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Comparative study of heavy metals in bottom ash from hospital incinerators in the State of Kuwait

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ABSTRACT

During the period from 11–26 January 1999, 144 bottom ash samples were collected from incinerators (48 samples each) in three hospitals in the State of Kuwait, viz. Al-Sabah, Ibn Sina and Psychological Medicine. Three subsamples were collected every morning from three different sites and depths at the primary chamber of each incinerator. Analyses were done with a flame and flameless Atomic Absorption Spectrophotometer (AAS) to determine the concentrations of eight trace metals, viz. chromium (Cr), zinc (Zn), lead (Pb), cadmium (Cd), nickel (Ni), iron (Fe), manganese (Mn), and copper (Cu). The aim of the study was to collect information about the bottom ash samples of hospital waste incinerators in the State of Kuwait in order to determine the proper method of disposal. The results showed that the mean concentrations of heavy metals for bottom ash samples from three incinerators ranged between 730–27,800 $\mu g/g$ of Zn, 727–12,333 $\mu g/g$ of Fe, 192–5,866 $\mu g/g$ of Pb, 100–2000 $\mu g/g$ of Cr, 138–1,988 $\mu g/g$ of Cu, 31–928 $\mu g/g$ of Mn, 21–141 $\mu g/g$ of Ni and 1–56 $\mu g/g$ of Cd. The mean concentrations indicated an abundance of Zn > Fe > Pb > Cr > Cu > Mn > Ni > Cd. The study suggests that care should be taken when the incinerator bottom ash is handled and disposed of. Ash should be stored in covered containers and disposed of in a safe and proper manner at a special landfill.

Keywords: Ash; hazardous waste; heavy metals; hospital waste; incinerators.

INTRODUCTION

Many hospitals have been built in the State of Kuwait mainly within the Al-Sabah Medical Center Complex. Sixteen governmental hospitals are found in the State of Kuwait with a total of 4400 beds (Health Kuwait 1995). The quantity of hospital waste produced per day per bed differs greatly from one country to another, and above all depends on the established procedures at the hospital (DOH & HS 1990). Nearly 33000 metric tons of medical waste are generated by governmental and private hospitals in Kuwait every year with about 10–15% of all hospital waste classified as infectious waste (Rutala & Mayhall 1992). These quantities represent about 31% of the total hazardous solid waste generated in Kuwait (Kuwait EPA 1998). Waste generation has increased steadily over the years and is expected to continue to do so in the future.

Hospital waste is defined as all types of waste discarded by hospitals, nursing homes or other health care facilities, that are not recycled or otherwise reused. It includes disposable foodservice items and office waste, as well as medical waste including infectious and pathological waste (Rushbrook 1999). Infectious waste is defined as the portion of medical waste that can transmit an infectious disease, often described as clinical waste. It can be considered as any waste which consists wholly or partly of human or animal tissue, blood or other body fluids, excretions, drugs or other pharmaceutical products, swabs or dressings, or syringes, needles or other sharp instruments (DOH & HS 1990, US EWG 1997).

In the State of Kuwait there are 12 governmental hospital incinerators, manufactured by different companies, that are being used to burn infectious waste. All of the incinerators were installed during 1979–1980, except two newer incinerators of Italian design located at the Infectious Diseases Hospital and the Psychological Medicine Hospital. These were installed in 1993 and each one has a capacity of 500 kg/hour. The incinerators used at the hospitals contain two combustion chambers with design capacities between 350 and 650 kg/hour. These incinerators are of different levels of efficiency, and are installed away from the hospitals in order to avoid any environmental contamination by gases resulting during the incineration process. The hospitals are incinerating all solid waste generated each day, with one shift/day (about 8 hours) operation. The operation of the incinerators follows a daily cycle consisting of (a) removal of residual ash from the incinerator in the morning, (b) start-up, ignition and initial burning up to the firing temperature, (c) loading of waste into the incinerator as it arrives, and (d) burning down waste in the incinerator. The residual ash removed in step (a) is put into bags and placed in the general waste container for transport to the municipal waste landfill.

