VCM

Gas-Liquid Chromatographic Determination of Vinyl Chloride in Vinyl Chloride Polymers, Food Simulating Solvents, and Other Samples

CHARLES V. BREDER, J. LAWRENCE DENNISON, and MARGARET E. BROWN
Division of Chemical Technology, Food and Drug Administration, Washington, DC 20204

ABSTRACT

The determination of vinyl chloride (VC) in polyvinyl chloride (PVC), vegetable oil, food simulating solvents, mouthwashes, and blood anti-coagulant solutions by gas-liquid chromatography is described. PVC polymers are dissolved in either tetrahydrofuran or dimethyl acetamide and vegetable oils are diluted with an equal volume of tetrahydrofuran. The resulting solutions are injected into a gas-liquid chromatograph equipped with a flame ionization detector. Mouthwashes, blood anticoagulant solutions, and 3 food simulating solvents, 3% acetic acid, 50% ethanol and heptane, are analyzed by direct injection into a chromatograph. Sensitivities are such that 0.05 ppm VC in solution or 1 ppm VC in PVC can be quantitated.

PREPRINT

Submitted for Publication in November 1975 issue of JAOAC

Polyvinyl chloride has been used for years as a food packaging material on the assumption that nothing migrated from the package to the food (1). This assumption was shown to be erroneous in early 1973 (2) when it was found that alcoholic liquors packaged in PVC bottles were contaminated with vinyl chloride (VC) extracted from the plastic. This discovery led many producers of PVC resin and of products packaged in PVC to develop methods for measuring the VC content of their materials. Although Viola reported in 1970 that inhalation of very high concentrations (30,000 ppm) of VC in air produced tumors in test animals (3,4), it was not until 1974 when Maltoni (5) reported the occurrence of angiosarcoma of the liver at much lower concentrations that the need for analytical methods became urgent.

In view of the currently uncertain oral VC toxicity, it is desirable to have highly sensitive analytical methods to measure the levels of VC which migrate from PVC into food. In testing for extractables from food packaging materials, it has been customary to use food simulating solvents rather than foods themselves (6). That practice is followed here with procedures described for 3% acetic acid, 50% ethanol, and heptane as the simulating solvents. Building on industrial methods (E. G. DeCapita, 1974, B. F. Goodrich Chemical Co., Akron, OH; J.H. Heckman, 1973, The Society of Plastics Industry, Inc., Washington, DC) already available in some areas, our laboratory has selected and used the following gas-liquid chromatographic (GLC) procedures which permit the quantitative determination of VC at the 1 ppm level in PVC and at the 0.05 ppm level in solution.

METHOD

CAUTION:

Since VC is a gas and is carcinogenic (3-5) by inhalation, special handling precautions must be taken to preserve the integrity of the standards as well as to ensure the safety of the analyst. Only the septa-sealed vials described under Method were found satisfactory.

Reagents

(a) Vinyl chloride.--Three 1b cylinder (99.9% pure), Matheson, or equivalent.

(b) Ethanol.--50%. Redistilled water and 100% ethanol (1+1).

(c) Heptane.--Baker grade, (J. T. Baker) or equivalent. Distill slowly using 3-ball Snyder column between round bottom flask and distillation head. Discard first 20% of distillate; collect and use middle 60% distillate.

(d) Acetic acid.--3%. Distilled glacial acetic acid (middle 60% distillate) and redistilled water (3+97).

(e) Tetrahydrofuran.--Fisher Certified, or equivalent. Demonstrate absence of VC interferences on GLC column to be used for analysis.

(f) Vegetable oil.--Use vegetable oil from glass or polyethylene bottles. Demonstrate absence of VC inteferences by GLC.

(g) Dimethyl acetamide.--Fisher Certified, or equivalent. Demonstrate absence of VC interferences on GLC column to be used for analysis.

Apparatus

(a) Sample vials.--Two ml. Hewlett-Packard No. 5080-8712, or equivalent.

