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Characterization of leachate from Henchir El Yahoudia closed landfill[#]

Mitsuo Yoshida, Ahmed Sothom*, Nebil Souissi**, Latifa Bousselmi*, Naceur Jedidi*, Ahmed Ghrabi* and Mounir Ferchichi****

** Laboratoire Eau & Environnement, Institut National de Recherche Scientifique et Technique, Tunisie*
*** Laboratoire de Chimie Analytiques et Environnement, Département de Chimie, Faculté des Sciences de Tunis,1060 Tunis, Tunisie.*
**** Agence National de Protection de l'Environnement, Tunisie*

Abstract
The leachates collected from uncontrolled open-dumping type landfill called the Henchir El Yahoudia, were studied on the basis of field observation and laboratory analyses. The leachate body forms a leachate-mount and is migrating into salt lake water of Sebkhat Sejoumi. The chemical property of leachate rather shows it possesses a nature of non-matured landfill. The leachate is contaminated by heavy metals, especially by Pb, Ni, Cd, and Cr, of which concentration exceeds the regulation values. Gas chromatography proved that the leachate is contaminated with various organic compounds.
Keywords
Landfill, Leachate, Pollution, Heavy metals, Organic compounds, Gas chromatography

I. Introduction

Water passing through solid waste landfill, termed leachate, was previously not a matter of concern. However it is now widely known that leachate from landfills may be one of the most important source of groundwater pollution. Indeed, leachate contains larger pollutant loads than raw sewage or many industrial wastes (Qasim and Chiang, 1994).

Municipal solid waste landfills (MSWLFs) generate significant amounts of a highly contaminated leachate. Some leachate directly originates from the disposed waste itself, moisture, decomposition of garbage, and other putrefactive material. But much of it may come from runoff or surface water that first infiltrates the landfill and percolates downward through the waste material. Direct contact of the water with the waste results in severe contamination of this water. If the leachate migrates into groundwater or seeps out of the landfill, significant environmental pollution can occur. In general, as more water infiltrates and flows through the landfill, more pollutants are leached. MSWLF leachate quality is highly variable, but it generally contains more pollutants than raw sewage or many industrial wastes (Nathanson, 2000).

The leachate depends on the type and depth of waste, age of the landfill, rate of water infiltration, landfill operation, and other factors. In some cases, when sewage sludge or incinerator ash is co-disposed in an MSWLF, the generation and quality of leachate may be significantly affected (Johnson et al., 1999). Hazardous wastes inadvertently disposed can lead to more serious environmental threats from a wide variety of toxic substances carried into the leachate.

In order to prevent such environmental pollution, solid waste landfills must be properly controlled and well managed. The domestic waste production in Tunisia is equal to 1,500,000 T in 1983 corresponding to about 500 g/person/day. It is mainly composed of

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organic matters (68 %) and plastic (11%). Until 1999, the majority of the domestic waste from Tunis City area had been discharged on the biggest and oldest landfill called 'Henchir El Yahoudia' operated since 1969. This landfill is closed in 1999 and a big program of characterization for rehabilitation as a national park is launched by the national agency of environment protection (ANPE). Effective pollution control requires an understanding of the quantity and quality of landfill leachate. This study is a contribution to the characterization of organic and heavy metal contamination of the landfill leachate at Henchir El Yahoudia.

II. Landfill Leachate

Many parameters are used to measure the quality of leachate, including BOD (max. 20,000mg/L has been reported), COD, redox potential, pH, heavy metals, chemical components, and others (Table 1). In this paper the authors overview the nature of landfill leachate and preliminarily report some results of landfill leachate generated in the closed landfill in Tunisia.

