

Solidification/Stabilization of Heavy Metals from Air Heater Washing Wastewater Treatment in Thermal Power Plants

Amini, H. R.¹, Saeedi, M.^{2*} and Baghvand, A.³

¹Department of Civil and Environmental, Engineering, University of Florida, Orlando, FL, USA

²Department of Hydraulics & Environment, College of Civil Engineering, Iran University of Science & Technology, Tehran, Iran

³ Faculty of Environment, University of Tehran, Tehran, Iran

Received 15 May 2007;

Revised 20 Feb. 2008;

Accepted 5 March 2008

ABSTRACT: In the present investigation, for the first time in Iran, dewatered sludge waste from air heater washing wastewater treatment of a thermal power plant was subjected to investigation of the cement base stabilization and solidification experiments in order to reduce the mobility of heavy and other hazardous metals as well as increasing the compressive strength of the solidified product for possible reuse of the waste. The solidification was done with two cement based mix designs with different waste/cement ratio in different samples. The results of leaching test on the solidified samples revealed that regarding the sand-cement mixture even with 25% waste/cement ratio, the leaching of heavy metals has completely been controlled up to 95%. In cement stabilization process the leaching of V, Ni, Zn and Cr could be decreased from 314.1, 209.1, 24.8 and 5.5 mg/L respectively in the raw waste to 6, 32.1, 3.6 and 3.6 mg/L in a mixture with 20% waste/cement ratio. During stabilization with cement-sand, the TCLP leachate contents of mentioned metals have been decreased to 4.2, 16.2, 2.5 and 2.2 mg/L with waste/cement ratio of 20%. X-ray diffraction studies showed that portlandite, calcite, lime, larnite and quartz have been shaped during the stabilization process. The compressive strength test results revealed that in both mixture samples, decreasing the compressive strength with increasing the amount of waste content in the mixture occurs. In sand-cement solidified samples with waste/cement ratio 25% and in cement solidified samples with waste/cement ratio 20%, a 40% decrease occurs in the compressive strength in comparison with the waste free mixtures.

Key words: Power plants waste, Heavy metals, Stabilization, Solidification Corresponding Author

INTRODUCTION

Most of electricity is generated by thermal power plants in Iran. In most of thermal power plants usually natural gas is burnt from spring to late falls. As a result of increased municipal consumption of natural gas and consequently its pressure loss during late autumn and winter time, fuel oil is burnt to generate electricity in thermal power plants of Iran (Iran MOE, 2005). In thermal power plants, the air heaters are indirect heat exchange devices that transfer energy from flue gas to incoming fresh air in order to increase the efficiency of the energy generation (El-Wakil, 1985). Due to existence of particulate matter in flue gas and scaling of

heat transfer surface, air heaters have to be washed and cleaned frequently. The resulting wastewater contains different heavy and other hazardous metals particularly V, Ni, Zn, Cr, Pb (Elliott, 1989). This wastewater is then treated in effluent treatment plants by chemical precipitation technology. Sludge from this process is then dewatered but still retains the same contaminants and is classified as specific industrial waste which regardless of the quantity should be characterized in detail (i.e. toxicity leaching characteristics) under the specific wastes act of Iran (Iran DOE, 2005). Regarding Iranian regulations, if the waste is categorized as hazardous, facility owners are not allowed

*Corresponding author: Email- msaeedi@iust.ac.ir

to dispose or landfill it in municipal solid waste landfills unless they are stabilized. For development of a more efficient stabilization method, waste characterization studies should be conducted first. Characterization of this waste has been conducted and reported before (Saeedi & Amini, 2007). Stabilization/solidification as an effective technology for treatment of hazardous wastes has been numerously recommended and used on different hazardous wastes in the world (Malone & Jones, 1979; Cullinane *et al.*, 1986; Cullinane & Jones, 1986; Wetzman, *et al.* 1988; Barth *et al.*, 1990; Conner, 1990; Dermata & Meng, 1995; Jang & Kim, 2000; Leist *et al.*, 2003; Duchense & Laforest, 2004; Bagnoli *et al.*, 2005). Pojasek (1979) introduced the scientific principles of the solidification/stabilization technology and some related tests to evaluate the effectiveness of the method. Barth *et al.* (1990) showed that using cement and pozzolanic materials as binders in stabilization of heavy metals containing waste was effective to reduce the leaching of those pollutants. During the method, a binder material is added to the waste and cured so as to produce a solid mass that has minimum leaching of pollutants. Different materials are used as binders during this method. One of the most popular, subjected to sludge waste containing inorganic compounds, particularly heavy metals, is cement based mixtures. Stabilization of heavy metals in wastes have been conducted using either cement based binders (Park, 2000; Jang & Kim, 2000; Jing *et al.*, 2004; Sophia & Swaminathan, 2005; Duchense & Laforest, 2004; Bagnoli *et al.*, 2005) or non cement based binders (Leist *et al.*, 2003; Jing *et al.*, 2004).