(b) Vial caps.--With Teflon lined septa. Hewlett-Packard No. 5080-8713, or equivalent. Handcapper for vials.--Hewlett-Packard No. 8710-0979, or equivalent.

(c) Mini-Vials.--5 ml, with caps and Teflon lined septa. Alltech Associates No. 9500, or equivalent.

(d) Screw cap bottles.--1 and 2 oz narrow mouth. Ace Scientific Supply Co. No. 10-4256, or equivalent.

(e) Disposable glass inserts.--4 mm od glass tubing cut into 6" lengths.

(f) Gas chromatograph.--Hewlett-Packard Model 7620A, or equivalent, equipped with temperature programmer, flame ionization detector, injection port entrance enlarged by drilling to 1/4", 6" x 1/4" stainless steel injection port liner fitted with disposable glass inserts. Operating conditions: detector temperature 250°C; flows (ml/min) - hydrogen 55, air 600; helium carrier; electrometer setting, 2×10^{-12} amp. full scale.

(g) Chromatographic columns.

A. Coiled glass, 6' x 4 mm, packed with 10% Carbowax 20M on 100-120 mesh Chromosorb W(HP); temperatures (°C) - column 70° for 4 min, program from 70° to 150° at 30°/min, hold at 150° for 10 min, injection port 200°; helium flow adjusted to give VC retention time of 1-2 min.

B. Coiled glass, 6' x 4 mm, packed with 20% OV-101 on 80-90 mesh Anakrom A; temperatures (°C) - column 60° for 4 min, program from 60 to 175° at 30°/min, hold at 175° for 10 min, injection port 200°; helium flow adjusted to give VC retention time of 1-2 min.

C. Coiled stainless steel, 10' x 1/8", packed with 60-80 mesh Chromosorb 104; temperatures (°C) - column 100° for 6 min, program from 100 to 200° at 30°/min, hold at 200° for 30 min, injection port 100-140°; helium flow adjusted to give VC retention time of 3-4 min.

D. The following column with the described set-up (see Fig 1) is used for backflushing the dimethyl acetamide solvent (E. G. DeCapita, B. F. Goodrich Chem. Co.). Beginning at injection port, connect stainless steel, 1' x 1/8" od column through 1/8" tee to stainless steel, 6' x 1/8" od column; connect other end to detector, (both columns are packed with 60-80 mesh Porapak S); connect auxiliary helium carrier flow through on/off valve to side arm of tee. Temperatures (°C) - column 130°, injection port 200°; primary helium carrier - with auxiliary on/off valve off, adjust primary carrier flow to give VC retention time of 1-2 min, disconnect 6' column from detector and measure flow; auxiliary helium carrier - remove injection port septum retainer and septum, turn on auxiliary on/off valve, and adjust auxiliary flow so that gas flow at detector end of 6' column is equal to rate obtained for primary carrier flow. Once primary and auxiliary flows are adjusted, turn off auxiliary on/off valve, replace injection port septum retainer and septum, and

reconnect the 6' column to the detector. Program - inject sample; after 4 min remove injection port septum retainer and septum and simultaneously turn on auxiliary on/off valve; replace glass insert; after additional 10 min turn off auxiliary on/off valve and replace septum retainer and septum; allow additional 2-5 min for system to stabilize before repeating program with next sample.

(h) Gas chromatograph-mass spectrometer.--Finnigan 1015C quadrupole mass spectrometer coupled with Varian 1700 GC thru Gohlke all-glass jet separator. Mass spectrometer was operated under computer control in a Mass Fragmentography Mode® monitoring m/e 26, 62, 64 with Finnigan system 6000 data system. Operating conditions; temperatures (°C) injector 210°, column 70°, separator 240°, transfer line to mass spectrometer 200°, after VC eluted, column vented and programmed to 200° to clear solvent from column; carrier gas; Helium-20 ml/min; column 6'x4 mm packed with 10% carbowax 20M on 80 - 100 mesh Chromosorb W(HP).

