Journal of Hazardous Materials A79 (2000) 215–227
Journal of Hazardous Materials
www.elsevier.nl/locate/jhazmat

Characterisation and management of incinerator wastes

R. Ibáñez, A. Andrés, J.R. Viguri, I. Ortiz, J.A. Irabien*

Departamento de Química, Universidad de Cantabria, Avda de los Castros s/n. 39005, Santander, Spain

Received 5 November 1999; received in revised form 30 May 2000; accepted 1 June 2000

Abstract

Management of municipal and hospital wastes by means of incineration processes generates solid residues, such as bottom and fly ashes and air pollution control residues with high content of heavy metals, inorganic salts and other organic compounds. Characterisation of 24 ash samples, collected from four municipal solid waste incinerators (MSWI) and six hospital medical waste incinerators (HMWI) located in the Basque Country Region (Northern Spain), were carried out at the request of Spanish Regulations and European Economic Community guidelines.

The ecotoxicity values, EC_{50}, of the TCLP leachates show a high variability ranging from 12,967 to 1,000,000 mg l^{-1} in MSWI samples and from 2917 to 333,150 mg l^{-1} in HMWI samples. Results from chemical characterisation of DIN 38414-S4 leachates show a high concentration of lead, sulphate and chloride in MSWI samples and chromium in HMWI samples.

Keywords: Incineration residues; Ecotoxicity; Characterisation

1. Introduction

Municipal solid waste incinerators (MSWI) and hospital medical waste incinerators (HMWI) can be operated as integrated waste management systems. They offer a reduction in both the mass, about 70%, and volume, about 90%, of waste subjected to final disposal, as well as the possibility of energy recovery [1]. For infectious hospital wastes, another major objective of the incineration process is the destruction of infectious organisms that may exist in the waste. Two additional objectives achievable through proper operation of waste incinerators are minimising organic content in the solid residue and controlling atmospheric emissions to acceptable levels [2].

* Corresponding author. Tel.: +34-942-201597; fax: +34-942-201591.
E-mail address: irabienj@ccaix3.unican.es (J.A. Irabien).

PII: S0304-3894(00)00268-5

MSW typically includes cellulose materials, clothing, food, automobile tires, plastic, glass, etc. Composition and quantities of MSW can vary due to factors like community, area and population size, seasonal changes, local and regional economic differences, social structure, collection systems, etc. [3]. HMW can include general refuse wastes, like paper, flowers, food, plastic cups, as well as laboratory and pharmaceutical chemicals (alcohols, disinfectants, etc.), and infectious wastes like contaminated sharps, human blood and blood products, tissues and body parts, cultures, etc. [2].

MWS and HMS incineration facilities generate combustion residues such a bottom and fly ashes and solid waste from air pollution control (APC). Bottom ashes are not included in the List of Hazardous Wastes established by the Council of the European Union. The List of Hazardous Wastes includes fly ash and solid waste from gas treatment (APC) from incineration or pyrolisis of municipal and similar commercial, industrial and institutional wastes encoded 19.01.03 and 19.01.07 wastes, respectively [4].

Fly ashes, particulate matter carried over from the furnace and removed from the flue gas, can be themselves a major environmental problem. According to some authors [5] these residues present potential toxicity issues because of, their heavy metal amount and salt content, which can modify the leaching behaviour, and therefore, require proper management. Due to the fact that the legal standards for the emission of contaminants are getting more stringent, the air pollution control systems of the incinerators must be improved, resulting in an increase of the amount of APC residues (combined materials collected in the electrostatic precipitators or fabric filter devices) which should be regarded as hazardous wastes as well [6]. Safe management of these residues is still a problem. Some alternatives, like incorporating incineration residues in products ranging from roadbase and masonery bricks to ceramic products, [7–9], have been developed but landfilling is still the management option most widely used. Solidification/stabilisation of these wastes using cement or waste pozzolans prior to deposition usually is necessary to produce appropriate materials for landfill disposal [10,11].

Management options for these types of residues require extensive characterisation. Wastes generated in MSWI and HMWI show the presence of heavy metals, like Cd, Cr, Pb, Zn, etc., soluble salts and some organic materials [1–4]. The Spanish Regulations on this subject [12,13], define hazardous wastes as those containing materials shown in a list 'C, code' of 51 hazardous elements, compounds and families of compounds and showing one or more of the 14 hazardous properties (H1 to H14). The ecotoxiciy (H14) is evaluated after application of bioassays to the leachates.

The proposal of a European Directive on landfill of wastes [14] classifies different types of waste and classes of landfill depending on the types of waste to be disposed off. Landfills are classified in three different classes: for hazardous wastes, for inert wastes and, a broad in-between category, for municipal, non-hazardous and other compatible wastes. An acceptance criterion based on the characteristics of the solution obtained by the laboratory leaching test DIN-38414-S4 was proposed in the 1991 draft Landfill Directive E.C. [15]. The suggested limits are shown in a table, which fixes the ranges by which wastes will be characterised for the proposal of landfilling according to the composition of their leachates.