Sophia and Swaminathan (2005) have used different binders such as cement and fly ash in order to stabilize electroplating waste and reported that the use of cement have shown better results. Along side producing a solid mass, cement can possibly make some changes in the chemical composition of the waste so as to decrease the toxicity of the compounds in the product. The solid mass produced from stabilized waste was also subjected to the same laboratory tests executed on the raw waste in order to study the effectiveness of the used

method. Stabilization of heavy and other hazardous metals in sludge waste from air heater washing wastewater treatment in fuel oil burning thermal power plants has not been studied before.

Shahid Rajae thermal power plant is located at 100 km west of Tehran and consists of four 250MW natural gas and fuel oil burning units. Wastewater from air heater washing in Shahid Rajae thermal power plant is treated by precipitation through aluminum sulphate and lime. In the present investigation for the first time in Iran, dewatered sludge waste from air heater washing wastewater treatment were subjected to investigations stabilization/solidification treatment in order to reduce the leachability of heavy and other hazardous metals particularly V, Ni, Zn and Cr. While the main target of the study was reducing toxicity leaching characteristics of those metals, producing a solid material with considerable mechanical strength in order to probable reuse or safe disposal in landfills were in mind. Almost 20 t/year of this waste is generated in Shahid Rajae thermal power plant.

MATERIALS & METHODS

In January 2005, 35 waste samples were taken from dewatered sludge originating from the precipitation of air heater washing wastewater from Shahid Rajae thermal power plant. The collected samples were stored in a cool place in sealed bags until analysis. Seven composite samples were prepared by homogenizing and combining every fifth sample. The samples were air dried at room temperature to constant mass before being divided and screened for further characterization studies (Saeedi & Amini, 2007). After the characterization studies all samples were mixed and homogenized thoroughly for further solidification/stabilization experiments.

Density of samples was determined using ASTM D 4254 method. Samples' pH was determined using a Cyber Scan PC510 pH meter. The chemical composition of samples was determined by X-ray fluorescence (XRF; Phillips PW 2404). Mineralogical composition of previously calcined (at 1000 °C) samples was determined by X-ray diffraction analysis (Bruker

D4 Endeavor XRD). The acceleration voltage and current were 40kV and 30mA respectively. Leaching tests were performed according to toxicity characteristic leaching procedure (TCLP) U.S.EPA-1311 method to determine metals mobility under natural worst case conditions (USEPA, 1992). The liquid/solid ratio was 20 L/kg. The mixture was stirred for an 18 hour period at a rate of 30±2 rpm and then filtered with a 0.7 µm filter. The pH of the mixtures were measured and decreased by adding nitric acid to be less than 2. After TCLP test, the elemental (Cd, Co, Cr, Mn, Ni, Pb, V and Zn) concentrations were determined using atomic absorption spectrometry (Buck Scientific 210 VP model). The morphology of the raw and solidified waste samples was observed using a research polarize microscope (RPM). A Zeiss RPM device was used and photography was taken by a Canon J5 scientific camera with size 150X. Photographs of samples were prepared by making a 30 µm thin section slid sample from the waste.

The mixtures were made using two cement based mix designs. One consisting of “cement-waste-water and the other “sand-cement-waste-water”. The mix design was generally based on the ASTM-C109-90 standard mix design with the difference that waste was added with a specific waste/cement ratio in each sample. Also one blank sample was made for each of the two mixtures to make the results comparable and accuracy check.

Table 1. Mix design of Cement solidified samples

Waste/Cement Ratio (%)	Waste (gr)	Cement (gr)	Water (gr)
0	0	301.50	146.20
10	30.15	301.50	150.80
20	60.30	301.50	155.30
30	90.45	301.50	159.80
40	120.60	301.50	164.30
50	150.75	301.50	168.80

Table 2. Mix design of Sand-Cement solidified samples

Waste/Cement Ratio (%)	Waste (gr)	Cement (gr)	Sand (gr)	Water (gr)
0	0	82.22	226.11	39.9
5	4.11	82.22	226.11	39.9
10	8.22	82.22	226.11	39.9
15	12.33	82.22	226.11	39.9
20	16.44	82.22	226.11	39.9
25	20.55	82.22	226.11	39.9

The weight of each material in each sample is provided in Tables 1 and 2. Cubic 50 mm samples were prepared and cured for 7 and 14 days and the compressive strength was tested according to the ASTM-C109-90 standard. This test was done with an ELE-Elect 2000 Digital device.

