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Application of multidimensional gas chromatography–mass spectrometry to the determination of glycol ethers in air

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ABSTRACT

The applicability of multidimensional gas chromatography–mass spectrometry to the analysis of five glycol ethers in air was demonstrated. Air samples were collected on charcoal tubes and desorbed with 5% methanol in methylene chloride as is described in method 1403 of the National Institute for Occupational Safety and Health Manual of Analytical Methods. The glycol ethers were determined by multidimensional gas chromatography–mass spectrometry. The limit of detection was 5 to 7 μg/sample for each compound.

INTRODUCTION

The analytical technique of multidimensional gas chromatography (MDGC) has been applied successfully to a number of complex analytical separations, such as soil fumigants [1], hydrocarbons and inert gases [2], polynuclear aromatic compounds in crude oil [3], alcohols in gasoline [4] and dibenzodioxins and dibenzofurans [5]. The increased resolving power of this analytical technique over single-column analyses lies in the ability to combine the selectivity of two or more columns with different liquid phases into a unified analysis scheme for improved chromatographic resolution. The inclusion of a mass spectrometer as a chromatographic detector further improves the specificity of the analysis [6].

Because one of the major problems encountered in the chromatographic analysis of industrial hygiene samples is the presence of interfering compounds, additional method development is needed to solve this problem. With the increased resolving power available though the technique of MDGC, the time required to address interference problems is greatly reduced. The overall goal of our research was to apply the analytical technique of MDGC to industrial hygiene sampling and analytical methods for glycol ethers.

The problem addressed in this research was the simultaneous determination of multiple glycol ethers in air samples containing hydrocarbons and other organic compounds. Other researchers have successfully applied the technique of MDGC to the determination of diethylene glycol monoethyl ether [2-(2-ethoxyethoxy)ethanol] in flavor extracts [7].

Concern about occupational exposure to glycol ethers in general has arisen due to reports of adverse reproductive effects [8] of 2-methoxyethanol, 2-ethoxyethanol and related compounds. In light of this concern, industrial hygienists at the National Institute for Occupational Safety and Health (NIOSH) have initiated workplace studies of potential occupational exposure to glycol ethers and related compounds. During one study, air samples were collected on charcoal tubes at a newspaper printing facility in which glycol ether-based fountain and cleaning solutions were used in conjunction with mineral spirits. This report details the method development work and subsequent analysis of these samples for selected glycol ethers using MDGC with mass spectrometric (MS) detection in this sample matrix.

EXPERIMENTAL

Analysis work was performed on a Hewlett-Packard Model 5890 gas chromatograph equipped with two split/splitless capillary injectors, one flame ionization detection (FID) system, a Hewlett-Packard Model 5971 mass selective detector, a Valco 10-port high-temperature (polyimide rotor seal) sampling valve (Hewlett-Packard Part No. 18900C-432) with 1/16-in. fittings (1.6 mm) contained in a separate heated compartment (240°C) above the gas chromatograph column oven, and a Hewlett-Packard Model 7673A autosampler.

Data reduction and system control for MDGC–MS were accomplished with a Hewlett-Packard Model 59970C ChemStation equipped with 2 Mbyte of random access memory, a color video monitor, 40 Mbyte disk drive for on-line storage of data and an additional 80 Mbyte disk drive along with Revision 3.2 mass selective detector operating system (Pascal) software.

A Hewlett-Packard Model 5890 gas chromatograph without multidimensional capability and equipped with a Hewlett-Packard Model 5970 mass selective detector was used for the bulk sample analyses.

