Development of a screening method for the determination of xenobiotic organic pollutants in municipal landfill leachate using solvent extraction and comprehensive GCxGC-qMS analysis

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Abstract: In the present study, we propose a method for the evaluation of different classes of xenobiotic organic compounds enclosed in the municipal landfill leachate using comprehensive two-dimensional gas chromatography coupled with quadrupole mass spectrometry (GCxGC-qMS). Here we show that, due to high peak capacity of comprehensive two-dimensional gas chromatography, in a single run it is possible to separate compounds with different physical-chemical properties (such as aliphatic and aromatic compounds, polyaromatic hydrocarbons, phenols, phthalates, aldehydes, ketones, nitrogen containing compounds, organo-phosphoric flame retardants etc.), compounds which have proved to be endocrine disruptors, compounds that are persistent, bioaccumulative and toxic, carcinogenic, mutagenic, teratogenic, reprotoxic or harmful for the environment. Even though a solvent extraction method has been optimised, the extraction step still remains the main problem for a comprehensive characterization of all classes of organic toxicants enclosed in the municipal landfill leachate.

Keywords: Municipal landfill leachate • Comprehensive two-dimensional gas chromatography • Mass spectrometry • Solvent extraction

1. Introduction

The municipal solid wastes resulting from different human activities constitutes one of the most important problems for society. It is estimated that in different regions of the world, their production varies from 0.5 to 4.5 kg per person per day [1]. Even if at local and international levels specific rules for managing this waste is established, the realities of municipal solid waste management are still far from being solved.

The most common disposal methods of the municipal solid waste are landfills and incinerators [2]. The main problems associated with incinerators are generated by the gaseous emissions of municipal solid waste burning [3], while the problems of the landfill deposition are generated by the gaseous emissions of volatile organic compounds, airborne particulate matter and leachate [4]. Landfill leachate is generated by the infiltration and percolation of water into and through the waste layers of a landfill site [5]. This water draws out different classes of compounds from wastes, most of them with a high toxicity for the environment and human health.

The basal composition of most leachates is characterized by four groups of pollutants: dissolved organic matter, inorganic salts, metals and xenobiotic organic compounds [6]. From these groups of pollutants, heavy metals and xenobiotic organic compounds are generally classified as hazardous substances [7].
The major chemical forms of metals in leachates consist of organic and inorganic complexes and free ions which are predominantly distributed in the truly-dissolved and colloidal fractions [8]. The composition of organic compounds in the municipal landfill leachates is not well known due to the complexity of municipal solid waste, as well as to the biotransformation of organic matter under anaerobic oxidation processes, although some studies showed that more than 200 organic compounds have been identified [5,9-11]. The most commonly occurring organic compounds are: hydrocarbons, halogenated compounds, polyaromatic hydrocarbons, phenols, nonylphenol isomers, phthalates, carboxylic acids and esters, ketones, aldehydes, nitrogen containing compounds, perfluorinated compounds, pharmaceuticals, sterols etc. [4,5,9-16].

Due to the complexity of municipal landfill leachates the analysis of xenobiotic organic compounds involves different chromatographic techniques such as gas chromatography (GC) and high performance liquid chromatography (HPLC) coupled with mass spectrometry [5,12,14-19]. Unfortunately these techniques aren’t able to differentiate between compounds with similar physical-chemical properties a single run, and for a better characterization of the leachate composition more than one analysis is generally necessary.

The aim of this study was to develop a method for the identification, in just a single run, of wide classes of toxics enclosed in the municipal landfill leachate, using comprehensive two dimensional gas chromatography coupled with quadrupole mass spectrometry (GCxGC-qMS).

2. Experimental procedure

2.1. Apparatus and reagents

For the purpose of experiments a Thermo Trace GCxGC gas chromatograph equipped with a dual CO₂ cryogenic modulator, an Autosampler Triplus 1 and coupled with a quadrupole mass spectrometer model Thermo ISQ (Courtaboeuf, France) was used.

