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GC/MS STUDIES ON ALCOHOL DERIVATIZATION PROCEDURES APPLIED TO LEWISITE 1 DUE TO THE INCREASED INSTABILITY OF SOME ETHERS

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2-Clorovinildicloroarsina (Levizita 1) este foarte dificil de identificat prin gaz cromatografie. Pentru obținerea de rezultate relevante este necesară procedura de derivatizare. Levizita 1 reacționează rapid la temperatura camerei cu alcoolii, până la echilibru rezultând cloreterii şi biseterii corespunzători. Reacțiile nu sunt cantitative, eterii rezultați din reacțiile cu alcoolii inferiori nefiind stabili în mediul de reacție. Produşii de reacție cu alcooli C5 – C8 au fost stabili, ei fiind identificați prin spectrometrie de masă.

2-Chlorovinylarsine dichloride (Lewisite 1) identification by gas chromatography is not a simple analysis, because it requires high concentration levels in sample (several mg/ml), very clean systems with new columns, a specially prepared injection port liner and on-column injection. Moreover, derivatization is highly demanded for reliable analysis. Lewisite 1 reacts quickly with alcohols at room temperature, producing the corresponding 2-Chlorovinylarsine chloridether and bisether to equilibrium. The reactions are not quantitative, due to the instability of ethers resulted from the reaction with lower alcohols.. The reaction products with C5 – C8 alcohols were stable and identified by mass spectrometry.

Keywords: Chemical Weapons Convention; Lewisite 1, derivatization; ethers

1. Introduction

The analysis of the chemical warfare agents and their degradation products is definitively an important task under the frame of Chemical Weapons Convention (CWC), administered by the Organization for the Prohibition of Chemical Weapons (OPCW), [1, 2]. The CWC is an international treaty that bans the use of chemical weapons and aims for elimination of the chemical weapons, forever and everywhere in the world.

Lewisite is one of the most important organic arsenic compounds known as chemical warfare agents (CWA). Even if the Lewisite has never been used as a CWA, this potential weapon is still considered as a threat, due to relative easiness

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in its production and also, because the Lewisite onsets rapidly its destructive effects [3]. Lewisite 1 (2-Chlorovinylarsine dichloride) was produced during World War I (WW I) and WW II as a CWA through Friedel Craft's alkylation's of arsenic (III) chloride with ethine. During production process, the by-products 2,2'-dichlorodivinylarsine chloride (Lewisite 2) and 2,2',2"-trichlorotrivinylarsine (Lewisite 3) are also produced. A mixture of these chlorovinylarsine compounds was usually filled into chemical munitions [4]. Nowadays old chemical munitions are still contaminating the soil and water. Sometimes the original CWA is found in hydrolyzed or oxidized forms. Small quantities of these products cannot be detected and accurately quantified by gas chromatographic (GC) analysis [5]. Yet, some substantial stockpiles of Lewisite are preserved in the United States, Russia, Japan and China [6]. It was estimated that the Japanese army abandoned 674,000 chemical bombs, including Yellow shells, at Haerbaling, China at the end of the WW II. Yellow shells were chemical weapons (CW's), consisting in 1:1 mixture of mustard gas and Lewisite. Beside, Russia produced these kind of CWA at the end of WW II [7]. These stockpiles are considered today as sources of potential hazard for public health.

Identification of Lewisite 1 and its hydrolysis products using gas chromatography is rather difficult, due to improper chromatographic properties of the chemical itself, like the unusual adsorption to the split-splitless injection liner or to the capillary columns, the thermal decomposition in injectors at the highest programmable temperatures (200 – 270°C) and the low volatility of the hydrolysis products [8-9]. Because of their high reactivity, the Lewisites analysis in underivatized forms has always lead to the rapid degradation of chromatographic column performances. There are several derivatization reagents known to be suitable for the Lewisites detection in different matrices.

