
Mercury mobility and availability in highly contaminated solid wastes from a chlor-alkali plant

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Abstract: This article suggests an approach of sustainable development in Cuba based on the environmental impact assessment of mercurial sludge generated by a chlor-alkali Cuban plant. It consists of a study of mercury mobility and availability in the sludge samples using sequential extraction procedure. High values of total mercury content (2320 ± 40 mg/kg) in the sludge sample as well as in the toxicity characteristic leaching procedure (TCLP) extract (0.46 ± 0.02 mg/l) were obtained. The highest Hg concentration ($52.2 \pm 1.5\%$) was found in the mobile fraction (F1 + F2) indicating a high risk of Hg mobilisation by the presence of water-soluble and exchangeable mercury compounds such as HgCl_2 , HgSO_4 and HgO . The water-soluble fraction (F1) accounts for the $13.7 \pm 0.8\%$ of total Hg representing a significant environmental risk due to its easy availability in environmental weathering conditions. The mercury fractionation analyses clearly demonstrate that the chlor-alkali Cuban plant does not represent a sustainable technology from environmental point of view. Furthermore, this study highlights the presence of a wide range of mercury compounds which represents a significant parameter for developing a sustainable technology to treat the mercurial sludge generated by the chlor-alkali Cuban plant.

Keywords: mercury; mercurial sludge; sequential extraction; mercury mobility and availability; environmental impact assessment; sustainable development; chlor-alkali plant; fractionation.

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1 Introduction

Environmental impact studies in soils and sludge that are highly contaminated with mercury require the identification of the mercury species being involved. Speciation is the most critical measurement for determining the characteristics of Hg-species, enabling the prediction and explanation of their mobility, bioavailability and toxicity (Issaro et al., 2009). Nowadays, mercury speciation analysis represents a useful strategy for an

accurate environmental risk assessment. The species in which mercury is present in a given sample determine its fate, transport and bioavailability in soil (Barnett et al., 1997; Wallschläger et al., 1998a, 1998b).

In many cases the large numbers of individual species (e.g., in metal-humic acid complexes) will make it impossible to determine the speciation of an element (Templeton et al., 2000) in an environmental sample. An established practice to assess the speciation of an element is to identify various classes of species of an element and to determine the sum of its concentrations in each class, known as the fractionation process (Buffle et al., 1997).

Fractionation have been defined by the International Union of Pure and Applied chemistry as the process of classifying an analyte or a group of analytes from a certain sample according to physical (e.g., size, solubility) or chemical (e.g., bonding, reactivity) properties (Templeton et al., 2000). The concept of fractionation has been also defined as a way of subdividing in fractions the total content of the element (Tack and Verloo, 1995).

Evaluating the environmental impact of an element may sometimes be achieved without determining its speciation by the use of a fractionation process even though the fractions are only operationally defined (Templeton et al., 2000). According to Liu et al. (2006) the mercury fractionation in soil and sediment may be defined operationally (e.g., water soluble, exchangeable, and organo-chelated Hg fractions).

Sequential extraction procedures (SEPs), thermal desorption analysis, and spectroscopic techniques are three major approaches to determine Hg speciation in soil. Sequential extraction is a widely used method for Hg speciation and can provide useful information related to the environmental behaviour of Hg in soil, such as solubility, mobility, and bioavailability (Biester and Scholz, 1997; Han et al., 2003; Panyametheekul, 2004). Thermal desorption analysis has also been used for the analysis of Hg species in solid samples offering the advantages of being simple, fast, and cost-effective (Bombach et al., 1994). Spectroscopic techniques, such as x-ray absorption fine structure spectroscopy or s-ray microprobe spectroscopy, can provide a direct indication of Hg speciation. The application of this approach is however limited by its relatively poor detection limit (Kim et al., 2000, 2003). SEPs are frequently used to determine the partitioning of contaminants associated with different categories of soil constituents and to elucidate the transfer potential and thus the availability and mobility according to the extractability by various solvents (Sánchez et al., 2005).