Procedure

Preparation of VC standards: Accurately weigh 2 oz narrow mouth bottle, Mini-Vial cap, and septum. Add 50 ml appropriate solvent to weighed bottle. Cap and reweigh. In a hood, prepare VC stock solution in this bottle by quickly uncapping bottle and adding 0.5 - 2 g liquid VC from inverted freezer-cooled cylinder of VC. Immediately cap bottle and mix well by shaking. Reweigh and calculate VC concentration by weight.

Dilute this stock solution by withdrawing aliquots through septum with syringe and injecting into weighed, sealed containers of appropriate solvent. Reweigh and calculate VC concentration either in weight/weight or in weight/volume units. Prepare working standards in 0.04 - 0.2 ppm range.

Prepare standards in 3% acetic acid by diluting 50% ethanol VC stock solution with 3% acetic acid in tared containers.

Preparation of Sample and Analysis: To maintain sample integrity, transfer sample solutions to glass containers and seal with caps and Teflon lined septa. When using electrometer setting of 2×10^{-12} amp. full scale, inject up to 20 µl containing $\leq$ 6-10 ng VC.

Polymer materials: Cut PVC articles into ca 0.5 sq cm pieces. Accurately weigh 1g into 1 oz narrow mouth bottle containing 1" x 3/8" Teflon coated stirring bar. Pipet 20.0 ml of either tetrahydrofuran or dimethyl acetamide into bottle. Cap bottle with Mini-Vial cap and septum. Stir bottle contents by means of magnetic stirrer until complete solution of polymer is observed (ca 1 hr). Inject PVC solutions in tetrahydrofuran, using Column C. Inject PVC solutions in dimethyl acetamide, using Column D.

Aqueous samples (50% ethanol, 3% acetic acid, mouthwashes, and blood anticoagulant solutions): Inject samples directly into chromatograph, using Column A.

Heptane solutions: Inject samples directly into chromatograph, using Column B.

Vegetable oil: Dilute samples of vegetable oil with an equal volume of tetrahydrofuran. Inject resulting solutions directly into chromatograph using Column C.

Solutions such as mouthwashes, blood anticoagulant solutions, PVC solutions, vegetable oils, etc., leave residue in glass insert of injection port liner. Remove and discard this insert after each injection during either temperature program step or backflushing step by: (1) removing injection port septum retainer and septum, (2) replacing disposable glass insert, and (3) replacing injection port septum retainer and septum.

Quantitatively measure VC levels in samples by comparing VC GLC response with response of VC standards prepared in same solvents. Exceptions: Use VC standards in 50% ethanol to quantitate blood anticoagulant solutions and mouthwashes.

Discussion and Results

Vinyl chloride boils at -14°C. As a result, it elutes from the GLC columns before the solvents. Low column temperatures are used to better resolve the VC peak from the solvents. However, the low temperatures require very long times to completely elute the solvents from the columns. In order to shorten the analysis time, the solvents are either temperature programmed or backflushed from the columns. Low boiling impurities in some solvents interfered with VC. For heptane and acetic acid, distillation effectively removed these interferences. GLC columns containing a liquid

coating on an inert support worked well for these systems. For tetrahydrofuran and dimethyl acetamide, distillation did not remove the interferences and other types of columns were tried. GLC columns packed with porous polymers such as Chromosorb 104 and Porapak S were found to resolve the VC peak from the interferences for these 2 solvents. In some cases it was necessary to try different brands or lots of these 2 solvents to minimize VC interferences.

Glass and stainless steel columns were used interchangeably and no differences were observed between the two. The disposable glass inserts were necessary in the analysis of solutions leaving a residue in the injection port. Failure to remove these residues after each injection led to VC interferences on subsequent injections.