The Al-Sabah Hospital is a general hospital which has 324 beds and a bed occupancy rate (BOR) of 56.22% (Health Kuwait 1995). The hospital has an old Hoval-580 incinerator, commissioned in 1980, with a design capacity of 560 kg/hour. Waste is fed into the primary chamber by an automatic hydraulic system. The primary and secondary chambers have minimum temperatures of 650°C and 850°C, respectively. According to information obtained from the operators, about 150 bags (10 kg per bag) are being handled daily, i.e. 1500 kg/day hazardous waste are incinerated. There is no gas cleaning system linked to the old incinerator and de-ashing is performed manually (Rushbrook 1999).

The Ibn Sina Hospital, specializing in ophthalmology, nephrology, burns, oncology and radiotherapy, has 306 beds and a BOR of 49.68% (Health Kuwait 1995). The hospital has an old Hoval-350 incinerator manufactured in 1979, with a capacity of 350 kg/hour. Waste is manually fed into the primary chamber through a door. The primary and secondary chambers have minimum temperatures of 600°C and 800°C, respectively. According to information obtained from the operators, about 100 bags (10 kg per bag) are being handled daily, i.e. 1000 kg/day hazardous waste are incinerated. There is no gas cleaning system attached to the incinerator and de-ashing is performed manually (Rushbrook 1999).

The Psychological Medicine Hospital, serving patients referred from throughout the country, has 456 beds and a BOR of 93.1% (Health Kuwait 1995). The hospital has an incinerator of Shunt Italian design commissioned in 1993 with a capacity of 500 kg/hour. The primary and secondary chambers have minimum temperatures of 850°C and 950°C, respectively. According to information obtained from the operators, about 120 bags (10 kg per bag) are being handled daily, i.e. 1200 kg/day hazardous waste are incinerated. The plant is equipped with a water-scrubber, gas cleaning system and de-ashing is performed manually (Rushbrook 1999).

Hospital incinerator ashes

The incineration process will remain one of the most viable methods for disposal of medical hazardous wastes. Incineration reduces the original volume by 65–70%, and generates bottom ash (BA) and fly ash (FA) (Lombardi *et al.* 1998). Facilities which incinerate hazardous wastes with significant ash or halogen content will generate combustion chamber bottom ash and various types of residues collected by subsequent air pollution control equipment. Under the Resource Conservation and Recovery Act (RCRA) EPA (1990a), these ashes and residues are generally classified as hazardous waste. The principal contaminants of interest are heavy metals and any undestroyed organic material (Oppelt 1987). Ash is the noncombustible inorganic residue remaining after the ignition of combustible substances, and bottom ash means the solid material that remains on a hearth or falls through the grate after incineration is completed (US EPA 1990b). Thermal oxidation of solid wastes yields quantities of ash at approximately 5–10% of the original waste quantity (Bisson & Shaner 1993). Some ash however, is carried along with the gases as small particles, or particulate matter, and various types of residues are collected by subsequent air pollution control equipment. These two ashes can have notably different ways in which they are formed and they usually have quite different physical properties as well.

Little data has been reported describing the concentrations of the constituents of medical incinerator ash. Heavy metals have been found in hospital incinerator emissions and are expected to be present in incinerator bottom ash (COTA 1990). There are a number of published studies on the heavy metal content in fly ash samples, while there is little information on heavy metal content in bottom ash samples (Al-Muzani & Jacob 1996). Lead (Pb) is one of the selected elements that could enter the food chain and is present in bottom ash. Lead that has been reported in the different types of ash varies widely in concentration from as low as 31 mg/kg (ppm) to 36,000 mg/kg (ppm). Cadmium (Cd) concentration in municipal solid waste (MSW) bottom ash ranges between 1.1–46 mg/kg (ppm) (Korzun & Heck 1990).