The Valco valve actuator in the MDGC system was rewired to allow automated control of the valve from the software in the ChemStation computer. The Valco valve was configurated for "heart-cutting" [9] from the first column onto the second analytical column, as shown in Fig. 1. To facilitate changing the columns, pieces of blank 0.2 mm I.D. fused-silica tubing (Scientific Glass Engineering, Austin, TX, U.S.A.) were routed from the valve ports 1, 2, 3 and 4 into the gas chromatograph oven and column connections were made with 1/16-in. (1.6 mm) zero-dead-volune unions (Supelco, Bellefonte, PA, U.S.A.). The connections of the fused-silica tubing to the valve were made using a fused-silica adapter for 1/16-in fittings (part No. FS1R.5) obtained from Anspec (Ann Arbor, MI, U.S.A.). The blank fused-silica tubing connected to port 4 was inserted into injector "B", which was a source of carrier gas for the second column when the valve was in the "OFF" position. A 1.25-m piece of blank fused-silica tubing connected port 3 (see Fig. 1) to the FID system and acted as a restrictor so the flow in column 2 would not change appreciably during valve

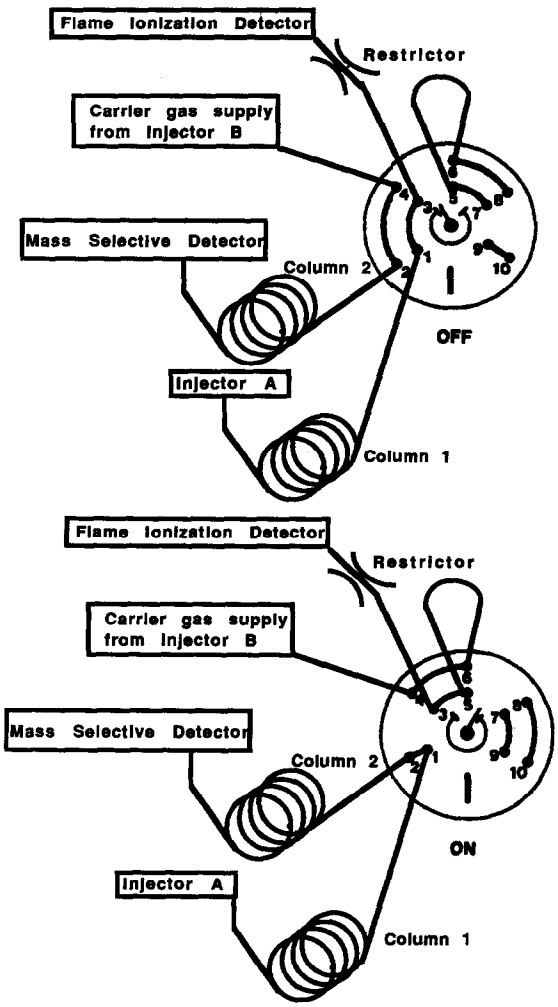

Fig. 1. Schematic diagram of the valve-based multidimensional gas chromatograph–mass spectrometer system used for the analyte of glycol ether-containing samples. (Top) Illustration of the valve in the off position. (Bottom) Illustration of the valve in the on position when a heartcut is being made.

switching operations [10]. Ports 5 and 6 were connected by a short length of 1/16-in. stainless-steel tubing and associated fittings. Ports 7, 8, 9 and 10 were plugged and not used.

The column flow balancing procedure involved opening and closing the Valco valve at 3-min intervals and lowering the head pressure on column 2 (controlled by injector "B" head pressure regulator) by 7 kPa (1 p.s.i.) before each closing. The chromatographic baseline was monitored by the mass selective detector to determine when baseline disturbance was at a minimum during valve switching operations. Optimal column head pressure on column 2 was 35 kPa (5 p.s.i.). Column head pressure on column 1 was maintained at 115 kPa (17 p.s.i.).

During the course of the experimental work, peak tailing of the solvent (5% methanol in methylene chloride) as it passed through the valve was observed with FID. This problem was due primarily to polar solvent (methanol) interaction with the valve assembly as the solvent passed through, since tailing was greatly reduced when solutions containing the glycol ethers in only methylene chloride were analyzed or when column 1 was connected directly to the FID system. To reduce any peak tailing due to interaction with active sites in the valve transfer lines, the blank fused-silica tubing was replaced with lengths of phenyl-methyl silicone deactivated uncoated fused-silica tubing (Anspec).