Land disposal of solid wastes can lead to environmental impacts associated to the leaching of pollutants to surface and ground water. Therefore, the leaching test play a major role to assess the possibility of use and treatment within regulatory limits. Different leaching tests have been developed for different purposes [16,17]. The single bath extraction (equilibrium test) is usually suggested by the regulations in order to classify wastes as hazardous or non-hazardous based on the pollutant concentrations in the leachate and/or bioassays [18]. Both the European Community and Spanish Regulations have established an equilibrium test for the characterisation of hazardous wastes in solubility terms after evaluation of the chemical composition or biotoxicity of the liquid phase [13,14].

In the present study two methods, based on the leaching tests suggested by the Spanish and European Community frameworks for waste characterisation have been carried out on residues coming from different MSW and HMW incinerators and APC systems. The aim of the study is to report characterisation parameters, which can be useful in the classification of such wastes with reference to the different frameworks. Taking into account that the classification of a waste as hazardous or non-hazardous will determine the management options allowed for it, a great effort must be done to assure that harmonisation among the different frameworks, especially those involving European Union countries, is achieved.

2. Materials and methods

2.1. Residual ashes

Experimental work has been carried out, based on 12 residual ashes from MSWI and 12 residual ashes from HMWI, all of them located in the Basque Country Region (Northern Spain). Residues are summarised in Table 1. Samples corresponding to MSWI wastes (codes MI) include fly and bottom ashes collected from an incineration facility located in a highly industrialised urban area (samples 3, 4, 9, 10), fly ashes from a facility located in a rural area (samples 5, 6), fly ashes and APC residues from an incineration facility located in an urban area in the coast, with an important fishery industry (samples 1, 2, 11, 12) and fly ashes collected in an incinerator working with sludges generated in a wastewater treatment plant (samples 7, 8). HMWI residues have been collected from four general hospitals located in the most populated areas of the Basque Country Region (samples 1, 2, 5, 6, 9, 10, 11, 12) and two hospitals dedicated to rehabilitation and repose (samples 3, 4, 7, 8).

2.2. Characterisation of residues

Characterisation of incineration residues has been carried out with respect to a regulatory point of view. Two different methods of characterisation have been used:

1. Evaluation of the ecotoxicity, based on the EC_{50} parameter (TCLP leaching test) [13].
2. Determination of the chemical composition of leachates (Cd, total Cr, Cu, Ni, Pb, Zn, SO_4^{2-}, Cl^-) in DIN 38414-S4 leaching test according to the Draft of the European Economic Community Directive on the Landfill of Wastes [15], Table 2.

Complete description of the experimental method followed in this work is given in reference [19]. A summarised description of the methodology is given in Fig. 1.

Table 1
MSWI and HMWI residues used in this work

Incineration activity		Incineration residues	
	Description	Code	Description
MSWI	MSW from seaside activities area incineration	MI-1	Fly-ash (grey, particulate)
	MSW from seaside activities area incineration	MI-2	Fly-ash (grey, particulate)
	MSW from industrial area incineration	MI-3	Fly-ash (black, particulate)
	MSW from industrial area incineration	MI-4	Fly-ash (black, particulate)
	MSW from rural area incineration	MI-5	Bottom-ash (grey, particulate)
	MSW from rural area incineration	MI-6	Bottom-ash (grey, particulate)
	Wastewater treatment sludge incineration	MI-7	Fly-ash (brown, clear)
	Wastewater treatment sludge incineration	MI-8	Fly-ash (brown, clear)
	MSW from industrial area incineration	MI-9	Bottom-ash (black)
	MSW from industrial area incineration	MI-10	Bottom-ash (black)
	MSW from seaside activities area incineration	MI-11	APC residue (grey)
	MSW from seaside activities area incineration	MI-12	APC residue (grey)
HMWI	General hospital, gas combustion furnace	HI-1	Bottom-ash (dark grey, unburned)
	General hospital, gas combustion furnace	HI-2	Bottom-ash (dark grey, unburned)
	Long stay and repose hospital, fuel comb. furnace	HI-3	Bottom ash (grey, unburned)
	Long stay and repose hospital, fuel comb. furnace	HI-4	Bottom-ash (grey, unburned)
	General hospital, gas combustion furnace	HI-5	Bottom-ash (brown-grey, unburned)
	General hospital, gas combustion furnace	HI-6	Bottom-ash (grey, unburned)
	Long stay and repose hospital, fuel comb. furnace	HI-7	Fly-ash (brown- grey)
	Long stay and repose hospital, fuel comb. furnace	HI-8	Fly-ash (grey)
	General hospital, gas combustion furnace	HI-9	Fly-ash (brown- grey)
	General hospital, gas combustion furnace	HI-10	Fly ash (brown- grey)
	General hospital, gas combustion furnace	HI-11	Fly-ash (brown)
	General hospital, gas combustion furnace	HI-12	Fly-ash (brown)

Table 2
Limit concentrations of chemical parameters in the DIN 38414-S4 leachates [15]