Heavy metals have been found in hospital incinerator ash. Lead and cadmium are found in radioisotope shielding as well as pigments and additives in plastics. The US EPA has reported that plastics comprise approximately 20% by weight of all hospital waste, compared with 5–10% in municipal solid waste (US EWG 1997). This waste contains higher than average amounts of heavy metals, which contribute to the observation of high metal content in ash (US EPA 1987, Rutala *et al.* 1989, Bisson & Shaner 1993). Lead is present in soldered cans and bottle capsules, leaded gasoline, discarded lead batteries etc. All kinds of batteries can contribute nickel, cadmium, mercury and zinc (Roberts 1998). Cadmium (Cd), one of the more toxic metals that is both carcinogenic and teratogenic, is widely used as a coating material, paint pigment, in batteries and as a component of red plastic bags that gives them their colour. Plastics are the major sources of lead and cadmium in the bottom ash (US EWG 1997). Manganese (Mn) is an important element for the production of batteries and dry cells. Nickel (Ni) is found in alloys and batteries, chromium from chrome plating, contaminated laundry detergent and bleaches. Copper is formed due to corrosion of brass and copper products. There are many other ways in which small amounts of these (and other) toxic metals may appear in medical waste.

The potential health hazards due to the toxicity of heavy metals that may be present in residual ash are of great concern, and this paper will highlight the concentration and pollution levels of eight trace metals in the bottom ash of incinerators in the State of Kuwait to determine the proper method of disposal.

MATERIALS AND METHODS

During the period from 11–26 January 1999, 144 bottom ash samples were collected from three hospital incinerators (48 samples each). The study covered two older Hoval incinerators and one incinerator of newer Italian design; these are at the Al-Sabah, Ibn Sina and Psychological Medicine hospitals, respectively. Three sub-samples were collected every morning from three different locations and depths at the primary chamber of each incinerator and kept in tightly closed non-contaminating plastic bags (about 1 kg) to avoid any contamination. All samples were labeled with information concerning the hospital name and the date of collection.

Ash samples were crushed in a porcelain mortar and pestle, passed through a #40-mesh sieve and stored in glass bottles. All ash samples were dried in the oven at 105°C for 3 h to remove humidity. Between 0.25–0.5 grams of well- homogenized dry ash sample was placed a 150-ml Teflon beaker previously cleaned with concentrated nitric acid and double de-ionized distilled water (DDDW). The samples were dried at 105°C, then 2-ml of concentrated HNO_3 was added to the Teflon beaker, and evaporated to near dryness at 80°C. Thereafter 6-ml of an acid mixture ($HNO_3/HClO_4/HF$) (3:2:1) was added, the solution was heated to a temperature between 60–80°C evaporated to near dryness on a controlled temperature hot plate. The temperature was gradually increased to 120°C to remove the $HClO_4$ residue and bring a clear solution. The solution was cooled to room temperature. A 5-ml aliquot of dilute hydrochloric acid (0.1 N) was used to rinse the beaker and the residue was transferred to a 25-ml volumetric flask. Another 5-ml of 0.1 N HCl was added to the beaker and transferred to the flask to make up the volume with 0.1 N HCl. It is highly important that the first digestion with HNO_3 is used to remove most organic matter in the sample. The suspension was filtered through #44 Whatman filter paper and then analyzed with a Shimadzu Atomic Absorption Spectrophotometer (AAS), model #AA-680, equipped with a graphite furnace (flameless) for the analyses of Cd, Pb and Ni, and AAS flame for Mn, Cr, Cu, Fe and Zn, according to the standard methods for the analysis (APHA *et al.* 1985, Kuwait EPA 1998). Sample solutions following standard levels were prepared according to specific procedures used for ash samples. The instrument was calibrated using reference standards obtained from the National Institute for Standards and Technology, Washington DC, USA.

RESULTS AND DISCUSSION

Tables 1a, 1b and 1c contain the mean concentrations of trace metals in the bottom ash samples collected from the 3 incinerators and the average for the 16 samples included in the study. The measurements are in $\mu g/g$ (ppm) and are illustrated graphically in Figs. 1a and 1b.