RESULTS & DISCUSSION

The results of the physical, chemical and leaching characteristics of the raw waste have been reported before (Saeedi & Amini, 2007). In order to be able to compare the results of the experiments the determined characteristics of the raw waste are presented in all appropriate tables of the results. The physical characteristics of the raw and solidified waste samples are presented in Table 3. The pH of all solidified samples is more than 12.0. This shows the effect of cement in the samples and the basic properties from this material which has completely desolated the acidic properties of the raw waste. Density results from the raw waste shows that this waste is lighter than cement and sand, so it is expected that the density decreases in samples with higher waste content (Table 3). It is obvious that in solidified samples, as the waste/cement ration increases, the density of the product decreases. Chemical composition of raw and solidified waste samples determined by XRF method is presented in Table 4. As we were concerned on the presence of heavy metals in this study, all the related components have been determined and presented. The main constituent

Table 3. Physical characteristics of the raw and solidified waste samples

Sample Code	Waste/Cement Ratio (%)	Density (kg/m ³)	pH
Mean Raw Waste	-	1879	6.31
Cement Solidified	Blank	0	2061
	1	10	2028
	2	20	1976
	3	30	1916
	4	40	1888
Sand + Cement Solidified	5	50	1847
	Blank	0	2084
	1	5	2077
	2	10	2062
	3	15	2042
4	20	2020	
5	25	2000	

Table 4. Chemical composition of raw and solidified waste samples

Compound	Sample						Sample						
	Mean Raw Waste	Blank	1	2	3	4	5	Blank	1	2	3	4	5
Waste/Cement Ratio (%)	-	0	10	20	30	40	50	0	5	10	15	20	25
Compound							Concentration						
Na ₂ O (%)	0.50	0.35	0.29	0.43	0.35	0.38	0.40	0.27	0.36	0.28	0.36	0.34	0.28
MgO (%)	1.76	-	-	-	-	-	-	-	-	-	-	-	-
Al ₂ O ₃ (%)	2.59	3.92	3.08	3.79	3.46	3.77	3.81	3.71	3.75	3.82	3.80	3.78	3.82
SiO ₂ (%)	5.91	25.82	21.14	22.71	21.63	21.75	21.83	37.53	40.60	34.69	39.41	37.99	34.69
P ₂ O ₅ (%)	3.39	0.062	0.130	0.429	0.414	0.544	0.691	0.078	0.114	0.165	0.219	0.240	0.165
Fe ₂ O ₃ (%)	68.88	2.21	7.23	9.91	11.24	12.96	14.89	5.11	4.13	5.06	5.70	6.62	5.06
MnO (%)	0.46	0.087	0.075	0.102	0.103	0.110	0.116	0.073	0.074	0.079	0.083	0.079	0.079
K ₂ O (%)	0.17	0.47	0.49	0.65	0.51	0.49	0.50	0.41	0.54	0.38	0.48	0.45	0.38
CaO (%)	2.64	61.49	63.56	61.81	58.96	56.77	55.97	49.46	48.61	51.04	45.46	46.14	51.04
TiO ₂ (%)	0.08	3.115	1.849	2.851	2.709	2.845	3.065	3.861	3.593	4.062	3.886	3.583	4.062
V (mg/kg)	64413	11	234	505	563	689	815	41	93	164	213	268	164
Ni (mg/kg)	17375	21.9	1038.6	2158.7	2504.7	2978.0	3416.1	182.1	474.3	825.8	980.3	1279.7	825.8
Zn (mg/kg)	1511	51.6	47.8	73.3	91.9	110.2	118.3	82.2	93.4	64.5	122.0	104.9	64.5
Sr (mg/kg)	627	182	199	202	201	208	203	104	114	113	114	116	113
Cr (mg/kg)	6236	16	328	641	714	845	1011	52	115	204	252	336	204
Cd (mg/kg)	1	0.50	0.07	0.05	0.23	0.38	0.05	0.08	0.19	0.08	0.16	0.10	0.08
Co (mg/kg)	129	3.45	6.83	21.12	24.36	28.38	33.04	5.38	7.77	9.85	11.20	13.35	9.85
Hg (mg/kg)	1	0.039	0.291	0.273	0.263	0.216	0.255	0.086	0.069	0.074	0.078	0.080	0.074
Mo (mg/kg)	36	2.71	2.89	2.95	3.07	3.44	3.10	1.91	1.60	1.98	1.61	1.88	1.98
Ag (mg/kg)	-	0.036	0.201	0.170	0.130	0.065	0.197	0.243	0.176	0.195	0.162	0.179	0.195
Bi (mg/kg)	-	0.230	0.110	0.012	0.060	0.010	0.030	0.420	0.580	0.410	0.570	0.460	0.410
Pb (mg/kg)	229	22	22	22	22	22	22	22	22	22	22	22	22
Sb (mg/kg)	-	38.17	17.49	21.91	22.46	27.06	19.81	29.52	39.39	32.79	39.79	32.75	32.79
Sc (mg/kg)	-	110.53	86.85	101.55	99.81	97.98	100.12	78.76	77.58	82.83	75.33	78.04	82.83
Sn (mg/kg)	-	98.15	5.24	32.38	37.80	54.10	12.63	54.50	108.14	74.90	98.74	72.37	74.9
W (mg/kg)	-	1.53	1.04	1.88	0.46	1.52	0.62	0.38	0.55	0.30	0.55	0.38	0.3
Cu (mg/kg)	-	23	24	43	46	54	60	20	26	27	28	33	27
La (mg/kg)	-	26.59	21.23	9.59	35.48	17.94	22.38	14.34	4.84	4.99	6.52	6.96	2.99
Rb (mg/kg)	-	11.1	8.2	8.7	9.3	8.9	9.8	11.6	10.6	13.0	12.1	11.6	13
Zr (mg/kg)	-	64	66	62	62	63	58	62	51	60	53	48	60
Ba (mg/kg)	467	627	629	630	630	631	631	623	631	624	619	625	624
As (mg/kg)	7	7.26	7.26	7.28	7.25	7.23	7.23	7.24	7.24	7.25	7.24	7.24	7.25