The chromatographic columns used were as follows: column 1: 30 m × 0.25 mm I.D. fused-silica capillary DB-1, 1.0-μm film (J & W Scientific, Folsom, CA, U.S.A.); column 2: 30 m × 0.25 mm I.D. fused-silica capillary DB-WAX, 0.5-μm film (J & W Scientific). The oven temperature program used for MDGC–MS analysis of the glycol ether samples was 40°C initial temperature, 30°C/min for 1 min, 15°C/min to 180°C, and hold for 16.7 min. The temperature program used for the bulk sample analyses was 35°C for 2 min, 15°C/min to 300°C, and hold for 5.4 min. A 30 m × 0.25 mm I.D. fused-silica capillary DB-1, 1.0-μm film (J & W Scientific) column was also used for the analysis of the bulk sample on the Hewlett-Packard Model 5890 gas chromatograph–Model 5970 mass selective detector.

Toluene, methanol and methylene chloride were obtained from Burdick & Jackson Labs. (Muskegon, MI, U.S.A.). Bulk samples of 1-butoxy-2-propanol and 1-(2-butoxyethoxy)-2-propanol were obtained from Elfco (West Warwick, RI, U.S.A.). 2-Butoxyethanol (butyl cellosolve), dipropylene glycol methyl ether (4 isomers) and 2-(2-butoxyethoxy)ethanol (butyl carbitol) were obtained from Chem Services (West Chester, PA, U.S.A.). Five bulk samples of solutions used at the printing plant were obtained and labeled A–E. Since some of these solutions contained large amounts of water, they were prepared for qualitative analysis by addition of 10 μl of the bulk solution to 1 ml of methylene chloride. The resulting methylene chloride solutions were analyzed by GC–MS to determine composition.

Charcoal tubes (100 mg front section; 50 mg backup section) used for the collection of the glycol ether samples were obtained from SKC (Eighty Four, PA, U.S.A.). Samples for glycol ethers were collected at 50 to 100 ml/min for 4 to 6 h using SKC Model 222 sampling pumps. Front and back sections of the charcoal tube samples were transferred individually to 2-ml vials and desorbed with 1 ml of 5% methanol in methylene chloride for 30 min [11]. Glycol ethers were determined by autosampler injection (1 μl injection, splitless mode) into the MDGC–MS system.

Desorption efficiency of the glycol ethers was determined by fortification of blank charcoal tubes with aliquots of solutions containing the four analytes of interest. The desorption spikes were done using three tubes at three levels. These fortified tubes were analyzed as described above.

RESULTS

Bulk samples

A set of five bulk samples and nine charcoal tube samples collected at a newspaper printing plant was submitted for the determination of glycol ethers during the course of an investigation by NIOSH industrial hygienists. The solutions

comprising the bulk samples were used in the offset printing process and in cleaning the printing plates and contained glycol ethers, kerosene and other organic compounds. GC–MS analysis of bulk sample A identified aliphatic hydrocarbons, pine oil and surfactants. The material safety data sheet indicated that bulk sample B contained only 1-butoxy-2-propanol, but mass spectral analysis also identified 1-(2-butoxyethoxy)-2-propanol, 2-butoxyethanol and other impurities. Bulk sample C was found to contain aliphatic hydrocarbons (a lighter fraction of naphthas than kerosene) and 2-(2-butoxyethoxy)ethanol. Bulk sample D contained dipropylene glycol methyl ether (four isomers). Bulk sample E contained a series of hydrocarbons which was indicative of kerosene. All of the components contained in the bulk samples were present potentially in the air samples. The analysis of the bulk samples also showed that the hydrocarbons would co-elute with glycol ethers using single column analysis, so quantitation of the glycol ethers was attempted by MDGC–MS.

