	92.2187	28.7920	94.3287	63.4267	2.1100	.0333
1004	93.5137	28.4464	95.9255	65.0673	2.4118	.0371
1004	92.5891	28.5730	94.8862	64.0161	2.2971	.0359
742	92.9907	29.2930	95.0617	63.6977	2.0710	.0325
742	91.0686	28.8995	93.1213	62.1701	2.0527	.0330
755	92.1931	28.6575	94.3110	63.5356	2.1179	.0333
556	97.0982	29.8646	99.1925	67.2336	2.0943	.0311
536	92.2743	28.9010	94.2326	63.6733	1.9583	.0308
556	94.3809	28.8452	96.2427	65.5357	1.8618	.0284
304	92.8696	28.4962	93.7166	64.3734	0.8470	.0132
296	95.2900	28.3615	95.9417	66.9285	0.6517	.0097

* Capacity = $\frac{\text{gms. adsorbed}}{\text{gms. of sorbent}}$

TABLE IX

MIC Cartridge Weight Data for
 Manufacturer B When Run at Dry Conditions

<u>Run Concentration PPM</u>	<u>Initial Cartridge Weight gms.</u>	<u>Cartridge Case Weight gms.</u>	<u>Final Cartridge Weight gms.</u>	<u>Initial Charcoal Weight gms.</u>	<u>Δ Wt. gms.</u>	<u>Capacity* gms./gms.</u>
964	143.7970	44.2071	147.6212	99.5899	3.8242	.0384
964	139.3924	44.1402	143.1268	95.2522	3.7344	.0392
964	139.6118	44.3160	143.2263	95.2958	3.6145	.0379
752	140.2087	44.1644	143.4822	96.0443	3.2785	.0341
744	143.7710	44.1916	146.8790	99.5794	3.1080	.0312
738	138.8642	44.3099	142.0502	94.5543	3.1860	.0337
549	139.7707	44.3373	142.7427	95.4334	2.9720	.0311
536	146.4896	44.6737	149.5727	101.8159	3.0831	.0303
536	146.5881	44.0215	149.7832	102.5666	3.1951	.0312

* Capacity = $\frac{\text{gms. adsorbed}}{\text{gms. of sorbent}}$

TABLE X

NIC Breakthrough Result as a Function
of Challenge Concentration at Dry Conditions

<u>Manufacturer</u>	<u>Average Challenge Concentration PPM</u>	<u>Average 1% Breakthrough Time (min.)</u>
A	1004	16.1
	742	20.2
	556	23.3
	300	39.4
B	964	20.1
	744	18.4
	536	29.9

TABLE XI

MIC Breakthrough of OV Cartridges at 50% Relative Humidity
for Manufacturer A at 742 PPM.

Breakthrough Concentration PPM	Time to Breakthrough Run # 27 (min.)	Time to Breakthrough Run # 28 (min.)	Time to Breakthrough Run # 29 (min.)	AVG Time to Breakthrough (min.)
.6	15.5	14.3	14.9	14.9
1.2	17.4	17.2	17.1	17.2
2.0	18.1	17.8	18.6	18.2
2.7	18.9	18.6	19.3	18.9
3.3	19.3	19.0	19.9	19.4
4.0	19.8	19.6	-	19.7
4.8	20.2	-	20.7	20.4
5.5	-	20.4	-	-
6.2	-	-	21.5	-
6.9	21.2	21.0	-	21.1
8.3	21.7	-	22.3	22.0
9.0	-	21.7	-	-
9.6	22.2	-	22.8	-
11.1	22.6	22.3	23.2	22.4
12.4	-	-	23.7	-
13.2	23.3	-	-	-
13.8	-	22.9	-	-
15.2	23.8	-	24.3	24.1
16.0	-	23.4	-	-
17.3	24.3	-	-	-
18.0	-	23.7	-	-
18.8	-	-	24.9	-
20.8	25.0	24.2	25.3	24.8
23.6	25.5	24.6	25.8	25.3
26.4	-	25.0	26.2	25.6
27.8	26.2	-	-	-
28.4	-	-	26.5	-
30.5	-	-	26.7	-
31.2	-	25.6	-	-
33.3	-	-	27.1	-
34.8	-	26.1	27.3	26.7
36.0	27.3	-	-	-
36.1	-	-	27.5	-
38.3	27.6	26.4	27.7	27.2

TABLE XII

MIC Breakthrough of OV Cartridges at 73% Relative Humidity
for Manufacturer A at 802 PPM.

Breakthrough Concentration PPM	Time to Breakthrough Run # 30 (min.)	Time to Breakthrough Run # 31 (min.)	Time to Breakthrough Run # 32 (min.)	AVG Time to Breakthrough (min.)
.6	13.1	13.5	10.5	12.4
1.2	20.2	19.8	17.2	19.1
2.0	22.0	23.1	21.3	22.1
2.7	25.3	26.7	-	26.0
3.3	27.3	28.6	-	28.0
4.0	29.2	30.6	-	29.9
4.8	30.7	33.1	-	31.9
5.5	32.2	34.4	-	33.3
6.2	33.3	35.5	-	34.4
6.9	34.3	37.0	-	35.7
7.6	36.4	38.2	-	37.3
8.3	37.1	40.0	-	38.6
9.6	39.3	-	-	-
10.4	40.8	-	-	-
11.2	42.0	-	-	-

TABLE XIII

HIC Breakthrough of OV Cartridges at 50% Relative Humidity
for Manufacturer B at 780 PPM.

Breakthrough Concentration PPM	Time to Breakthrough Run # 33 (min.)	Time to Breakthrough Run # 34 (min.)	Time to Breakthrough Run # 35 (min.)	AVG Time to Breakthrough (min.)
.5	-	-	6.5	-
.6	6.4	5.7	-	6.1
1.2	9.8	8.5	9.5	9.3
1.9	-	-	11.6	-
2.0	11.6	7.8	-	9.7
2.6	-	-	14.9	-
2.7	13.8	15.6	-	-
3.3	16.8	18.6	18.3	17.9
4.0	19.2	20.6	19.7	19.8
4.8	22.4	23.2	22.6	22.7
5.4	-	-	25.8	-
5.5	24.1	25.2	-	24.7
6.1	-	-	27.7	-
6.2	25.5	27.0	-	-
6.8	-	-	28.8	-
6.9	26.8	28.2	-	27.5
7.5	-	-	29.9	-
7.6	-	28.9	-	-
8.2	-	-	30.7	-
8.3	28.3	29.9	-	-
9.6	29.3	31.0	32.4	30.9
10.4	-	31.6	-	-
11.0	-	-	33.3	-
11.2	30.4	-	-	-
11.8	-	32.5	-	-
12.4	31.0	-	34.3	-
13.2	-	33.2	-	-
13.7	-	-	34.9	-
13.8	31.7	-	-	-
15.2	32.2	34.1	35.5	33.9
16.6	32.7	-	-	-
18.0	33.2	35.0	36.7	35.0
19.4	-	35.5	-	-
20.1	33.8	-	-	-
20.8	-	-	37.5	-
22.2	34.4	36.3	-	-
22.8	-	-	38.2	-
23.6	34.7	36.8	-	-
24.9	-	-	38.7	-
25.0	-	37.1	-	-
25.7	35.1	-	-	-
27.8	35.6	37.7	39.4	37.6

TABLE XIV

MIC Breakthrough of OV Cartridges at 73% Relative Humidity
for Manufacturer B at 790 PPM.

<u>Breakthrough Concentration PPM</u>	<u>Time to Breakthrough Run # 36 (min.)</u>	<u>Time to Breakthrough Run # 37 (min.)</u>	<u>AVG Time to Breakthrough (min.)</u>
.5	3.1	3.8	3.5
1.2	8.9	9.4	9.2
1.9	17.2	25.3	21.3
2.6	28.6	41.9	35.3
3.3	43.7	49.7	46.7
4.0	49.6	59.0	54.3
4.8	61.9	-	-

TABLE XV

MIC Cartridge Weight Data for
 Manufacturer A When Run at Humidified Conditions

<u>Run Concentration PPM</u>	<u>% RH</u>	<u>Initial Cartridge Weight gms.</u>	<u>Cartridge Case Weight gms.</u>	<u>Final Cartridge Weight gms.</u>	<u>Initial Charcoal Weight gms.</u>	<u>Δ Wt. gms.</u>	<u>% Weight Change gms</u>
742	50%	92.2614	24.5228	94.9300	67.7386	+2.6686	+3.
749	50%	93.1737	28.9867	95.7700	64.1870	+2.5963	+4.
742	50%	94.5000	28.9481	97.3150	65.5519	+2.8150	+4.
810	73%	94.7372	29.1856	101.4540	65.5516	+6.7168	+10.
794	73%	96.5528	29.5317	103.2941	67.0211	6.7413	+10.
802	73%	91.8054	-	-	-	-	-

TABLE XVI

MIC Cartridge Weight Data for
 Manufacturer B When Run at Humidified Conditions

Run Concentration PPM	%RH	Initial Cartridge Weight gms.	Cartridge Case Weight gms.	Final Cartridge Weight gms.	Initial Charcoal Weight gms.	Δ Wt. gms.	% Weight Change gms
770	50%	136.4440	44.1488	140.0340	92.2952	+3.5900	+3.
802	50%	139.8043	44.1769	143.8000	95.6274	+3.9957	+4.
788	50%	134.7357	44.3861	138.8820	90.3496	+4.1463	+4.
782	73%	134.5478	44.1747	144.3730	90.3731	+9.8252	+10.
796	73%	135.7601	44.0982	145.3590	91.6619	+9.5989	+10.

TABLE XVII

Methyl Amine Breakthrough of OV
Cartridges at 64 LPM by Certification Test Method

Manufacturer	Z RH	Challenge Conc. PPM	Initial Cartridge		Precond. Cond.	Wt. After Precond. (gms.)	Cartridge		Δ Wt. Precond. (gms.)	Δ Wt. Change During Test (gms.)	Time to		
			Weight (gms.)	Case Weight (gms.)			Sorbent Weight (gms.)	2 PPM Breath Min.			5 PPM Breath Min.	10 PPM Breath Min.	
B	76.5	1148	140.0	44.5	-	-	95.5	-	-	+1.5	5.7	-	6.2
B	76.5	1148	140.0	44.5	-	-	95.5	-	-	+1.5	5.0	-	5.5
B	50	1148	139.1	44.5	-	-	94.6	-	-	+0.9	4.7	-	4.9
B	50	1148	140.9	44.9	-	-	96.0	-	-	+0.2	4.6	-	4.8
B	50	1161	140.0	44.1	85ZRH/25LPM/6hrs.	158.1	95.9	+18.1	+1.8	3.1	-	27.1	
B	50	1161	141.0	44.9	85ZRH/25LPM/6hrs.	159.0	96.1	+18.0	+1.0	4.8	-	25.2	
A	50	1020	92.0	29.9	85ZRH/25LPM/6hrs.	107.1	62.1	+15.1	0	-	1.8	18.2	
A	50	1020	93.5	29.5	85ZRH/25LPM/6hrs.	108.5	64.0	+15.0	+0.4	-	1.6	17.8	
A	71.5	1148	93.2	30.0	-	-	63.2	-	-	+1.0	3.7	-	4.0
A	76.5	1148	91.0	29.9	-	-	61.1	-	-	+1.0	3.5	-	3.7
A	50	1148	93.0	29.9	-	-	63.1	-	-	+0.9	2.7	-	3.0
A	50	1148	94.0	30.0	-	-	64.0	-	-	+0.9	3.2	-	3.5

TABLE XVIII

MIC Breakthrough of Acid Gas
Cartridges for Manufacturer A

Breakthrough Concentration (PPM)	Breakthrough Time for Run # 19 (mins.)	Breakthrough Time for Run # 20 (mins.)	Breakthrough Time for Run # 23 (mins.)	Breakthrough Time for Run # 24 (mins.)
.4	-	-	1.5	-
.7	-	-	-	1.1
1.2	-	-	-	1.4
1.3	-	68	-	-
1.6	-	-	-	40.7
1.8	-	-	1.6	-
2.0	-	72	-	-
2.1	-	-	-	45.3
2.2	-	-	2.0	-
2.6	-	74	4.0	48.4
2.9	-	-	30.5	-
3.0	-	-	-	50.3
3.2	-	-	35.0	-
3.3	78.0	76	-	-
3.6	-	-	40.4	52.0
3.9	-	77	-	-
4.0	-	-	43.1	55.4
4.2	-	78	-	-
4.3	-	-	46.5	-
4.5	-	79	-	57.9
4.6	-	-	48.6	-
4.9	-	80	-	-
5.0	-	-	51.3	59.7
5.2	-	81	-	-
5.4	-	-	53.2	-
5.5	-	-	-	61.1
5.7	-	-	54.6	-
6.0	-	-	56.0	62.5
6.1	-	82	-	-
6.4	-	83	57.7	-
6.5	-	-	-	63.9
6.8	80.3	-	58.3	-
7.0	-	-	-	65.8
7.1	-	84	59.7	-
7.4	-	-	-	66.8
7.7	-	85	-	-
8.0	-	-	-	68.2
8.4	-	86	-	69.0
8.9	-	-	-	70.0
10.2	83.0	-	-	-

Run #19 Upstream Concentration 693 PPM at Dry Conditions.

Run #20 Upstream Concentration 819 PPM at Dry Conditions.

Run #23 Upstream Concentration 998 PPM at 73% RH.

Run #24 Upstream Concentration 868 PPM at 73% RH.