of the waste is Fe_2O_3 that is confirmed by XRD results in Table 5. Percentile of Fe_2O_3 in Shahid Rajaei power plant waste is much higher than reported magnetite content of some other studied wastes (Saikia *et al.*, 2005; Oman *et al.*, 2002). Mean concentrations of some trace elements such as Cr, Ni, V and Zn in raw waste are in the upper range which makes them more noticeable, but some other elements such as As, Cd and Hg have lower concentrations. As it can be seen in Table 4, fuel oil related metals (V, Ni, Zn, Sr, Cr and Ba) are present in high concentrations in the waste. Some elements such as Ag, Bi, Cu, La, Pb, Rb, Sb, Sc, Sn, W, Zr are reported in the solidified samples which were not observed in the raw waste. These elements are possibly present because of the cement and/or sand addition in each sample. As their contents slightly decrease as the waste/cement ratio increases, e.g. lead.

Mineralogy is the main way to understand the coalescent status of elements in the waste. Toxicity of the waste is dependent not only on the polluting elements concentration, but also on the speciation of the elements and nature of the host phases (Forestier & Libourel, 1998). Table 5 shows the XRD analyses of the raw and solidified waste samples. As it could be seen, the raw waste has an amorphous mineralogical structure with magnetite and as nearly most of the waste has an amorphous texture, there was no specific peak

on the XRD graph. Although, no peak points were reported in the XRD test results of the raw waste and it was mainly an amorphous material, but portlandite, quartzite and other minerals peaks were obviously reported from the solidified samples (Table 5). As the waste/cement ratio increased, the peak point of the elements, e.g. portlandite and quartzite, fell. This is because of the amorphous structure of the waste which replaces the crystalline structure of sand and/or cement. It is clear that the particle properties of the waste are linked to its leaching behavior. For example, the presence of non-porous continuous outer surface and dense particle interior may prevent heavy metal leachability from the waste. In this regard, the study of the morphology of the waste and its influence on the leachability of heavy metals could be of practical importance (Li *et al.*, 2004; Ramesh & Kozinski, 2001). Figure 1 shows some photos from RPM photography of the raw waste. It can be seen that most of the sample has an amorphous texture and no crystalline textures are observed. Some compounds of wet oxidized ferrous can be seen that are most likely Fe_3O_4 , $FeOOH$ or $Fe_2O_3 \cdot H_2O$ colored reddish dark brown. But in the solidified samples, the cement paste matrix and the sand grains can be seen in the photos (Figs. 2 and 3). By adding the waste to the mixture in comparison with the blank samples, it can be seen that some parts of brownish waste appears in the photos.

Table 5. Results of XRD of raw and solidified waste samples

	Sample	Waste/Cement Ratio (%)	Minerals
Raw Waste	All seven waste samples	-	Amorphous + Magnetite
	Blank	0	Portlandite + Calcite + Lime + Larnite
Cement	1	10	Portlandite + Calcite + Lime + Larnite
	2	20	Portlandite + Calcite + Lime + Larnite + Amorphous
	3	30	Portlandite + Calcite + Lime + Larnite + Colmanite + Amorphous
	4	40	Portlandite + Calcite + Lime + Larnite + Talk + Amorphous
	5	50	Portlandite + Calcite + Lime + Larnite + Talk + Amorphous
Sand + Cement	Blank	0	Quartz + Portlandite + Calcite
	1	5	Quartz + Portlandite + Calcite
	2	10	Quartz + Portlandite + Calcite
	3	15	Quartz + Portlandite + Calcite + Amorphous
	4	20	Quartz + Portlandite + Calcite + Amorphous
	5	25	Quartz + Portlandite + Calcite + Amorphous