Air samples

This preliminary analysis of these bulk samples indicated that the increased resolution offered by the "heart-cutting" approach would be needed for the analysis of air samples. The identification of compounds present in air samples would be quite difficult due to the large number of compounds present together in each sample, the similarity of mass spectra for glycol ethers and hydrocarbons, and the lack of parent ions for the glycol ethers due to the presence of the hydroxyl group [12]. The possibility also existed that two or more compounds would co-elute at the same retention time on a single analytical column. This possible co-elution of hydrocarbons and glycol ethers in the analysis of air samples was illustrated by the FID chromatograms shown in Fig. 2. The peaks which are due to the glycol ethers are lost in the large number of peaks, primarily due to the hydrocarbons present in the air sample. The technique of MDGC, using "heart-cutting", seemed particularly well suited for the analysis of these air samples, since small segments of the chromatographic effluent of the first column containing the glycol ethers could be directed to a second column of different polarity for further resolution.

For MDGC analysis, the gas chromatograph was configured as shown in Fig. 1, with column 2 connected directly to the mass selective detector. Column 2 was heated to a maximum temperature of 180°C. Above this temperature, there was an excessive amount of column bleed, which had mass spectral fragments similar to the glycol ethers being determined by the mass selective detector. The rationale for the column placement order in the multidimensional analysis system was that the injection onto the non-polar column (column 1, DB-1) would provide an initial separation of polar and non-polar components. Portions of the column 1 effluent containing the glycol ethers could then be directed via the valve to a more polar column (column 2, DB-WAX) which would further resolve the individual glycol ethers. The hydrocarbons which co-eluted with the glycol ethers on the non-polar column were sufficiently separated from the ethers on the polar column to allow baseline resolution in most cases.

Based on the preliminary analysis of the glycol ether standards, two or three "heartcuts" from a sample would be necessary to keep large amounts of the hydrocarbons, present on the air samples, from being "cut" onto the second column. The analysis method was constructed by chromatography of the individual glycol

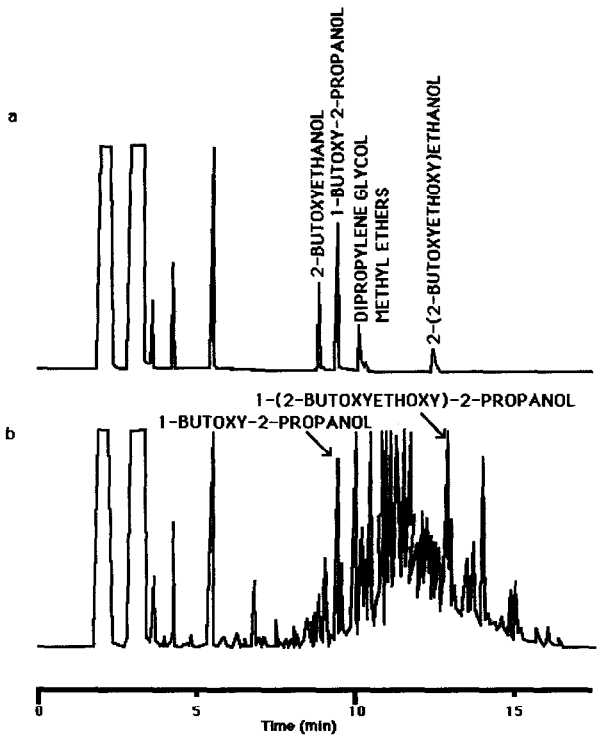

Fig. 2. (a) Single-column GC–FID of glycol ether standard containing 22.5 μg/ml 2-butoxyethanol, 22 μg/ml 1-butoxy-2-propanol, 24 μg/ml dipropylene glycol methyl ether and 24 μg/ml 2-(2-butoxyethoxy)-ethanol. (b) Single-column GC–FID of charcoal tube air sample containing 109 μg 1-butoxy-2-propanol and *ca.* 18 μg 1-(2-butoxyethoxy)-2-propanol (sample G1).