Difficulty was encountered in preparing VC stock solutions in 3% acetic acid due to the relative insolubility of VC in that solvent. Therefore, VC stock solutions in 50% ethanol were injected into 3% acetic acid to yield standards in the 0.04-0.2 ppm range.

VC standards prepared in vegetable oil could not be handled by direct injection into the chromatograph. It was found that the VC did not completely or reproducibly flash from the oil in the injection port under the described conditions. Attempts to aid VC release by increasing the temperature of the injection port above 200°C merely led to "dirty" chromatograms. This may have been due to the partial breakdown of the oil at these high temperatures. The problem of incomplete VC release from the oil was overcome by diluting the oil with an equal volume of tetrahydrofuran.

Injection of the diluted oil gave larger VC peaks that were reproducible. Therefore, VC standards for oil analysis were prepared in THF-oil (1+1). Figure 2 shows the effect of the diluent. The VC response for the diluted sample is about double that obtained for the same amount of neat oil.

The lifetime of standards stored in sealed vials varied with the solvent and the number of times the septa had been pierced. Generally, a set of standards in the 0.04-0.2 ppm range were used for no more than 2-3 weeks. Table 1 gives VC retention time and response data obtained in all the solvent systems in which standards were prepared.

The reproducibility in preparing and analyzing VC standards was determined for heptane and 50% ethanol solutions. Four independent series of standards were prepared in each solvent. One series in each solvent was chosen as the reference against which the other 3 series were compared. In the earlier part of the work, each series of standards was checked for linearity and a calibration curve was used for some of the quantitation. The recoveries obtained are shown in Table 2 and actual chromatograms are shown in Figure 3. The standard deviation (S_d) for the percent recovery in heptane and 50% ethanol was 12.7 and 8.1, respectively. Most of the poorer values were observed for VC concentrations below the 0.05 ppm level which we consider the quantitation limit. Discarding these values, the standard deviations calculate as 6.3 and 8.3, respectively.

In order to test these procedures, a number of random samples were obtained and analyzed. Twelve bottles of mouthwash purchased in October

1974, 10 in PVC and 2 in glass, and one in PVC purchased in July 1971 were analyzed for VC content in October 1974. Table 3 gives the results of these analyses. The identity of the VC peak in the mouthwashes was confirmed by halogen specific microcoulometric GLC and by GC-MS. The theoretical 3/1 ratio of the 62/64 mass units of vinyl chloride was observed in the mass spectrometer. Three bottles of vegetable oil packaged in PVC bottles purchased in March 1974 and one bottle purchased in July 1971 were analyzed in January 1975. The 1974 oils were found to contain 0.65, 0.66, and 0.68 ppm VC and the 1971 oil 7.0 ppm VC.

Thirty samples of blood anticoagulant solutions packaged in PVC blood bags were analyzed for VC content. VC was not detected in any of the samples at a detection limit of 0.015 ppm. This detection limit was established by spiking an anticoagulant solution with VC until a peak about 5 times the noise level was observed.

Thirty highly plasticized PVC blood bags were analyzed for VC content by preparing a 5% polymer solution in either tetrahydrofuran or dimethyl acetamide. These solutions were injected into the gas chromatograph, using the appropriate column. Polymer additives such as pigments and plasticizers did not seem to interfere with the analyses. These were either collected in the disposable glass insert or remained on the GLC column under the conditions of analysis. Column C, used for tetrahydrofuran solutions, provided the cleanest chromatograms with GLC turn-around times of 40-45 min. Column D with its backflush program, used for dimethyl acetamide solutions, provided adequate chromatograms with shorter GLC turn-around

times of 15-20 min. No VC was found in any of the samples at a detection limit of about 0.3 ppm. To check the adequacy of these procedures in both solvents, recoveries were determined for 5% solutions of blood bags spiked with VC. These solution samples were provided as part of a round-robin study on VC methodology (J. J. Brezinski, 1974, Union Carbide Corp., South Charlston, WV). Table 4 shows that the recoveries averaged 98% in one solvent system and 92% in the other solvent system.