Code	Parameter	Hazardous waste range	Inert waste	Code	Parameter	Hazardous waste range	Inert waste
1.01	pH value	4–13	4–13	1.11	Phenols	20–100 mg l^{-1}	<10 mg l^{-1}
1.02	TOC	40–200 mg l^{-1}	<200 mg l^{-1}	1.12	Fluoride	10–50 mg l^{-1}	<5 mg l^{-1}
1.03	Arsenic	0.2–1.0 mg l^{-1}	<0.1 mg l^{-1}	1.13	Ammonium	0.2–1.0 gN l^{-1}	<50 mg l^{-1}
				1.14	Chloride	1.2–6.0 g l^{-1}	<0.5 g l^{-1}
1.04	Lead	0.4–2.0 mg l^{-1}	The	1.15	Cyanide[b]	0.2–1.0 mg l^{-1}	<0.1 mg l^{-1}
1.05	Cadmium	0.1–0.5 mg l^{-1}	total	1.16	Sulphate[c]	0.2–1.0 g l^{-1}	<1.0 g l^{-1}
1.06	Chromium	0.1–0.5 mg l^{-1}	of	1.17	Nitrite	6–30 mg l^{-1}	<3 mg l^{-1}
1.07	Copper	2–10 mg l^{-1}	these	1.18	AOX[d]	0.6–3-0 mg l^{-1}	<0.3 mg l^{-1}
1.08	nickel	0.4–2.0 mg l^{-1}	metals:	1.19	Solvents[e]	0.002–0.1 mg Cl l^{-1}	<10 μg Cl l^{-1}
1.09	Mercury	0.02–0.1 mg l^{-1}	<5 mg l^{-1}	1.20	Pesticides[e]	1–5 μgCl l^{-1}	<0.5 μg Cl l^{-1}
1.10	Zinc	2–10 mg l^{-1}	–[a]	1.21	Lipho. Sub	0.4–2–0 mg l^{-1}	<1.0 mg l^{-1}

[a] No single value above the minimum fixed for hazardous waste.
[b] Readily released.
[c] If possible <500 mg l^{-1}.
[d] Adsorbed organically-bound halogens.
[e] Chlorinated.

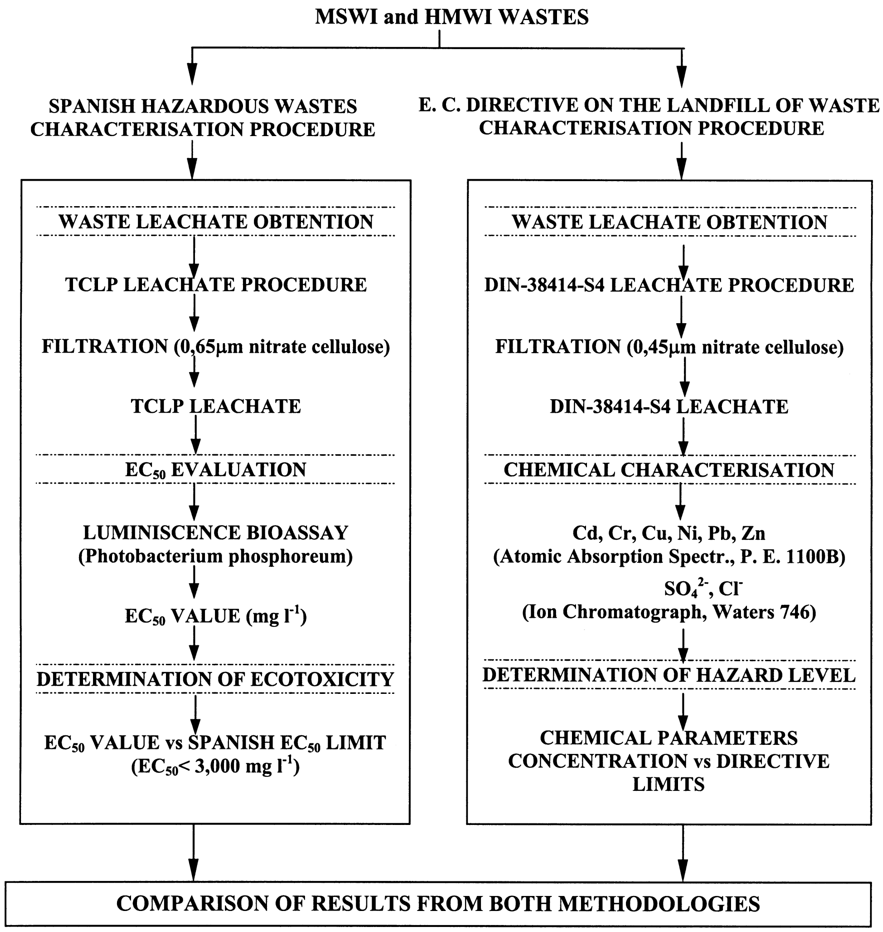


Fig. 1. Experimental procedure.

Ecotoxicity results are compared to the value $EC_{50} < 3000\,mg\,l^{-1}$ given by the Spanish regulations for the ecotoxicity characterisation of industrial wastes (H14).

Chemical composition of leachates is compared to the values shown in Table 2. Wastes, which pollutants concentration in the leachate is in range for hazardous wastes should be treated before disposal. A waste, which does not show any pollutant concentration above the maximum values fixed for inert wastes could be destined to inert waste landfill sites.