Standardisation studies performed in the framework of the Standards, Measurement and Testing Program of the European Union resulted in a three-step sequential extraction procedure (BCR EUR 14763 EN). The so-called BCR protocol (Ure et al., 1993; Quevauviller, 1998) was recommended for the study of heavy metals distribution in sediment samples. However, mercury was not included among the elements investigated in the range of standardisation tests. A modified BCR procedure was established after a systematic study of the potential sources of uncertainty in the previous BCR procedure (Sahuquillo et al., 1999) and was later applied to mercury for assessing mobility in sediments (Sahuquillo et al., 2003). According to Issaro et al. (2009) there are a wide range of sequential extraction protocols that have been developed by the scientists to determine the mercury species in soils and sediments. As SEPs for mercury fractionation which have been extensively used are: Di Giulio and Ryan (1987), Panyametheekul (2004), Han et al. (2006), Neculita et al. (2005) among others. Specifically, the sequential extraction procedure developed by Neculita et al. (2005) is a fractionation technique that

has been widely used for mercury speciation analysis in highly contaminated soils from chlor-alkali plants (Rodriguez et al., 2000; Bernaus et al., 2006).

The chlor-alkali industry, which produces caustic-soda, hydrogen and chlorine by the mercury technology, has been as one of the biggest Hg users and emitters, accounted for 90% of the global Hg utilisation prior to 1980 (Lacerda and Salomons, 1998), and has been one of the main sources of mercury pollution throughout the world (USEPA, 1997). Several studies have been carried out in the last decades to assess the impact of chlor-alkali plants on the environment (Maserti and Ferrara, 1991; Biester et al., 2002a, 2002b; Neculita et al., 2005; Zagury et al., 2006; Ulrich et al., 2007, Reis et al., 2009, 2010).

The mercury used in chlor-alkali plant has been decreasing due to process improvement (Eurochlor, 2011) and conversion to the membrane process. However, the effects of the mercury pollution were observed for a long time after production plants had closed down (Turner and Lindberg, 1978; Parks, 1984; Maserti and Ferrara, 1991).

In Cuba, the main source of mercury pollution is located in the central region of the country specifically in the electrochemistry plant 'Elpidio Sosa' (ELQUIM). This factory has caused the widespread contamination of mercury in the surrounding environment (Gonzalez, 1991). In 2008 was approved by the Cuban Government the technological change of mercury cells to membranes. The use of a membrane based production process avoids the generation of new mercury contaminated wastes. Nevertheless, the negative impact to the environment and human health could persist for much longer due to the existence of thousands of tons of mercury wastes buried in niches, unless a properly management policy of these wastes is implemented.

This factory has been producing mercury solid wastes for more than forty years. The sludge containing mercury is produced by mixing the exhausted mercury of the electrolytic cell with sodium sulphide in a first step and with sodium chloride, calcium carbonate, magnesium hydroxide and diatomaceous earth in a second step. This sludge is currently unsafely disposed in concrete niches and the contact with ground water or rain may cause mercury to leach and contaminate the soil and underground waters.

The elevated mercury content of this mercurial sludge as well as the high toxicity levels have been previously reported by Busto et al. (2011). Nevertheless, no research has been carried out to identify the different mercury-bindings forms (mercury species) that are present in this sludge. This study aims to investigate the mobility and availability of mercury in highly contaminated solid wastes from a chlor-alkali Cuban plant using a fractionation method to determine the type and amount of mercury fractions present in the solid waste. This study represents a novel contribution from sustainable development point of view in Cuba based in first place, in the assessment of the environmental impact that the chlor-alkali Cuban plant represent nowadays. On the other hand, the knowledge of the mercury fractions present in the sludge sample constitute a significant data for further studies aimed on to develop a feasible technology to decontaminate this mercury waste for allowing a sustainable development of the country.