Table 1: Leachate parameters (modified from Tchobanoglous et al., 1993)

Physical	***Organic constituents***	***Inorganic constituents***	***Biological***
pH Redox potential EC (electric conductivity) Color Turbidity SS (suspended solids) TDS (total dissolved solids) VSS (volatile suspended solids) VDS (volatile dissolved solids) Temperature Odor	COD (chemical oxygen demand) TOC (total organic carbon) Phenols Volatile acids Tannins, lignins Organic-N Ether soluble MBAS (methylene blue active substances) Chlorinated hydrocarbons Other organic chemicals	Chloride Sulfate Phosphate Nitrate-N Nitrite-N Ammonia-N Sodium Potassium Calcium Magnesium Hardness Heavy metals (Pb, Cu, Ni, Cr, Zn, Cd, Fe, Mn, Hg, Ba, Ag) Arsenic Cyanide Fluoride Selenium	BOD (biological oxygen demand) Coliform bacteria (total, fecal, fecal streptococci) Standard plate count

The decomposition, stabilization, and extraction of pollutants from a landfill depend upon several factors, composition of the wastes, degree of compaction, presence of inhibiting materials, amount of moisture present, water input and output, rate of water movement, hydrological property, and temperature. The quality of leachate is principally the result of physical, chemical, and biological processes, and additional variables are water movement, nutrients, and the presence of toxic or inhibitory elements and compounds.

The gradual decomposition process in MSWLF has been divided into several stages (Qasim and Chiang, 1994; McBean et al., 1995; Oweis and Khera, 1998; McBean and Rovers, 1999). In it initial stage (= "Phase I" by McBean and Rovers, 1999), an aerobic decomposition predominates. An example of the aerobic decomposition of a general organic constituent ($CH_aO_bN_c$) is (McBean et al.,1995):

$$CH_aO_bN_c + 1/4(4a\text{-}2b\text{-}3c)O_2 \rightarrow CO_2 + 1/2(a\text{-}3c)H_2O + cNH_3$$

This stage is normally very short (less than a month; McBean and Rovers, 1999) because of the limited amount of oxygen in the landfill and high oxygen demand of the MSW. Aerobic decomposition process is characteristically rapid, relative to subsequent anaerobic decomposition. During this stage a large amount of heat is produced that rises the landfill temperature above the ambient temperature. Peak temperature of 160F (71C) can occur a few day to a few weeks after the application of cover (Oweis and Khera, 1998). Leachate is not much produced during this stage, and it would be expected to dissolve highly soluble salts, such as NaCl and others (Qasim and Chiang, 1994).

As oxygen is depleted, decomposition by anaerobic micro-organisms generally predominant. Generalized decomposition process is expressed by:

$$C_aH_bO_cN_d \rightarrow n(C_wH_xO_yN_z) + mCH_4 + sCO_2 + rH_2O + (d\text{-}nz)NH_3$$

where r = (c-ny-2s) and s = (a-nw-m). In this stage (= "Phase II" by McBean and Rovers, 1999), large amount of fatty acids such as acetic acid (CH_3COOH), and carbon dioxide are produced. These acids reduce the pH to between 4 and 5. The low pH condition contributes to mobilize inorganic materials such as heavy metals. Leachates produced during this stage are generally characterized by high BOD values (commonly greater than 10,000 mg/L) and high ratios of BOD to COD (commonly greater than 0.7), which indicates that high proportions of soluble organic materials are readily biodegradable. The anaerobic decomposition is much activated when the population of methane bacteria builds up. Volatile acids and other organic matters are, therefore, converted to methane and carbon dioxides. Thus the concentration of volatile acids is reduced to lower levels, and gas composition becomes a mixture of carbon dioxide and methane. The pH starts to rise which encourages methane production (= "Phase III-IV" by McBean and Rovers, 1999). At near neutral pH, conductivity falls because of fewer inorganic materials are solubilized. The redox potential should be lower than that during the early stages of anaerobic decomposition, reflecting the augmentation of methane production and increase in pH (Qasim and Chiang, 1994). This stage lasts for years, or even decades. Organic matter in landfills ranges from small, volatile acids with low molecular weight to large, refractory fluvic- and humic-like compounds of intermediate and high molecular weights. The biodegradability of organic matter in leachate is generally inversely proportional to the molecular weight of the various components of the organic matter; i.e. lower molecular weights indicate a higher degree of biodegradability (McBean and Rovers, 1999). In the followed stage, the rate of bacterial decomposition may decrease due to substrata depletion (= "Stage V" by McBean and Rovers, 1999). Slowly, portions of landfill may reestablish aerobic conditions as oxygenated water continue to percolate into the landfill (Qasim and Chiang, 1994).