3. Results and discussion

Table 3 shows the results of TCLP leachate pH and ecotoxicity, expressed as EC_{50}, obtained from the bioluminescence bioassay. Ecotoxiciy results allow the classification of wastes according to the limit value of $EC_{50} \leq 3000\,mg\,l^{-1}$ given by the Spanish Regulations

Table 3
Results of TCLP leachate ecotoxicity for the residues included in this work

Waste code[a]	Leachate pH	EC_{50} (mg l^{-1})	Waste code[a]	Leachate pH	EC_{50} (mg l^{-1})
MI-1	9.64	1000000	HI-1	5.45	19532
MI-2	11.51	1000000	HI-2	5.59	29697
MI-3	9.53	1000000	HI-3	6.32	24441
MI-4	5.34	36300	HI-4	5.77	14580
MI-5	10.80	665370	HI-5	6.74	47300
MI-6	11.27	197320	HI-6	6.51	333150
MI-7	11.28	134986	HI-7	5.71	30010
MI-8	10.58	89210	HI-8	5.68	19038
MI-9	5.56	12967	HI-9	5.96	2917
MI-10	5.54	19207	HI-10	6.19	13841
MI-11	9.10	946081	HI-11	4.76	7978
MI-12	11.87	72250	HI-12	5.04	18294

[a] See Table 1.

for the ecotoxiciy characterisation of wastes (H14). According to previous studies [18,19], in order to obtain a broader and more realistic classification, three ecotoxiciy levels have been defined:

1. Hazardous wastes, with EC_{50} values lower than 3000 mg l^{-1}.
2. Wastes with moderate hazard, with EC_{50} values ranging from 3000 to 30,000 mg l^{-1}.
3. Non-hazardous wastes, with EC_{50} values higher than 30,000 mg l^{-1}.

According to this classification 4% (1 sample) of the incineration residues should be classified as hazardous, 50% (12 samples) can be considered as non-hazardous wastes and 46% (11 samples) could be classified as wastes with moderate hazard, this distribution is shown in Fig. 2. Two facts should be noticed:

1. The ecotoxiciy behaviour of the incineration residues is dependent on the origin of the wastes treated in the incineration processes, as it can be observed in Fig. 3. Residues generated in municipal facilities show EC_{50} values higher than 30,000 mg l^{-1}, exception made of samples MI-6 and MI-12, obtaining the following distribution: 83.3%

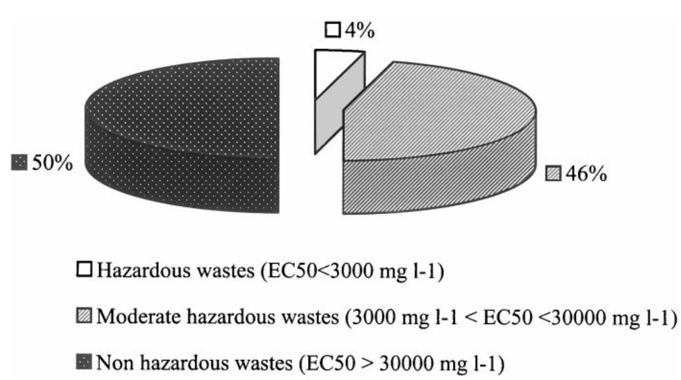


Fig. 2. Distribution of wastes according to the TCLP leachate EC_{50} parameter.

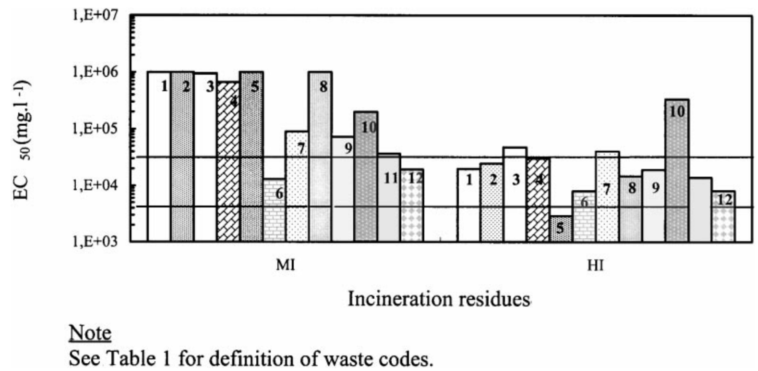


Fig. 3. Ecotoxicity, EC_{50} levels of the TCLP leachates from incineration activities.

non-hazardous wastes and 16.6% wastes with moderate hazard. Residues generated in hospital facilities show a different distribution as 33.3% of this wastes could be classified as non-hazardous wastes, 58.3% should be classified as wastes with moderate hazard and 8.3% should be considered as hazardous wastes.

2. The acidity (pH=2.9 or 4.9) of the extractant used in the TCLP leaching procedure, E.P.A. [20] leads to an experimental leachate pH in the range between 5.5–11.8 considering residues generated in municipal incineration facilities while those leachates coming from hospital incineration facilities wastes keep in a pH range of 4.7–6.7. Some influence of the leachate pH in the ecotoxiciy results of bioassays has been reported by several authors [21]. In this work experimental values of EC_{50} and TCLP leachate pH do not show a clear relationship, as can be observed in Fig. 4.