TABLE XIX

MIC Breakthrough of Organic Vapor/Acid Gas Cartridges for Manufacturer B

Breakthrough Concentration PPM	Time to Breakthrough Run # 21 (min.)	Time to Breakthrough Run # 22 (min.)	Time to Breakthrough Run # 25 (min.)	Time to Breakthrough Run # 26 (min.)
.2	-	54.4	-	-
.4	-	-	0.7	-
.6	-	60.2	-	-
.7	42.0	-	-	-
1.0	44.9	63.4	-	-
1.2	-	-	-	0.6
1.3	57.0	-	-	-
1.4	-	66.7	-	-
1.5	-	-	1.0	-
1.6	-	-	-	.9
1.7	62.9	-	-	-
1.8	-	-	1.3	-
1.9	-	69.2	-	-
2.0	69.2	-	-	-
2.1	-	-	-	13.9
2.3	72.7	-	-	-
2.4	-	72.9	-	-
2.6	76.6	-	1.9	22.2
2.8	-	76.4	-	-
3.0	80.4	-	-	23.8
3.2	-	78.2	8.5	-
3.3	82.9	-	-	-
3.6	84.8	80.3	19.3	29.3
4.0	89.0	82.3	24.0	33.5
4.2	90.0	-	-	-
4.3	-	-	28.3	-
4.4	-	83.6	-	-
4.5	-	-	-	39.1
4.6	-	-	32.2	-
4.8	-	85.5	-	-
5.0	-	-	35.0	44.5
5.3	-	87.6	-	-
5.4	-	-	37.8	-
5.5	-	-	-	50.9
5.7	-	90.0	42.0	-
6.0	-	-	46.5	56.3
6.4	-	-	49.0	-
6.8	-	-	52.1	-

Run # 21 Upstream Concentration 841 PPM at Dry Conditions.

Run # 22 Upstream Concentration 861 PPM at Dry Conditions.

Run # 25 Upstream Concentration 965 PPM at 73% RH.

Run # 26 Upstream Concentration 870 PPM at 73% RH.

TABLE XX

Acid Gas and Organic Vapor/Acid Gas Cartridge Weight Data for MIC Runs

<u>Manufacturer</u>	<u>Run Concentration PPM</u>	<u>Condition</u>	<u>Initial Cartridge Weight gms.</u>	<u>Cartridge Case Weight gms.</u>	<u>Final Cartridge Weight gms.</u>	<u>Initial Charcoal Weight gms.</u>	<u>Δ Wt. gms.</u>	<u>% Weight Change</u>
A	693	D	127.0005	30.1879	121.9219	96.8126	-5.0786	-5.3
A	819	D	128.6261	30.1205	124.4626	98.5056	-4.1635	-4.2
B	841	D	174.8617	43.4559	180.5594	131.4058	+5.6977	+4.3
B	861	D	170.8290	43.3175	176.2600	127.5115	+5.4310	+4.3
A	998	RH	126.5425	29.3978	132.8800	97.1447	+6.3375	+6.5
A	868	RH	129.8021	30.0890	137.2805	99.7131	+7.4784	+7.5
B	965	RH	172.4988	43.2341	183.2900	129.2647	+10.7912	+8.3
B	870	RH	171.9637	43.0439	184.0852	128.9198	+12.1215	+9.4

Manufacturer A - Acid gas cartridges
 Manufacturer B - Organic vapor/acid gas cartridges

D - Dry Environment
 RH - 73% Relative Humidity

TABLE XXI

MIC Breakthrough Results Employing Jonas Model Stacked
 OV Cartridges at Dry Conditions for Manufacturer B

<u>Breakthrough Concentration (PPM)</u>	<u>Breakthrough Time for Cartridge #1 (mins.)</u>	<u>Breakthrough Time for Cartridge #2 (mins.)</u>	<u>Breakthrough Time for Cartridge #3 (mins.)</u>	<u>Breakthrough Time for Cartridge #4 (mins.)</u>
.8	8.2	26.4	44.6	64.2
1.6	8.3	27.5	-	-
2.3	9.9	28.6	47.5	67.1
2.9	-	29.1	-	-
3.6	10.5	-	48.3	68.0
4.3	-	29.5	-	-
5.0	-	-	48.8	68.5
5.6	11.1	29.9	-	-
7.0	-	30.3	49.4	69.4
9.0	-	-	49.8	-
9.7	-	30.8	-	-
10.4	12.0	-	50.1	70.1
11.7	-	31.1	-	-
13.2	-	-	-	70.6
13.8	12.4	-	50.6	-
14.4	-	31.4	-	-
15.2	-	-	-	70.9
17.2	12.8	31.7	-	71.2
18.0	-	-	51.1	-
18.6	-	31.9	-	-
20.7	13.1	32.0	51.3	71.5

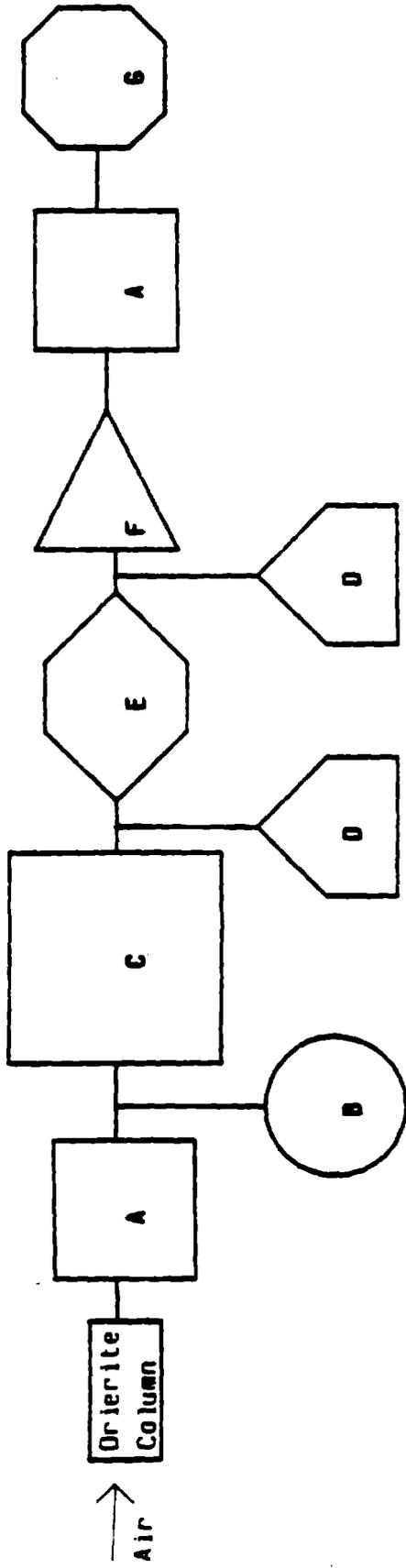
TABLE XXII

Cartridge Weight Data for MIC Employing Jonas
Model Stacked OV Cartridges at Dry Conditions for Manufacturer B

Cartridge #	Run Concentration PPM	Initial Cartridge Weight gms.	Cartridge Case Weight gms.	Final Cartridge Weight gms.	Initial Charcoal Weight gms.	Δ Wt. gms.	Capacity* gms./gms.
1	945	69.0570	22.3574	72.3998	46.6996	3.3428	.0716
2	948	68.0443	22.2853	70.9387	45.7590	2.8944	.0633
3	964	70.1623	22.3016	72.7216	47.8607	2.5593	.0535
4	945	70.5125	22.0375	71.6093	48.4750	1.0968	.0226

* Capacity = $\frac{\text{gms. adsorbed}}{\text{gms. of sorbent}}$

Figure 1
Experimental Design



- A - Flow Control Mechanism
- B - Vapor Generator
- C - Buffer Reservoir Tank
- D - Vapor Detector
- E - Cartridge Cell
- F - Cold Trap or Sorbent Trap
- G - Vacuum Source