Lewisite 1 reacts with thiols, forming 2-chlorovinylarsine dithioetherc by a substitution reaction:

$$Cl(CH{=}CH)AsCl_2 + 2\ RSH \dashrightarrow Cl(CH{=}CH)As(SR)_2 + 2\ HCl \qquad (1)$$

Lewisite 2 reacts with thiols by a similar reaction, forming 2,2'-dichlorodivinylarsine thioether:

$$[Cl(CH{=}CH)]_2AsCl + RSH \dashrightarrow [Cl(CH{=}CH)]_2AsSR + HCl \qquad (2)$$

The derivatives can be detected using GC-electron capture detector (GC/ECD) and identified using mass spectrometry (MS). Lewisite 3 does not react with thiols. It can be accurately determined using GC/ECD without derivatization.

Several thiols were used as derivatization reagents in the detection of the Lewisites from different matrices, such as: 3,4-dimercaptotoluene (DMT); 1-

propanthiol (PT); 1,2-ethanedithiol (EDT), and 1-butanthiol (BT) [10]. EDT and DMT derivatization reactions reach easily yields of 100% and 95%, respectively. In case of PT and BT derivatization reactions, four derivative compounds, which are not found in the existent GC/MS analytical database, are formed.

This paper suggested the derivatization reaction with alcohols as a potential alternative method for the identification of Lewisites from environmental matrices. Lewisite 1 reacts with alcohols resulting 2-chlorovinylarsine chloridether and 2-chlorovinylarsine chloridebisether [11]:

$$(ClCH{=}CH)AsCl_2 + ROH \dashrightarrow (ClCH{=}CH)As(OR)Cl + HCl + ROH$$

$$\dashrightarrow (ClCH{=}CH)As(OR)_2 + 2\,HCl \qquad (3)$$

Lewisite 2 reacts with alcohols resulting 2,2-Dichlorodivinylarsinether:

$$(ClCH{=}CH)_2AsCl + ROH \dashrightarrow (ClCH{=}CH)_2AsOR + HCl \qquad (4)$$

The gas chromatography-mass spectrometry (GC/MS) method, which uses the alcohol derivatization techniques, could be efficient for the qualitative analysis of Lewisites and their decomposition products. It seems the normal C1-C8 alcohols are the best candidates for this purpose [12]. Hence, the methods of detection and identification of Lewisites as derivative compounds in soil (sand) matrices were evaluated.

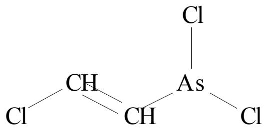
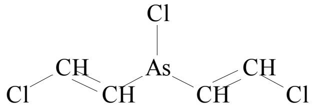
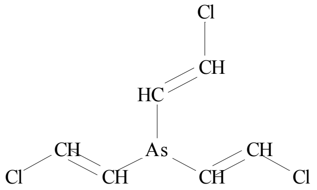
2. Experimental part

2.1. Chemicals

The Lewisites mixture used during these researches contains about 90% Lewisite 1, up to 10% Lewisite 2 and less than 1% Lewisite 3 (each molecular species is predominantly represented as trans-isomers) and originates from our own sources under the legal regulations. The purity of the Lewisite was measured by GC/MS analysis. A solution containing 37,8 µg/ml technical Lewisite in hexane (200 µl of Lewisite in 10 ml hexane) was analyzed by GC/MS according with recommended procedures [13]. Molecular components of the available Lewisite are presented in the Table 1.

Table 1

The Lewisite components

Chemical name	***CAS number***	***MW^a***	***Structure***
2-Chlorovinylarsine dichloride (Lewisite 1)	541-25-3	207.32	
2,2'-dichlorodivinylarsine chloride (Lewisite 2)	40334-69-8	233.36	
2,2',2"-trichlorotrivinylarsine (Lewisite 3)	40334-70-1	259.39	

^{a} Molecular weight (MW)

Other chemicals, including pesticide analysis-grade solvents, were provided by Merck (Germany).