2 Proposed methodology

The present survey consists on a laboratory investigation based on to determine mercury mobility and availability in the sludge samples generated from chlor-alkali Cuban plant. It is on the basis of the mercury fractionation analysis using a sequential extraction

procedure is established in order to assess the environmental risk that this sludge represents and therefore its impact on the sustainable development of the Cuban region. The suggested methodology is composed of the following stages:

- 1 the environmental data selection
- 2 the quantification of the mercury pollution levels
- 3 the evaluation of the environmental risk.

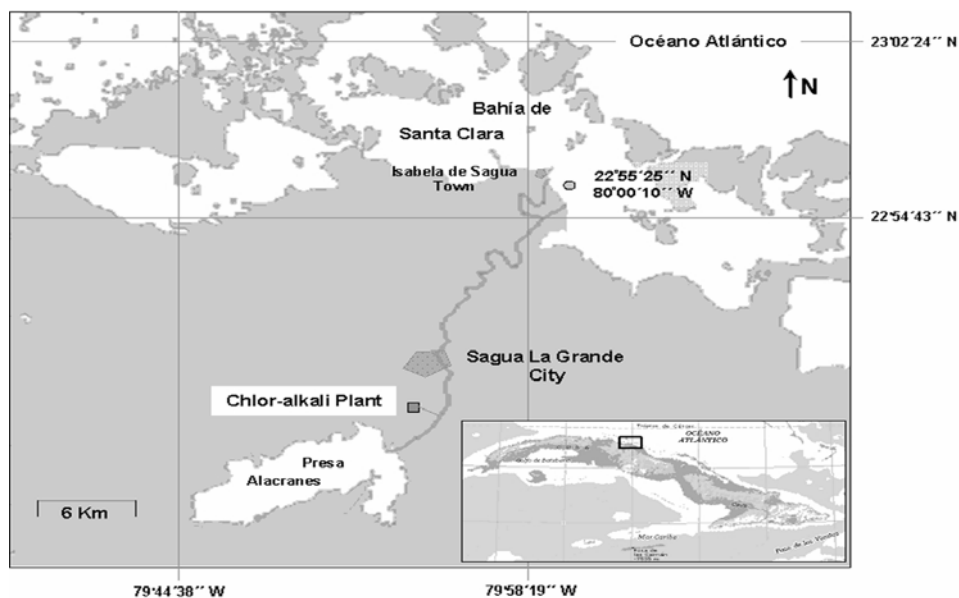
2.1 Environmental data selection

The first stage of the present survey is focus on to obtain a suitable characterisation of the environmental sample collected in the field (mercurial sludge niches) for further laboratory analyses. This environmental data selection stage was conducted as follows:

2.1.1 Choice of the environmental sample

This choice was made taking in to account in first place that Mercury Cell Chlor-alkali plants over the world are not consider any more a good industrial practice (Directive 2008/1/EC) which represent a negative impact for the sustainable development of the regions mainly in developing countries. On the other hand, the choice of the sample was motivated due to the lack of knowledge on the risk that this mercurial sludge sample could represents for the environment and human health.