Figure II

Upstream MIC Calibration Curve

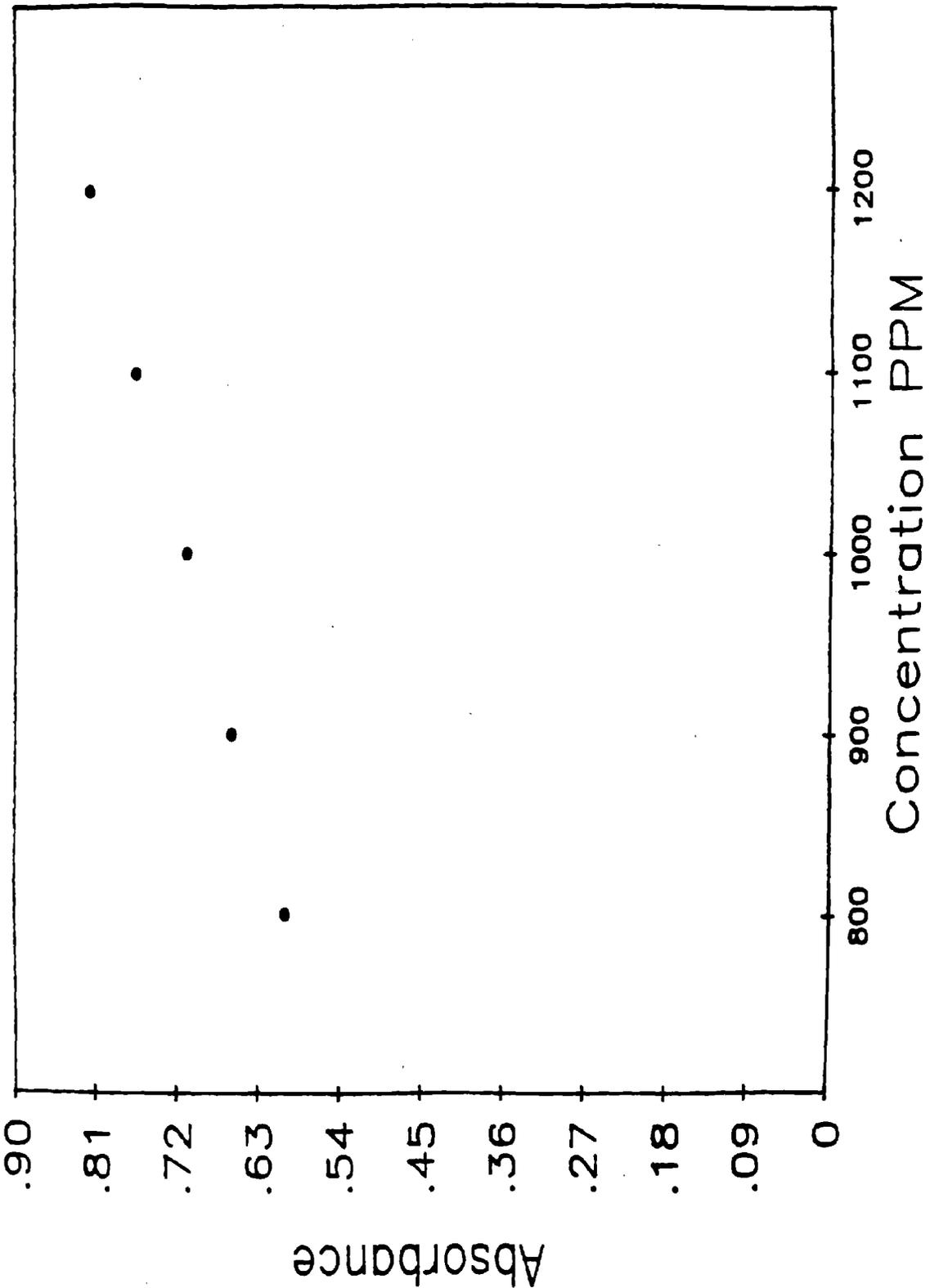


Figure III

Downstream MIC Calibration Curve

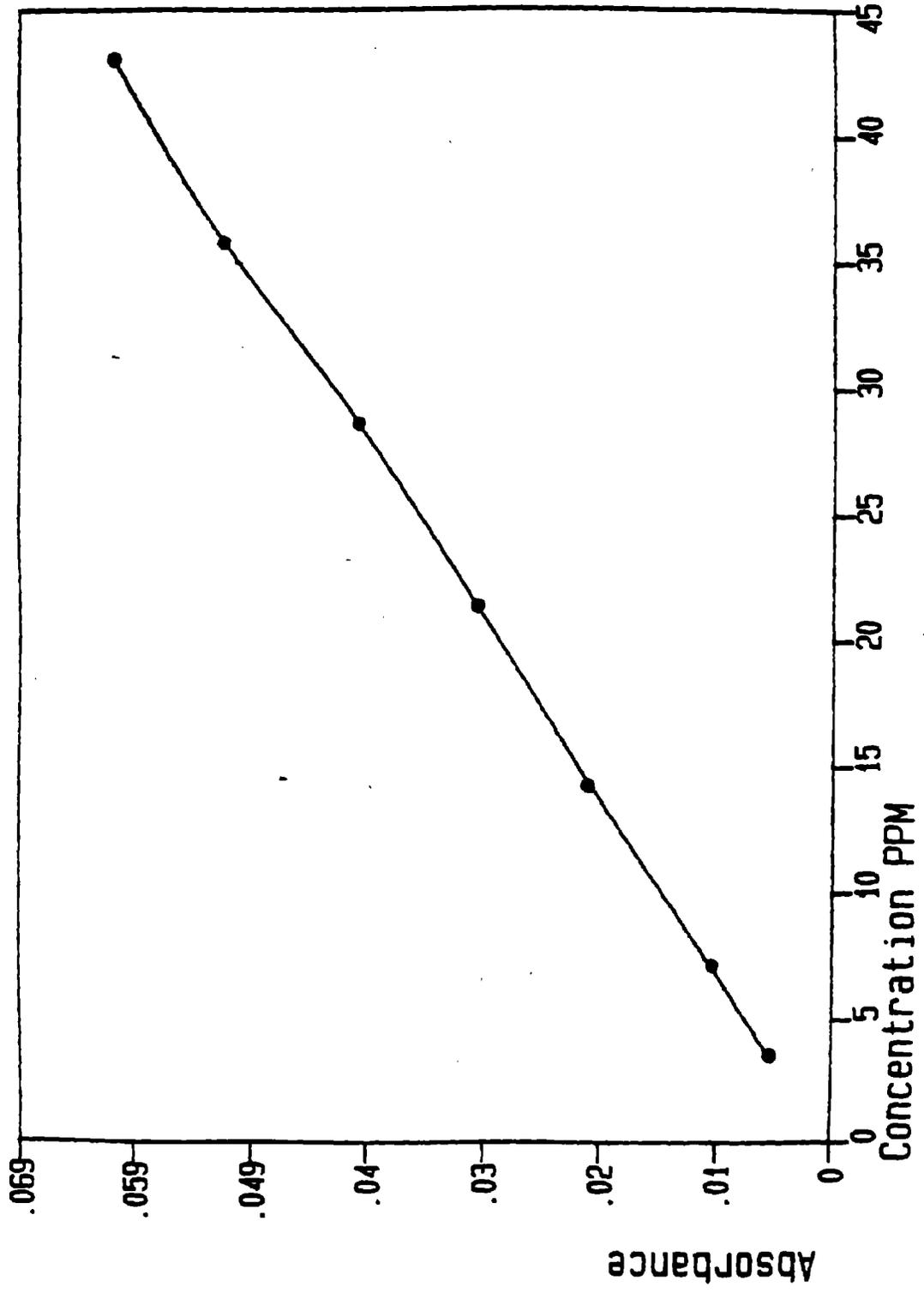


Figure IV

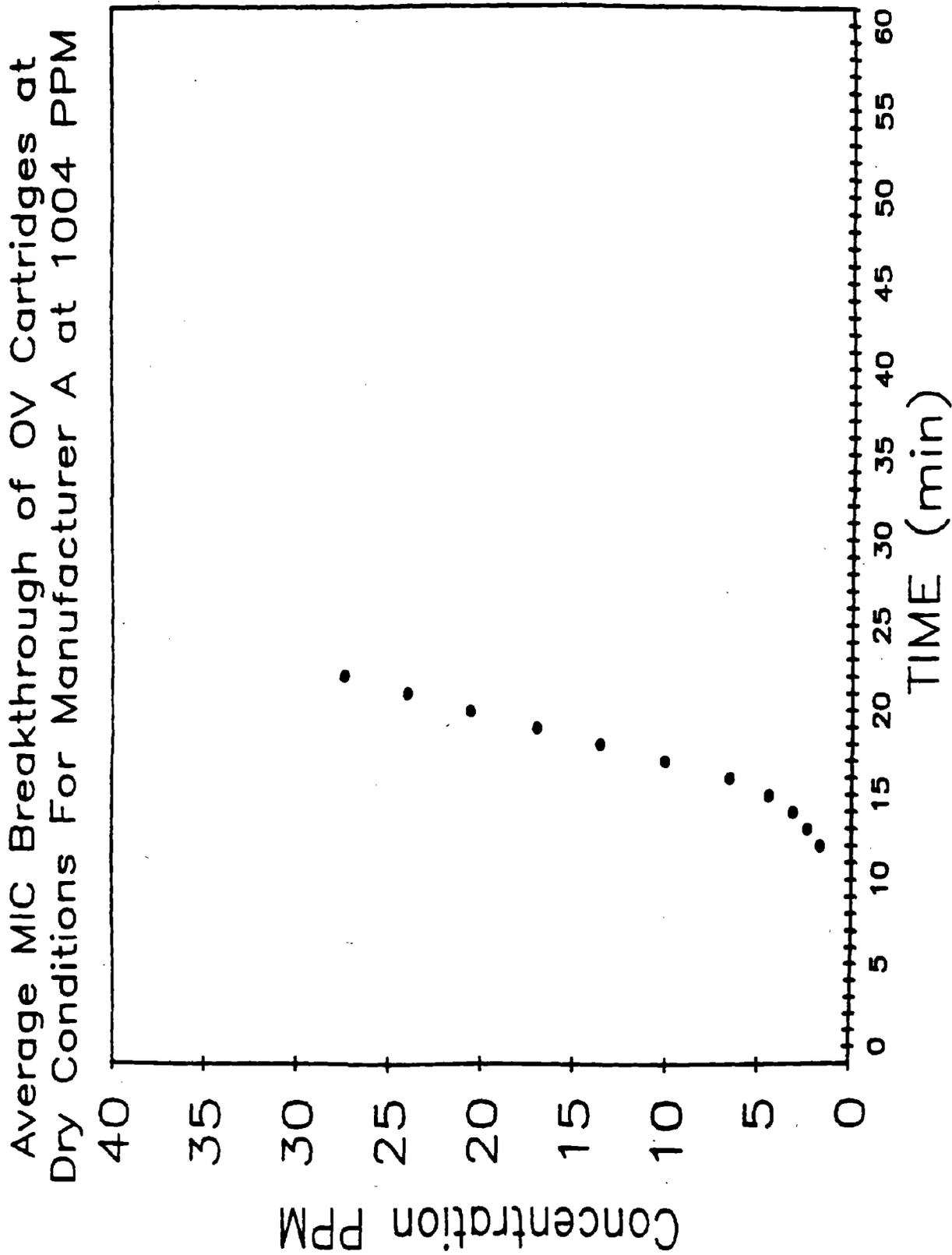


Figure V

Average MIC Breakthrough of OV Cartridges at Dry Conditions For Manufacturer A at 742 PPM

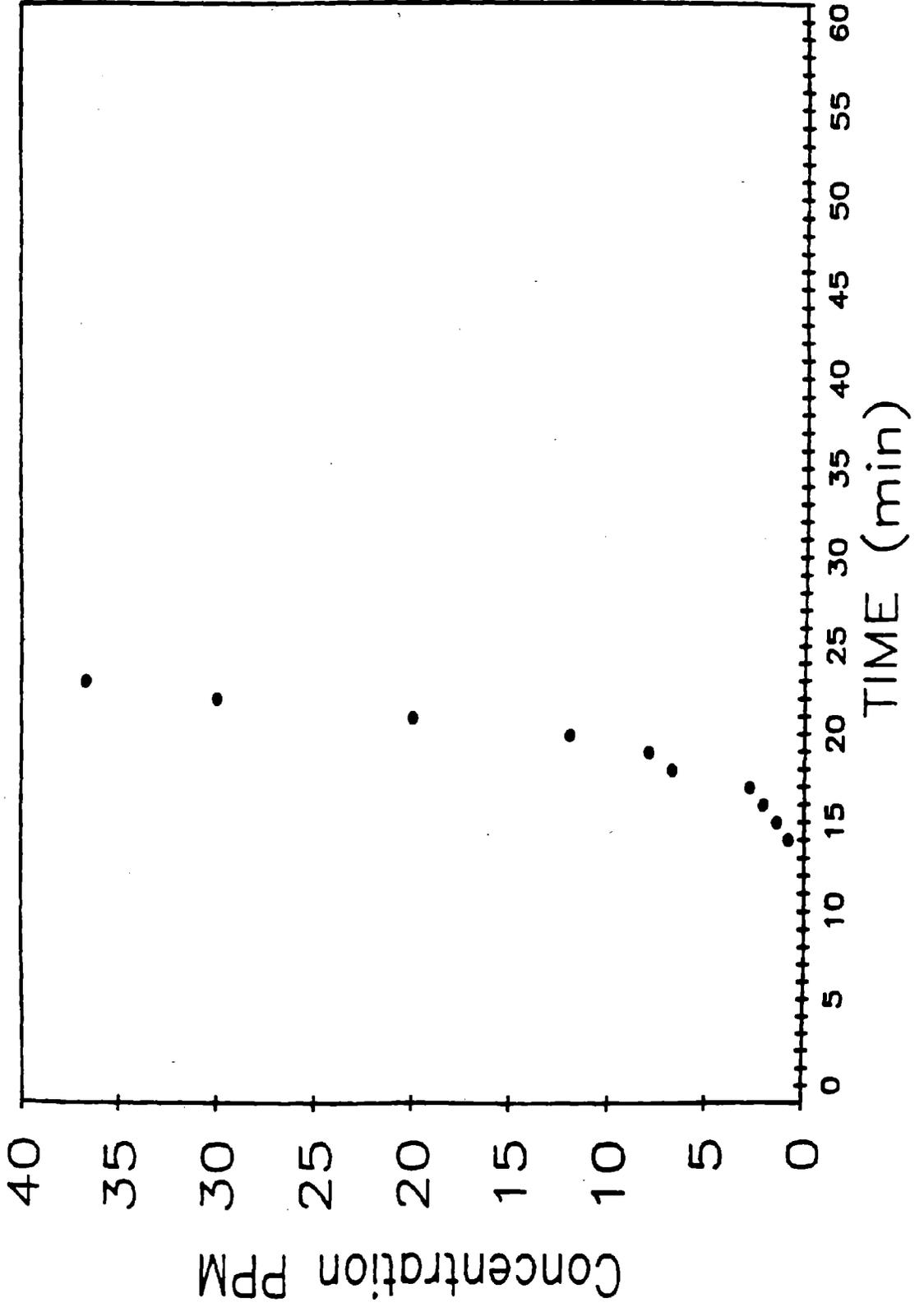


Figure VI

Average MIC Breakthrough of OV Cartridges at Dry Conditions For Manufacturer A at 556 PPM

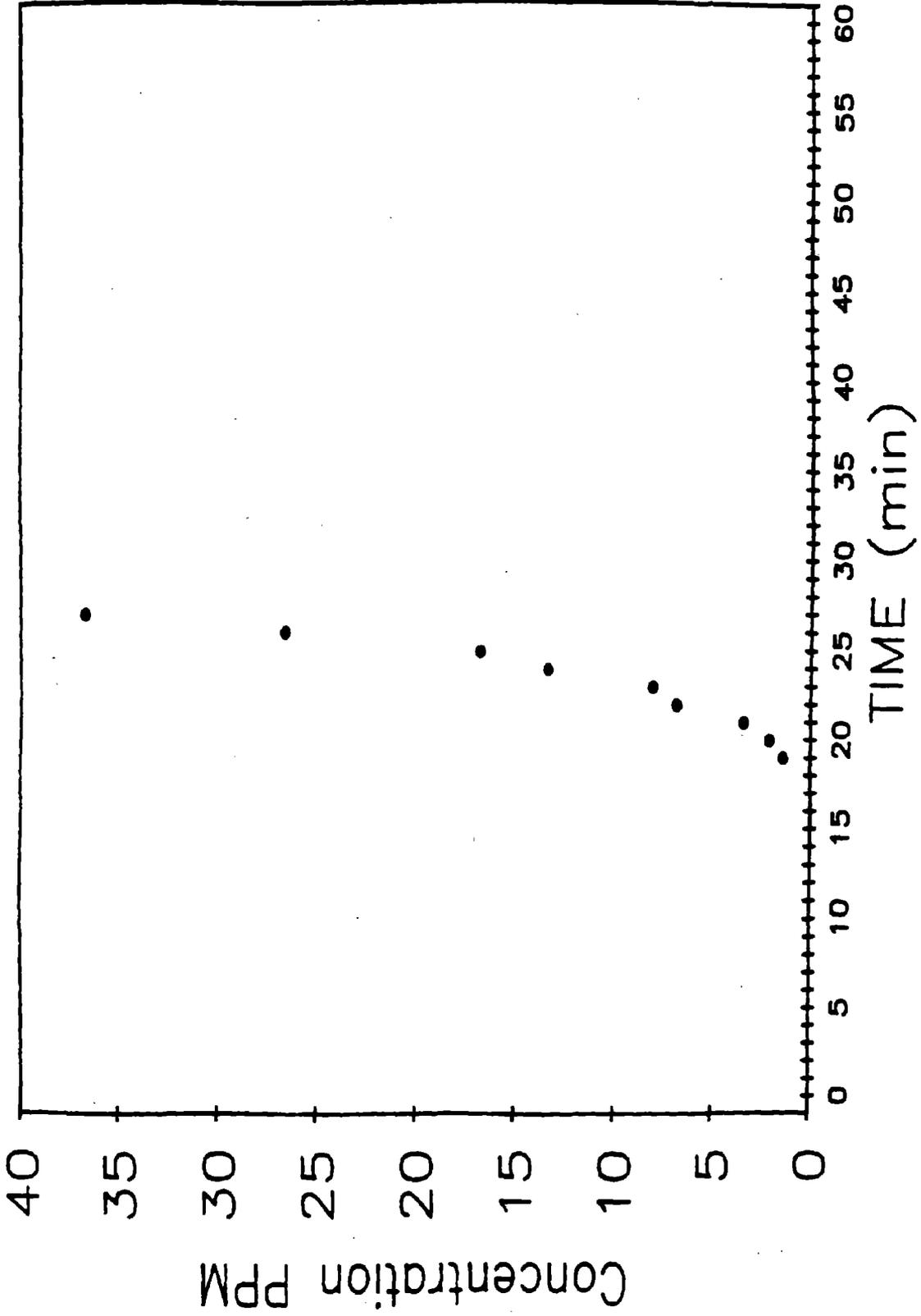


Figure VII

Average MIC Breakthrough of OV Cartridges at Dry Conditions For Manufacturer A at 300 PPM