ether standards, in the order of their increasing elution time. Each glycol ether was analyzed without the "heartcut" to determine the approximate time interval for the "heartcut", using the flame ionization detector. The same sample was then analyzed with the "heartcut" to verify that all of the peak was being transferred onto the second analytical column during the "heartcut". During the period which the valve is in the heartcut mode, the flow through column 1 is reduced due to the additional pressure drop caused by column 2 being connected in series with column 1. Because of this, the transfer of the analyte from column 1 to column 2 requires the heartcut time to extend beyond the expected elution time of the analyte from column 1 alone. The determination of the appropriate end time was made on a trial and error basis. After the analytical conditions were established for the first compound, standards of the other glycol ethers identified in the bulk samples were treated in the same fashion, with either the initial heartcut modified or a new heartcut made to include each new compound. Based on this approach, the five glycol ethers under study could be analyzed by using two heartcuts (a cut from 8.1 to 11.5 min and a second cut from 13.55 to 15.1 min). One interesting aspect of the valve arrangement was that when the valve was switched, a small amount of air leaked into the chromatographic tubing. This air

peak was detected with the mass selective detector and provided a reference point for each of the heartcuts.

After the initial analytical method development was completed, a problem with the separation of 1-(2-butoxyethoxy)-2-propanol and 2-(2-butoxyethoxy)ethanol was noted in the analysis of the air samples. Both compounds appeared to be eluting at the same retention time. The initial analytical work on these two compounds indicated that there was a difference of 0.5 min in their respective retention times in the MDGC–MS system. At the time when this problem was found, the samples already had been prepared for analysis, so 1-(2-butoxyethoxy)-2-propanol was not included as a standard because it had not been found in the preliminary analyses of 2 samples. In the sample (G1) where 1-(2-butoxyethoxy)-2-propanol was found, its identity had to be confirmed by examination of the full scan mass spectrum.

The separation of the glycol ethers from the aliphatic compounds using the valve made it possible to identify the five glycol ethers of interest accurately in the air samples. The use of the mass selective detector added to the selectivity of the method, since individual ion chromatograms could be extracted from the total ion chromatogram data. Fig. 3 shows the chromatograms for a standard and one of the samples obtained during a MDGC–MS analysis. The extracted ion chromatograms for ion *m/e* 45 ($C_2H_5O^+$) for both standards and samples were integrated and the results were used for quantitation of the glycol ethers. Calibration results were linear over the range of 5–200 μg/ml for all five glycol ethers using peak area data. For dipropylene glycol methyl ether, the individual peak areas for the two major isomers were summed for data calculations. The limit of detection [13,14] for the five glycol ethers was typically 5–7 μg/sample.

The desorption efficiencies of the glycol ethers were: 2-butoxyethanol 100%, 9–180 μg/sample; 2-(2-butoxyethoxy)ethanol 80%, 9–190 μg/sample; 1-butoxy-2-propanol 94%, 9–180 μg/sample; and dipropylene glycol methyl ether (two major

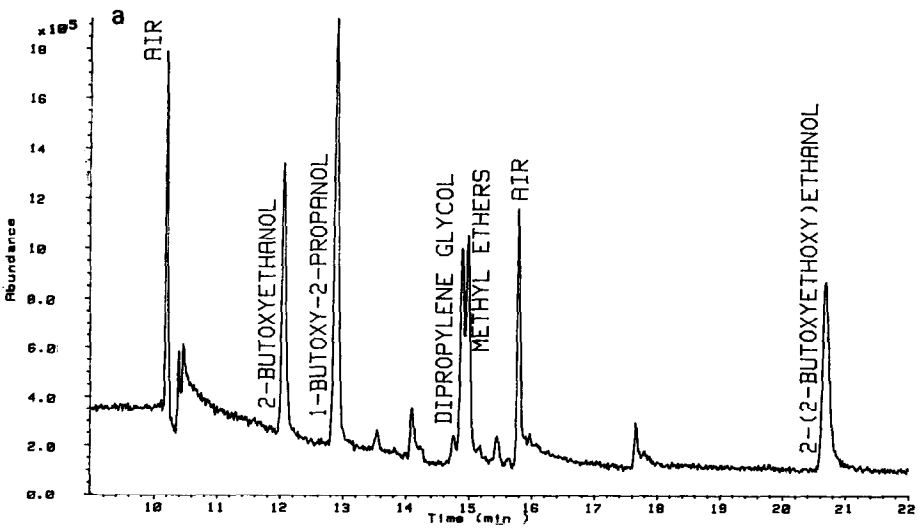

Fig. 3.