Table 4 shows the results of pH, metal and anion concentrations of leachates coming from the DIN 38414-S4 leaching procedure.

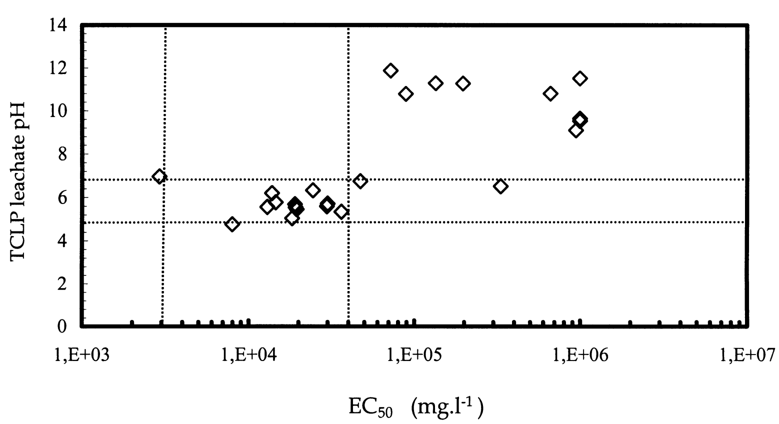


Fig. 4. TCLP leachate pH vs. EC_{50}.

Table 4
Results of DIN-38414-S4 leaching of MSWI and HMWI ash residues used in this work

Waste Code[a]	pH	Chemical leachate composition ($mg\,l^{-1}$)								
		Cd	Cr	Cu	Ni	Pb	Zn	Σ (metals)	SO_4^{2-}	Cl^-
MI-1	12.8	0.09	0.22	0.61	0.23	3.93	2.84	7.92	579	2325
MI-2	11.4	0.05	b.r.[b]	b.r.	0.18	2.60	0.60	3.43	555	2240
MI-3	12.0	b.r.	b.r.	0.91	b.r..	1.38	0.23	2.52	b.r.	220
MI-4	11.4	b.r.	b.r.	0.18	0.27	0.93	0.36	1.56	b.r.	210
MI-5	12.9	0.07	0.41	0.20	0.21	1.38	0.85	3.12	b.r.	2875
MI-6	12.7	0.05	1.10	0.18	0.21	1.12	0.44	3.10	b.r.	2930
MI-7	12.7	0.05	b.r.	b.r.	0.11	0.50	0.22	0.88	b.r.	30.0
MI-8	11.0	b.r.	b.r.	b.r.	0.06	0.15	0.04	0.25	b.r.	21.0
MI-9	7.70	<0.05	b.r.	0.07	0.08	0.05	0.28	0.51	273	25.0
MI-10	7.87	<0.05	b.r.	b.r.	b.r.	0.06	0.28	0.18	290	20.0
MI-11	12.3	0.07	0.08	b.r.	0.05	0.57	b.r.	0.77	b.r.	450
MI-12	12.6	0.05	0.05	b.r.	0.11	0.58	0.07	0.86	b.r.	505
HI-1	11.7	0.05	2.65	b.r.	0.17	0.25	0.05	3.17	n.d.[c]	n.d.
HI-2	11.7	0.05	0.70	b.r.	0.18	0.25	0.05	1.23	n.d.	n.d.
HI-3	5.80	0.06	0.75	0.19	0.17	0,10	0.06	1.33	n.d.	n.d.
HI-4	5.50	b.r.	0.87	b.r.	0.17	0.15	<0.05	1.23	n.d.	n.d.
HI-5	11.5	0.06	2.21	0.04	0.27	0.18	0.06	2.82	n.d.	n.d.
HI-6	11.2	0.11	2.41	0.34	0.24	0.17	0.07	3.34	n.d.	n.d.
HI-7	9.90	0.11	0.09	b.r.	0.29	0.30	0.07	0.86	n.d.	n.d.
HI-8	10.1	0.10	0.14	b.r.	0.33	0.23	0.07	0.87	n.d.	n.d.
HI-9	10.8	0.08	9.75	b.r.	0.22	0.22	0.07	10.34	n.d.	n.d.
HI-10	10.6	0.11	4.48	b.r.	0.24	0.23	0.06	5.12	n.d.	n.d.
HI-11	8.71	0.09	<0.05	b.r.	0.33	0.26	0.07	0.79	n.d.	n.d.
HI-12	8.70	0.16	0.05	0.05	0.30	0.43	0.07	1.06	n.d.	n.d.
Standard values[d]	4–13	0.1–0.5	0.1–0.5	2–10	0.4–2	0.4–2	2–10	5	200–1000	1200–6000

[a] See Table 1.
[b] b.r.: below range of analytical technique.
[c] n.d.: not determined.
[d] Standards for the landfill of wastes [15].

The information given in Table 4 has been compared to the limit concentrations of chemical parameters proposed by the EEC Landfill Directive [15], shown in Table 2, in order to classify the residues.