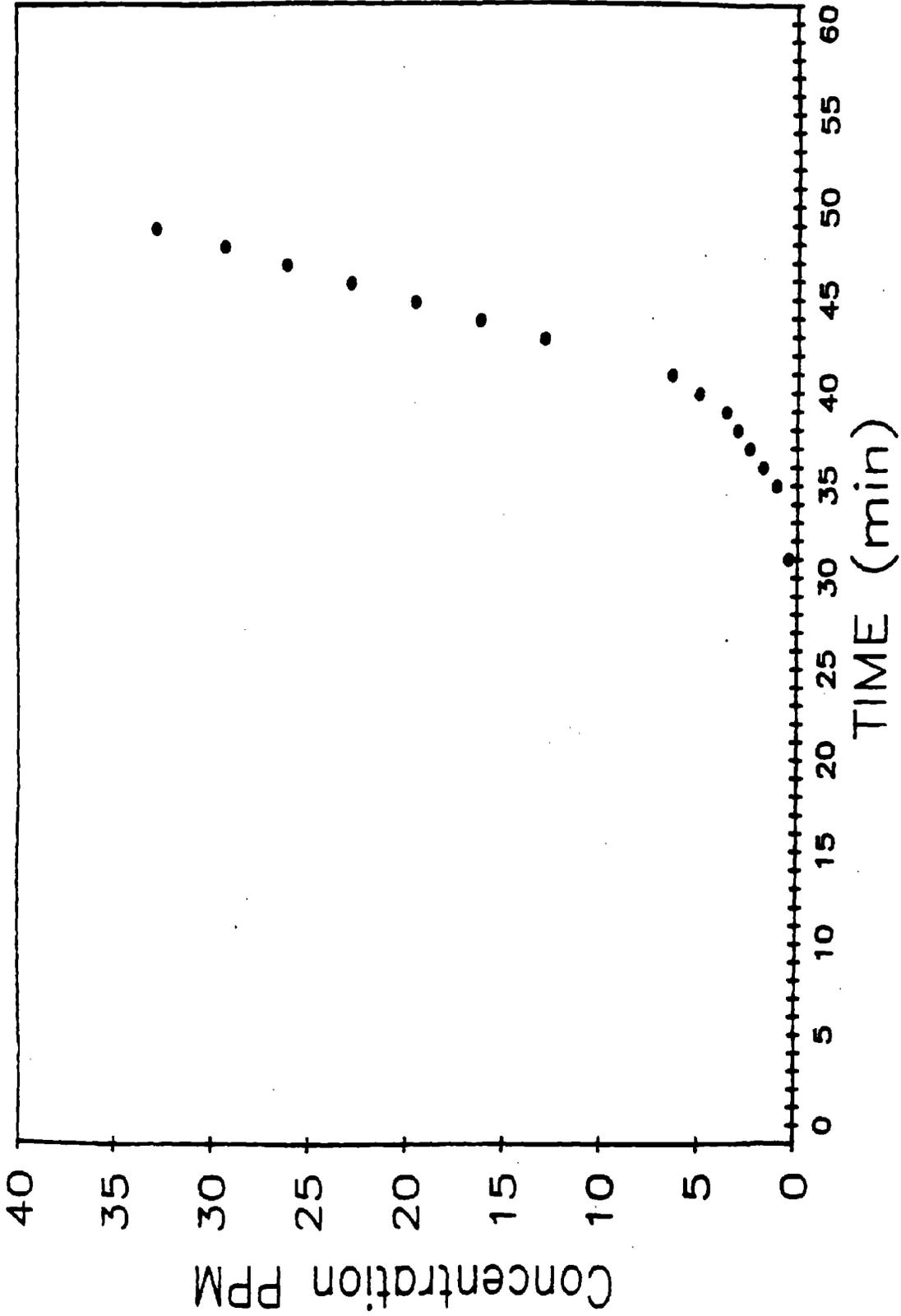


Figure VIII

Average MIC Breakthrough of OV Cartridges at Dry Conditions For Manufacturer B at 946 PPM

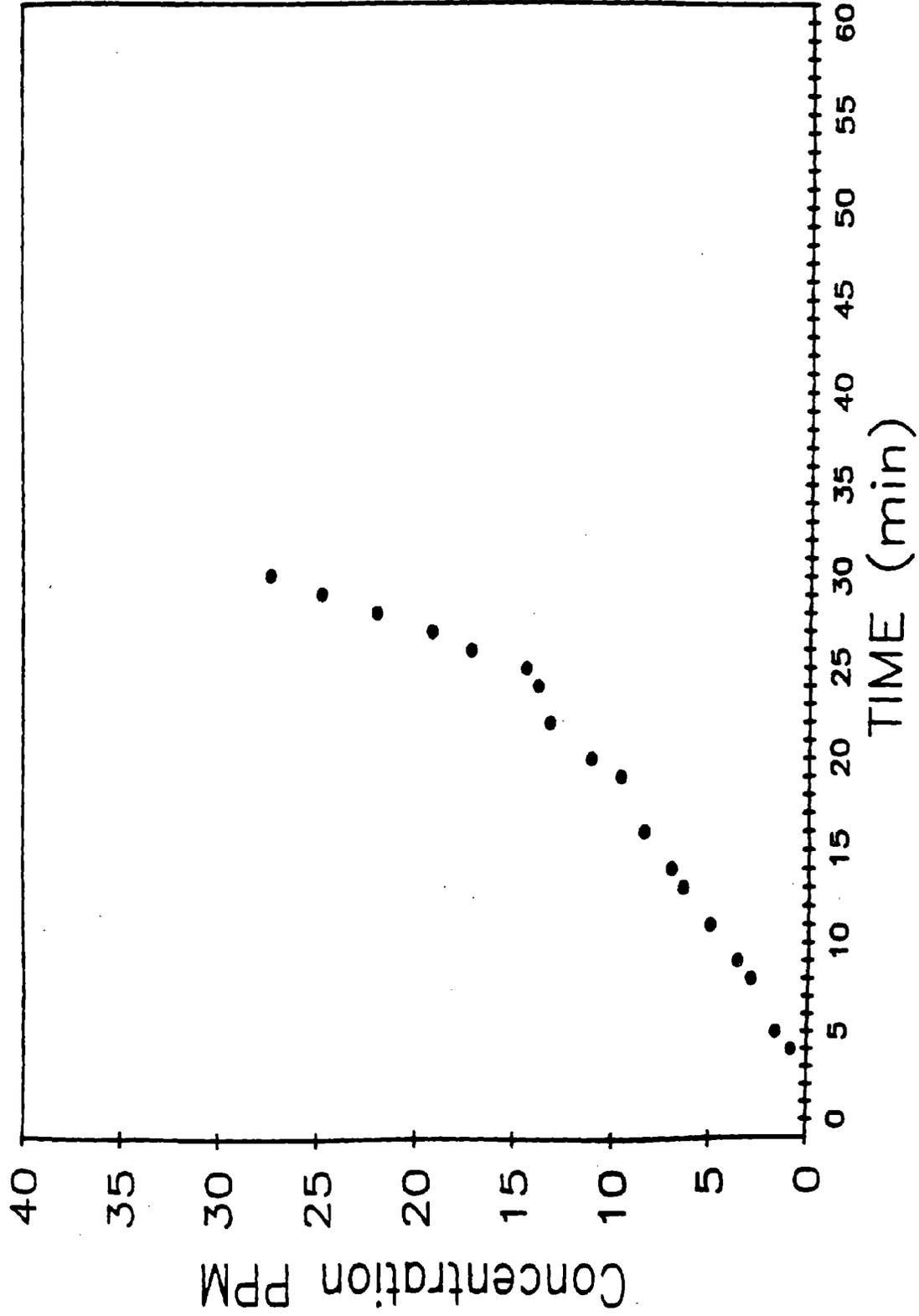
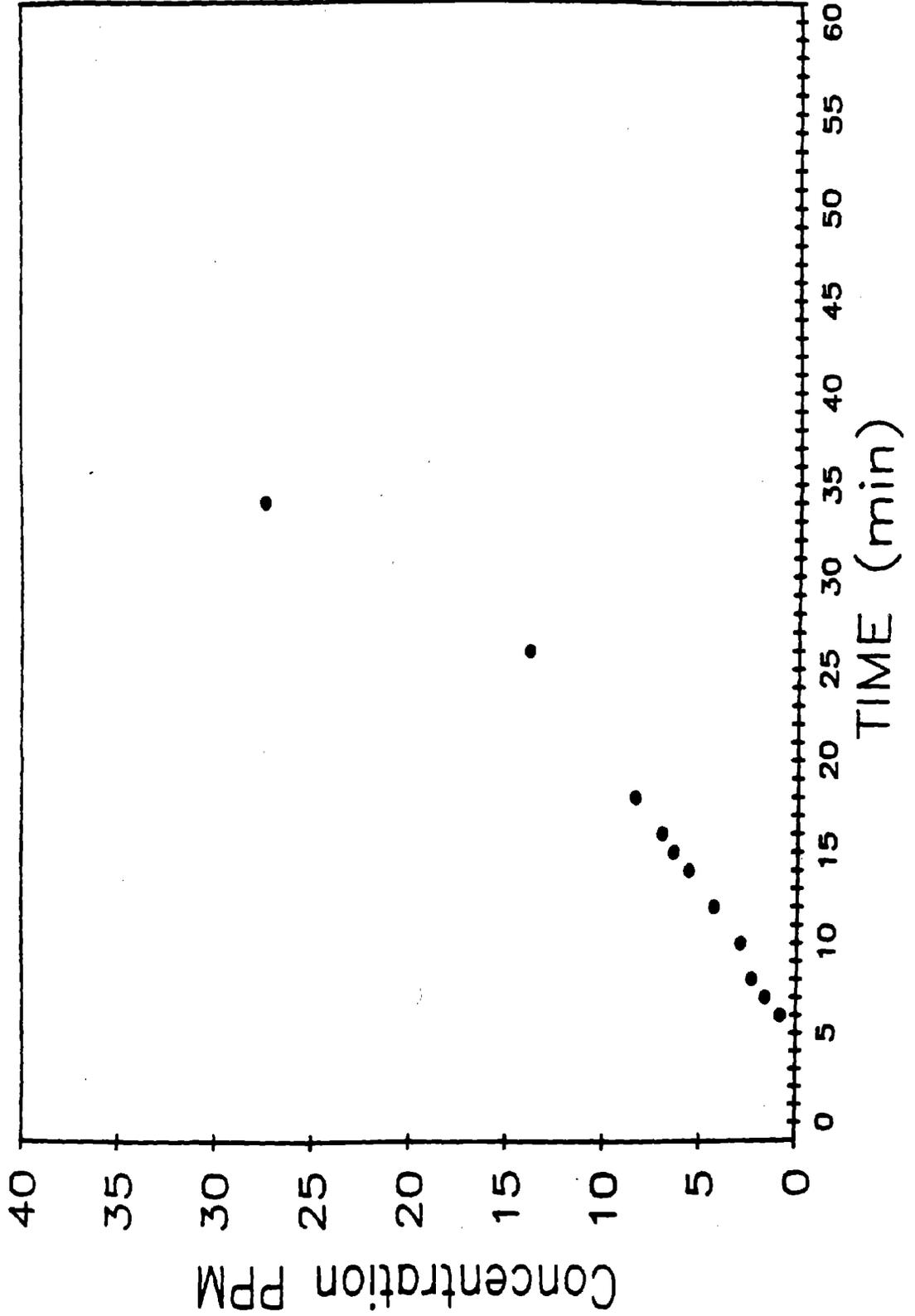


Figure IX

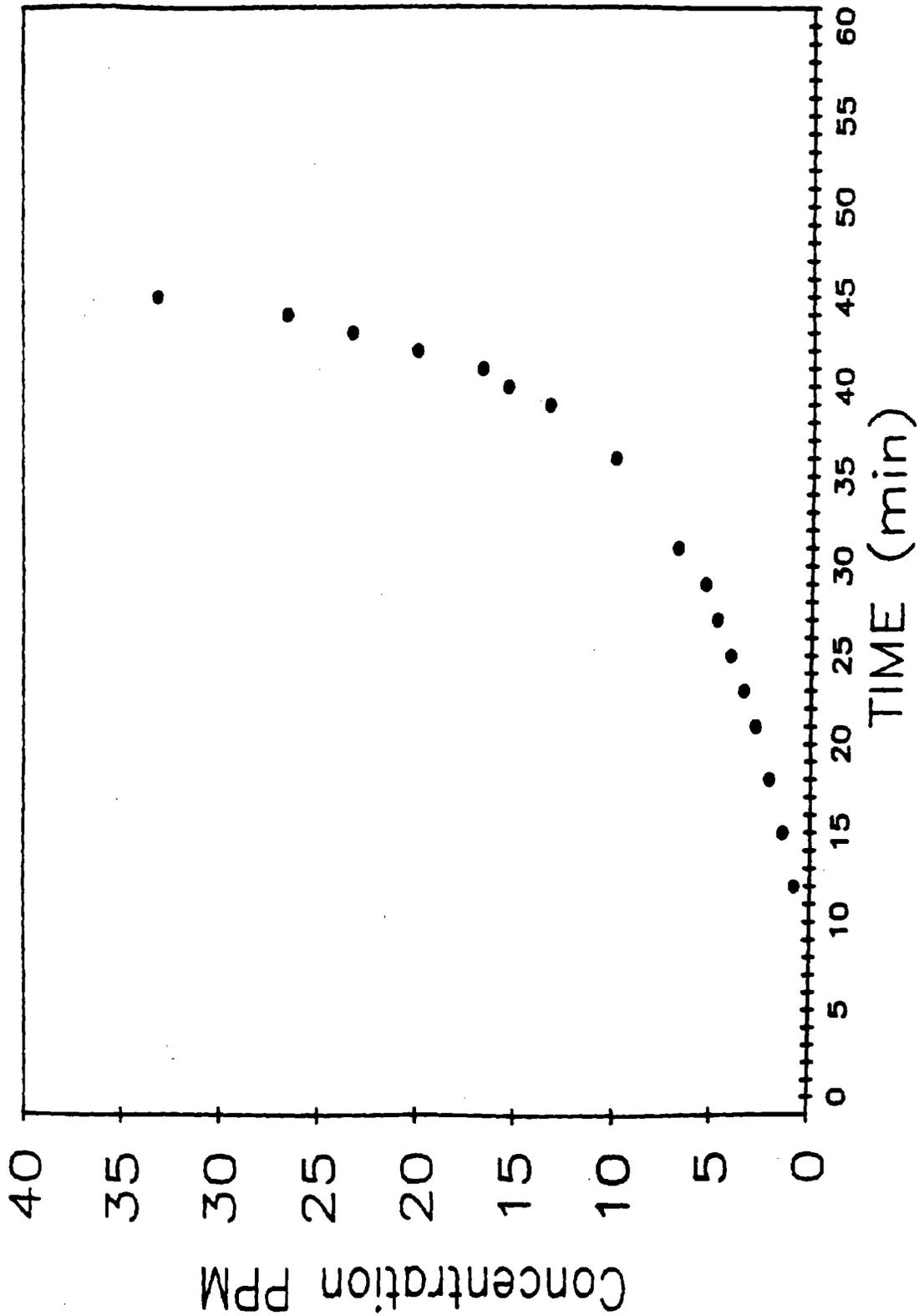
Average MIC Breakthrough of OV Cartridges at Dry Conditions For Manufacturer B at 744 PPM