The results is that leachate is typically composed of hundreds or organic and inorganic contaminants categorized into following four groups (McBean and Rovers, 1999):

1) Anthropogenic organic compounds directly originate from household or industrial chemicals.
2) Organic matters that primarily consists of degradation products of solid organic matter in the waste material, that typically have concentrations lower than 1 mg/L.
3) Inorganic species including calcium, magnesium, sodium potasium, ammonia, iron, manganese, chloride, sulfate, and bicarbonate.
4) Heavy metals including cadmium, chromium, copper, lead, nickel, and zinc.

The leachate from a single location within a landfill is highly variable over time. In addition, the spatial heterogeneity on leachate quality can be observed; e.g. some locations within a landfill are at one phase of decomposition, while others is at different stages of decomposition.

III. Field Observation, Sampling and Analysis

III-1. Description of the Landfill

The Henchir El Yahoudia landfill is located at the southeast of Tunis. It is bordered in the south-east by Sebkhat Sejoumi (salt lake) and in the west by El Mourouj City, of which area occupies around 80ha (Figure 1). During 1960s and 70s, the landfill was operated as an open-dumping one without any control. Since 1982 the wastes discharged had been more or less controlled, managed and covered by soil to limit nuisances, which was a kind of 'sanitary type' landfill operation.

The landfill deposits consist of black-colored sludge as the matrix part, fragments of plastic bag, wooden pieces, metal pieces, concrete blocks and other domestic items. It is noticeable that hospital wastes, batteries, and industrial metallic wastes are contained in the deposits, which are potentially hazardous.

The basement of the landfill deposits is composed of Cretaceous-Paleogene limestones and calcareous claystones, Neogene-Quaternary unconsolidated clays and silts, which have been expected as impermeable layers (or say 'natural liner') for the pollution by the landfill leachates.