According to this criteria 8.3% of MWSI residues could be classified as inert, 66.6% are classified as hazardous, with chemical parameters concentration between the hazardous waste range, and 25% of this residues are classified as hazardous, with chemical parameters concentration above the hazardous waste range. This distribution is shown in Fig. 5a.

In the same way, 8.3% of HMWS residues could be classified as inert, and 25% are classified as hazardous with chemical parameters concentration between the hazardous waste range but upto 66.6% of HMWS residues are classified as hazardous, with chemical parameters concentration above the hazardous waste range. This distribution is shown in Fig. 5b.

Different wastes coming from the same type of incineration process are classified in a homogeneous way as hazardous wastes due to the chemical composition of leachates, as it can be seen in Table 5. Pb (samples MI-1 and MI-2) and Cr (sample MI-6) are present

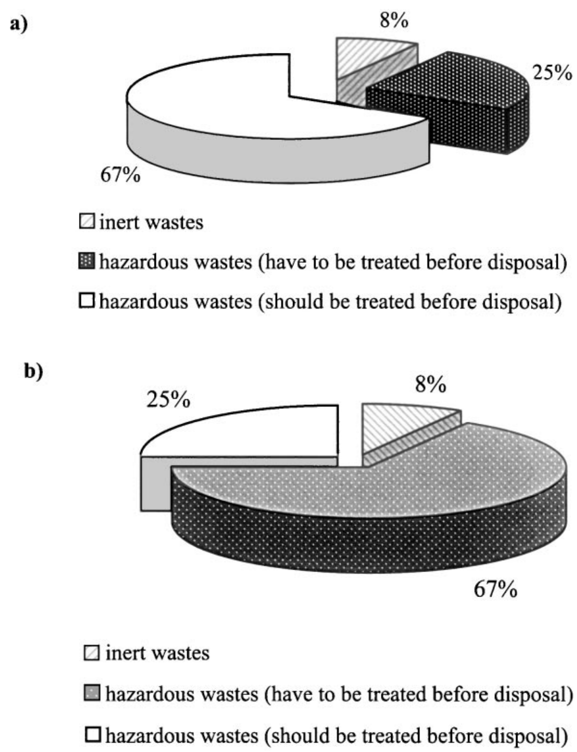
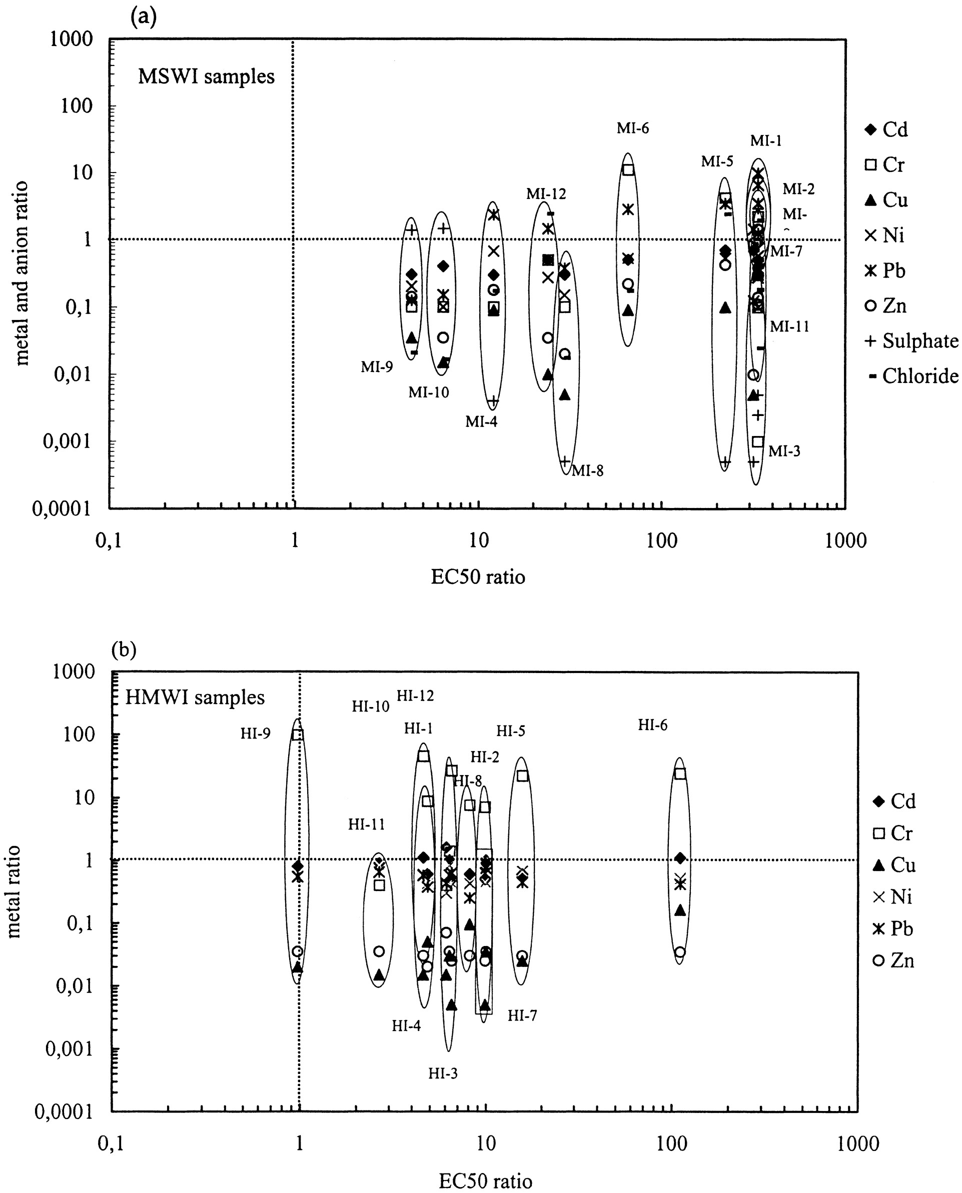