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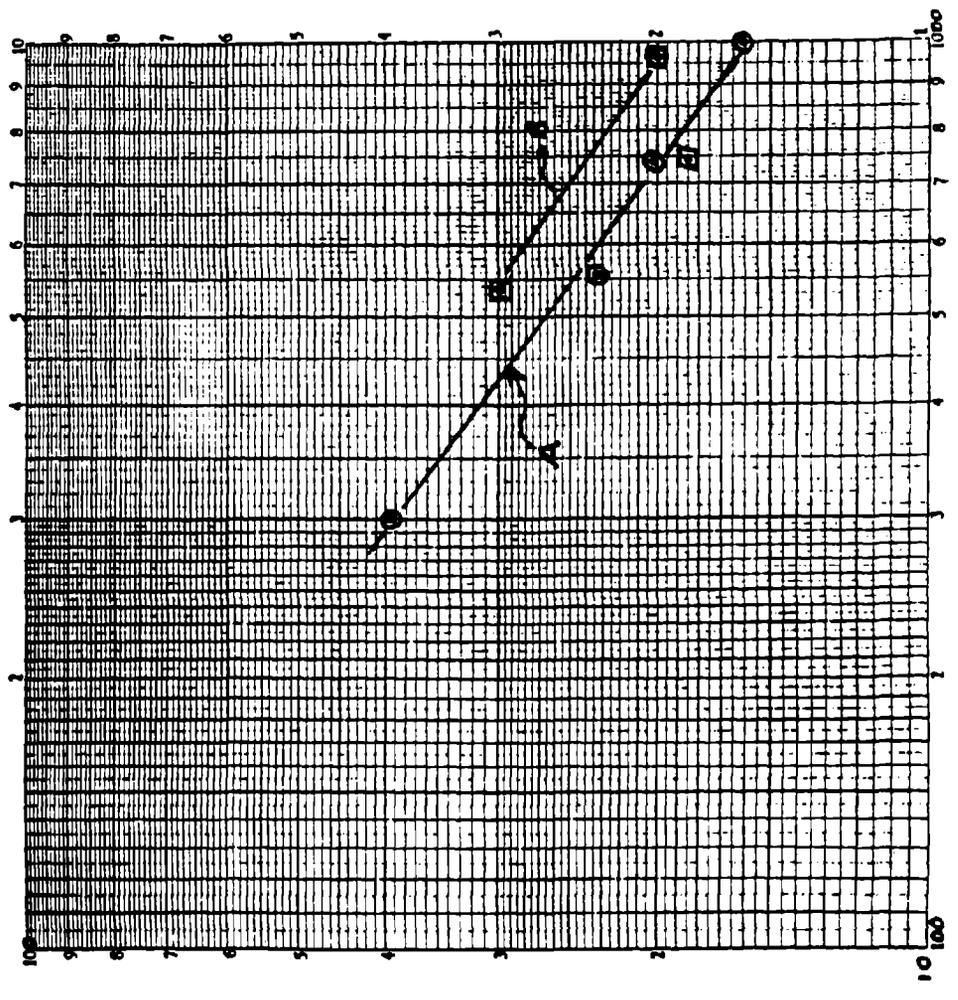
Figure X

Average MIC Breakthrough of OV Cartridges at Dry Conditions For Manufacturer B at 536 PPM



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Figure XI
MIC Breakthrough as a Function of Challenge Concentration at Dry Conditions



MIC Challenge Concentration PPM

1% Breakthrough Time (min)

Figure XII

Average MIC Breakthrough of OV Cartridges at 50% RH For Manufacturer A at 742 PPM

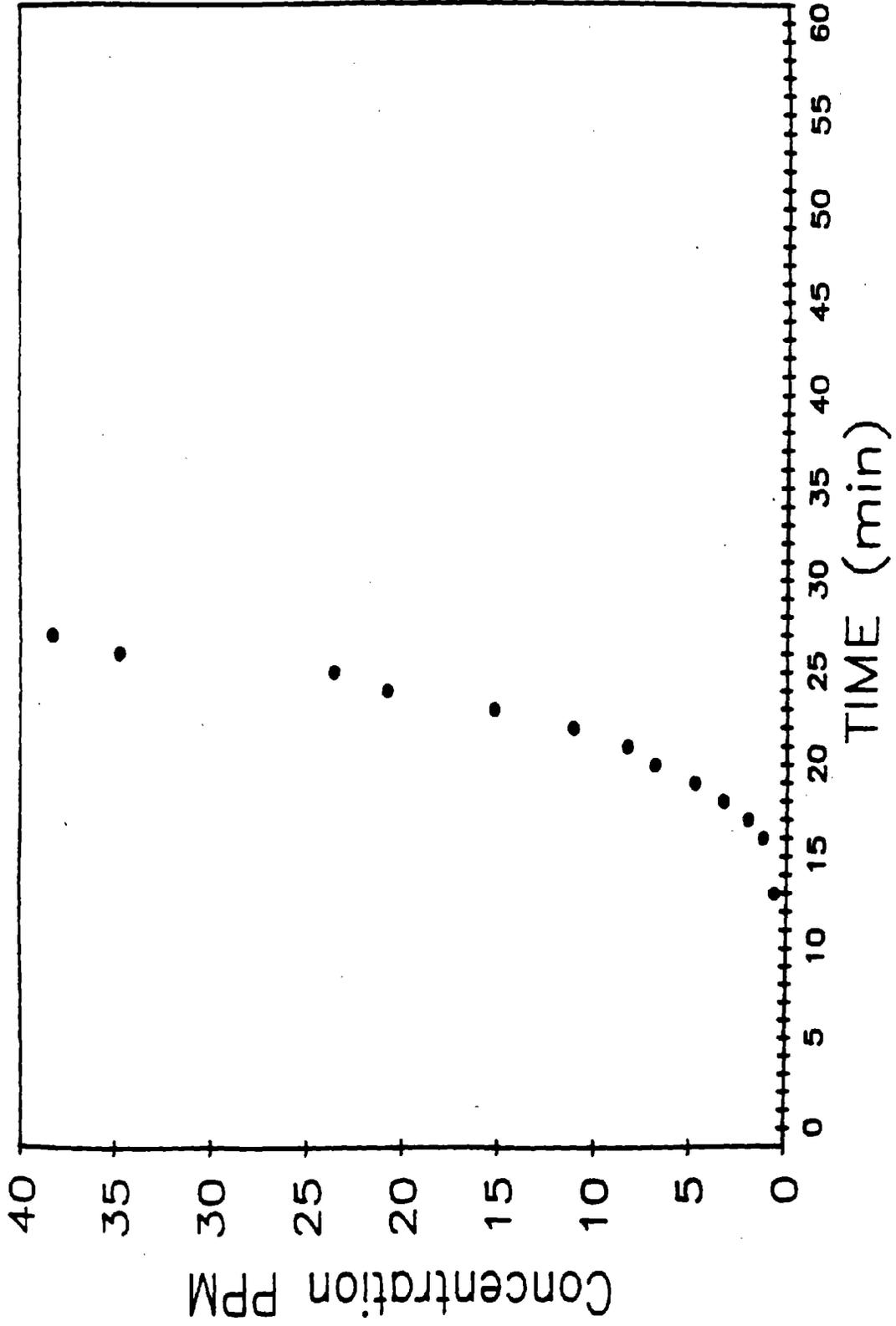


Figure XIII

Average MIC Breakthrough of OV Cartridges at 73% RH For Manufacturer A at 802 PPM

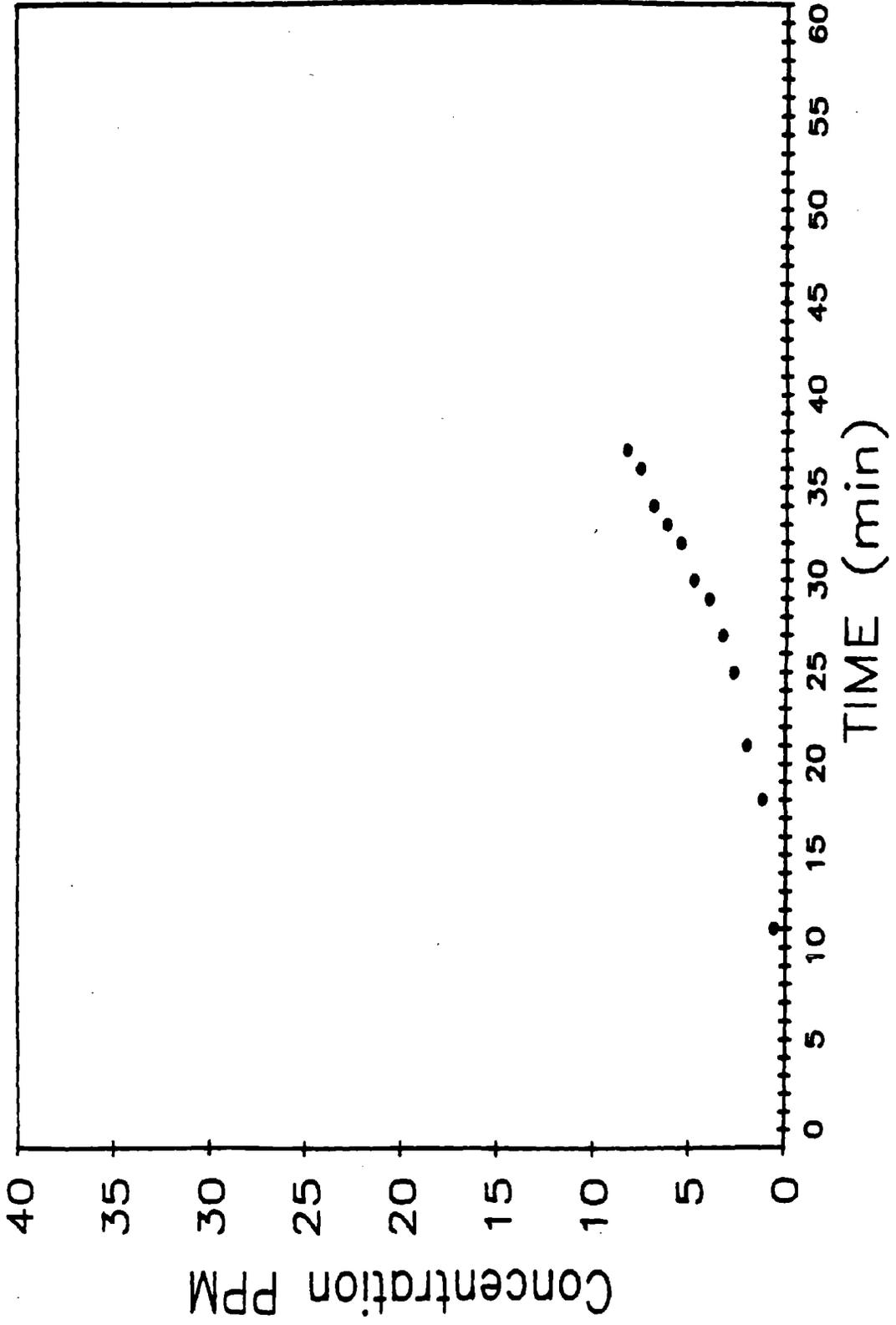


Figure XIV

Average MIC Breakthrough of OV Cartridges at 50% RH For Manufacturer B at 780 PPM