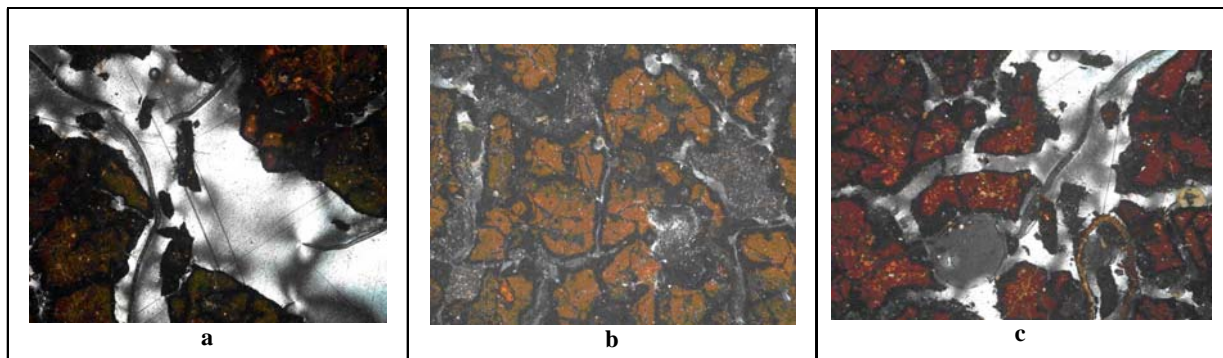


Fig. 1. RPM photography of raw waste

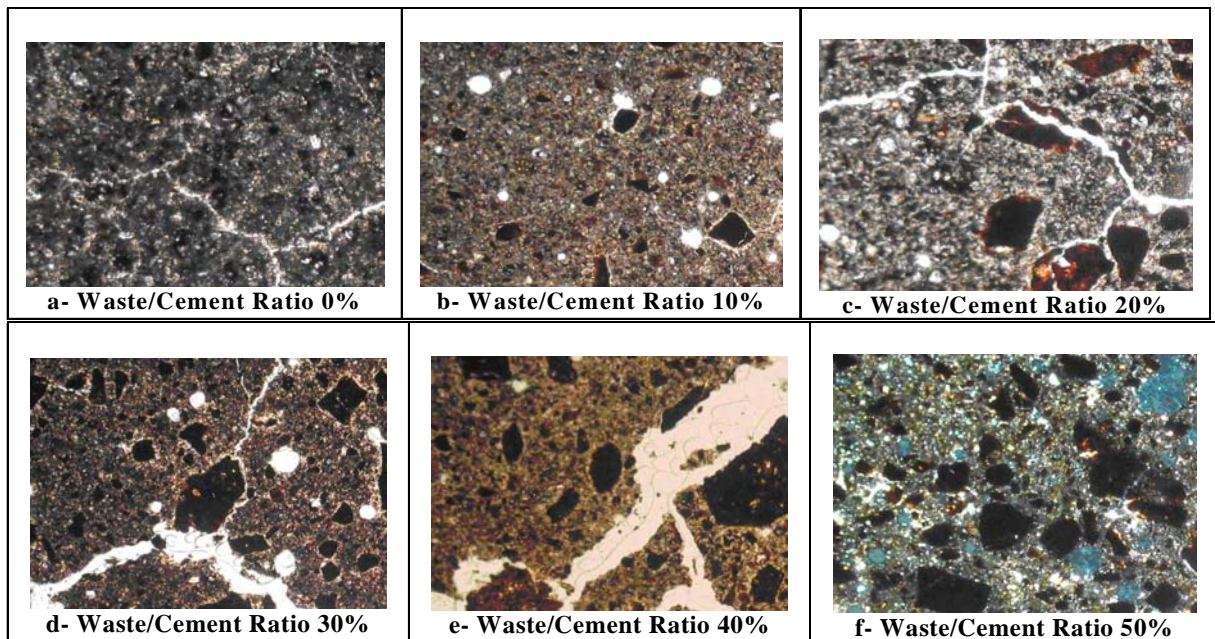


Fig. 2. RPM photography of Cement solidified samples

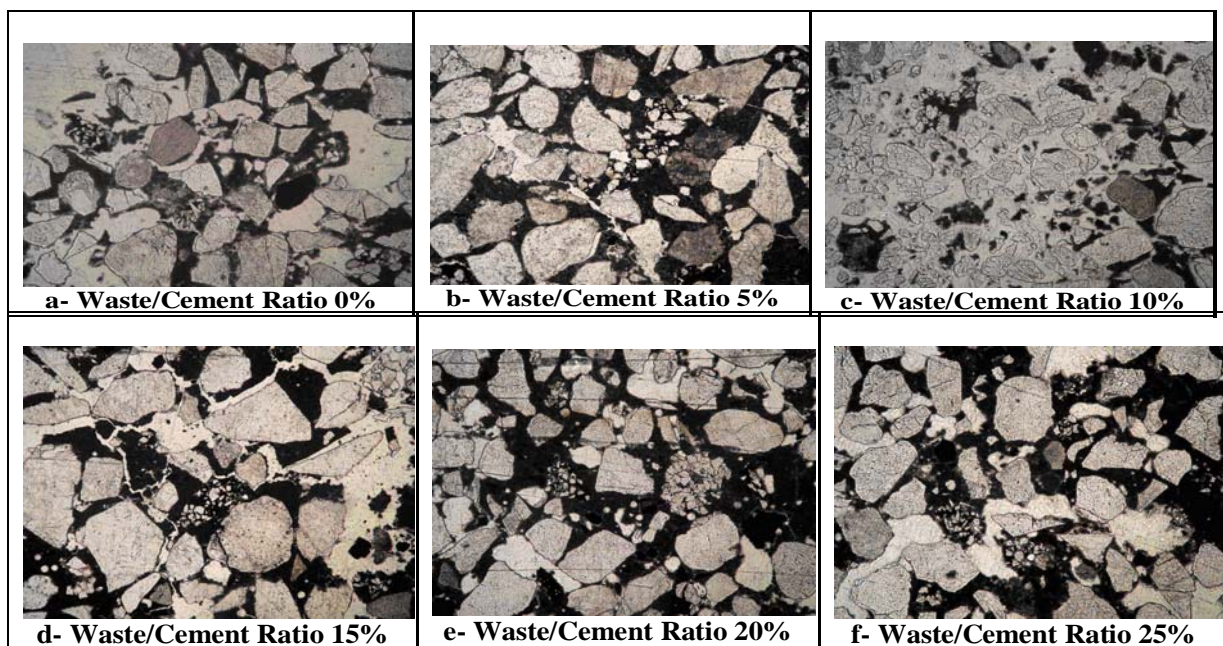


Fig. 3. RPM photography of Sand-Cement solidified samples

As the waste/cement ratio increases in the samples, the brownish parts of waste replace more surface of the area of the photo and more break lines can be seen in the samples which will cause to more heavy metals leachability from the solidified waste.

Different leaching tests have been developed to determine the interaction of wastes with the surrounding environment. For instance, leaching tests can provide a good insight into the mobility of heavy metals (Armesto & Merino, 1999). In addition, leaching tests play a major role to assess the possibility and use of treatment within regulatory limits (Ibanez *et al.*, 2000). In this study the TCLP test has been used. The concentrations of studied heavy metals (Cd, Co, Cr, Mn, Ni, Pb, V and Zn) after TCLP test are presented in Table 6. Results showed that mean elemental concentrations of Cd, Co, Cr, Mn, Ni, Pb, V and Zn in raw waste leachate were 0.06, 1.55, 5.49, 36.32, 209.10, 0.58, 314.06 and 24.84 mg/L respectively. Mean Cr concentration in leachate is higher than its EPA threshold leaching test concentration. Mean concentrations of Ni and V in leachate are also extremely high and some contaminants can be leached from the waste and may be released to environment after disposal (Lopes *et al.*, 2001). Therefore, the studied waste

has been classified as hazardous and should be stabilized before disposal. Elemental (Cd, Co, Cr, Mn, Ni, Pb, V and Zn) concentrations in leachate after the TCLP test of the solidified samples showed that in the cement solidified samples with waste/cement ratio 10% and 20%, the leaching of the studied elements shows more than 90% decrease comparing to that of the raw waste (Table 6). In samples solidified with waste/cement ratio of 30%, 40% and 