Figure 1 Schematic map of Sagua La Grande City in Cuba



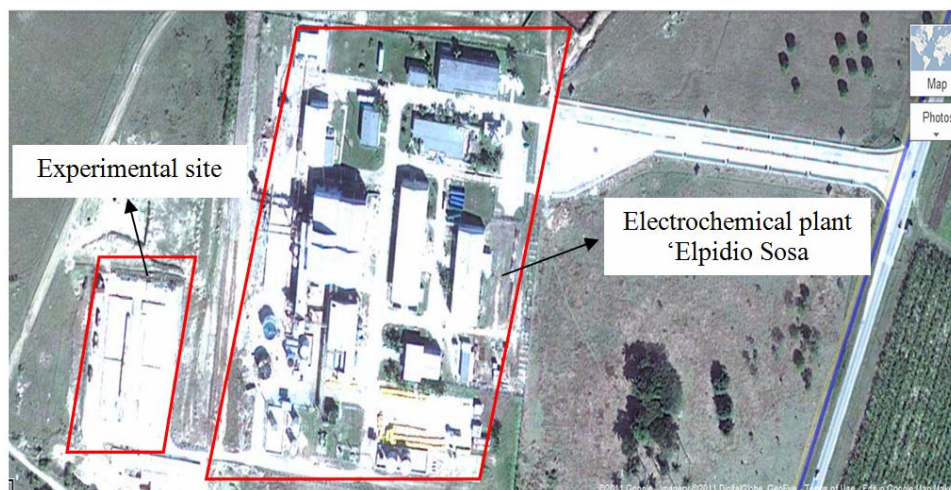
Source: Taken from Díaz-Asencio et al. (2009)

2.1.2 Site description

Mercurial sludge was sampled from a site near to the Chlor-alkali plant 'Elpidio Sosa' that produces chlorine and soda, located in the north of the central region of Cuba (Sagua La Grande City). A schematic map of the Caribbean, showing the specific location of the Cuba's region where the survey was conducted is illustrated in Figure 1.

The mercurial sludge generated from the electrolytic process is buried in concrete niches that are scattered around the factory. The niches are 9.5 m long, 4.5 m wide and 3.5 m high. They allow storage of 150 m³ of sludge. A satellite picture of the electrochemical plant and the specific experimental site (concrete niches) where the survey was done is showed in Figure 2.

Figure 2 Satellite picture of electrochemical plant 'Elpidio Sosa' and the experimental site (see online version for colours)



2.1.3 Sampling and sample preparation

The mercury solid waste sample used in this study was collected from the niche that was open at the sampling time. A composite sample was prepared from equal amounts of sludge taken from three different points on a diagonal line (at 20 cm of the two extremes of the niches and in the centre point) as well as at three depths (0–20, 20–40 and 40–60 cm) (Buduba, 2004). Immediately upon arrival at the laboratory, samples were air-dried for seven days, hand-crushed in a mortar and passed through a 2 mm sieve and thoroughly mixed.

2.1.4 Sample characterisation

The pH of the solid waste was measured after 18 h using a pH meter (ORION 520A, Laboratory Extreme, Kent, Michigan, USA) in a suspension of 50 ml of distilled water with 10 g of waste sludge (Cottenie et al., 1982). Electrical conductivity (EC) was determined in saturation extract (Jackson, 1965) with a microprocessor conductivity meter (LF 537, Weilhem, Germany). The extract was obtained from a suspension of 50 ml of distilled water with 10 g of waste sludge. The suspension was stirred for 30 min

and filtered using 0.45 µm pore membrane filters (CM, Porafil, Macherey-Nagel, Düren, Germany). Carbonate content was determined by back-titrating an excess of 0.50 M H₂SO₄ added to 0.25 g of the sample with 0.50 M NaOH (Nelson, 1982). Organic matter was estimated by weighing before and after ashing 1 g of the sample at 400°C for 2 h (Van Ranst et al., 1999).

2.2 *Quantification of the Hg pollution levels*

The second stage of the present study is focus on to quantify the mercury pollution levels of the analyzed sample. This stage was carried out considering total mercury content determination and mercury toxicity level (TCLP test) of the sludge sample as follows:

2.2.1 *Total mercury content determination*

Total mercury content was determined by cold vapour atomic absorption spectrometry (Mercury Analyzer MAS-50, Coleman, Oak Brook, Illinois, USA) after a specific destruction as reported by Cottenie (1982). The destruction procedure involved adding 0.05 g of V₂O₅, and 10 ml of concentrated HNO₃ to 0.5 g of sample and digestion for 30 min at 160°C. After the samples were cooled down 15 ml of concentrated H₂SO₄ was added and the digestion was completed for 2 h without extra heating. A standard solution of 0.25 mg/l Hg was prepared from 1,000 mg/l stock solution (Mercury Standard Solution, MERCK, Darmstadt, Germany). The calibration curve (correlation factor of 0.9981) was obtained by measuring transmittance after injection of different volumes (0, 0.5, 1, 2, 4 and 8 ml). Pseudo total metal content was determined after destruction in aqua regia extract (Ure, 1990), followed by metal determination using inductivity coupled plasma optical emission spectrometry (ICP-OES, Vista MPX CCD Simultaneous, Varian, Mulgrave VIC, Australia). Each determination was carried out in triplicate and all reagents used were of analytical grade.

2.2.2 *Mercury toxicity level*

Mercury toxicity level in the mercurial waste was evaluated according to the EPA TCLP Procedure (USEPA, 1992). The extraction fluid used depends on the alkalinity of the residual solid phase. According to the TCLP procedure, pH (1) value was measured by mixing 5 g of sludge sample and 96.5 ml of deionised water in a 250 ml beaker after stirring for 5 min. This value offers information about the acidic or alkaline properties of the waste. The value of pH (2) is tested after adding 3.5 ml 1 mol/l HCl to the suspension, followed by heating to 50°C for 10 min. This provides an indication on the alkalinity of the solid waste. For the analysed sample, pH (2) was above 5. Hence, extractant fluid 2 composed of 5.7 ml glacial CH₃CH₂OOH in 1l deionised water was used.

For the TCLP test, 1 g of the sample was introduced in a 100 ml centrifuge tube, and 20 ml of extractant fluid 2 was added. Suspension was agitated during 18 h in the end over end shaker operating at approx. 30 rpm. After agitation, the final pH (3) was measured. The TCLP leachate was filtered using 0.45 µm pore membrane filters (CM, Porafil, Macherey-Nagel, Düren, Germany). The filtrate was acidified to pH < 2 using concentrated HNO₃ and stored at 4°C before analysis. Analysis of Hg determination was carried out by CVAAS as described before.

2.3 Evaluation of the environmental risk

The final stage of this research is focus on to determine the mercury mobility and availability in the sludge analyzed sample. The goal of this analysis is to assess the environmental risk that this mercurial sludge represents for the environment and human health taking in to account upcoming negative impacts for the sustainable development of the region. To reach this goal a sequential extraction procedure was used and it is explained in detail as follows:

2.3.1 Sequential extraction procedure

The speciation analysis was done employing the Neculita et al. (2005) procedure. The procedure consists of four steps resulting in fractions (Table 1) defined as: F1, water-soluble; F2, exchangeable under alkaline conditions (pH 8.4); F3, bound to organic matter and F4, residual Hg fraction, considered to be weakly soluble and that can only be released by a strong attack of the sludge matrix.

Table 1 Extractants and Hg fractions used in the sequential extraction procedure^a

<i>Fraction ID</i>	<i>Extractant</i>	<i>Extractant (ml): sludge(g) ratio</i>	<i>Hg fraction</i>
F1	Deionised water	20:2	Water soluble
F2	0.5 mol/l NH ₄ -EDTA	20:2	Exchangeable
F3	0.2 M NaOH and 4% CH ₃ COOH	20:2	Organic
F4	HNO ₃ /H ₂ SO ₄	25:0.5	Residual

Note: ^aExtractions were conducted at $20 \pm 2^\circ\text{C}$ for 2h using the end over end shaker.

Following the Neculita scheme, the extraction was performed using 2 g of accurately weighed sludge sample mixed with 20 ml of solvent in a 100 ml centrifuge tube. The tubes were thoroughly shaken for 2 h at $20 \pm 2^\circ\text{C}$ using the end over end shaker. The supernatant was obtained between each extraction and rinse step, by centrifuging at 3,000 rpm for 15 min at 10°C followed of filtration using $0.45\mu\text{m}$ pore membrane filters. Rinsing steps consisted of washing the leached residues twice with deionised water (20 and 10 ml) for 15 min. Rinses were always subsequently added to the solvent extract from the same sample. The resulting combined supernatant from the first three extraction steps was analyzed for total Hg content by CVAAS. Residual Hg was extracted by adding the same reagents as for total Hg determination in the sludge sample directly in the original 100 ml centrifuge tube. The sample was then transferred into a 100 ml standard volumetric flask. The digestion was performed using the same procedure as previously described for total Hg in the sludge sample.