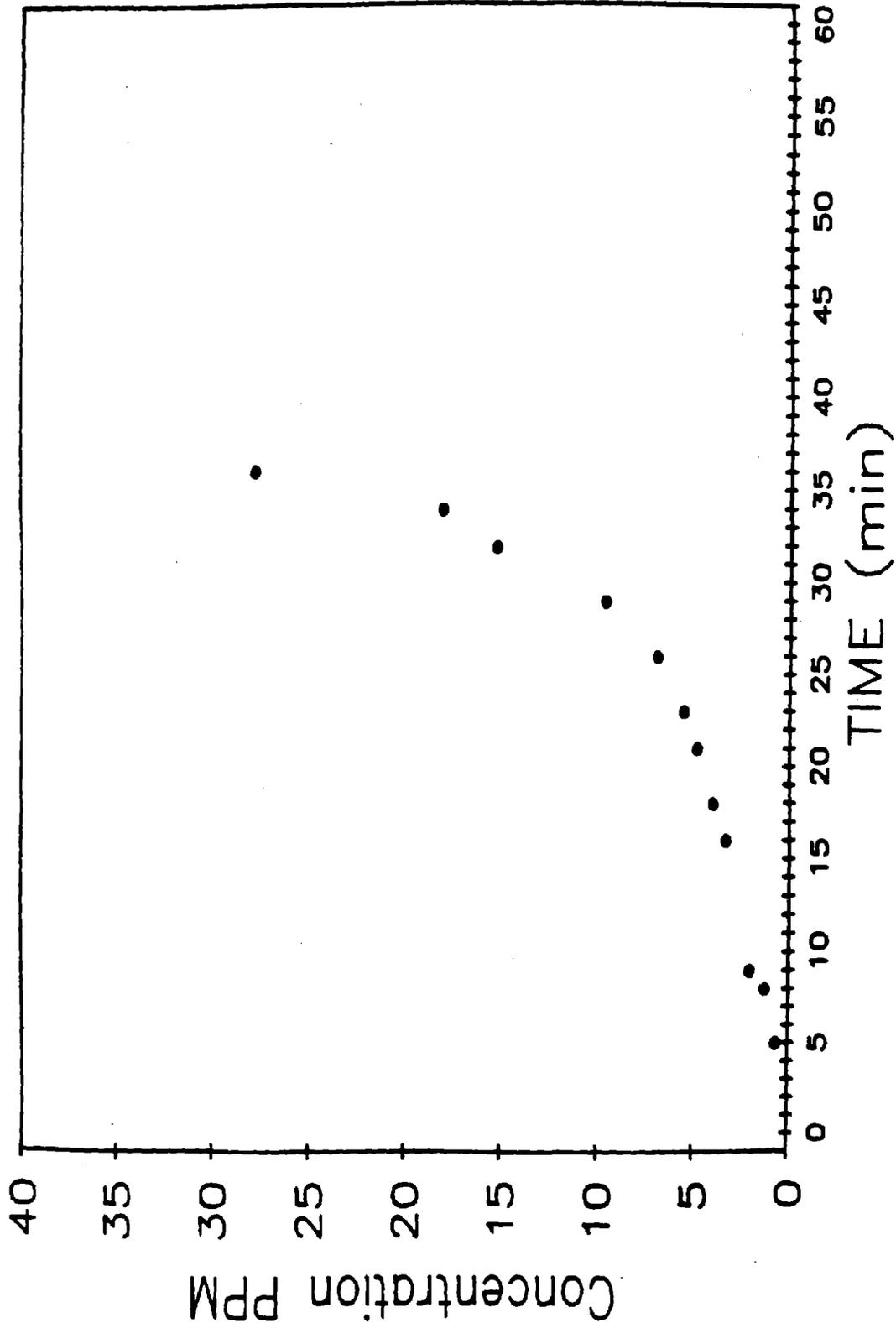


Figure XV

Average MIC Breakthrough of OV Cartridges at 73% RH for Manufacturer B at 790 PPM

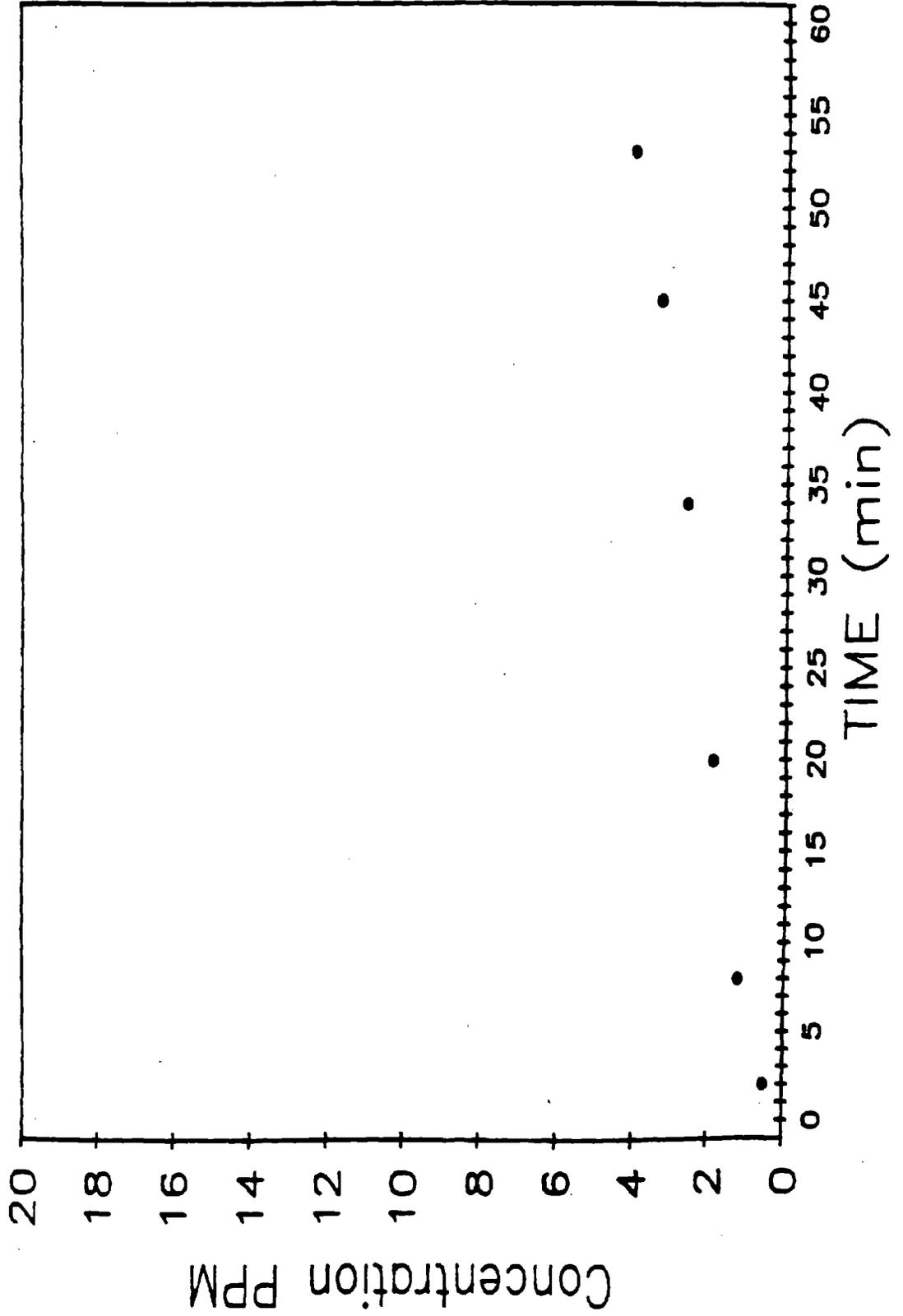


Figure XVI

MIC Breakthrough of Acid Gas Cartridges at Dry Conditions For Manufacturer A at 693 PPM

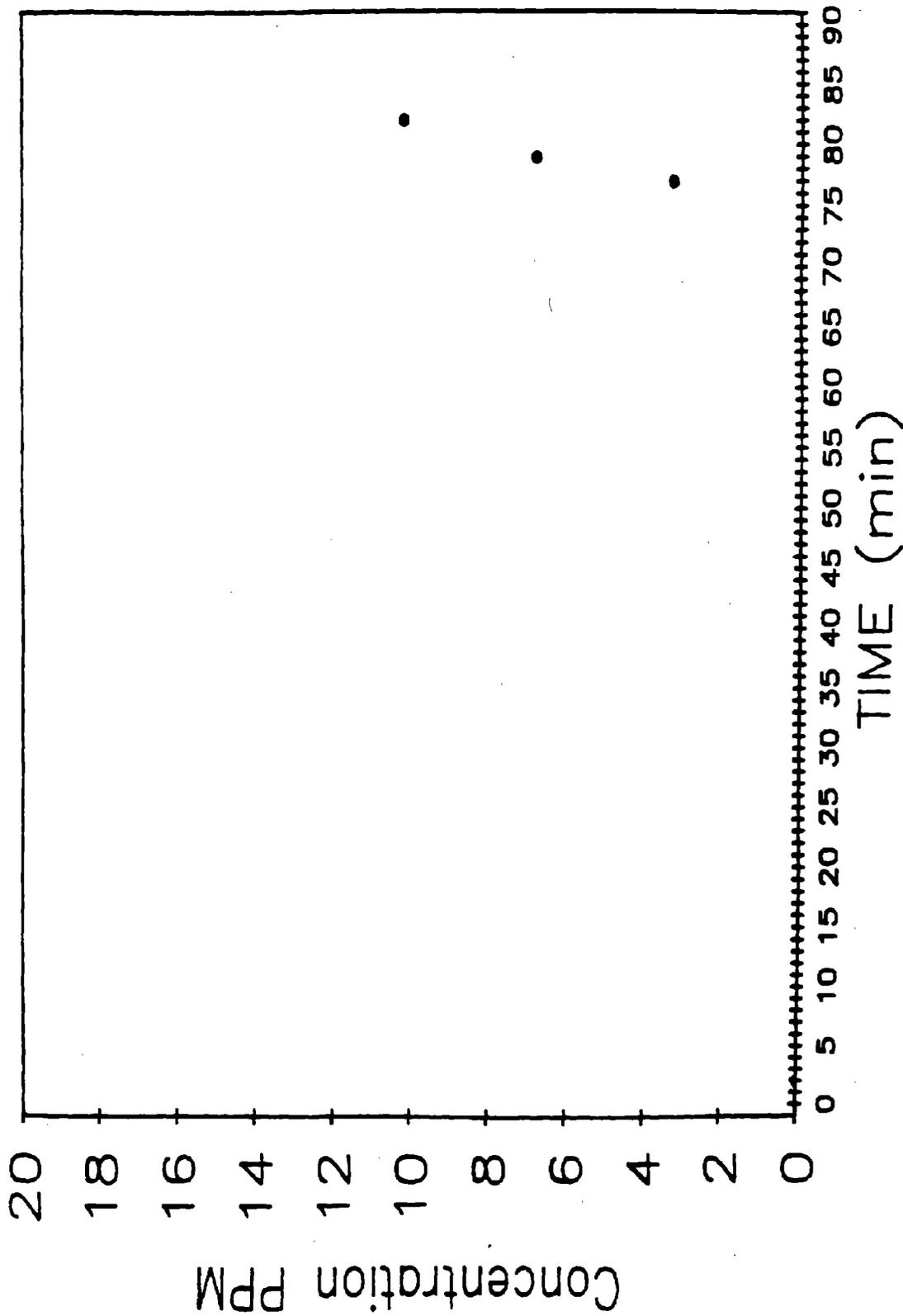


Figure XVII

MIC Breakthrough of Acid Gas Cartridges at Dry Conditions For Manufacturer A at 819 PPM