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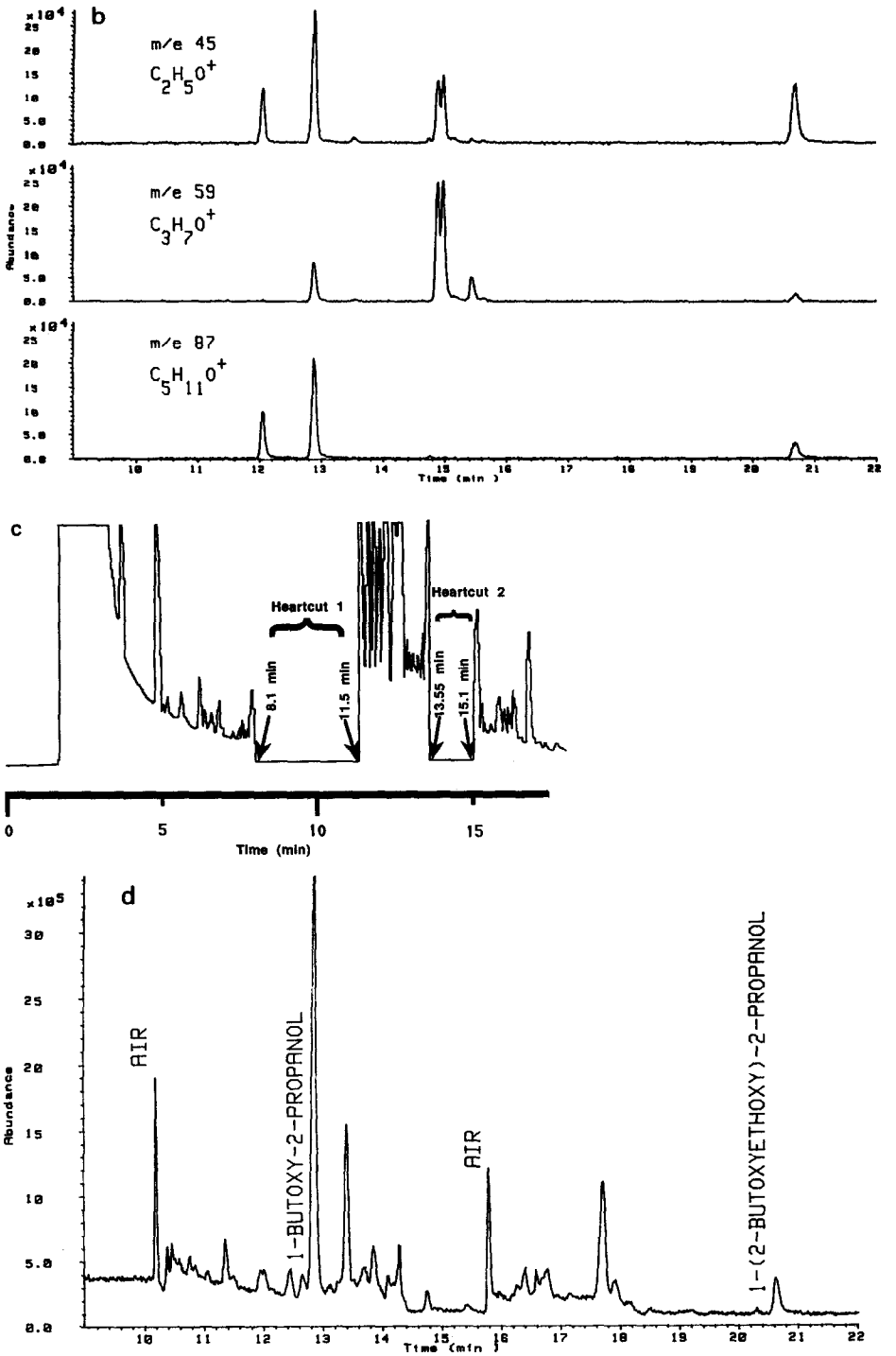
b
m/e 45
$C_2H_5O^+$
m/e 59
$C_3H_7O^+$
m/e 87
$C_5H_{11}O^+$
Abundance
Time (min)
c
Heartcut 1
Heartcut 2
8.1 min
11.5 min
13.55 min
15.1 min
Time (min)
d
AIR
1-BUTOXY-2-PROPANOL
AIR
1-(2-BUTOXYETHOXY)-2-PROPANOL
Abundance
Time (min)