For GCxGC analysis, helium of high purity at a constant flow rate of 1 mL min⁻¹ was used as carrier gas. For the mass spectrometer, the frequency of acquisition was 50 Hz and for data collection total ion current (TIC) MS signal was used, scanning between 50 and 250 m/z, using EI ionization mode. The temperature of the ion source was 200°C, voltage ~70 eV and 280°C transfer line. The analyses were performed with a gradient of temperature program. A temperature program of 60°C slowly heated to 275°C at 5°C min⁻¹ with a final hold time of 1 minute was used. One mL of sample was automatically injected in splitless mode. The inlet temperature was set at 280°C and the modulation period of the cryogenic modulator was 8 seconds.

The acquisition was performed using X-Calibur software and the GCxGC representation was realized using Chrom-Card software.

Identification of compounds of the municipal landfill leachate extract was based on GCxGC retention times using the external standard method for the compounds enclosed in the standard mixture and computer matching of mass spectra with those of standards (NIST (classical) data of GCxGC-MS system) for the unknown compounds.

For the optimization of the GCxGC separation, a mixture containing 45 compounds with different polarity purchased from Merck and Supelco were prepared. The composition of the mixture, as well as some properties of tested compounds, is given in Table 1. This composition was established according to the studied literature which present the most frequent compounds likely to be present in municipal landfill leachate.

2.2. Solvent extraction

The extraction efficiency of three different organic solvents (hexane, dichloromethane and diethyl ether) was tested. For this purpose a volume of 400 mL artificial water sample (ultra pure, deionized water obtained with a Millipore system at 18.2 MΩ cm) was spiked with 2 mL of standard mixture. 5 g of NaCl was dissolved in each sample in order to increase the affinity of organic compounds for the organic solvent. Subsequently, the obtained samples were extracted with 15 mL of selected organic solvents in a separating funnel. The mixture was then vigorously shaken for 5 minutes and the aqueous and organic phases were allowed to separate. Next, the organic layer was drained through a cartridge containing 10 g of anhydrous Na₂SO₄ into a clean flask. The remaining water layer was twice treated with 15 mL of selected organic solvents. Finally, the Na₂SO₄ cartridge was rinsed with 10 mL of selected organic solvents and then all portions were combined in the flask. The organic solvents were evaporated at approximate 2 mL with a rota-evaporator system. Subsequently, the resultant extracts were evaporated to dryness under nitrogen and the residues were dissolved in 2 mL of organic solvent and analyzed by GCxGC-qMS in the conditions described above.

For the analysis of different classes of toxics in the municipal landfill leachate, the samples were neutralized at pH 7 with a solution of 0.1 M NaOH and then filtered through a cellulose acetate membrane (0.45 μm porosity) in order to remove the dissolved organic matter. 5 g of NaCl was dissolved in 400 mL of
Table 1. The chemical name, molecular formula, boiling point and concentration of tested compounds.

| Nr  | Chemical Name                        | Molecular formula | Boiling point (°C) | Concentration in mixture (µg mL⁻¹) |
|-----|--------------------------------------|-------------------|-------------------|-----------------------------------|
| 1-11| Hydrocarbons from (C10-C20)          | CᵦH₂n+₂           | 150.8-342.7       | 12                                |
| 12  | Nonanal                              | C₇H₁₆O            | 195               | 15                                |
| 13  | Decanal                              | C₉H₁₈O            | 207-209           | 15                                |
| 14  | Methyl Decanoate                     | C₁₁H₂₂O₂          | 224               | 15                                |
| 15  | Methyl Dodecanoate                   | C₁₃H₂₆O₂          | 261-262           | 15                                |
| 16  | p-xylene                             |                   | 138.3             | 15                                |
| 17  | Propylbenzene                        |                   | 159               | 15                                |
| 18  | Butylbenzene                         |                   | 181-183           | 15                                |
| 19  | Naphthalene                          |                   | 218               | 15                                |
| 20  | 1,2,3,4-tetrahydronaphthalene (Tetralin) |              | 206-208           | 15                                |
| 21  | 1-methylnaphthalene                  |                   | 244.4             | 15                                |
| 22  | 2-methylnaphthalene                  |                   | 243.1             | 15                                |
| 23  | 2-ethylnaphthalene                   |                   | 258.5             | 15                                |
| 24  | Fluorene                             |                   | 295               | 12                                |
| 25  | Acenaphthene                         |                   | 279               | 12                                |
| 26  | Acenaphthylene                       |                   | 280               | 12                                |
| 27  | Anthracene                           |                   | 340               | 12                                |
Continued Table 1. The chemical name, molecular formula, boiling point and concentration of tested compounds.