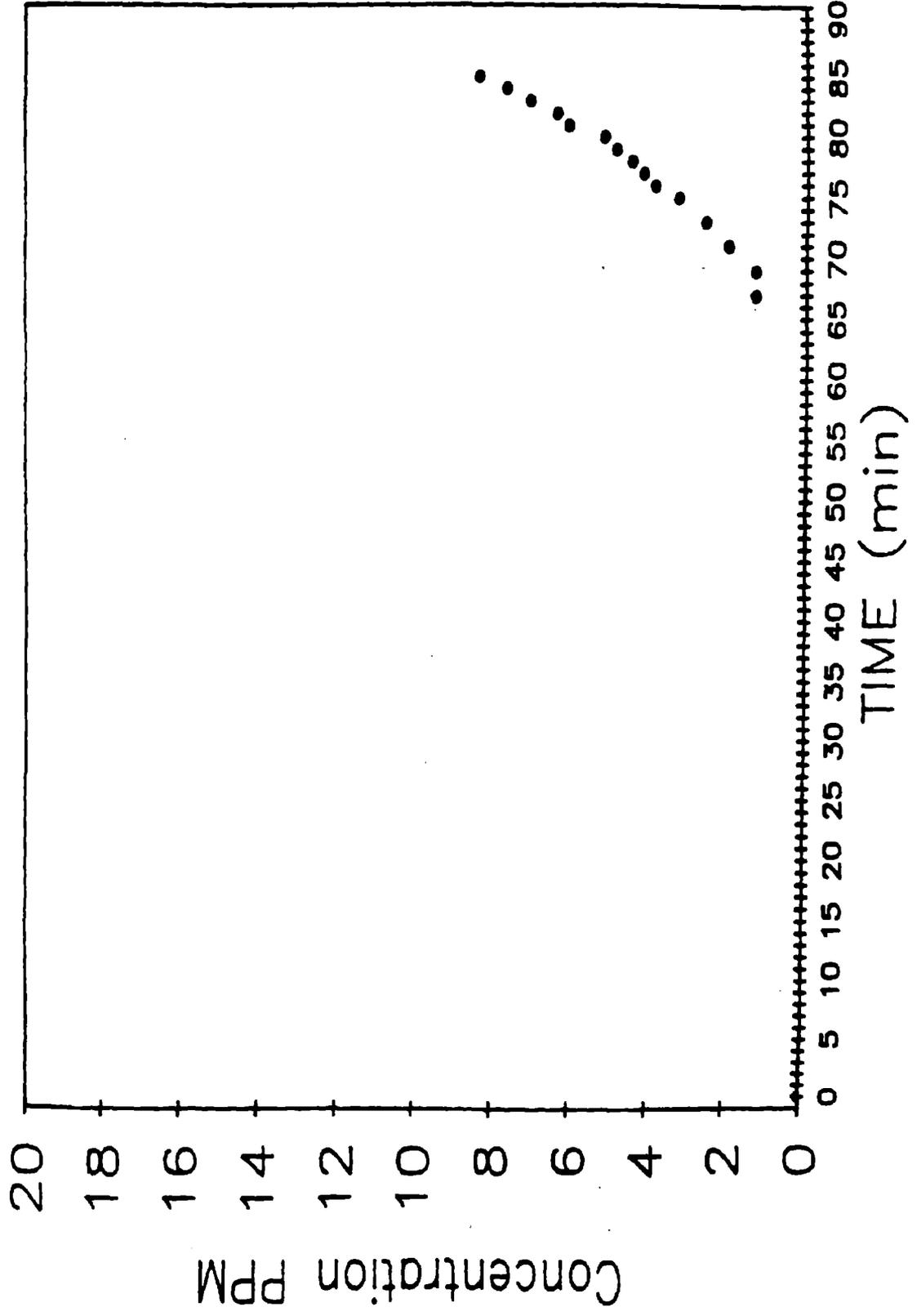
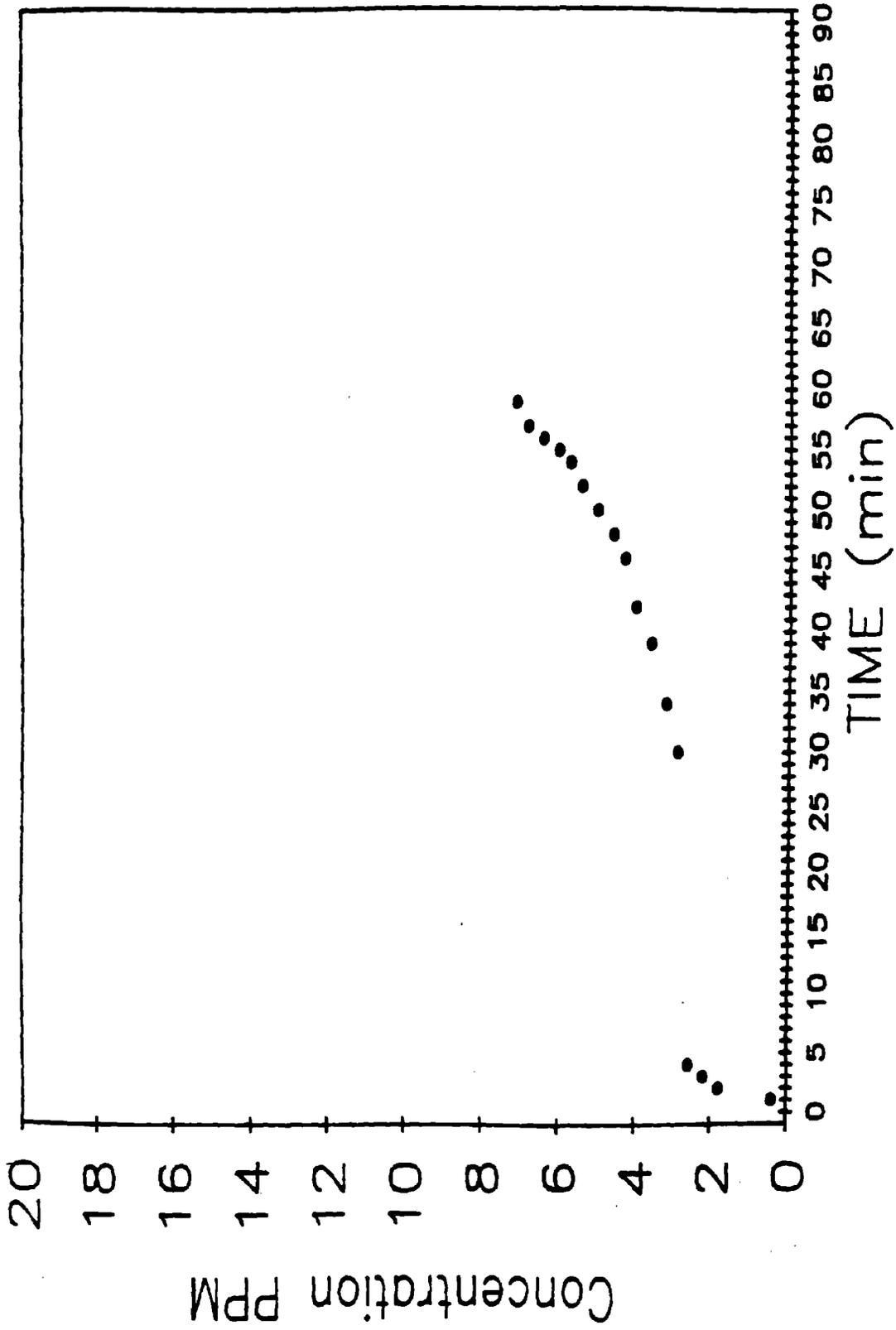


Figure XVIII

MIC Breakthrough of Acid Gas Cartridges at
73% RH for Manufacturer A at 998 PPM



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Figure XIX

MIC Breakthrough of Acid Gas Cartridges at 73% RH For Manufacturer A at 868 PPM

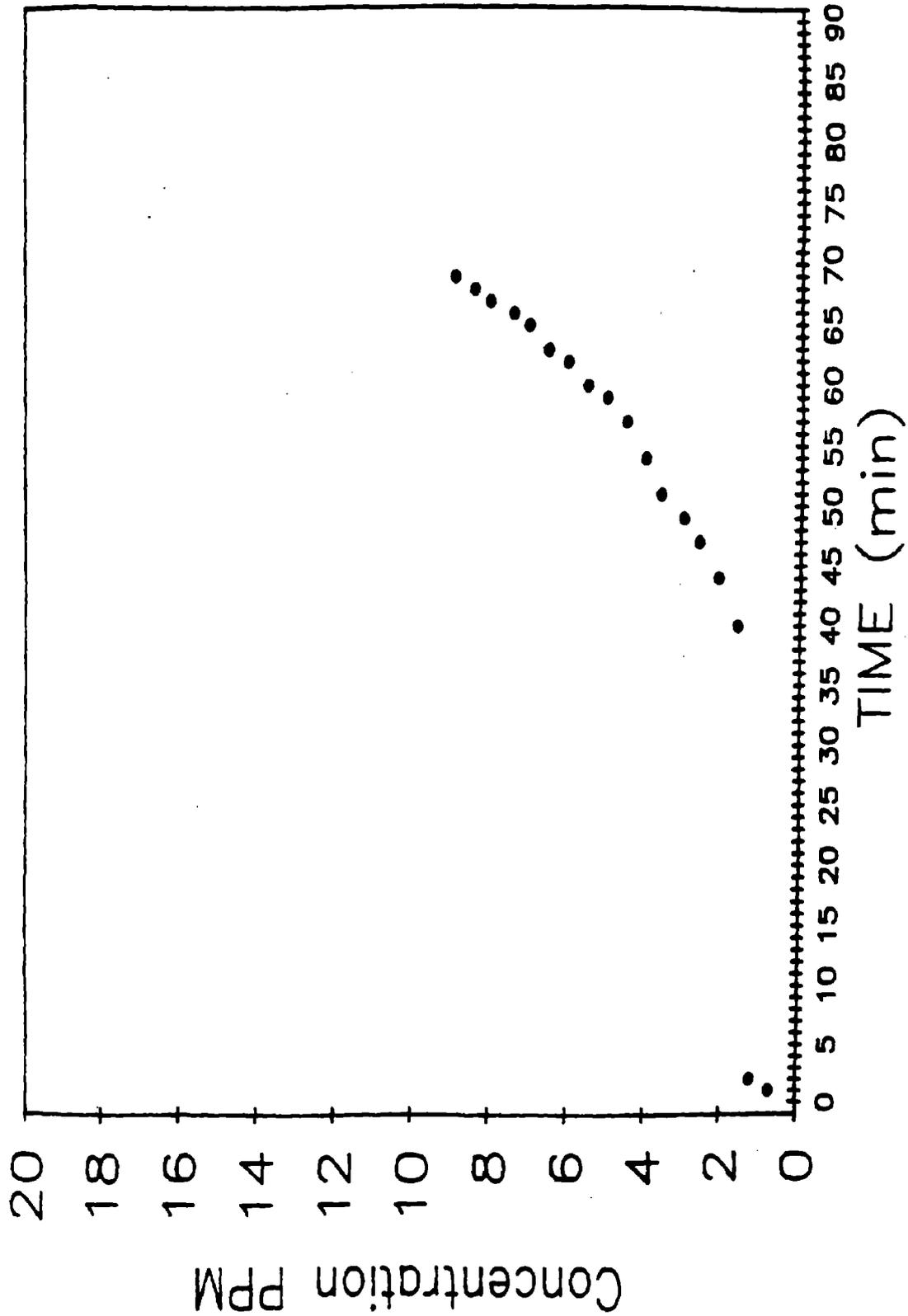


Figure XX

MIC Breakthrough of OV-AG Cartridges
at Dry Conditions For Manufacturer B
at 841 PPM

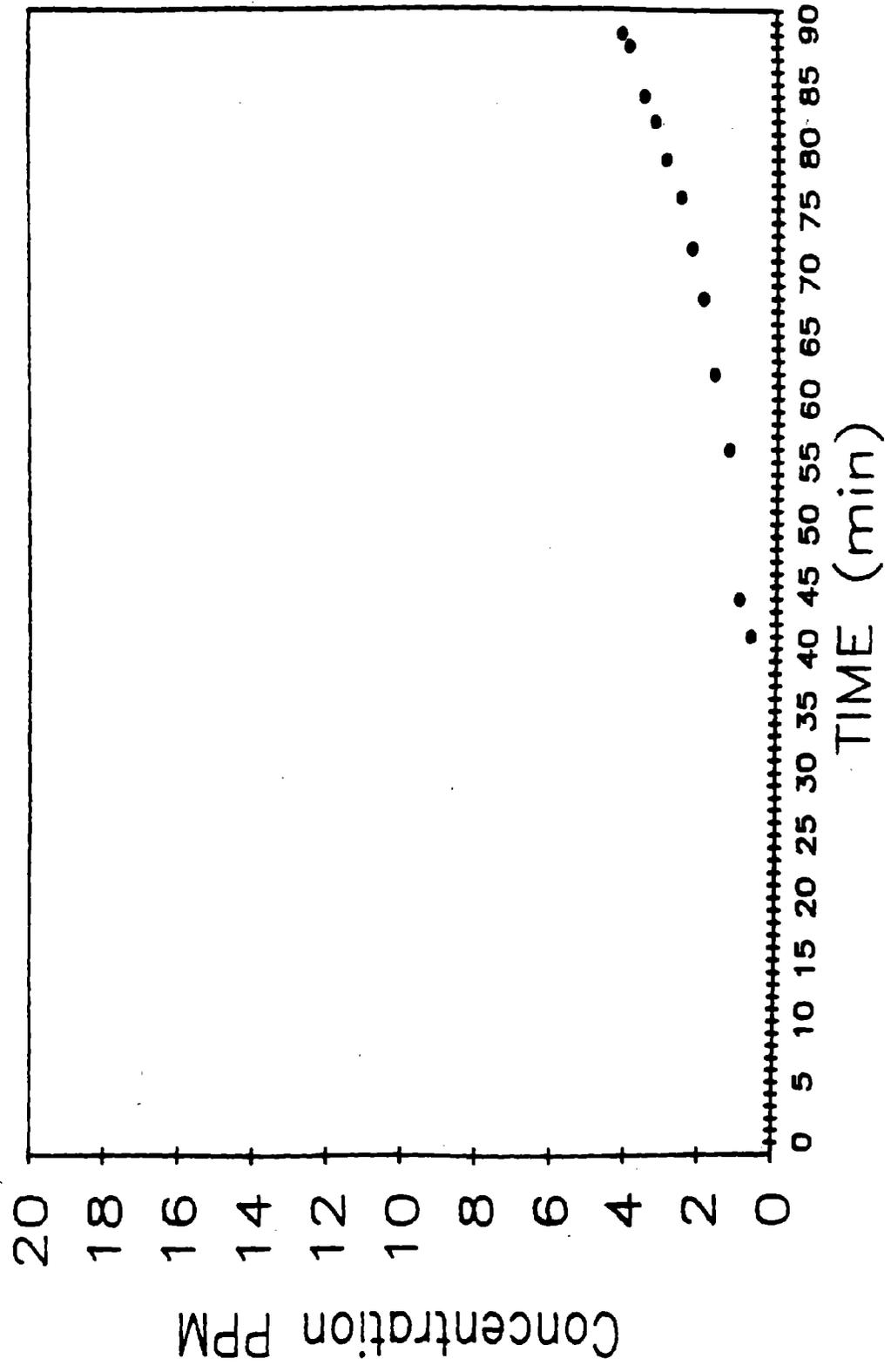


Figure XXI

MIC Breakthrough of OV-AG Cartridges
at Dry Conditions for Manufacturer B
at 861 PPM