Fig. 3.

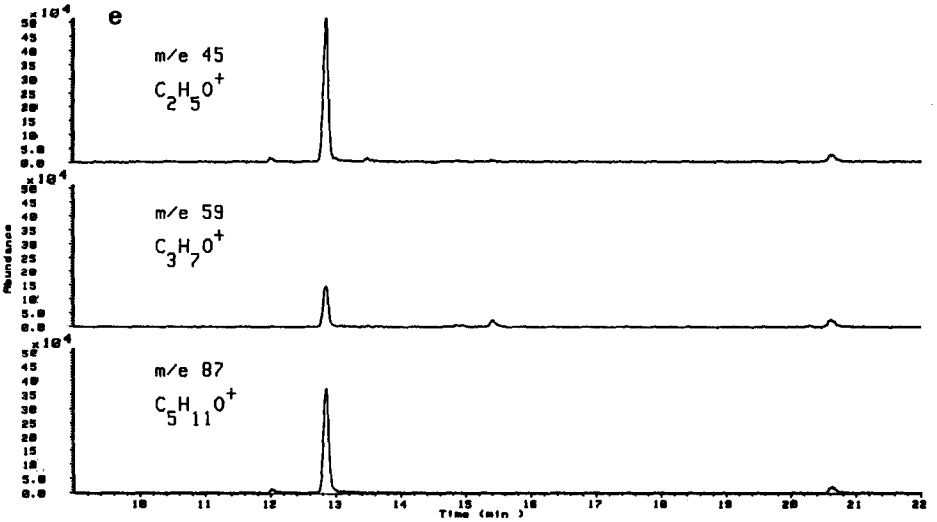

Fig. 3. (a) Total ion and (b) extracted ion chromatograms from multidimensional gas chromatographic analysis of standard containing 22.5 μg/ml 2-butoxyethanol, 22 μg/ml 1-butoxy-2-propanol, 24 μg/ml dipropylene glycol methyl ether and 24 μg/ml 2-(2-butoxyethoxy)ethanol. (c) Flame ionization chromatogram of charcoal tube air sample (sample G1) extract showing regions (8.1–11.5 min and 13.55–15.1 min) which were heartcut onto column 2. (d) Total ion and (e) extracted ion chromatograms of heartcut from charcoal tube air sample containing 109 μg 1-butoxy-2-propanol and *ca.* 18 μg 1-(2-butoxyethoxy)-2-propanol (sample G1).

TABLE I

RESULTS FROM ANALYSES OF AIR SAMPLES FOR GLYCOL ETHERS

ND = Less than limit of detection present (*ca.* 7 μg/sample).

Sample	2-Butoxy-ethanol		1-Butoxy-2-propanol		2-(2-Butoxy-ethoxy)ethanol		1-(2-Butoxy-ethoxy)-2-propanol	
	μg/sample	mg/m³	μg/sample	mg/m³	μg/sample	mg/m³	μg/sample	mg/m³
G1	ND[a]	–	109	3.6	ND		18[b]	0.6
G2	ND	–	ND[a]	–	9.7	0.4	ND	–
G3	ND	–	ND[a]	–	9.5	0.5	ND	–
G4	ND	–	ND[a]	–	ND[a]	–	ND	–
G5	ND	–	ND	–	35	1.6	ND	–
G6	104	2.6	ND	–	ND[a]	–	ND	–
G7	9.6	0.5	ND	–	ND[a]	–	ND	–
G8	313	13	ND	–	ND[a]	–	ND	–
Blank	ND		ND	–	ND	–	ND	–

[a] Peaks observed at correct retention times for these compounds and mass spectra obtained indicating presence at levels below the limit of detection.