| Nr | Chemical Name         | Molecular formula | Boiling point (°C) | Concentration in mixture (µg mL⁻¹) |
|----|-----------------------|-------------------|-------------------|-----------------------------------|
| 28 | Phenanthrene          | ![Phenanthrene](image) | 332               | 12                               |
| 29 | Fluoranthene          | ![Fluoranthene](image) | 383.5             | 12                               |
| 30 | Benz(a)anthracene     | ![Benz(a)anthracene](image) | 438               | 30                               |
| 31 | Phenol                | ![Phenol](image) | 181               | 30                               |
| 32 | p-cresol              | ![p-cresol](image) | 202.6             | 30                               |
| 33 | 2,3-dimethylphenol    | ![2,3-dimethylphenol](image) | 217               | 30                               |
| 34 | 3,4-dimethylphenol    | ![3,4-dimethylphenol](image) | 227               | 30                               |
| 35 | 2-isopropylphenol     | ![2-isopropylphenol](image) | 213-214           | 30                               |
| 36 | Bis phenol A          | ![Bis phenol A](image) | 220               | 30                               |
| 37 | 2,6-dimethylaniline   | ![2,6-dimethylaniline](image) | 215               | 15                               |
| 38 | Diphenyl amine        | ![Diphenyl amine](image) | 302               | 30                               |
| 39 | o-toluidine           | ![o-toluidine](image) | 203-204           | 15                               |
| 40 | Benzamide             | ![Benzamide](image) | 288               | 30                               |
| 41 | o-Toluamide           | ![o-Toluamide](image) | 254.3             | 30                               |
| 42 | Benzophenone          | ![Benzophenone](image) | 305               | 15                               |
| 43 | Camphor               | ![Camphor](image) | 204               | 15                               |
filtered sample and the organic compounds were then extracted three times with 15 mL of dichloromethane in a separating funnel. The organic passes where collected and pre-treated according the protocol described above. The residue was dissolved in 2 mL of dichloromethane and analysed by GCxGC-qMS. All used solvents were of analytical grade purity.

3. Results and discussions

3.1. GCxGC separation

GCxGC separations of the tested compounds were performed using a conventional phase orthogonal set of columns which consisted in the first dimension of a column with a non-polar stationary phase such as Factor Four VF1-MS (100% dimethylpolysiloxane) 20 m × 0.25 mm ID, ×0.25 µm film thickness (Varian) and in the second dimension (fast separation), a mid-polar column of DB-1701 ((14%-Cyanopropyl-phenyl)-methylpolysiloxane)) 1.5 m × 0.1 mm ID, 0.1 µm film thickness (Agilent Technologies). This combination of columns provides a good resolution, both for polar and non-polar compounds and a very good distribution of the compounds on the GCxGC chromatogram (Fig. 1).

3.2. Optimization of solvent extraction

The extraction efficiency of the selected organic solvents was quantified by the recovery of the spiked compounds after liquid-liquid extraction. For a better quantification of the results, the repeatability of three replicated experiments was checked. The efficiency of the tested solvents as well as the relative standard deviations (RSD) of three replicated experiments are presented in Table 2.