50% the decrease of leaching of heavy metals is about 80% but the leaching concentrations of some elements is still high, e.g. Mn, Ni and V. In sand-cement solidified samples even in samples with the highest waste/cement ratio, a 95% decrease in metals leaching after TCLP test can be seen which shows that this mixture has had good effect in minimizing the leaching of toxic elements from the waste (Table 6). Also, comparing TCLP leach results in samples of the two mixtures with equal waste/cement ratio, e.g. 10% and 20%, it can be seen that the sand-cement solidified sample has more potential in reducing the leaching of toxic elements comparing to that of the cement solidified samples, i.e. 80% more leaching reduction. This shows that the sand-cement mixture has better effect than the cement mixture in minimizing the leaching of heavy metals.

Table 6. Concentrations of heavy metals in leachate after TCLP test on raw and solidified waste samples

	Sample Code	Waste/Cement (%)	←————— Compound Concentration (mg/L) —————→							
			Cd	Co	Cr	Mn	Ni	Pb	V	Zn
Mean										
Raw Waste	-	-	0.06	1.5	5.5	36.3	209.1	0.6	314.1	24.8
Cement	Blank	0%	0.21	2.71	1.51	17.40	14.30	3.58	2.52	1.10
	1	10%	0.22	2.86	2.29	18.69	20.97	2.05	7.52	2.54
	2	20%	0.21	3.32	3.68	24.05	32.11	1.86	6.02	3.57
	3	30%	0.21	3.25	4.91	27.23	36.28	1.62	14.40	4.45
	4	40%	0.21	3.02	5.36	27.00	42.12	1.45	50.68	4.84
	5	50%	0.16	3.27	5.86	29.52	54.14	1.40	54.60	5.32
Sand + Cement	Blank	0%	0.14	1.86	0.60	13.65	6.68	2.45	2.29	0.90
	1	5%	0.15	1.98	1.23	14.34	6.28	1.52	6.40	1.29
	2	10%	0.14	1.88	1.40	13.78	10.04	1.04	7.48	1.52
	3	15%	0.16	1.86	1.94	15.95	15.48	0.98	6.74	2.06
	4	20%	0.17	1.94	2.25	16.85	16.20	0.85	4.24	2.51
	5	25%	0.17	2.11	2.36	15.93	18.03	0.71	3.64	2.57

The main reason seems to be better structural combination between sand grains and cement paste which gives better macro and micro encapsulation of the waste material, comparing to the conditions which comes up with the bounding of the just cement paste in the cement solidified samples.