Other techniques, such as headspace analysis (7,8), are being explored in an effort to develop more simple and sensitive procedures.

In summary, GLC procedures have been presented which permit the quantitative determination of VC in PVC at the 1 ppm level and in solution at the 0.05 ppm level. In some samples where few interferences are present, quantitation can be accomplished at somewhat lower levels. The presence or absence of VC at still lower levels may often be observed. However, it must be recognized that identification cannot be accepted on the basis of a small GLC response alone, and additional confirmation such as GC-MS must be performed.

Acknowledgments

The authors wish to thank John A. Roach of the Division of Chemical Technology, Food and Drug Administration, Washington, DC, for his GC-MS confirmation of VC in commerical mouthwashes.

References

(1) Schaffner, R. M., & Lombardo, P. (1975) JAOAC 58,0000-0000

(2) Fed. Regis. (1973) 38, 12931

(3) Viola, P. L. (1970) Tenth Int. Cancer Conf., Houston, TX Session 56, p. 742 (Abstract 29)

(4) Viola, P. L., Bigotti, A., & Caputo, A. (1971) Cancer Res. 31, 516-522

(5) Maltoni, C., Lefemine, G. (1974) Environ. Res. 7, 387-405

(6) Code of Federal Regulations Title 21, §121.2514 and §121.2526

(7) Williams, D. T., & Miles, W. F. (1975) JAOAC 58, 272-275

(8) Wilks, R. A., Jr., & Gilbert, S. G. Mater. Res. Stand. 8, 29-32

FIG. 1 -- GC set-up used for backflushing dimethyl acetamide solvent.