Total mercury content was determined by cold vapour atomic absorption spectrometry (Mercury Analyzer MAS-50, Coleman, Oak Brook, Illinois, USA) after a specific destruction as reported by Cottenie (1982). The destruction procedure involved adding 0.05 g of V₂O₅, and 10 ml of concentrated HNO₃ to 0.5 g of sample and digestion for 30 min at 160°C . After the samples were cooled down 15 ml of concentrated H₂SO₄ was added and the digestion was completed for 2 h without extra heating. A standard solution of 0.25 mg/l Hg was prepared from 1,000 mg/l stock solution (Mercury Standard

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3 Results and discussion

Let us remind the reader, that our choice has been motivated by the lack of knowledge about the real mercury behaviour (mobility and availability) in the sludge sample which implicates a significant risk for the environment and therefore a detrimental impact on the sustainable development of the region.

3.1 Chemical characteristics of the mercurial sludge

The mercurial sludge exhibited an alkaline pH of 9.9 ± 0.01 . This is mainly due to the presence of calcium carbonate and magnesium hydroxide, two components added during the stabilisation of the waste. Carbonate content was in the order of the 60% (Table 2), whereas pseudo total analysis revealed high Ca and Mg levels (Table 3). The presence of carbonates may also be partly due to the use of diatomaceous earth, another component of the mercurial sludge. As reported by Antonides (1998), this compound also contributes with the organic matter content in a 6% (weight).

The high value of EC would allow us classifying the sample as highly saline according to FAO (Rhoades et al., 1992). This value for EC indicates a significant presence of soluble salts which can be linked with the high content of K and Na obtained from the ICP-OES analysis. Relatively high values of Fe were found. This would be linked to the input of diatomaceous earth as an important component of the sludge (291 g/kg of sludge). As reported by Antonides (1998) diatomaceous earth includes normally about 2% (weight/weight) of Fe. Other potentially toxic trace elements were analysed to assess whether they could also be of environmental concern. Contents of these trace elements were elevated compared to normal ranges present in soils (Kabata-Pendias and Pendias, 1984).

Table 2 Chemical characteristics of the mercury solid waste^a

<i>Parameter</i>	<i>Sample</i>
pH-H ₂ O	9.9 (0.01)
Organic matter (g/kg)	163 (2)
CaCO ₃ (g/kg)	633 (8)
EC ^b (mS/cm)	48 (1)

Notes: ^aValues in parentheses are standard deviation of three replicates.

^bElectrical conductivity.

Table 3 Pseudo total metal content and total Hg content^a

<i>Metal content</i>	<i>Sample</i>
Ca (g kg ⁻¹)	207 (1)
Fe (g kg ⁻¹)	114 (1)
Al (g kg ⁻¹)	73 (1)
Na (g kg ⁻¹)	67.4 (3)
Mg (g kg ⁻¹)	21 (1)
Cu (g kg ⁻¹)	2.8 (0.3)
Hg (g kg ⁻¹)	2.3 (0.4)
K (g kg ⁻¹)	1.6 (0.2)
Mn (mg kg ⁻¹)	223 (2)
Zn (mg kg ⁻¹)	157 (1)
Pb (mg kg ⁻¹)	128 (2)
Cr (mg kg ⁻¹)	33 (1)
Cd (mg kg ⁻¹)	32 (2)
Ni (mg kg ⁻¹)	24 (1)

Note: ^aValues in parentheses are standard deviation of three replicates.