Fig. 5. Wastes distribution according to the proposed EC landfill directive: (a) municipal waste incinerators; (b) hospital medical waste incinerators.

Table 5
Chemical parameters responsible for the residues characterisation as hazardous wastes

Wastes containing chemical parameters above the hazardous range			Wastes containing chemical parameters in hazardous range	
Sample code[a]	Parameters above hazardous range	Parameters in the hazardous range	Sample code[a]	Parameters in the hazardous range
MI-1	Pb	Cr, Zn, SO_4^{2-}, Cl^-	MI-3	Pb
MI-2	Pb	SO_4^{2-}, Cl^-	MI-4	Pb
MI-6	Cr	Pb, Cl^-	MI-5	Cr, Pb, Cl^-
HI-1	Cr	–	MI-7	Pb
HI-2	Cr	–	MI-9	SO_4^{2-}
HI-3	Cr	–	MI-10	SO_4^{2-}
HI-4	Cr	–	MI-11	Pb
HI-5	Cr	–	MI-12	Pb
HI-6	Cr	Cd	HI-7	Cd
HI-9	Cr	–	HI-8	Cd, Cr
HI-10	Cr	Cd	HI-12	Cd, Pb

[a] See Table 1.



Note:
See Table 1 for definition of waste codes.

Fig. 6. Relationship between EC_{50}/3000 and pollutants ratio values: (a) municipal waste incinerators; (b) hospital medical waste incinerators.

in concentrations higher than the hazardous range (indicated in Table 2). Pb, Cr, Cl^-, and $SO_4{}^{2-}$ are pollutants found in MSWI leachates in the hazardous range, Zn can be found but not in levels high enough to classify MSWI wastes as hazardous (except sample MI-1).

HMWI wastes are associated to high Cr concentrations, Cd (samples HI-6, HI-7, HI-8 and HI-10) and Pb (sample HI-12) can also be found. Cu and Ni do not contribute to the hazardous classification of the wastes considered in this work.

The relationship between EC_{50} and the values of chemical leachate parameters for each incineration activity is shown in Fig. 6. This Figure shows the ratio of the DIN 38414-S4 leachate parameter concentration to the limit concentration, given in Table 2, versus the ratio of the TCLP EC_{50} value to the limit value of 3000 mg l^{-1}. Four areas can be distinguished in this Figure depending on the relationship between the chemical parameter ratio and ecotoxiciy ratio.

Fig. 6a shows that 11 MWSI samples present some chemical parameter ratio greater than one (indicating hazardous behaviour) but an ecotoxicy ratio greater than one (indicating non-hazardous behaviour) as well. This fact indicates that MWSI residues can not be classified homogeneously following the ecotoxicity and chemical concentration criteria. Sample MI-8 has been classified homogeneously as non-hazardous using both criteria. Organic pollutants may be responsible of the experimental differences.

Fig. 6b shows that the ecotoxicity shown by HMWI wastes can not be related to the chemical parameters concentration which have been evaluated. Sample HI-11 is classified homogeneously as non-hazardous using both criteria.

The experimental results indicate that the bioluminescence bioassay using Photobacterium Phosphoreum (Microtox®) does not correlate well with the concentration of pollutants, which have been found in this work in the leachates of incinerator residues.

Some previous papers have indicated that different bioassays are not equally sensitive to different types of pollutants [22,23]. It can be concluded that the use of just one bioassay and, even worse, the use of a definitive EC_{50} value for classifying a waste as ecotoxic or non-ecotoxic may ignore categorical degrees of toxicity [24]. Bioassays may be recommended as screening methods, but donot allow a proper control of pollutants in the leachates of wastes.

4. Conclusions

Ash residues from MSW (12 samples) and HMW (12 samples) incineration facilities located in the Basque Country (Northern Spain) have been characterised using Spanish Regulations and European Economic Community guidelines. The application of DIN-38414-S4 and TCLP leaching tests to incinerator residues show different results in the characterisation of such wastes as hazardous or non-hazardous depending on the regulatory parameter associated to the leaching test.

The chemical characterisation of the DIN-S4 leachate of the waste proposed by the European Economic Community for waste disposal cannot be easily related to the TCLP leachate ecotoxicity established by the Spanish Regulation in the characterisation procedure of hazardous wastes.