2.2. Sample preparation

a) 50 g of soil (fine granulation sand, dried in an oven at a temperature about 200^0 C) was mixed with 200 µl of 37,8 µg/ml solution of Lewisite in hexane. The mixture was homogenized and stored at a refrigerator at 4^0 C.

b) 10 g of soil sample was extracted with hexane in 2-4 successive steps and the organic extract was analyzed by AAS. All extractions were carried out using ultrasonication (10–20 minutes). The presence of the As in samples was monitorized by the peak at the lamp wavelength of 193.7 nm.

c) The derivatization reactions of Lewisites mixture with different alcohols were performed at room temperature. In screw-capped bottles of 2 ml it was added 1 ml of the alcohol and 20 µl Lewisites sample and the resulted solutions were manually stirred for 30 seconds. The GC/MS analyses were performed immediately after mixing.

2.3. Chromatographic instruments and conditions

A Thermo Electron Corporation model GC-Focus MS-DSQII with an AI 300 autosampler was used for all GC/MS determinations. The analytical conditions used during measurements were: column: a fused-silica capillary column TR 5MS (30 m × 0.32 mm i.d., 0.25 μm film thickness), carrier gas: He (99.999%), flow 1 ml/minute, injection temperature: 250 °C (splitless), column temperature: 60°C (2 min), 60–300°C (linear gradient at 10°C/min). MS conditions: ion source temperature: 250°C, ionization: EI (70 eV), ionization current: 60 μA, mass scanning: 40–650 *m*/*z* and 1 scan/s acquisition was started 2 min after injection.

2.4. Total arsenium measurement

Total amount of arsenic in the hexane extracts of each sample was measured after acidic degradation with nitric acid - sulfuric acid mixture, using a Perkin Elmer AA Analyst 800 spectrometer with graphite oven for the electro thermal atomization, autosampler and fond correction with Zeeman effect. The arsenic from the samples was determined by the peak at the lamp wavelength of 193.7 nm.

3. Results and discussions

3.1. Lewisites analysis without derivatization

Mixture of the crude Lewisites samples was analyzed using GC/MS for the identification of the sample composition. Because the Lewisites hydrolyse easily, the hexane was used as aprotic solvent. The TIC chromatogram of the analyzed crude Lewisites sample is given in the Figure 1.

Main constituents of the above analyzed sample are Lewisite 1 (both cis and trans isomers, at 9.91 minutes retention time (t_r) and 9.37 minutes, respectively) and Lewisite 2 (predominantly cis-cis and trans-trans isomers at 12.67 minutes and 12.89 minutes, respectively). Lewisite 3 was identified as trace at 16.58 minutes. The GC analysis identified a series of other compounds, as follows: arsenium oxide (t_r of 15.98 minutes), a trimmer of Lewisite 1 (t_r of 23.43 minutes) and a dimer of Lewisite 2 (t_r of 23.33 minutes). These secondary compounds appear due to the decomposition and polymerization of the products in the split-splitless injector at temperatures up to 250°C. Two inconvenient events occur during serial analysis: the deposition of Lewisites on injection system, and the column and GC microserynge degradation in contact with corrosive Lewisite. In order to minimize these inconveniencies, washing of the GC column were systematically performed after each analysis. Nevertheless, the method's sensitivity for the Lewisites detection remains a poor one, and the linearity toward the smallest concentration levels is also questionable. All the aspects concerning the inappropriate events, as the adsorption of the chemicals in the injector part and subsequent reactions in the analytical system, cause significant problems for analysis at the trace concentration levels. For this reason, the method could be used only in the case of large Lewisites quantities in the investigated samples.