As can be see in Table 2, the results of the experiments showed that, for liquid-liquid extraction of tested compounds, the best compromise is dichloromethane, an aprotic polar solvent which is able to provide a good extraction efficiency both for non-polar and for polar compounds, even though for some compounds with high polarity, like phenol and o-toluamide, the recovery was less than 50%. The recoveries for all alkylbenzenes were less than 50% for all solvents, and we believe that these compounds were partially lost by evaporation during the sample preparation.

For the non polar solvent (hexane), good recoveries were obtained for non-polar compounds like hydrocarbons and poly-aromatic hydrocarbons, whereas for the polar compounds like phenols and amides the recoveries were less than 20%.

In the case of diethyl ether, the extraction efficiencies were between 0 and 86%. It was also observed that liquid-liquid extraction with diethyl ether gave a poorer repeatability, mostly for polar compounds (the values of RSD exceeding 15%) and this could be a consequence of poor extraction efficiency for these compounds. For the most polar tested compound (benzamide), it can not be extracted with any of the solvents due to its high polarity.

3.3. Analysis of different classes of toxicants in municipal landfill leachate

The developed extraction and separation methods were applied for the analysis of different classes of organic compounds in a real sample of municipal landfill leachate. For this purpose, 400 mL of a municipal landfill leachate was extracted, following the protocol described above, and analyzed by GCxGC-qMS. As can be seen in Fig. 2, the municipal landfill leachate contains a huge number of organic compounds which are difficult to separate in a single run using a conventional GC method.

Taking into consideration that in comprehensive two-dimensional gas chromatography the compounds are well organised on the GCxGC chromatogram according to their polarity and volatility, using this technique it is also possible to estimate the type of the organic compounds enclosed in the municipal landfill leachate.
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**Figure 1.** The GCxGC chromatogram of standard mixtures.

**Figure 2.** The GCxGC chromatogram of a municipal landfill leachate extract.
### Table 2. The extraction efficiency of three different solvents.