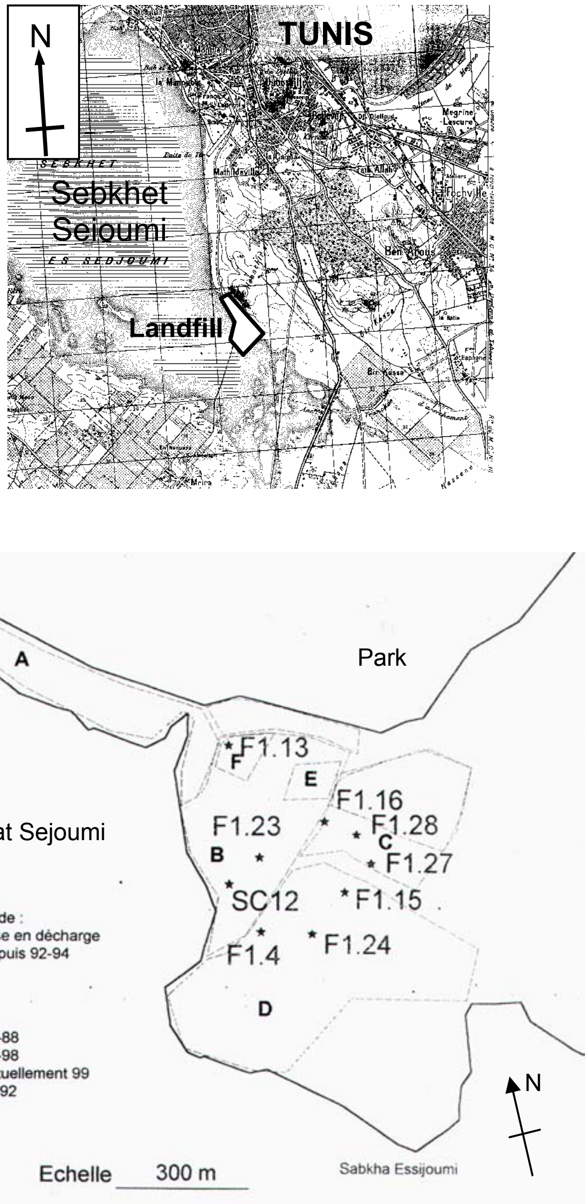

Figure 1 : Locality map for Henchir El Yahoudia landfill and sampling sites.

III-2. Sampling Sites

Leachate sampling was performed at a total of nine sites shown in Figure 1. Owing to a lack of detailed record of landfill operation, it is generally difficult to identify clearly the area operated as the sanitary type landfill from open-dumping landfill parts. However, according to the result of excavation survey conducted by ANPE (April 2000), present sampling sites are probably located in the zone of such sanitary type landfill. Leachate samples were collected from VC-cased piezometer-holes penetrated into the landfill deposits after the excavation survey, using a hand-pumping tool. The depth of the holes is around 5 to 7 meters which reach a basal part of the landfill at each site. Table 1 summarizes the ID of sampled holes, its location, and the depth of leachate level (water table) observed in April 2000 (wet season). In addition to the leachate samples mentioned above, one lake water sample was also collected from the near-shore water body of Sebkhat Sejoumi nearby the L9(SC12) site that might be contaminated by a spill of the landfill leachate. On the basis of topographic feature of landfill and the spatial variation of leachate level, a leachate-mount could be recognized within the landfill, and the leachate is migrating towards the Sebkhat (lake) side. Actually a number of leachate spills could be observed at the edge of landfill exposed along the lake shoreline where the surface of leachate-mount intersects with the topographic surface.

III-3. Parameters of Analysis

Leachate analysis was undertaken at the Laboratoire Eau & Environnement, INRST to obtain the following fourteen parameters:

- Physical parameters : pH, EC, S.S.
- Water pollution parameters : COD, TOC, TIC, BOD5, N, Cl-
- Heavy metals contamination : Pb, Zn, Cu, Ni, Cd, Cr by Atomic Adsorption Spectrometry (AAS)
- Organic compounds analysis by GC-FID and GC-MS

Table 1 : Localization of samples and corresponding levels of leaches production

Sampling Site (ID of the hole)	Localisation	depth of leachate level (m)
L1 (F1.4)	South-east	1.75
L2 (F1.13)	North-east	
L3 (F1.15)	West	
L4 (F1.16)	West	0.60
L5 (F1.23)	East	1.70
L6 (F1.24)	South-west	1.85
L7 (F1.27)	West	0.80
L8 (F1.28)	West	0.35
L9 (SC12)	East	1.45

IV. Results

IV-1. Physical Parameters

The pH of leachate varies from slightly acid (L4) to neutral (Table 2). It is generally known that the more pH is lower (<6.5) the more leachate is younger (ADEME,1996). The electric conductivity (EC) of leachates range from 10 to 50 mS/cm while that of the water sample from Sebkhat (salt lake) shows much higher value (107.9 mS/cm). A positive correlation can be recognized between pH value and EC in leachate samples.

Table 2 : Physical characterization of leachate samples

Sampling Site (ID of the hole)	pH	EC (mS/cm)	S.S. (g/L)
L1 (F1.4)	7.69	44.5	4.390
L2 (F1.13)	7.71	44.7	12.850
L3 (F1.15)	7.64	32.5	11.050
L4 (F1.16)	6.67	18.6	57.788
L5 (F1.23)	7.33	27.5	1.208
L6 (F1.24)	7.20	29.5	8.591
L7 (F1.27)	7.25	32.0	16.880
L8 (F1.28)	7.23	31.8	3.470
L9 (SC12)	7.65	32.3	5.160
Sebkhat (lake water)	7.26	107.9	5.156

The total suspended solids (S.S.) significantly varies from 1 to 60 g/L showing higher values in comparing with ordinal landfill leachates that mark less than 2 g/L (Qasim and Chiang,1994).