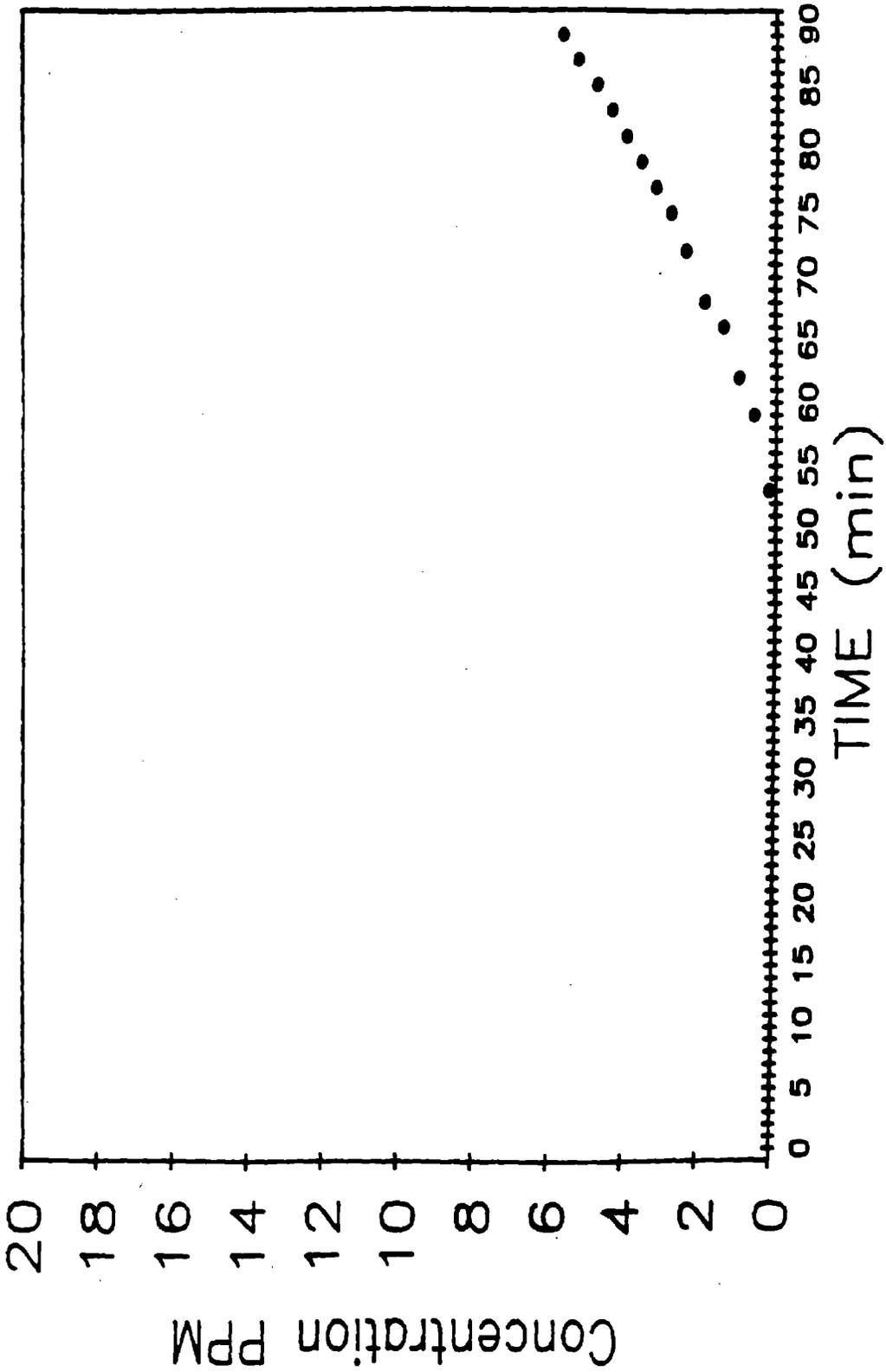


Figure XXII

MIC Breakthrough of OV-AG Cartridges at 73% RH for Manufacturer B at 965 PPM

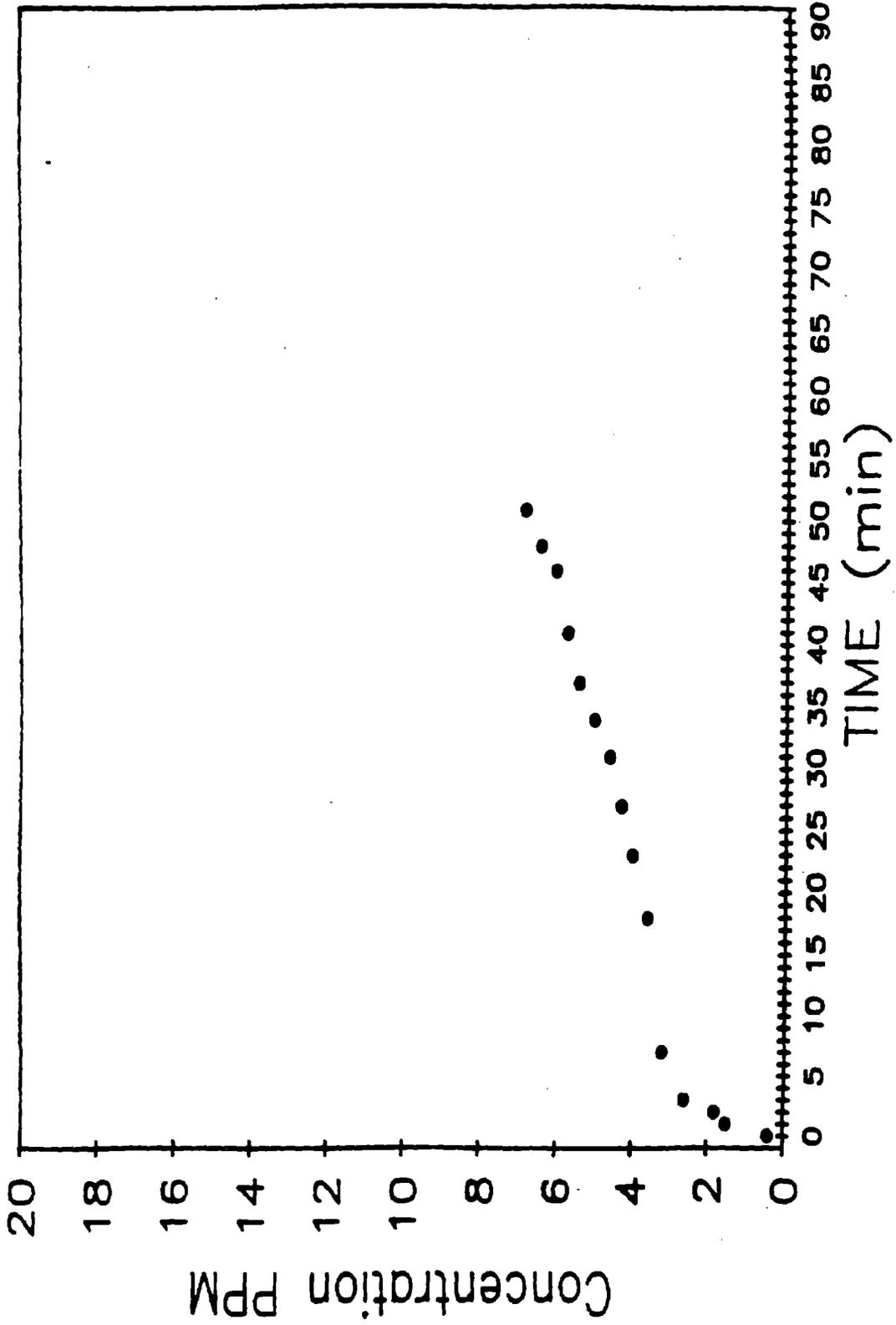


Figure XXIII

MIC Breakthrough of OV-AG Cartridges at 73% RH For Manufacturer B at 870 PPM

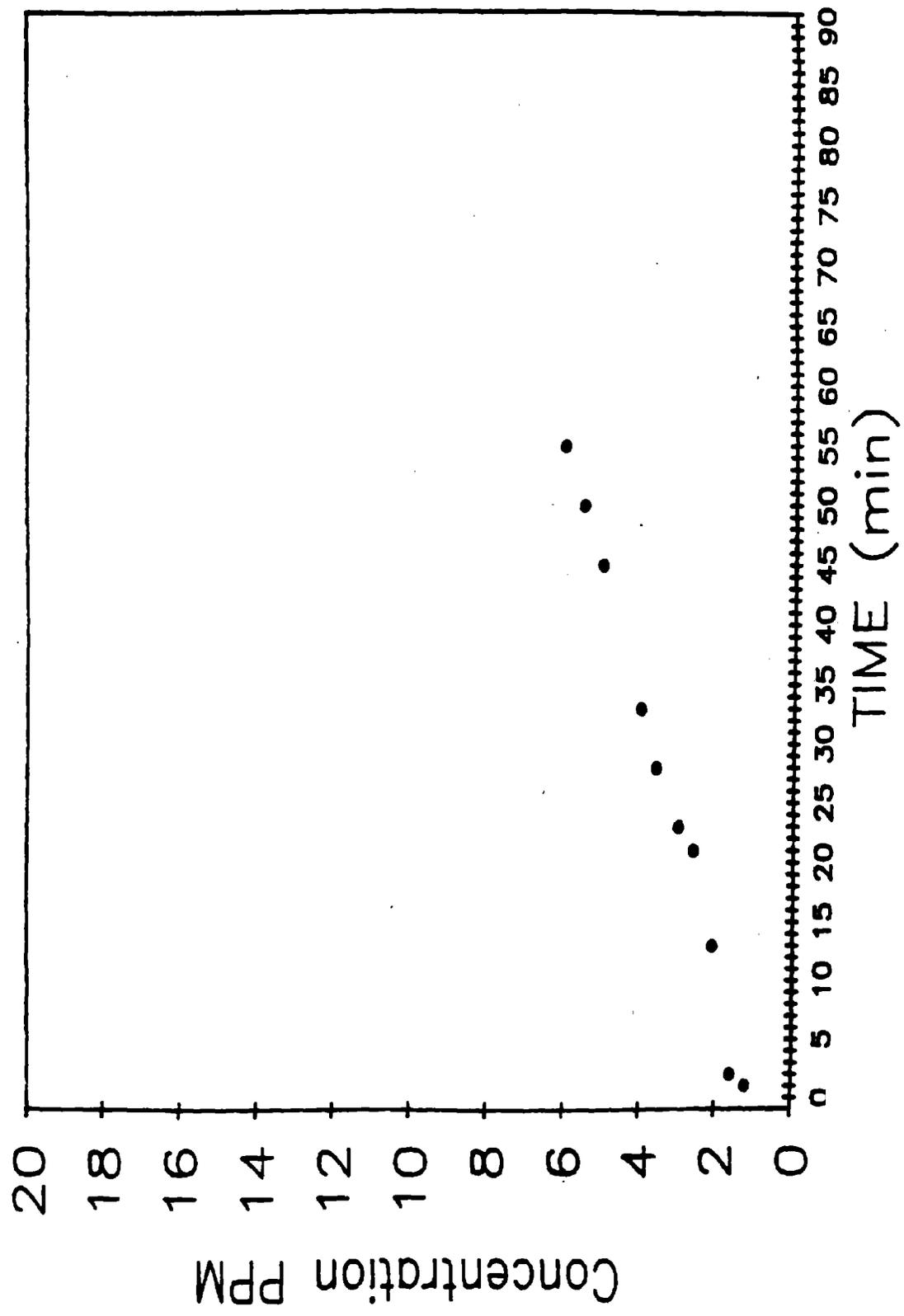


Figure 2.14

MIC Breakthrough Results Employing Jonas Model Stacked OV Cartridges at Dry Conditions For Manufacturer B

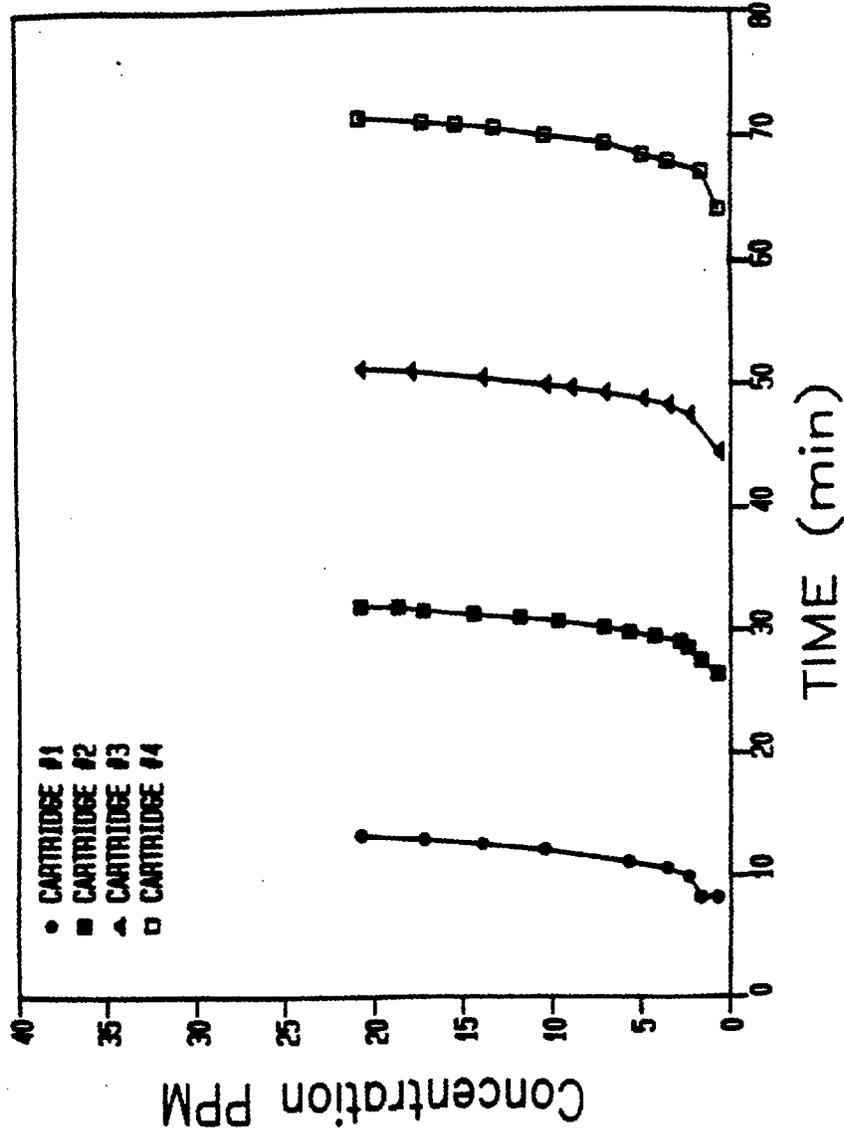


Figure XXV
One Percent MIC Breakthrough Time
As A Function of Sorbent Weight at
Dry Conditions for Manufacturer B