| Compounds name/Abbreviation | Amount Added (µg) | L-L extraction efficiency (%) | Dichloromethane | Hexane | Diethyl Ether |
|-----------------------------|-------------------|-------------------------------|-----------------|--------|--------------|
|                             | Found (µg) | Percentage | RSD (%) | Found (µg) | Percentage | RSD (%) | Found (µg) | Percentage | RSD (%) |
| n-Decane (C:10)             | 24       | 6.1       | 25.6    | nd      | -        | -       | nd      | -        | -       |
| n-Undecane (C:11)           | 24       | 4.8       | 49.8    | 12.7    | nd      | -        | -       | -        | -       |
| n-Dodecane (C:12)           | 24       | 13.2      | 55.1    | 9.9     | 7.0     | 29.3    | 6.2     | nd       | -       |
| n-Tridecane (C:13)          | 24       | 20.6      | 85.7    | 4.8     | 13.5    | 56.3    | 10.8    | 4.2      | 17.5    |
| n-Tetradecane (C:14)        | 24       | 20.7      | 86.1    | 8.9     | 18.0    | 74.6    | 6.1     | 5.1      | 21.2    |
| n-Pentadecane (C15:0)       | 24       | 20.9      | 87.1    | 12.8    | 20.6    | 85.7    | 7.0     | 6.4      | 26.8    |
| n-Hexadecane (C16:0)        | 24       | 23.8      | 99.1    | 12.7    | 22.3    | 93.0    | 7.8     | 7.9      | 32.9    |
| n-Heptadecane (C17:0)       | 24       | 21.1      | 87.8    | 8.7     | 23.3    | 97.2    | 4.2     | 7.9      | 32.9    |
| n-Octadecane (C18:0)        | 24       | 23.3      | 97.0    | 12.8    | 23.2    | 93.0    | 7.8     | 10.0     | 41.6    |
| n-Nonadecane (C19:0)        | 24       | 21.2      | 88.5    | 7.4     | 22.7    | 94.4    | 4.6     | 9.4      | 39.1    |
| n-Dodecane (C:20)           | 24       | 23.1      | 96.1    | 8.9     | 23.2    | 96.8    | 8.5     | 8.3      | 34.7    |
| Nonanal (C:9-al)            | 30       | 14.8      | 49.4    | 11.0    | 15.0    | 49.9    | 7.0     | 6.2      | 20.7    |
| Decanal (C:10-al)           | 30       | 23.4      | 78.1    | 9.9     | 20.0    | 66.7    | 14.8    | 7.9      | 26.3    |
| Methyl decanoate            | 30       | 26.9      | 89.5    | 11.7    | 21.3    | 71.1    | 8.0     | 21.7     | 72.3    |
| Methyl dodecanoate          | 30       | 28.6      | 95.2    | 10.7    | 25.2    | 83.9    | 11.6    | 25.8     | 85.9    |
| Propylbenzene               | 30       | 12.3      | 41.1    | 11.1    | 13.2    | 44.0    | 9.8     | nd       | -       |
| Butylbenzene                | 30       | 12.9      | 43.0    | 10.6    | 14.1    | 47.0    | 11.2    | nd       | -       |
| Naphthalene                 | 30       | 21.2      | 70.7    | 11.4    | 7.4     | 24.8    | 4.4     | 1.5      | 4.9     |
| Tetralin                    | 30       | 19.6      | 65.4    | 10.5    | 5.3     | 17.6    | 11.5    | 0.8      | 2.7     |
| 1-methylnaphthalene         | 30       | 26.0      | 86.5    | 11.4    | 22.2    | 74.1    | 5.7     | 20.2     | 67.2    |
| 2-methylnaphthalene         | 30       | 25.9      | 86.3    | 13.9    | 23.0    | 76.5    | 4.9     | 20.4     | 68.0    |
| Ethyl naphthalene           | 30       | 28.4      | 94.8    | 13.8    | 22.3    | 74.4    | 3.7     | 21.2     | 70.5    |
| Fluorene                    | 24       | 21.9      | 91.4    | 7.4     | 21.6    | 89.8    | 3.7     | 15.5     | 64.6    |
| Acenaphthene                | 24       | 21.8      | 90.8    | 5.9     | 18.9    | 78.7    | 3.1     | 16.4     | 68.2    |
| Acenaphthyline              | 24       | 22.8      | 94.9    | 8.2     | 19.2    | 79.9    | 5.3     | 16.6     | 69.3    |
| Anthracene                  | 24       | 14.5      | 86.4    | 8.9     | 15.6    | 65.0    | 7.5     | 15.0     | 62.5    |
| Phenanthrene                | 24       | 25.3      | 103.3   | 7.0     | 26.1    | 108.6   | 4.6     | 17.2     | 71.6    |
| Fluoranthene                | 24       | 25.0      | 104.3   | 8.3     | 25.2    | 104.8   | 6.5     | 18.2     | 75.7    |
| Benz(a)anthracene           | 60       | 64.2      | 107.0   | 5.6     | 65.7    | 109.5   | 3.6     | 50.5     | 84.2    |
| Phenol                      | 60       | 17.0      | 28.3    | 13.8    | nd      | -       | -       | nd       | -       |
| p-cresol                    | 60       | 43.0      | 71.7    | 10.1    | nd      | -       | -       | nd       | -       |
| 2,3-dimethylphenol          | 60       | 48.0      | 80.0    | 10.6    | 10.6    | 17.7    | 6.2     | 25.6     | 59.3    |
| 3,4-dimethylphenol          | 60       | 48.0      | 80.0    | 11.2    | nd      | -       | -       | nd       | -       |
| 2-Isopropylphenol           | 60       | 57.4      | 96.7    | 6.9     | 12.1    | 20.1    | 19.4    | 41.6     | 69.4    |
| Bis phenol A                | 60       | 65.8      | 109.7   | 10.9    | 22.4    | 37.3    | 10.5    | 32.0     | 53.4    |
| 2,6-dimethylaniline         | 30       | 25.5      | 85.1    | 12.4    | 8.0     | 26.7    | 14.6    | 9.5      | 31.7    |
| Diphenyl amine              | 60       | 62.2      | 103.6   | 12.6    | 50.0    | 83.3    | 14.2    | 39.5     | 65.9    |
| o-toluidine                 | 30       | 20.9      | 69.6    | 16.7    | 5.9     | 19.6    | 11.6    | 7.3      | 24.4    |
| Benzamide                   | 60       | nd        | -       | -       | nd      | -       | -       | nd       | -       |
| o-Toluamide                 | 60       | 19.2      | 32.0    | 14.3    | nd      | -       | -       | nd       | -       |
| Benzophenone                | 30       | 30.5      | 101.8   | 11.5    | 19.6    | 65.2    | 6.8     | 22.4     | 74.6    |