3.2 *Mercury pollution levels*

3.2.1 *Total mercury content results*

According to the results obtained from the CVAAS technique, the total mercury content is above 260 mg Hg/kg of sludge, allowing the material to be classified as hazardous high mercury waste according to US EPA: LDR (USEPA, 2008).

3.2.2 *Toxicity characteristic of the mercurial sludge (TCLP 1311 method)*

Mercury leaching from the sample exceeded the EPA TCLP limit of 0.2 mg/l. The high value of mercury (0.46 mg/l \pm 0.01) obtained from the TCLP test represents more than the double of the established permissible value. Hence, the waste is classified as toxic waste according to US EPA regulations (USEPA, 1992).

Considering the previous results obtained from to quantify the mercury pollution levels of the mercurial sludge sample generated by the chlor-alkali Cuban plant can be highlight that this waste is a hazardous and toxic residual. According to USEPA (2008) this sludge has to be treated (thermal treatment) for its final disposal in a safe way.

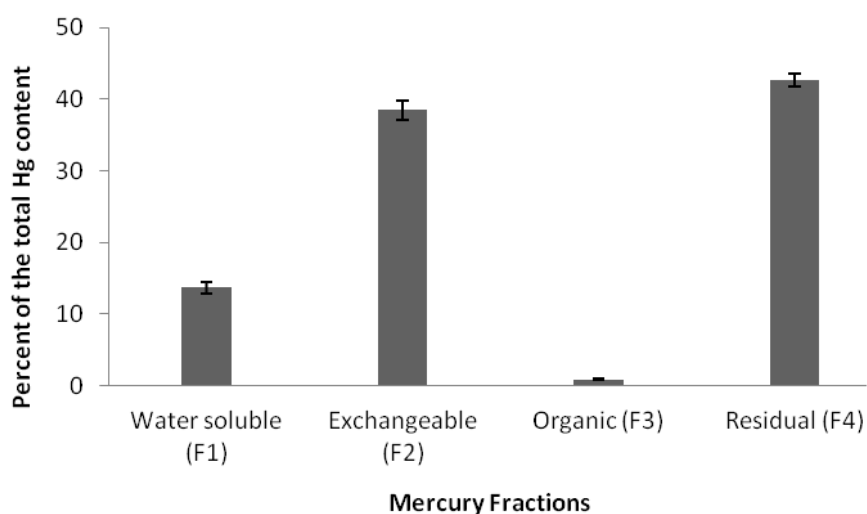
3.3 *Evaluation of the environmental risk (mercurial sludge fractionation)*

Sequential extraction of analysed sample indicates high mercury recovery percent (95.8 \pm 1.8%). Nevertheless, mercury recoveries lower than 100% can be explained by the loss of volatile Hg species during the manipulation (Neculita et al., 2005). The distribution among the different fractions follows the subsequent order: F4>F2>F1>F3 (Figure 3). The most important contribution was obtained in the residual fraction (F4), with average composition of 42.7 \pm 1% of total mercury if a separated analysis of Hg fractions is done.

According to the results obtained by Neculita et al. (2005) in the fractionation study carried out in highly contaminated soils from chlor-alkali plant, the residual fraction is linked to the presence of HgS.

In the chlor-alkali Cuban plant, where the mercury in the wastes is present as HgCl₂, the precipitation reaction with Na₂S promotes the formation of HgS. For this reason, in our study the residual fraction of mercury could be well correlated with the presence of HgS in the sludge sample. It is well known that the black HgS (metacinnabar) form can be obtained by the precipitation reaction from HgCl₂ solution using Na₂S solution (Biester et al., 2002b). The second main group of mercury species was extracted within the 'exchangeable phase' (F2) representing a $38.5 \pm 1.3\%$ of the total mercury content. This fraction can be correlated with soluble species of mercury in the oxic layer of the sludge matrix. The water-soluble fraction (F1) represented the $13.7 \pm 0.8\%$ of total Hg and it is recognised as very important from an environmental risk point of view due to its easy availability in environmental weathering conditions (Bloom et al., 2003). This fraction should be treated with caution because its mercury content (318.8 mg/kg) exceeds in a 22.6% the permissible limit established by the USEPA regulation (LDR: 40 CFR Part 273, 2008). Mercurial wastes which contain more than 260 mg Hg/kg of total mercury content must be treated before its final disposal (LDR: 40 CFR Part 273, 2008).