The chemical characterisation of pollutants in leachates allows a classification of residues in an homogeneous way and allows to identify lead, sulphate and chloride as the most important pollutants in MSWI wastes while chromium is the most significant pollutant found in HMWI wastes.

The EC_{50} value for classifying incineration wastes is not sufficient to determine the potential behaviour of the pollutants in the wastes and it should be related to the chemical composition of leachates as a more important parameter to be controlled after disposal.

Discrepancies in the classification of wastes due to the application of different leaching test and characterisation methods could lead to different management options. Limits should be established in relation to the leaching test, and some statistical evaluation of samples should be taken into account in the application of regulations.

Acknowledgements

This work has been supported by a Basque Country Government contract PGV9046.2.

References

[1] J.A. Stegemann, J. Scheneider, B.W. Baetz, K.L. Murphy, Waste Manage. Res. 13 (1995) 149.
[2] Environmental Protection Agency (EPA) Report EPA/625/6-89/024, Office of Air Quality Planning and Standards, Air and Energy Engineering Research Laboratory & Centre for Environmental Research Information, Office of Research and Development Cincinnati, OH, 1990.
[3] B. Bilitewski, G. Härdtle, K. Marek, in: A. Weiisbach, H. Boeddicker (Eds.), Waste Management, Springer, Berlin, 1994, p. 52.
[4] European Community (EC), List of hazardous wastes, Official Journal of the European Communities No. L 356/14 (94/904/EC), 31 December 1994.
[5] N. Alba, S. Gassó, T. Lacorte, J.M. Baldasano, J. Air Waste Manage. Assoc. 47 (1997) 1170.
[6] P. van Herck, C. Vandecasteele, D. Wilms,. in: J.D. Kilgroe (Ed.), Proceedings of the Air Waste Management Association International Speciality Conference on Thermal Treatment and Waste-to-Energy Technologies for Solid Waste Management 1995, Washington, Air and Waste Management Association, Pittsburgh, 1996, pp. 723–734.
[7] J.H. Tay, A.T.C. Goh, J. Environ. Eng. 117 (1989) 2.
[8] J.D. Hamernik, G.C. Frantz, ACI Mater. J. 88 (1991) 3.
[9] L.G. Carbone, W.H. Gutenmann, D.J. Lisk, Chemosphere 19 (1989) 12.
[10] S.E. Sawell, T.W. Constable, Environmental Protection Series Report 3/UP/8, Waste Water Technology Centre, Environment Canada, Ottawa, ON, 1993.
[11] S. Macakova, M.T. Hepworth, N. Pliesovska, J. Hatala, F. Siska, J. Solid Wastes Technol. Manage. 24 (1997) 1.
[12] BOE, Spanish Law 20/1986, 14 May 1986, Boletín Oficial del Estado, Vol. 120, 1986.
[13] BOE, Spanish Legislative Order of 13th October 1989, Boletín Oficial del Estado, Vol. 270, 1989.
[14] European Community (EC), Proposal for a Council Directive on the landfill of wastes, in: Draft on 5 March 1997, COM (97), 105 final-SYN 335, EC, Brussels, 1997.
[15] European Community (EC), Proposal for a Council Directive on the landfill of wastes, in: Draft on 33 May 1991, COM (91), 102 final-SYN 335, EC, Brussels, 1991.
[16] Environment Canada, Compendium of Waste Leaching Tests. in: Proceedings of the Environmental Protection Series Report EPS 3/HA/7, Waste Water Technology Centre, Environment Canada, Ottawa, 1990.
[17] H.A. van der Sloot, L. Heasman, Ph. Quevauviller, Harmonisation of leaching/extraction tests. in: Proceedings of the Studies in Environmental Science 70, Elsevier, Amsterdam, 1997, p. 227.

[18] R. Ibáñez, Ph.D. Thesis, University of Cantabria, Santander, Spain, 1996.
[19] J. Viguri, R. Ibáñez, A. Andrés, I. Ortiz, A. Irabien, Environ. Technol. 20 (1999) 171.
[20] Environmental Protection Agency (EPA), Toxicity Characterisation Leaching Procedure (TCLP), Final rule 261, 29 March, 55 FR, US Government Printing Office, Washington, DC, 1990, pp. 11798–11877.
[21] S.S. Peterson, J.C. Greene, W.E. Miller, D.C. Wilborn, in: Proceedings of the Third Annual Symposium on Solid Waste Testing Quality Assurance, Washington, 1987.
[22] S. Santiago, R.L. Thomas, G. Larbaigt, D. Rossel, M.A. Echeverria, J. Tarradellas, J.L. Loizeau, L. McCarthy, C.I. Mayfield, C. Corvi, Hydrobiologia. 252 (1993) 231.
[23] K. Tay, K.G. Doe, S.J. Wade, D.A. Vaughan, R.E. Berrigan, M.J. Moore, Environ. Toxicology Chem. 11 (1992) 1567.
[24] K.W. Thomulka, J.H. Lange, Ecotoxicology Environ. Safety. 32 (1995) 207.