Based on the complete data set for the trace element mean concentrations, a simple comparison has been made and the results of this comparison are summarized in Table 2. The results showed that the ash samples from the Al-Sabah incinerator contained as much as 727–8867 $\mu g/g$ of Fe, 730–6800 $\mu g/g$ of Zn, 601–2940 $\mu g/g$ of Pb, 127–928 $\mu g/g$ of Mn, 150–687 $\mu g/g$ of Cu, 200–667 $\mu g/g$ of Cr, 24–49 $\mu g/g$ of Ni and 2–10 $\mu g/g$ of Cd. The levels reported had an abundance of Fe > Zn > Pb > Mn > Cu > Cr > Ni > Cd in the ash samples.

It can be seen from Table 2 that the ash samples from the Ibn Sina incinerator contained as much as 867–27,800 $\mu g/g$ of Zn, 192–5,866 $\mu g/g$ of Pb, 1167–5,700 $\mu g/g$ of Fe, 100–2000 $\mu g/g$ of Cr, 138–1998 $\mu g/g$ of Cu, 31–298 $\mu g/g$ of Mn, 25–141 $\mu g/g$ of Ni and 1–56 $\mu g/g$ of Cd. The concentration levels showed an abundance of Zn > Pb > Fe > Cr > Cu > Mn > Ni > Cd.

Table 1(a). Al-Sabah Hospital.
Mean concentrations of heavy metals in bottom ash of incinerator $\mu g/g$ (ppm)

Samples No.	Cr M	Zn M	Pb M	Cd M	Ni M	Fe M	Mn M	Cu M
1	533	730	2940	4	41	727	350	207
2	200	1900	601	2	32	7667	333	240
3	500	5533	2366	2	28	4467	277	150
4	280	6800	1534	2	30	7567	127	687
5	587	4933	1910	2	49	8133	484	253
6	633	4933	2016	10	33	7700	485	200
7	633	5133	1732	4	37	7500	383	216
8	667	5467	1985	5	37	8867	597	247
9	467	4767	2058	4	31	7467	446	238
10	500	4833	2165	5	30	7433	552	228
11	433	6300	2496	4	24	8433	928	237
12	600	5933	2019	5	33	7500	544	309
13	600	5233	2615	5	33	7567	448	567
14	500	4400	2120	5	29	6600	440	561
15	667	6067	2314	5	32	8700	549	652
16	601	5533	2297	5	26	7800	424	569
Average	525.06	4905.94	2073	4.31	32.81	7133	460.44	347.56
STD	128.44	1498.95	502.71	1.89	5.84	1911.8	166.4	180.13

M = Mean concentrations of each 3 subsamples collected every day.
STD = Standard Deviation.
Regression statistics analysis of Al-Sabah elements vs Psychological elements.
R Square = 0.76.2
P-value = 0.0046 at 95% Confidence Level (CL).

Table 1(b). Ibn Sina Hospital.
Mean concentrations of heavy metals in bottom ash of incinerator μg/g (ppm)

Samples No.	Cr M	Zn M	Pb M	Cd M	Ni M	Fe M	Mn M	Cu M
1	333	12767	1860	2	48	4867	113	704
2	100	867	192	2	33	1167	31	138
3	633	7833	2135	5	53	3533	139	372
4	1000	14933	4762	3	46	3967	255	1046
5	733	9733	2729	1	25	2833	124	320
6	1233	27800	4654	8	44	4400	298	596
7	1567	17267	4888	3	141	4633	191	1998
8	1233	11233	4334	3	50	4800	273	904
9	1200	9633	3563	10	45	3667	155	455
10	993	15267	5749	56	67	5400	179	1189
11	1633	17133	6147	49	57	4433	192	808
12	1733	10800	5369	8	54	4833	232	548
13	1200	18733	5388	6	35	4700	191	549
14	1100	24800	4936	14	97	5700	213	1919
15	2000	17433	5854	2	36	3900	240	499
16	1733	15867	5866	20	47	4933	328	482
Average	1151.5	14506.19	4276.63	12.00	54.88	4235.38	197.13	782.94
STD	505.53	6279.03	1700.66	16.12	27.27	1057.29	73.02	530.2

M = Mean concentrations of each 3 subsamples collected every day.
STD = Standard Deviation.
Regression statistics analysis of Ibn Sina elements vs Psychological elements.
R Square = 0.856
P-value = 0.001 at 95% Confidence Level (CL).