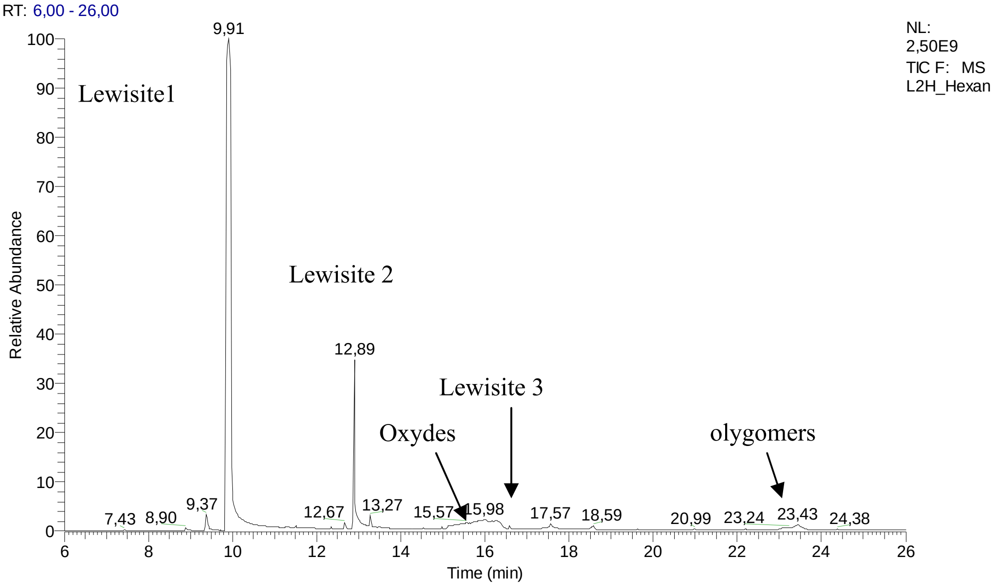


Fig. 1. Total ion chromatogram of Lewisites solution in hexane

3.2. GC/MS monitoring of the derivatization reaction with alcohols

Lewisite 1 reacts quickly at room temperature with alcohols, up to the reaction equilibrium state, which lead to the corresponding bisethers. The reaction mixtures which results after Lewisites derivatization were analyzed by GC/MS. In this study the derivatization agents were the following normal alcohols: methanol (MeOH), ethanol (EtOH), 1-propanol (1PrOH), 1-butanol (1BuOH), 1-pentanol (1PeOH), 1-hexanol (1HexOH), and 1-octanol (1OcOH). The methyl ether of Lewisite 1, chromatographically detected at 8.55 minutes, has proved to be a compound with a great instability. 3 hours after derivatization this compound is missing from the chromatogram. The ethyl, propyl and butyl ethers are also unstable. They quickly decompose themselves to polar compounds,