RSD: Relative standard deviation.
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Thus, it can be observed that in the analyzed sample, the most predominant compounds are non-polar compounds such as hydrocarbons and alkylbenzenes, and compounds with low or medium polarity such as poly-aromatic hydrocarbons, esters, aldehydes, ketones and phthalates. Other classes of polar compounds such as amines, amides or phenols were also identified. The identified compounds in the municipal landfill leachate and their classification according to their toxicity are given in Table 3.

As can be seen in Table 3, the analyzed municipal landfill leachate sample contained wide classes of toxicants, most of them being listed on Reach SinList. Thus, in the analyzed sample, compounds classified as endocrine disruptors; persistent, bioaccumulative and toxic; carcinogenic, mutagenic, teratogenic, reprotoxic or harmful for the environment, were identified.

Coupling GCxGC technique with quadrupole mass spectrometry gave the possibility to identify other compounds which were not included in standard mixture such as different phthalates, phenols, thioamides, organo-phosphoric flame retardants etc. The identified compounds, according to the mass spectra, are presented in Table 4.

Unfortunately, halogenated compounds such as dioxins and polychlorinated biphenyls (PCB) have not been identified and this could be a consequence of the mass spectrometer detection limit. Usually, for the analysis of halogenated compounds it is necessary to use more specific and sensitive detectors. In this way, GCxGC coupled with a micro-ECD or TOF MS detector could be a good alternative.

### 4. Conclusions

Municipal landfill leachate is a very complex matrix which contains a wide variety of organic compounds with different physical-chemical properties. Comprehensive GCxGC-qMS seems to be a suitable method for analysis, in single run, of different classes of toxicants.
**Table 4.** The compounds identified according to mass spectra.

| Compounds name/ Molecular formula | Identified compound mass spectrum/ mass spectrum from NIST library | Probability |
|----------------------------------|---------------------------------------------------------------|-------------|
| Dicyclohexyl phthalate            | ![Dicyclohexyl phthalate](image)                           | 83.65        |
| Bis(2-ethylhexyl)phthalate        | ![Bis(2-ethylhexyl)phthalate](image)                        | 54.35        |
| Diisobutylphthalate               | ![Diisobutylphthalate](image)                               | 48.91        |
| 4-tert-butylphenol                | ![4-tert-butylphenol](image)                                | 44.42        |
| N-Ethyl-o-toluenesulfonamide      | ![N-Ethyl-o-toluenesulfonamide](image)                       | 78.71        |
Continued Table 4. The compounds identified according mass spectra.

| Compounds name/ Molecular formula | Identified compound mass spectrum/ mass spectrum from NIST library | Probability |
|-----------------------------------|------------------------------------------------------------------|-------------|
| 2(3H)-Benzothiazolone             | ![Spectrum Image](image1.png)                                    | 86.05       |
| Benzamide,N,N-diethyl-4-methyl    | ![Spectrum Image](image2.png)                                    | 77.81       |
| Acetamide N-(4-aminophenyl)-N-methyl| ![Spectrum Image](image3.png)                                  | 45.22       |
| Piperidine 1-acetyl               | ![Spectrum Image](image4.png)                                    | 65.57       |
| 4-Methylamino-5-amino-fluorene    | ![Spectrum Image](image5.png)                                    | 75.22       |
enclosed in municipal landfill leachate and to shorten the time spent for their characterization.