Table 7. Compressive strength test results of solidified samples

7 Days Samples			
	Sample Code	Waste/Cement (%)	Compressive Strength (N/mm ²)
Cement	Blank	0%	255.25
	1	10%	182.85
	2	20%	180.64
	3	30%	145.38
	4	40%	129.50
	5	50%	120.78
Sand + Cement	Blank	0%	131.96
	1	5%	95.05
	2	10%	92.09
	3	15%	77.24
	4	20%	69.37
	5	25%	58.81
14 Days Samples			
Cement	Blank	0%	380.88
	1	10%	268.22
	2	20%	210.98
	3	30%	174.44
	4	40%	154.49
	5	50%	139.01
Sand + Cement	Blank	0%	163.31
	1	5%	134.65
	2	10%	129.63
	3	15%	127.35
	4	20%	121.17
	5	25%	99.93

As stated in Table 7, the compressive strength of the samples decreases as the waste/cement ratio increases. This is caused by the presence of waste in the mixture. The waste replaces the cement or sand-cement structure and decreases the bounding of their structure. The places that waste appears in the section of each sample weaken the bearing of the sample and cracks may occur under loads. In the sand-cement solidified mixtures, in samples with maximum waste/cement ratio, i.e. 25%, the compressive strength decreases

by 40% which still shows the samples can be useable in some specific purposes. In cement solidified samples with up to 20% waste/cement ratio, the compressive strength decreases by 45% but in samples with ratio of 30%, 40% and 50%, the decrease of strength is up to 65%. Also, in sand-cement solidified samples an average of 45% increase in strength can be seen in the 14 day samples comparing to the 7 day samples. This shows that a suitable curing operation has been done in the samples and they have lead to increased strength. In cement solidified samples with waste/cement ratio up to 20%, 14 day samples strength increases by 50% comparing to 7 day samples. In samples with waste/cement ratio 30% and more, this increase is around 20%.

CONCLUSIONS

For the first time, dewatered sludge waste from air heater washing wastewater treatment of a thermal power plant were subjected to stabilization/solidification treatment studies through chemical composition, mineralogy, electron microscopy and TCLP leaching characteristics test. The solidification was done with two cement based mix designs with different waste/cement ratios. The results of leaching test on the solidified samples showed that regarding the sand-cement mixture even with 25% waste/cement ratio, the leaching of heavy metals has completely been controlled up to 95% and this mixture can be suitable to make the waste non-hazardous. In cement solidified samples, with waste/cement ratio up to 20% with 90% decrease in leaching of heavy metals, this mixture has also a suitable reply in making the waste non-hazardous. Also considering the compressive strength test results in both mixture samples, in sand-cement solidified samples with waste/cement ratio 25% and in cement solidified samples with waste/cement ratio 20%, a 40% decrease occurs in the compressive strength in comparison with the solidified waste free samples. In an overall statement regarding the results of the present study it seems that this kind of waste with extremely high leachable contents of V, Ni, Cr and Zn can be treated through cement and cement-sand stabilization/solidification processes. It should be pointed out that the effectiveness of the cement-sand seems to better than application of just cement in reducing the metals leaching from the treated waste.

Furthermore it seems that waste/cement ratio in the solidified samples in both mixture types should not exceed than 20-25% for better performance of the processes. It seems the solid productions can be used for specific purposes that don't have much external loading, such as in paving.

ACKNOWLEDGEMENT

The current study was supported by Iran National Science Foundation (INSF) under contract number 86-5243.