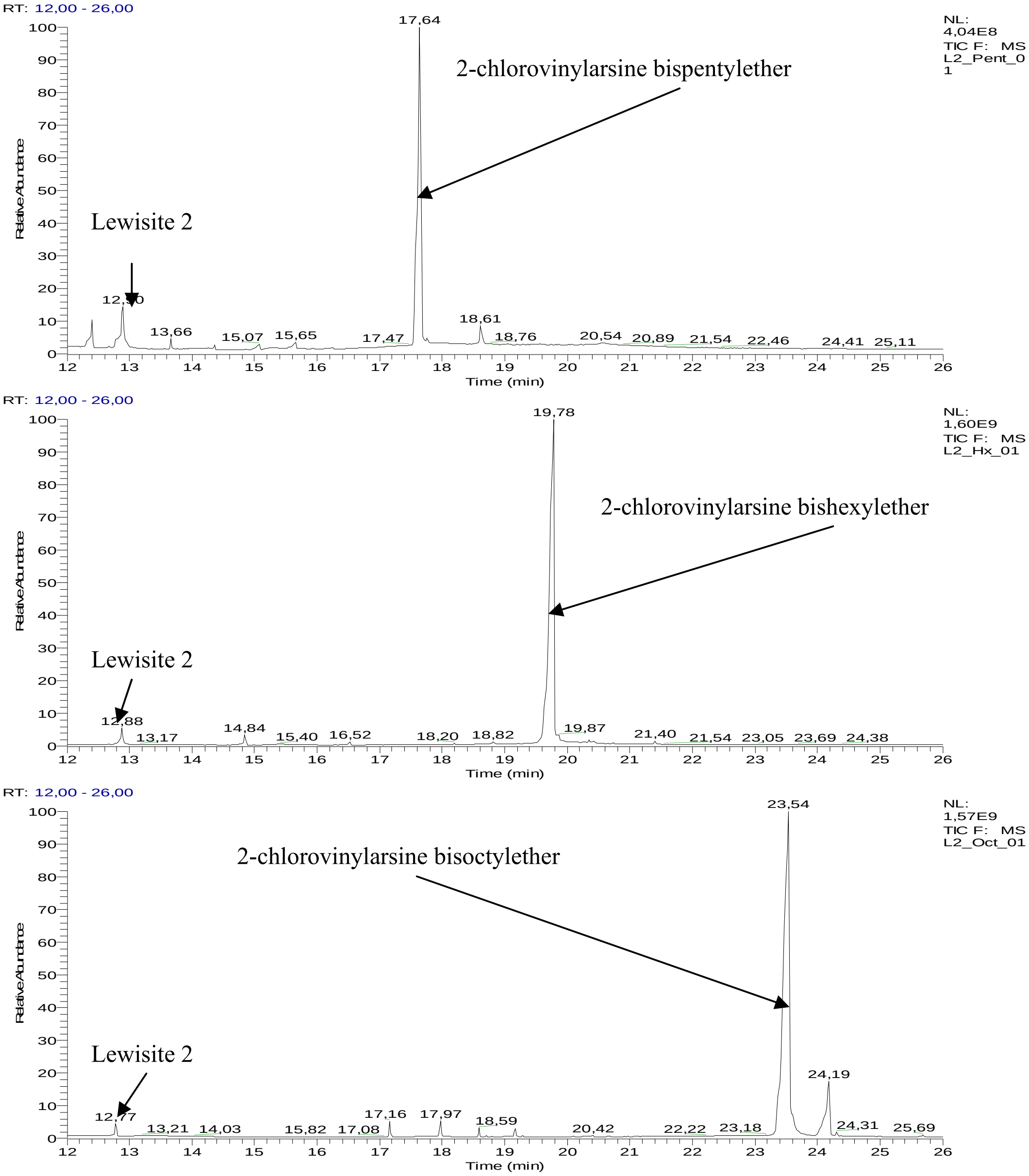


Fig. 2. Total ion chromatogram of Lewisites solution in hexane that supports derivatization reaction with alcohols (C5, C6, and C8, from top to bottom)

which could not be detected by particularly applied GC-MS method. Thus, it can be assumed that the reactions are not quantitative, and the resulted ethers from these derivatization reactions are not stable in their reaction mixtures. Also, the chromatograms of the Lewisites derivatives with the inferior alcohols (methanol,

ethanol, propanol and butanol) show that Lewisite 1 and Lewisite 2 derivative compounds have been completely decomposed and converted to undetectable products. On the contrary, the underivated and unconverted Lewisite 3, which was hardly detected in the initial solution, can be easily observed in the Levisites mixture sample derivatized with inferior alcohols. In the case of higher alcohols, the derivatives of the Lewisites are stable products and can be more easily observed. The pentyl, hexyl and octyl ethers of the Lewisite 1 were easily detected (Figure 2).

3.3. Formula identification of the detected compounds

Formula identification of the detected compounds by GC-MS was carried out by mass spectrometry using the NIST spectral database (in the case of methyl ether of Lewisite 1) and by spectral interpretation, for the rest of the detected compounds. EI (electron ionization) mass spectra of some derivative compounds with alcohols are shown in the Figure 3.