IV-2. Water Pollution Parameters

The results of leachate analysis are summarized in Table 3. The 5-day biochemical oxygen demand (BOD5) of leachate samples ranges from 1 to 7 g/L, the chemical oxygen demand does from 8 to 29 g/L, the total organic carbon (TOC) does from 0.9 to 2.1 g/L; those are typical values of leachate from a newly constructed sanitary landfill (Qasim and Chiang, 1994).

Table 3 : Water pollution parameters of leachate samples and Sebkhat water

Sample ID	$BOD_5(gO_2/L)$	$COD(gO_2/L)$	BOD_5/COD	TOC*(g/L)	TIC*(g/L)	Cl^-(g/L)
L1 (F1.4)	2	9.84	0.203	1.977	2.411	45.0
L2 (F1.13)	3	23.44	0.128	1.652	1.407	48.0
L3 (F1.15)	7	29.68	0.236	1.416	1.581	72.5
L4 (F1.16)	4	8.64	0.463	0.199	0.162	38.0
L5 (F1.23)	2	9.68	0.206	1.797	1.222	25.0
L6 (F1.24)	4	10.00	0.400	2.029	0.827	33.5
L7 (F1.27)	6	16.96	0.354	2.143	1.132	41.5
L8 (F1.28)	4	12.16	0.329	2.083	1.077	37.5
L9 (SC12)	1	8.15	0.123	0.921	1.868	31.5
Sebkhat (lake water)	0.5	3.60		0.171	0.058	265.0

* analyzed by filtered sample.

A young (recently generated) leachate is normally characterized by a high biodegradability (BOD5/COD > 0.3) which is the case of L4, L6, L7, and L8. A BOD5/COD close to 0.2 corresponds to the intermediate leachate: L1, L2, L3, L5, and L9 (ADEME,1996). Chloride concentration is relatively higher than common leachate values (5 g/L; ADEME, 1996), which may be related with the presence of salt lake Sebkhat Sejoumi.

IV-3. Heavy Metals

The leachate samples were significantly contaminated by heavy metals (Table 4). The concentration of four heavy metals, Pb, Ni, Cd, and Cr, marks above the regulation level in Tunisia. One of the origins for the Pb-Ni-Cd contamination could be attributed to discarded batteries within landfill wastes, which is often reported from other landfill sites. According to European experience on heavy metals contamination in leachate from controlled landfill, the Zn concentration generally shows between 10 and 30 mg/L, and the total of Ni, Cu, Cr, Pb, As, and Hg concentrations is less than 10 mg/L (ADEME, 1996). Compared to these generalized data the leachate from Henchir El Yahoudia landfill are not highly concentrated in heavy metals, but compared to Tunisian law for wastewater discharge in natural system the concentrations exceed to the regulation values.

Table 4: Concentration on heavy metals in leachate and lake water samples (unit: mg/L).

Sample ID	Pb	Zn	Cu	Ni	Cd	Cr
L1 (F1.4)	0.17	0.80	0.08	0.45	ND*	1.68
L2 (F1.13)	0.02	0.24	0.07	0.28	0.03	1.80
L3 (F1.15)	0.16	0.36	0.09	0.58	0.01	1.12
L4 (F1.16)	0.14	0.03	0.06	0.32	0.02	0.19
L5 (F1.23)	0.01	0.66	0.05	0.13	0.01	0.30
L6 (F1.24)	0.17	0.30	0.09	0.41	ND*	0.14
L7 (F1.27)	0.18	0.30	0.06	0.67	0.03	1.60
L8 (F1.28)	0.11	0.30	0.07	0.27	ND*	0.41
L9 (SC12)	0.06	0.25	0.04	0.35	ND*	0.96
Sebkhat (lake water)	0.87	0.05	0.14	1.34	0.19	0.73
Regulation**	0.1	5	0.5	0.2	0.005	0.5