The data from the Psychological Medicine incinerator showed that the ash samples contained as much as 3,933–16,067 μg/g of Zn, 4,233–12,333 μg/g of Fe, 616–2,307 μg/g of Pb, 208–2,034 μg/g of Cu, 183–663 μg/g of Cr, 99–389 μg/g of Mn, 21–52 μg/g of Ni and 1–16 μg/g of Cd. The levels indicated an abundance of Zn > Fe > Pb > Cu > Cr > Mn > Ni > Cd in the ash samples.

Figures 1a and 1b show that Ibn Sina incinerator ash had the highest contents of Cr, Zn, Pb and Ni while Al-Sabah incinerator ash had the highest content of Fe and Mn. Therefore, for 6 elements the highest mean concentrations were reported for the two older Al-Sabah and Ibn Sina incinerators. The detected mean concentrations of the elements varied daily depending on the composition and the amount of metals in the input waste stream at each hospital.

The high concentration of lead in the analyzed samples is due to its presence in soldered cans, bottle capsules, pigments, leaded gasoline and plastic which are the major sources of lead and cadmium in the bottom ash. Disposable gloves and talc powder in medical waste are a major source of Zn. Iron is present in some medical tools and damaged firebricks which are used as material for the primary chamber. For these reasons, the bottom ash samples analyzed were found to be more highly polluted with these three heavy metals (Pb, Fe, Zn) than other metals.

The bottom ashes for all the hospital incinerators in the Ministry of Health, Kuwait are collected and cleared from the primary combustion chamber of each incinerator every morning before starting the incineration process. The ash removal

Table 1(c). Psychological Medicine Hospital.
Mean concentrations of heavy metals in bottom ash of incinerator μg/g (ppm)

Samples No.	Cr M	Zn M	Pb M	Cd M	Ni M	Fe M	Mn M	Cu M
1	300	9333	1015	2	21	12333	158	2034
2	300	5567	1097	2	28	7933	159	469
3	183	11933	815	16	29	6367	182	532
4	300	9933	1002	3	40	5267	111	1266
5	300	10766	1856	3	52	7200	186	1177
6	200	13866	616	2	23	4233	116	675
7	333	9067	1042	2	33	4467	159	851
8	600	3933	2305	5	42	6867	389	216
9	600	4000	2307	5	37	6733	365	208
10	200	13400	1059	2	33	4533	99	1408
11	267	11400	1737	3	32	6467	137	1051
12	267	11000	1714	4	25	5167	108	762
13	300	9433	1816	3	30	4967	130	506
14	333	14967	1114	1	37	4733	186	422
15	367	16067	1307	3	36	6667	139	2001
16	633	4433	2074	5	38	7400	366	223
Average	342.69	9943.62	1429.75	3.81	33.50	6333.36	186.88	862.56
STD	137.90	3710.72	522.32	3.36	7.55	1921.60	93.48	567.30

M = Mean concentrations of each 3 subsamples collected every day.
STD = Standard Deviation.