Having a good overview over the main classes of compounds enclosed in the municipal landfill leachate, it is possible to establish the provenience of these compounds and to establish the most suitable technique for their treatment.

Even though the halogenated compounds such as dioxins and PCB can’t be detected due to the mass spectrometer limit of detection, the developed method could be used as a screening method for characterization of different classes of organic toxicants enclosed in municipal landfill leachates. The main problem remains the extraction step which should be selected for compounds with a wide range of polarity.

Aknowledgements

This research was supported under the framework of the Joliot Chair International Scientific Cooperation, funded by ESPCI ParisTech, Paris, France.

References

[1] A.A. Bakare, A.A. Mosuro, O. Osibanjo, Mutant Res-Gen Tox. En. 582(1-2), 28 (2005)
[2] P. Moy, N. Krishnan, P. Ulloa, S. Cohen, P.W. Brandt-Rauf, J. Environ. Manag. 87, 73 (2008)
[3] L. Morselli, C. De Robertis, J. Luzi, F. Passarini, I. Vassura, J. Hazard. Mat. 159, 505 (2008)
[4] R.J. Slack, J.R. Gronowb, N. Voulvoulis, Sci. Total Environ. 337, 119 (2005)
[5] D. Baderna, S. Maggioni, E. Boriani, S. Gemmab, M. Molteni, A. Lombardo, A. Colombo, S. Bordonal, G. Rotella, M. Lodi, E. Benfenati, Environ Res. 111, 603 (2011)
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[6] T.H. Christensen, P. Kjeldsen, H.J. Albrechtsen, H.J. Heron, P.H. Nielsen, P.L. Bjerg, P.E. Holm, Crit. Rev. Environ. Sci. Technol. 24, 119 (1994)
[7] http://eur-lex.europa.eu
[8] R. Li, D. Yue, J. Liu, and Y. Nie, Waste Manage. 29, 2527 (2009)
[9] E. Benfenati, P. Pierucci, R. Fanelli, A. Preiss, M. Godejohann, M. Astratov, K. Levsen, D. Barceló, J. Chromatogr. A 831(2), 243 (1999)
[10] J. Schwarzbauer, S. Heim, S. Brinker, R. Littke, Water Res. 36(9), 2275 (2002)
[11] J. Schwarzbauer, S. Heim, B. Krooss, R. Littke, Organic Geochem. 37(12), 2026 (2006)
[12] T. Eggen, M. Moeder, A. Arukwe, Sci. Total Environ. 408, 5147 (2010)
[13] Y. Xu, Y. Zhou, D. Wang, S. Chen, J. Liu, Z. Wang, J. Environ. Sci. 20, 1281 (2008)
[14] C. Zhang, R.P. Eganhouse, J. Pontolillo, I.M. Cozzarelli, Y. Wang, J. Chromatogr. A 1230, 110 (2012)
[15] A. Preiss, E. Berger-Preiss, M. Elend, S. Gerling, S. Kühn, S. Schuchardt, Anal. Bioanal. Chem. 403(9), 2553 (2012)
[16] C. Zhang, Y. Wang, S. Qi, J. Chromatogr. B 874, 1 (2008)
[17] J. Busch, L. Ahrens, R. Sturm, R. Ebinghaus, Environ. Pollut. 158, 1467 (2010)
[18] S. Liyan, Z. Youcai, S. Weimin, L. Ziyang, J. Hazard. Mat. 163, 1084 (2009)
[19] B. Ozkaya. J. Hazard. Mat. B124, 107 (2005)