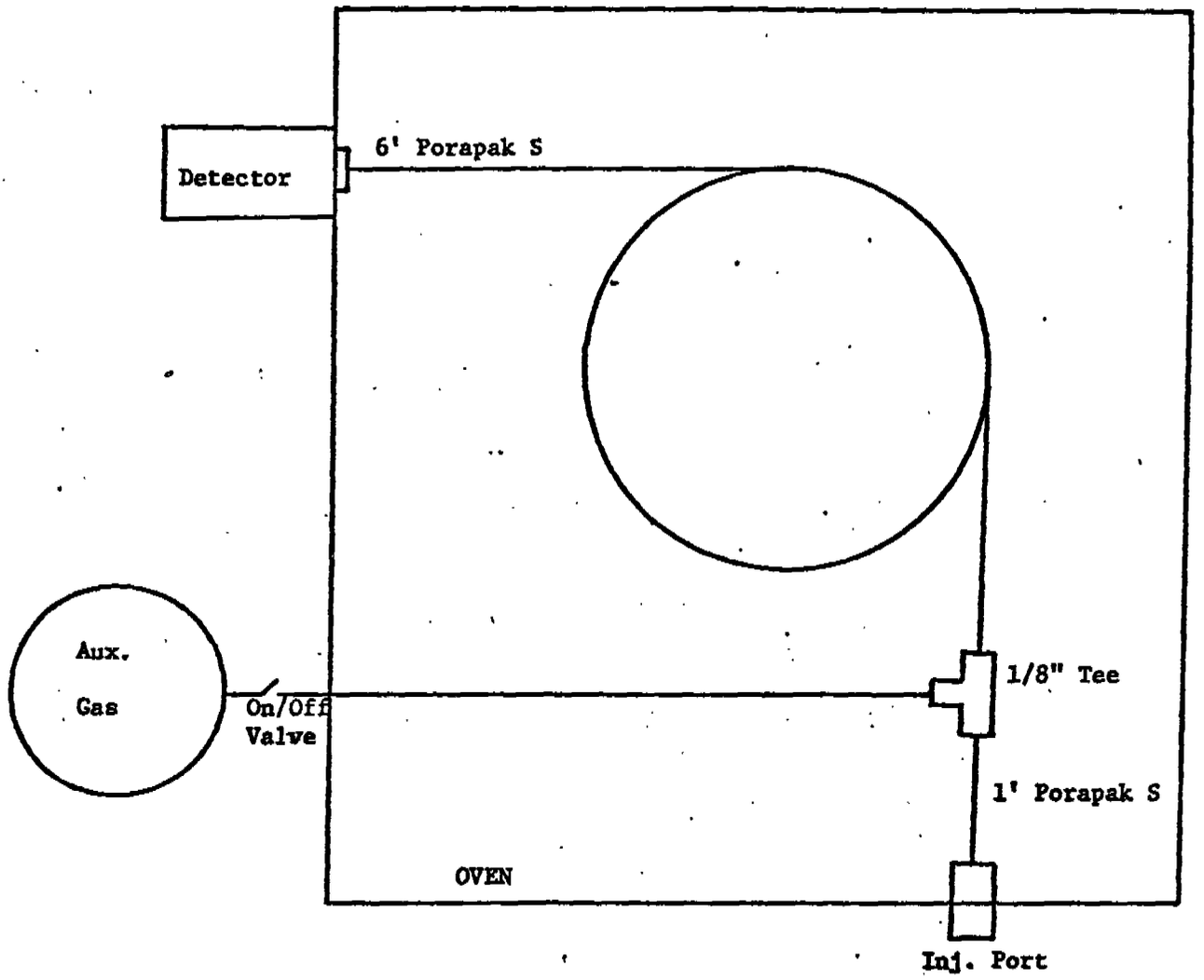

Detector
6' Porapak S
Aux.
Gas
On/Off
Valve
1/8" Tee
1' Porapak S
OVEN
Inj. Port

FIG. 2 -- Chromatograms showing the effect of diluent on recovery of VC from oil: A, 10 µl tetrahydrofuran diluent; B, 10 µl oil containing ca 0.6 ppm VC; C, 20 µl of 1+1 mixture of 0.6 ppm oil and tetrahydrofuran; electrometer; 8×10^{-12} amp. full scale.