* ND: below the detection limit
** The values are refered from the regulation of concentration in effluents to public domain water defined by the 'Norme Tunisienne PROTECTION DE L'ENVIRONNEMENT – REJECTS D'EFFLUENTS DANS LE MILIEU HYDRIQUE, N.T.106.002 (1989)'. The value for Cr here (0.5 mg/L) was adopted from the regulation value for trivalent chromium, while it is 0.01 mg/L for hexavalent chromium.

The heavy metals is also recognized in the lake water sample, where the concentration is distinctively higher than that of the landfill leachates, in the cases of Pb, Ni, and Cd. However, no reliable information on usual concentration of heavy metals in the Sebkhat has been published.

IV-4. Gas Chromatography

Gas chromatograph analysis was performed using a FID capillary system under the following condition:

System: SHIMADZU GC-17A ver.3
Column: DB-1 (J&W) non-polar
Carrier gas: Helium 100 Pa, 30.3 cm/sec, 1.29 mL/min
Temperature: 60 C (1min), 10 C/min (19 min), 250 C (1 min)
Sample injection: non-diluted raw material, split ratio 10

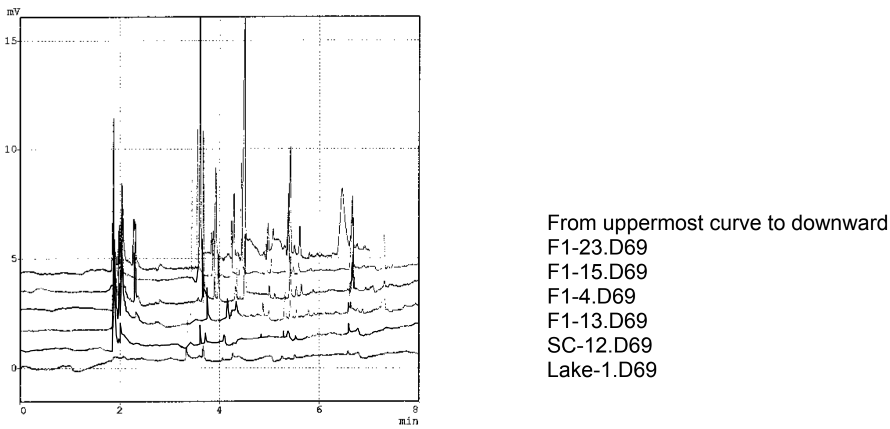

Figure 2: Gas chromatograms for the landfill leachate samples and Sebkhet Sejoumi lake water (Yoshida et al., 2000).

The chromatograms of leachate samples are shown in Figure 2. It is clear that similar peak pattern is appeared in these leachate samples. The peak of 1.86 minute retention time indicates the presence of dissolved methane in the leachate. The sample collected from the Sebkhet Sejoumi lake water shows partly corresponding chromatogram peak pattern with lower intensities. In particular, chromatograms of the leachate samples collected from near-shore sites (F1.4, SC12, and F1.13) give the same peaks observed in the lake water sample. It suggests that some of trace organic compounds in the lake water were derived from landfill leachate.

The landfill leachate sample collected from SC12 site was also analyzed by HP6890 GC-MS, where the sample was diluted by ethanol. The chromatogram is shown in Figure 3.