REFERENCES

- Armesto, L. & Merino, J.L. (1999). Characterization of some coal combustion solid residues. *Fuel*, **78**, 613-618.
- ASTM (American Society for Testing and Materials). (2000). Standard Test Methods for Minimum Index and Unit Weight of Soils and Calculation of Relative Density, D 4254. ASTM
- ASTM (American Society for Testing and Materials). (1990). Standard Test Method for Compressive strength of Hydraulic cement Mortars(Using 50-mm Cube Specimens), C 109 ASTM.
- Bagnoli, F., Bianchi, A., Cencarini, A., Fuoco, R. & Giannarelli, S. (2005). Trace metals & organic pollutants in treated & untreated residues from urban solid waste incinerators. *Microchem. J.*, **79**, 291-297
- Barth, E.F., Percin, P., Arozarena, M.M., Zieleniewski, J.L., Dosani, M., Maxey, H.R., Hokanson, S.A., Pryately, C.A., Whipple, T., Kravitz, R., Cullinane, M.J., Jones, Jr. L.W. & Malone, P.G. (1990). Stabilization and Solidification of Hazardous Wastes. U.S. EPA, Noyes Data Corporation, New Jersey
- Conner, J.R. (1990). Chemical Fixation and Solidification of Hazardous Wastes. Van Nostrand Reinhold, New York.
- Cullinane, M.J., Jones, L.W. & Malone, P.G.(1986). Handbook for Stabilization/ Solidification of Hazardous Waste. U.S.EPA Hazardous Waste Engineering Research Laboratory (HWERL), EPA/540/2-86/001.
- Cullinane, M.J. & Jones, L.W. (1986). Stabilization/ solidification of Hazardous Waste. US EPA Hazardous Waste Engineering Research Laboratory(HWERL), EPA/600/D-86/028.
- Dermata, D. & Meng, Z. (1995). Utilization of fly ash for stabilization/solidification of heavy metal contaminated soils. Proceedings of 2nd International Conference on Energy and the Environment, Prague, 563-581.
- Duchense, J., & Laforest, G. (2004). Evaluation of the degree of Cr ions immobilization by different binders. *Cement and Concrete Res.*, **34**, 1173-1177
- Elliott, T.C. (ed) (1989). Standard Handbook of Power Plant Engineering. McGraw-Hill, New York.
- El-Wakil, M.M. (1985). Power Plant Technology. McGraw-Hill, New York.
- Forestier, L.L. & Libourel, G. (1998). Characterization of fuel gas residues from municipal solid waste combustors. *Environ. Sci. Tech.*, **32**, 2250-2256.
- Ibanez R., Andres A. & Viguri J.R. (2000). Characterization of management of incinerator wastes. *J. Hazard. Mater., A*, **79**, 215-227.
- Iran DOE (2005). Waste Management Act of Iran. Code No. H32561T/28488.
- Iran MOE, Ministry of Energy (2005). Iran Energy Balance, year 2004. Tehran, (in Persian).
- Jang, A. & Kim, I.S. (2000). Solidification & stabilization of Pb, Zn, Cd & Cu in tailing wastes using cement & fly ash. *Min. Eng.*, **13**, 1659-1662.
- Jing, C., Meng, X. & Korfiatis, P. (2004). Lead leachability in stabilised/solidified soil samples evaluated with different leaching tests. *J. Hazar. Mater. B*, **114**, 101-110.
- Li, M., Xiang, J., Hu, S., Sun, L.S., Su, S., Li, P.S. & Sun, X.X. (2004). Characterization of solid residues from municipal solid waste incinerators. *Fuel*, **83**, 1397-1405.
- Leist, M., Casey, R.J. & Caridi, D. (2003). The fixation & leaching of cement stabilized arsenic. *Waste Manag.*, **23**, 353-359.
- Lopes, H., Trindade, T., Gulyurtlu, I. & Cabrita, I. (2001). Characterization of FBS ashes from co-combustion of coal with oily residues. *Fuel*, **80**, 785-793.
- Malone, P.G. & Jones, L.W. (1979). Survey of Solidification/Stabilization Technology for Hazardous Industrial Wastes. U.S.EPA-600/2-79-056.
- Oman, J., Dejanovic, B. & Tuma, M. (2002). Solutions to the problem of waste deposition at a coal-fired power plant. *Waste Manag.*, **22**, 617-623.
- Park, C.K. (2000). Hydration and solidification of hazardous wastes containing heavy metals using modified cementitious materials. *Cement and Concrete Research*, **30**, 429-435.

Pojasek, R.B. (1979). *Toxic and Hazardous Waste Disposal, Vol. 1, Processes for Stabilization/Solidification*. Ann-Arbor science Publishers, Ann-Arbor, MI.

Ramesh, A. & Kozinski, J.A. (2001). Investigations of ash topography/morphology and their relationship with heavy metals leachability. *Environmental Pollution*, **111**, 255-262.

Saeedi, M. & Amini, H.R. (2007). Characterization of a thermal power plant air heater washing waste: a case study from Iran. *Waste Management & Research*, **25**, 90-93.

Saikia, N., Kato, S. & Kojima, T. (2006). Compositions and leaching behaviors of combustion residues. *Fuel*, **85**, 264-271.

Sophia, A.C. & Swaminathan, K. (2005). Assessment of mechanical stability and chemical leachability of immobilized electroplating waste. *Chemosphere*, **58**, 75-82.

Wetzman, L., Hamel, L.E. & Barth, E. (1988). Evolution of solidification/stabilization as a best demonstrated available technology. *Proceedings of 14th Annual Research Symposium*, US EPA, Cincinnati, OH.

United States Environmental Protection Agency (U.S.EPA) (1992). *Test Methods for Evaluating Solid Waste Physical/Chemical Methods*, SW-846.