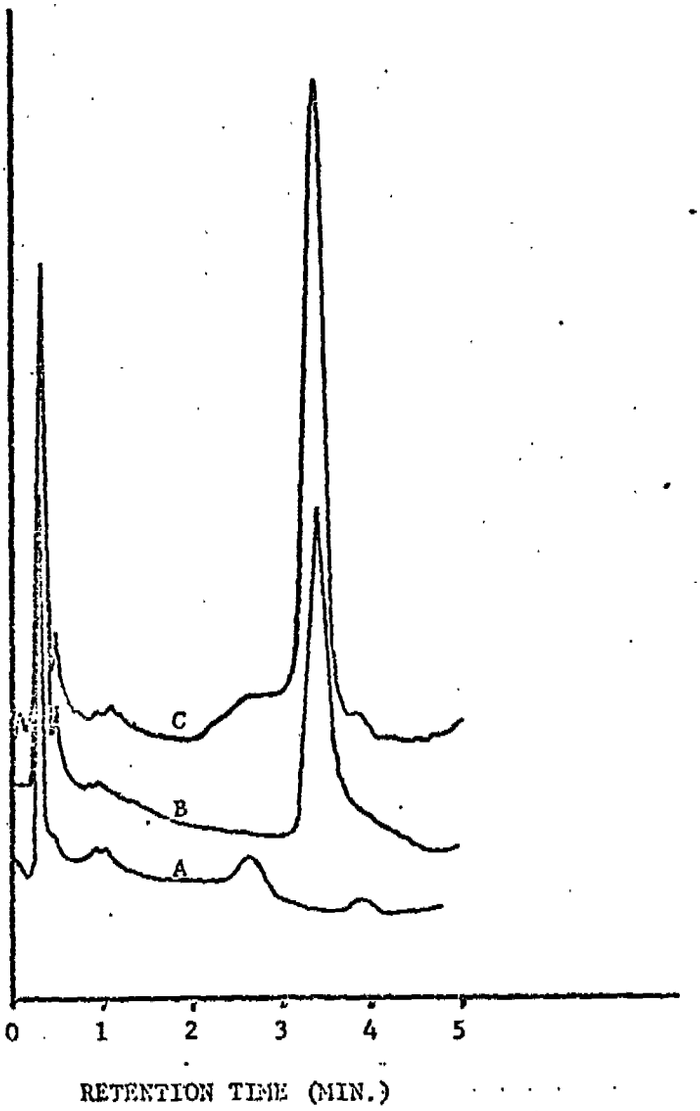
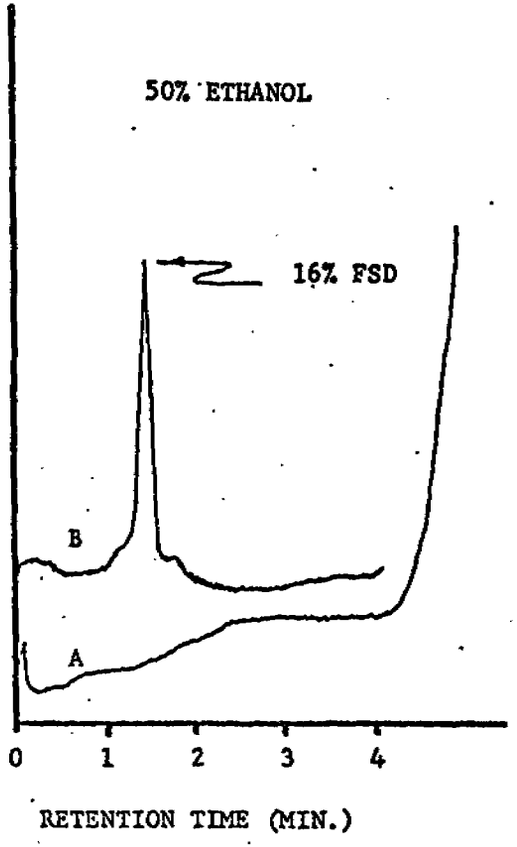

C
B
A
0
1
2
3
4
5
RETENTION TIME (MIN.)

FIG. 3 -- Gas chromatograms of 50% ethanol solutions and heptane solutions, 20 µl injections: A, blank; B, 1.6 ng VC; C, blank; D, 0.95 ng VC.


50% ETHANOL
16% FSD
B
A
0
1
2
3
4
RETENTION TIME (MIN.)

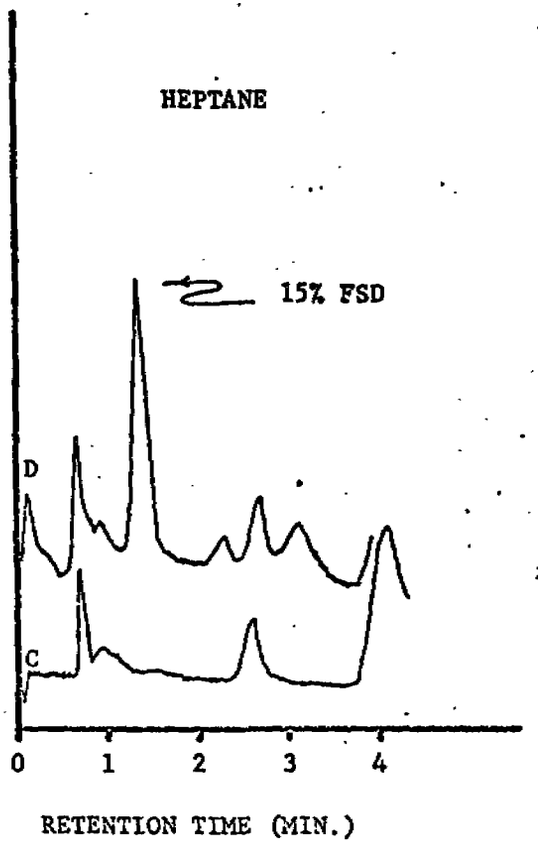

HEPTANE
15% FSD
D
C
0
1
2
3
4
RETENTION TIME (MIN.)