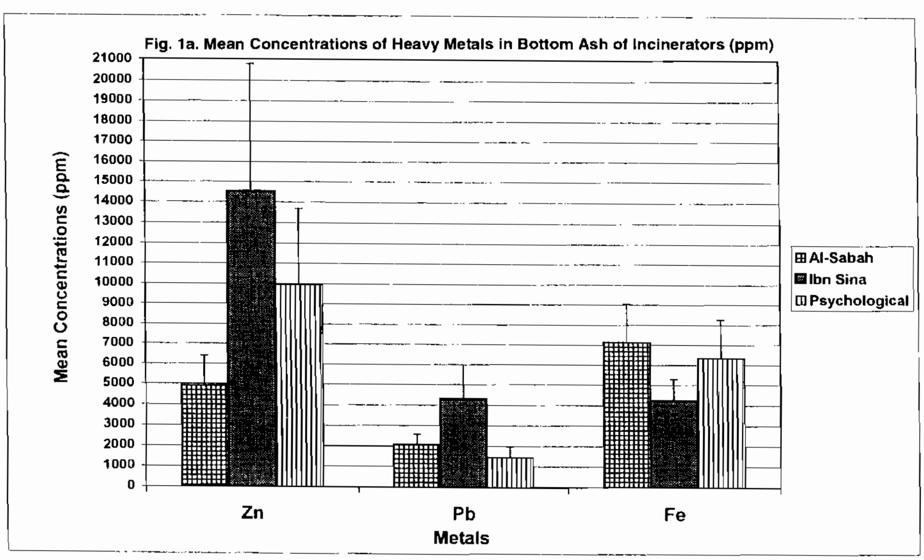

Fig. 1a. Mean concentrations of heavy metals in bottom ash of incinerators (ppm).

is usually done manually; the ash is put into bags and placed in the general waste container outside for transport to the municipal waste landfill. Thus, trace elements in the ash could become toxic to the surrounding biota when their concentrations exceed crop and animal tolerance limits for these elements. At the same time, high

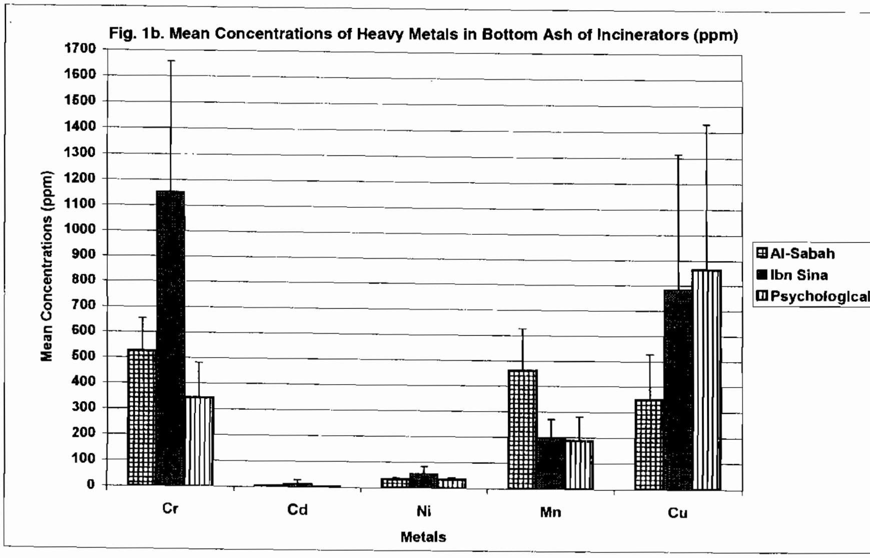

Fig. 1b. Mean concentrations of heavy metals in bottom ash of incinerators (ppm).

Table 2. Minimum and maximum mean concentrations of heavy metals in the bottom ash of three incinerators μg/g (ppm)

Incinerator	Zn	Fe	Pb	Cu	Cr	Mn	Ni	Cd
Al-Sabah								
Minimum	730	727	601	150	200	127	24	2
Maximum	6800	8867	2940	687	667	928	49	10
Ibn Sina								
Minimum	867	1167	192	138	100	31	25	1
Maximum	27800	5700	5866	1998	2000	298	141	56
Psychological								
Minimum	3933	4233	616	208	183	99	21	1
Maximum	16067	12333	2307	2034	633	389	52	16

concentrations of trace elements in soil could represent a major source of pollution to ground and surface water (Yaron *et al.* 1996). Toxic metals are of considerable environmental concern due to their toxicity and accumulative behavior (Al-Muzami & Jacob 1996). The US EPA proposed the Toxicity Characteristic Leaching Procedure (TCLP) as a test procedure to be used in determining whether or not a waste is classified as hazardous, and whether or not it can be land disposed. The heavy metals standards for hazardous waste according to TCLP are 1.0 mg/l for Cd, 5.0 mg/l for Cr and 5.0 mg/l for Pb (US EPA 1990a). The present study did not conduct the TCLP because it does not cover all the heavy metals analyzed during the study. Table 2 shows the maximum concentrations of Cr, Pb and Zn in the present study as 2,000 μg/g, 5,866 μg/g and 27,800 μg/g respectively and these would be expected to give higher limits than the US EPA standard test of 5.0 mg/l.