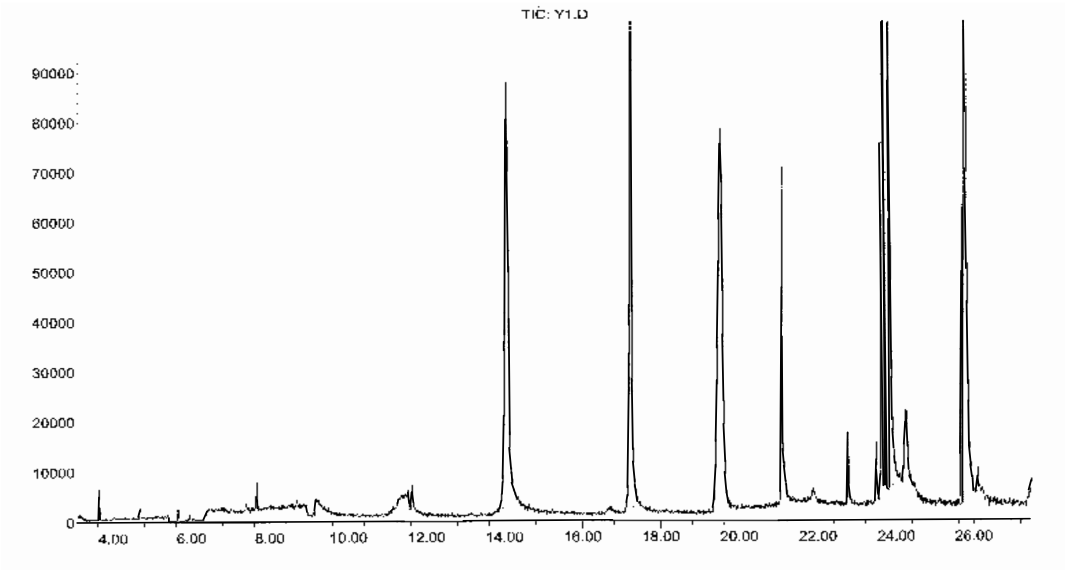

Figure 3: GC-MS Chromatogram for the SC12 leachate sample (Yoshida et al., 2000).

The result of GC-MS analysis indicates a possible presence of the following organic compounds in the leachate (identified by Nebil Souissi in Yoshida et al.(2000):

Dodecamethy-cyclohexasiloxane	$C_{12}H_{36}O_6Si_6$
Tetradecamethyl-cycloheptasiloxane	$C_{14}H_{42}O_7Si_7$
Methyl palmitate	$C_{17}H_{34}O_2$
Morphin silyliert	$C_{23}H_{35}NO_3Si_2$
Methyl cis-9, cis-12-octadecadienoate	$C_{19}H_{34}O_2$
Cis-13-octadecenoic methyl ester	$C_{19}H_{36}O_2$
Methyl n-butanoate	$C_5H_{10}O_2$
Methyl n-pentanoate	$C_6H_{12}O_2$
Methyl caproate	$C_7H_{14}O_2$
1,3,5,7-Tetraethyl-1-ethylbutoxysiloxycyclotetrasiloxane	$C_{14}H_{38}O_6Si_5$
3,6-dioxa-2,4,5,7-tetrasilaoctane	$C_{10}H_{30}O_2Si_4$
Tetradecamethyl-heptasiloxane	$C_{14}H_{44}O_6Si_7$
Methyl hexadec-11-enoate	$C_{17}H_{32}O_2$
Bistrimethylsilyl n-acethyl eicosasphinga-4,11-dienine	$C_{28}H_{57}NO_3Si_2$

V. Concluding Remarks

On the basis of present analytical results, the leachate from the Henchir El Yahoudia landfill shows a complex nature, which is probably caused by recently-closed site. The leachate is contaminated by heavy metals, especially Pb, Ni, Cd, and Cr, of which concentrations exceed from the Tunisian regulation. Various kind of organic compounds also contaminate in the landfill leachate. Proper counter-measure for leachate migration into lake basin and leachate treatment is recommended to prevent further environmental pollution in the area.

Reference

ADEME (1996) *Guide méthodologique pour la remise en état des décharges d'ordures ménagerès et assimilés*. Agence de l'Environnement et de la Maitrise de l'Energie, France.