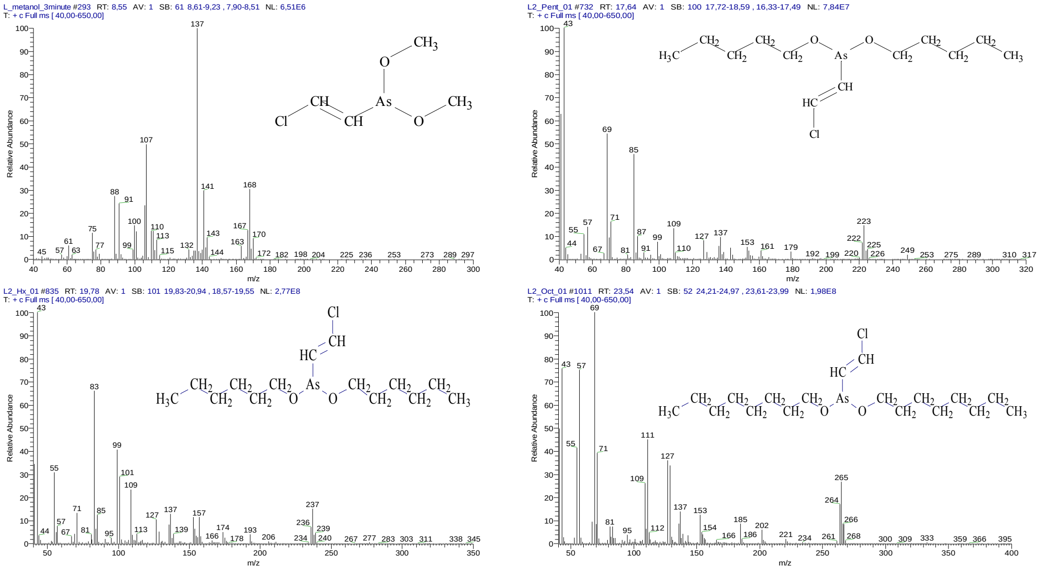


Fig.3. EI mass spectra of some derivative compounds with alcohols

The reaction product of Lewisite 1 and MeOH, 2-chlorovinylarsine bismethylether (M=198 g/mol) has a mass spectrum with the ionic fragments at m/z 167 due to the losses of a methoxy group $[M\text{-}OCH_3]^+$, a base peak at m/z 137 corresponding to the $[M\text{-}C_2H_2Cl]^+$ fragment and m/z 106/107 due to the losses of the 2-chlorovinyl and the methoxy groups.

In the case of pentyl derivative (M=310 g/mol), the ionic fragments observed in the mass spectrum were at m/z 223 due to the losses of a pentoxy group $[M\text{-}OC_5H_{11}]^+$, at m/z 249 corresponding to the ion $[M\text{-}C_2H_2Cl]^+$ and a peak $[As\,OC_5H_{11}]^+$ at m/z 162. The characteristic ionic fragment in the identification of the 2-chlorovinylarsine bishexylether (M=338 g/mol) was at m/z 236/237, due to the losses of the O-hexyl group, $[M\text{-}OC_6H_{13}]^+$. The 2-chlorovinylarsine bisoctylether (M=394 g/mol), the octyl derivative of the Lewisite 1, has the characteristic ionic fragment at m/z 264/265 that corresponds to $[M\text{-}OC_8H_{17}]^+$.

Table 2 summarizes the GC/MS analytical results obtained by derivatization reactions of the Lewisites with different alcohols.

Table 2

The derivatives of Lewisite 1, molecular formula, and retention time of the alcohol derivatives

Alcohol	**Sample code**	**t_R (min.)**	**Molecular formula**	**Chemical name**
MeOH	L_Metanol_3minute	8.55	$C_4H_8AsClO_2$	2-chlorovinylarsine bismethylether
EtOH	L2_Et_01	-	-	-
1PrOH	L2_1Pr_01	-	-	-
1BuOH	L2_Bu_01	-	-	-
1PentOH	L2_pent_01	17.64	$C_{12}H_{24}AsClO_2$	2-chlorovinylarsine bispentylether
1HexOH	L2_Hx_01	19.78	$C_{14}H_{28}AsClO_2$	2-chlorovinylarsine bishexylether
1OctOH	L2_Oct_01	23.54	$C_{18}H_{36}AsClO_2$	2-chlorovinylarsine bisoctylether

4. Conclusions

Lewisites, as unprocessed technical products, are hardly detected using GC/MS, due to their great reactivity and polarity. The derivatization of Lewisites with inferior alcohols lead to very unstable derivative products. The reactions of Lewisites with hexanol and octanol are the most sensitive reactions, leading to stable and ready analyzable ethers. Consequently, the alcohol derivatization of Lewisites with C5-C8 1-alcohols could be an efficient method for the detection and identification of the As-containing compounds from different environmental matrices.

The method can be successfully used as an alternative to the thiol derivatization method.

The AAS technique is of great interest in monitoring the As-containing compounds. It can be used when monitoring the Lewisites from environmental samples. The presence of the As in the sample could be an effective indication for the existence of the Lewisites in the investigated matrices.

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