Therefore, according to US EPA standards and the Basel Convention on the control of transboundary movements of hazardous wastes and their disposal (UNEP & SBC 1997), these ashes and residues are generally classified as hazardous waste.

CONCLUSION AND RECOMMENDATIONS

From the data analysis of heavy metals in the bottom ash samples of the three hospital incinerators, it was observed that the highest concentration levels were reported as 730–27800 $\mu g/g$ of Zn, 727–12333 $\mu g/g$ of Fe and 192–5866 $\mu g/g$ of Pb, and the lowest heavy metal concentration levels were reported as 1–56 $\mu g/g$ of Cd, 21–141 $\mu g/g$ of Ni and 31–928 $\mu g/g$ of Mn. Between the two groups occur Cr as 100–2000 $\mu g/g$ and 138–1998 $\mu g/g$ of Cu. The mean concentrations for the three incinerators' ashes showed a trend of Zn > Fe > Pb > Cr > Cu > Mn > Ni > Cd. The results of the regression analysis between the average values of the eight heavy metals for the two older incinerators and the new one indicate that there is no significant difference but there is some difference between the older incinerators (R Square = 0.462 and P-value = 0.064 at 95% Confidence Level).

Based on the above conclusions, we recommend that care should be taken in the specifications and disposal of plastic tools and packaging materials in hospitals in order to minimize their contribution to the ash composition. Care should also be taken when the incinerator ash and non-combustible residues are removed from the incinerators. Ash should be moved and stored in covered containers and should be disposed of in a safe and proper manner at a special landfill or hazardous waste land disposal facility to prevent potential leakage of toxic substances from these ashes and subsequent pollution of groundwater.

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دراسة مقارنة لتركيز العناصر الثقيلة (النذرة) في الرماد المتبقي لمحارق نفايات المستشفيات بدولة الكويت

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الخلاصة

شهدت دولة الكويت خلال السنوات الماضية توسعا ملحوظا في بناء المستشفيات الحكومية بمنطقة الصباح الطبية، يتولد عنها كمية من النفايات الطبية تقدر بحوالي 33 ألف طن سنويا، تحتوي هذه النوعية من النفايات المعدية التي تشمل النفايات الباثولوجية، والأنسجة والإفرازات البشرية والأسلحة والأدوات بجانب نفايات المختبرات المختلفة، وكلها تتطلب طرق معالجة وتخلص مناسبة، نظرا لتأثيراتها الصحية والبيئية.

وتتوافر بالمستشفيات الحكومية بدولة الكويت حاليا 12 محرقة مختلفة في بلد وتاريخ الصنع والكفاءة، ومعظمها تم بناءه منذ بناء المستشفيات، مما جعل كفاءة الحرق لها غير مناسبة، خاصة وأن درجة حرارة الحرق في غرفة الاحتراق الأولى تصل إلى 650 درجة مئوية.

ولقد أجريت هذه الدراسة التحليلية بهدف التعرف على نواتج الحرق من الرماد المتبقي لثلاث محارق مختلفة تتواجد في مستشفيات (الصباح- ابن سينا- الطب النفسي)، حيث تم جمع وتحليل عدد 144 عينة (48 عينة لكل محرقة) جمعت خلال الفترة من (11-26) يناير 1999، وتم تحليلها باستخدام جهاز الفصل الكروماتوجرافي وقياس تراكيز ثمان عناصر ثقيلة، هي (الكروم- الزنك- الرصاص- الكادميوم- النيكل- الحديد- المنجنيز- النحاس).

وقد بينت التحاليل للمحارق الثلاث أن الرماد يحتوي على تراكيز عالية من تلك العناصر، وأن هذه التراكيز تتناقص وفقا للترتيب التالي: الزنك، الحديد، الرصاص، الكروم، النحاس،

المنجنيز، النيكل، الكادميوم. وقد أوصت الدراسة بضرورة التعامل مع هذه النوعية من النفاية على أنها نفايات خطرة.