GERSTEL, 1998, *Sample introduction techniques for capillary gas chromatography*. GERSTEL Inc., Baltimore.

Hanashima, M., 1989(ed.), *Guidline for Final Solid Waste Disposal Landfill*. All Japan Municipal Waste Management Association (Zenkoku Toshi Seisou Kaigi), 320p.(in Japanese)

Heron, G., Bjerg, P.L., Graveson, P., Ludvigsen, L. and Christensen, T.H., 1998, Geology and sediment geochemistry of a landfill leachate contaminated aquifer. *J.Contaminant Hydrology*, 29, 301-317.

Johnson, C.A., Kaeppeli, M., Brandenberger, S., Ulrich, A. and Baumann, W., 1999, Hydrological and geochemical factors affecting leachate composition in municipal solid waste incinerator bottom ash. Part II. The geochemistry of leachate from landfill Lostorf, Switzerland. *J. Contaminant Hydrology*, 40, 239-259.

Krupa, S.V. and Legge, A.H., 2000, Passive sampling of ambient, gaseous air pollutants: an assessment from an ecological perspective. *Env. Pollution*, 107, 31-45.

Ludvigsen, L., Albrechtsen, H.-J., Heron, G., Bjerg, P.L. and Christensen, T.H., 1998, Anaerobic microbial redox processes in a landfill leachate contaminated aquifer (Grindsted, Denmark). *J.Contaminant Hydrology*, 33, 273-291.

McBean, E.A., Rovers, F.A. and Farquhar, G.J., 1995, *Solid Waste Landfill Engineering and Design*. Prentice Hall PTR, Englewood Cliffs, New Jersey, 521p.

McBean, E.A. and Rovers, F., 1999, Landfill leachate characteristics as inputs fpr the design of wetlands used as treatment systems. *In:* Mulamoottil, G., McBean E.A., Rover, F. (eds.), *Constructed Wetlands for the Treatment of Landfill Leachates*, 1-16, Lewis Publ., Roca Raton, 281p.

McNair, H.M. and Miller, J.M., 1997, *Basic Gas Chromatography (Techniques in Analytical Chemistry)*. A Wiley-International Publication, John Wiley & Sons, Inc., New York, 200p.

Nathanson, J.A., 2000, *Basic Environmental Technology: Water Supply, Waste Management and Pollution Control, 3rd edition*. Prentice Hall, Upside River, New Jersey, 513p.

Oweis, I.S. and Khera, R.P., 1998, *Geotechnology of Waste Management, 2nd Edition*. PWS Publishing Co., Boston, 472p.

Quasim, S.R. and Chiang W.(1994) *Sanitary Landfill Leachate: Generation, Control and Treatment*. Technomic Publ., Lancaster, 339p.

SHIMADZU, 1998, *Operation Manual GC-17A ver.3*. Shimadzu Corporation, Kyoto.

Sothom, A., Yoshida, M., Bousselmi, L., Jedidi, N., Ghrabi, A. and Ferchichi, M., 2000, Characterization of leachate of Henchir El Yahoudia landfill. *Proc.Intern.Conf. Wastewater Treatment and Reuse Adapted to Mediterranean Area (Tunis)*, Laboratoire Eau & Environnement, INRST, 17-20.

Tchobanoglous, G., Theisen, H. and Vigil, S., 1993, *Integrated Solid Waste Management - Engineering Principles and Management Issues.* Irwin/McGraw-Hill, Boston, 978p.

Wu, G. and Li, L.Y., 1998, Modeling of heavy metal migration in sand/bentonite and the leachate pH effect. *J.Contaminant Hydrology*, 33, 313-336.

Yoshida, M., Souissi, N. and Sothom A., (2000) Landfill Leachate: Its Nature and Trace Organic Compounds Separated by Gas Chromatography. *Water, Waste, and Environment Research*, 1 (2), 129-142.