[b] A standard for 1-(2-butoxyethoxy)-2-propanol was not used. Analyte was quantitated using 2-(2-butoxyethoxy)ethanol as standard.

isomers) 83%, 9–190 μg/sample. Only with dipropylene glycol methyl ether was the desorption efficiency observed to change with loading from 74% at 9 μg/sample to 91% at 190 μg/sample.

Four of the eight air samples contained significant amounts of glycol ethers. Table I lists the analysis results of the charcoal tube samples. No dipropylene glycol methyl ether was found in any of the samples. Preliminary analysis of samples G5 and G8 indicated that 1-(2-butoxyethoxy)-2-propanol was not present. Based on this finding and the previously described resolution difficulties with 2-(2-butoxyethoxy)-ethanol, 1-(2-butoxyethoxy)-2-propanol was not included in the standards used for quantitation. However, this compound was identified by mass spectral data interpretation in sample G1 and quantitated based on 2-(2-butoxyethoxy)ethanol calibration data.

The mass spectra of glycol ethers and hydrocarbons present in the samples analyzed in this study have many similar ions, making selected ion monitoring impractical to use alone for compound identification. The use of selected ion monitoring usually offers the advantage of increased sensitivity for a selected compound, particularly if the compound has a very characteristic ion. Unfortunately, the characteristic ions of glycol ethers correspond to the background ions found when using a DB-WAX capillary column. To determine if improvement in sensitivity was possible with selected ion monitoring in this instance, the glycol ether standards used for calibration of the air sample analyses were reanalyzed using this technique. Integration results from the selected ion monitoring chromatograms (ion m/z 45) produced calibration curves that gave slightly lower limits of detection [13,14] than integration data from the extracted ion chromatograms (2-butoxyethanol 2.4 μg/ml; 1-butoxy-2-propanol 1.4 μg/ml; 2-(2-butoxyethoxy)ethanol 4.9 μg/ml; dipropylene glycol methyl ether 2.5 μg/ml using ion m/z 59). The main reason that selected ion monitoring did not give significantly lower limits of detection in this instance was that the baseline noise caused by the column bleed interfered with the integration of the peaks due to the glycol ethers, particularly at low levels.

DISCUSSION

The successful determination of glycol ethers in air samples has shown the multidimensional gas chromatograph to be a useful analytical tool in the analysis of industrial hygiene samples containing low levels of difficult-to-separate components. This system has the resolving power to separate complex mixtures of analytes and may significantly reduce method development time. The selectivity of the mass selective detector enhanced the performance of the system by allowing characteristic ions of the glycol ethers to be monitored.

The use of this detector also aided in the identification of compounds, so that multicomponent standards could be used in the initial method development phases of the research. With a non-specific detection method, such as FID, individual standards and blanks must be prepared and analyzed in order to identify compounds by retention time. The ability to identify individual compounds by mass spectral data is particularly advantageous in a multidimensional gas chromatographic system, where retention times of the analyte of interest may change by alteration of the heartcut time interval.

The valve-based multidimensional gas chromatograph used in this study still has some unresolved problems. Peak tailing due to solvent interaction with the valve assembly was noted in the FID signal. Fortunately, this did not pose a problem with the determination of the glycol ethers. A qualitative test has been proposed by other researchers to evaluate the inertness of such a valve-based multidimensional system [15]. The interaction of the test compounds with the valve components was reported to be reversible when a cryofocusing system at the head of the second column was used. This information indicates that application of MDGC–MS to other samples containing polar, volatile or reactive compounds may require the addition of cryofocusing capability at the head of the analytical column (column 2).

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Disclaimer: Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

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