Figure 3 Mercury fractionation in chlor-alkali plant: contaminated solid waste using the sequential extraction procedure^a



Note: ^aThe values represent the mercury percent of each fraction from the total mercury content (n=4).

Source: Neculita et al. (2005)

Although the mercury content present in the fraction F3 (organic) only accounts for the $0.9 \pm 0.1\%$ of the total Hg content obtained in the analyzed sample, it still represents a significant amount (21.2 mg/kg) and therefore an environmental concern. This result can be correlated with the 16.3% of organic matter obtained in the sludge sample (Table 1). The affinity of Hg for organic matter and especially for S-containing groups of organic molecules is well known (Xia et al., 1999; Yue et al., 2006). Nevertheless, several studies

developed in polluted soils near chlor-alkali plants (Hempel et al., 1995; Bloom et al., 2003; Neculita et al., 2005) demonstrated that high organic carbon content do not entail a high proportion of methylmercury. For instance, it was reported by Neculita et al. (2005) that in CAP contaminated soils with organic carbon content of 18.2 g/kg the methylmercury only accounts in a 0.00008% of total Hg.

On the other hand, a significant environmental concern arose from the characterisation of fractions F1 and F2 in this sludge. It has been reported (Neculita et al., 2005; Bernaus et al., 2006) that (F1 + F2) represent the mobile Hg fraction which indicates the amount of mercury that can easily be leachable. The mobile fraction represents the highest potential for Hg mobility via pore water. In our study, the mobile Hg fractions (F1 + F2) corresponded with the highest percentages of Hg content ($52.2 \pm 1.5\%$ of total Hg) indicating an elevated risk for Hg mobilisation by the presence of water-soluble and exchangeable mercury compounds such as HgCl_2 , HgSO_4 and HgO .

4 Conclusions

The present study can be considered as a basic document addressing the assessment of the pollution by Hg that represents the mercurial sludge generated by the Chlor-alkali Cuban plant. The main findings of this work were:

- The high mercury content in the studied sludge, the TCLP result as well as the mercury fractionation analysis suggest potential mercury mobility via the sludge solution which represents a significant and negative impact from the environmental point of view.
- High total mercury content (2,320 mg/kg) found in the sludge sample and in the leachate extract from the TCLP test [representing more than the double of the limit value established by EPA (0.2 mg/l)] allows classifying the sample as toxic waste according to US EPA regulations.
- The fractionation results indicated that Hg content associated with the F4 fraction (residual), which is the least available Hg form based on its potential of solubilisation (mainly HgS), represented the 42.7% of total mercury content. Nevertheless, this value does not guarantee the necessary encapsulation of this metal in the sludge matrix.
- The mobile Hg fraction (F1 + F2) represents the major fraction of the total mercury found in the sample (52.2%) indicating a high risk of Hg mobilisation by the presence of water soluble and exchangeable mercury compounds such as HgCl_2 , HgSO_4 and HgO .

These results clearly indicate that the treatment with sulphide applied by the Cuban electrochemical plant is inefficient in immobilising and encapsulating mercury compounds that are present in the sludge matrix which represent a significant threat for the environment. A detrimental impact on the sustainable development of the Cuban region where the electrochemical plant is located can be correlated with the actual generation and encapsulation of this sludge.

Finally, a possible perspective for this study is to use this mercury fractionation data to develop a feasible treatment capable of decontaminating this hazardous waste at pilot or full scale given the Cuban conditions.

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