Table 1. VC response and retention time in various solvents[a]

Solvent	VC retention time, min.	VC-GLC response at 2 X 10^{-12} afs: Approx ng VC for 1/2 FSD	VC-GLC response at 2 X 10^{-12} afs: Approx % FSD for 20 µl inj. of 0.05 ppm[b]
50% Ethanol	1.4	5	9
3% Acetic acid	1.2	8	6
Heptane	1.4	3	11
Tetrahydrofuran and oil (1+1)	3.2	4	13
Tetrahydrofuran	3.2	4	11
Dimethyl acetamide	1.8	3	17

a Columns as indicated under preparation of sample and analysis.

b Weight/weight.

Afs = amp. full scale; FSD = full-scale deflection.

Table 2. Precision in preparing and analyzing VC solutions in heptane and 50% ethanol[a]

50% Ethanol				Heptane			
Series Number	Spiked, ppm[b]	Found[c], ppm	Rec., %	Series Number	Spiked, ppm[b]	Found[c], ppm	Rec., %
1	0.075	0.078	104	1	0.039	0.045	117[d]
	0.205	0.189	92		0.080	0.083	104
	0.112	0.097	87		0.123	0.126	102
					0.162	0.170	105
2	0.020	0.023	115[d]	2	0.037	0.054	146[d]
	0.029	0.033	114[d]		0.071	0.090	127
	0.035	0.036	103[d]		0.114	0.128	112
	0.045	0.047	104[d]		0.153	0.165	108
	0.105	0.106	101				
	0.128	0.136	106	3	0.050	0.055	110
	0.199	0.196	98		0.097	0.101	104
					0.142	0.147	104
3	0.173	0.179	103		0.186	0.200	108
	0.125	0.137	110				
	0.086	0.098	114				
	0.044	0.048	109[d]				
For all spiking levels		Av.	104				112
		Std. dev.	8.1				12.7
Spiking levels ≥ 0.05 ppm		Av.	102				108
		std. dev.	8.3				6.3

[a] Each series was quantitatively measured against a fourth set of standards.

[b] Weight/weight.

[c] Average of 2 injections.

[d] Below usual quantitation limit.

Table 3. VC content of several commercial mouthwashes

Sample	Size, oz	Alcohol declared, %	VC content, ppm
Glass Bottles			
Brand 1	12	18.5	ND[a]
Brand 2	3	25	ND
PVC Bottles			
Brand 3	7	14	ND
	14	14	0.87
	32	14	ND
Brand 4	12[b]	17	6.3
	16	17	7.9
Brand 5 a	16	5	0.29
b	16	15	0.24
c	16	25	trace[c]
Brand 6 a	32	5	0.37
b	32	18.5	0.77
c	32	25	0.36

[a] ND = none detected at detection limit of 0.02-0.03 ppm.

[b] Purchased in 1971.

[c] Less than 0.05 ppm, identity confirmed by GC-MS.

Table 4. VC recovery from spiked 5% solutions of PVC blood bags.

Tetrahydrofuran solutions			Dimethyl acetamide solutions		
VC added ppm[a]	VC found ppm[a]	Rec., %	VC added ppm[a]	VC found ppm[a]	Rec., %
0.42	0.38[b]	90	1.84	1.68	91
1.92	1.97	103	0	ND[c]	
1.12	1.16	104	0.72	0.58	81
0	ND[c]		1.00	0.88	88
0.78	0.74	95	0.36	0.38[b]	106
	Av.	98		Av.	92

[a] ppm = µg VC/g blood bag.

[b] Below usual quantitation limit.

[c] ND = none detected at detection limit estimated to be about 0.2 ppm PVC.