Rf Thermal Plasma Vitrification of Incinerator Bottom and Fly Ashes with Waste Glasses from Fluorescent Lamps

V Colombo[1], A Concetti[1], E Ghedini[1], M Gherardi[1], P Sanibondi[1], B Vazquez[1],

L Barbieri [2], I Lancellotti [2]

[1] *Department of Mechanical Engineering (D.I.E.M.) and Research Center for Applied Mathematics (C.I.R.A.M.) Alma Mater Studiorum - Università di Bologna, Via Saragozza 8, 40123 Bologna, Italy*

[2] *Deparment of Engineering of Materials and the Environment (D.I.M.A.), Via Vignolese 905, 41100 Modena, Italy*

Abstract: Thermal plasma vitrification is a successfully used technology to treat and recycle hazardous wastes. High plasma temperatures enable to destroy complex molecules and to encapsulate the toxic elements in a non-leaching glass or ceramic matrix, obtaining non-hazardous wastes with large volume reductions. In this work, hazardous incinerator residues (bottom and fly ashes) have been treated by means of a laboratory scale radiofrequency (RF) thermal plasma source with the addition of coarse scraps of glass from dismantled fluorescent lamps. The obtained samples were characterized by scanning electron microscopy analysis (SEM), energy dispersion spectroscopy (EDS), X-ray diffraction (XRD) and leaching tests. The latter showed that toxic elements were completely encapsulated in the glass matrix, with release values below the law limits. Results of this work demonstrate the feasibility of bottom and fly ash vitrification in a batch of glass scraps from dismantled fluorescent lamps and can also provide useful insights for the optimization of vitrification processes carried out by the more widespread arc plasma furnaces.

Keywords: inductively-coupled plasma torches, vitrification, hazardous waste

1. Introduction

The first ideas of utilizing thermal plasma technology for waste processing go back to the early-1970's during the energy crisis period [1]. Since then, many investigations came off, and in the 1980's thermal plasma technology evolded significantly by the strong drive for high-performance materials and the growing need for new material-processing technologies [2]. Some of these advances helped Japan, due to their limited land mass, to installed in the early-1990's the first truly commercial facility for the treatment of municipal solid waste incineration ash.

Waste treatment has become one of the main problems of our age, as traditional waste repositories, such as landfills and ocean dumpsites, become less and less available. Because of the ability of the plasma to vaporize anything and to destroy any chemical bond, plasma technology has become a valid and effective alternative to the treatment of wastes [3-6].

Different plasma technologies and other thermal treatments have been already used to vitrify incinerator bottom ash [7] as well as incinerator fly ash [8], but there has been no reported with the RF thermal plasma source yet. Therefore, the main objective of this work was to investigate the feasibility of using a RF thermal plasma source technology to treat hazardous incinerator residues, adding fluorescent lamps glass powders to produce a single-phase amorphous glass, and to characterize the glassy material obtained in terms of leaching behaviour.

2. Methods and Materials

2.1 RF inductively coupled discharges

Actually, DC plasma arc generators are considered a better alternative rather than AC ones for hazardous waste treatment, because of less flicker generation and noise, a more stable operation, better control, a minimum of two electrodes, lower electrode consumption, slightly lower refractory wear and lower power consumption. Nevertheless, inactivity periods are expected due to the electrodes routine maintenance. Moreover, reactive gas can not be used with some categories of electrodes, whereas with the Inductively Coupled Plasma Torches (ICPT), since the plasma gas does not come in contact with electrodes, possible sources of contamination are eliminated and a wide range of operating conditions including inert, reducing and oxidising, and other corrosive atmospheres are allowed for their operation. For these reasons, and for the flexibility showed when different operating conditions (powder, gas flow, ínjected material) are changed, ICPT can be considered as a valid alternative for the treatment of wastes.

2.2 Hazardous incinerator wastes

Bottom and fly ashes used during this work were from an Energy from Waste plant in Northern Italy, which processes approximately 51,000 ton of municipal solid waste per year.

Chemical analysis (XRF) shows the really different characteristics of bottom and fly ashes. Bottom ash contain higher amount of glass formers cations such as Si and Al, while fly ash contains higher percentages of Na, K and Ca coming from the gas treatment in the plant. Further, fly ash contain significant amount of heavy metals such as Cu, Pb, Cr and Cd.

2.3 Fluorescent lamps

Fluorescent lamps represent about 70% of the total consumption of electrical lighting in Italy. These lamps are a particular kind of discharge lamp, in which the light is generated by a fluorescent material and they are constituted mainly by glass and small amount of Hg (normally less than 5 mg in accordance with RoHS Directive), inert gas (generally argon) and phosphorous. Lamps are classified among the WEEE which contain dangerous substances (ERC 20 01 21*) and the majority of which are disposed by landfilling. European regulations require special disposal of fluorescent lamps separated from general and household wastes. The crushed materials are separated into glass, metal and powder. In particular fluorescent powder is treated by distillation in order to separate the mercury fraction and the glass resulting from the reclaiming process is considered no hazardous waste (ERC 19 12 05)[9].

3. Experimental

3.1 Experimental setup

The experimental setup used in this work is shown in Fig. 1. The laboratory scale RF thermal plasma source includes: radio frequency plasma torch, model Tekna PL-35 (with ceramic confinement tube for operation up to 30kW); 35 kW LEVEL unit RF power supply working at 3 MHz; a control console Tekna Plasma Systems (Sherbrooke, Quebec, Canada) RF-CS-30 with gas flowmeters for operation with Ar, Ar/H_2 or any other auxiliary gas (Air, N_2, O_2); Tekna Plasma Systems external cooling system; Tekna Plasma Systems powder feeder PF-400, from where particles are injected in the plasma discharge; adjustable water-cooled steel arm to put the graphite crucible inside the reactor chamber. This device, used also for substrate coating purposes, allows to regulate the distance between the exit of the torch nozzle and the crucible from 104mm (highest position) to 134mm (lowest position).

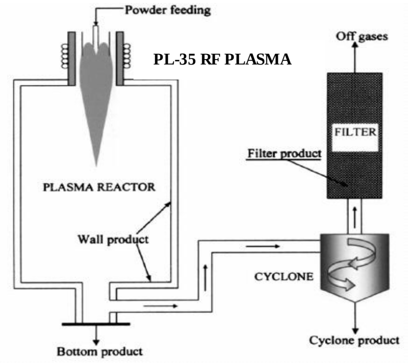

Figure 1. Schematic illustration of inductive plasma reactor system

3.2 Plasma treatment

The operating conditions used during each experimental test are shown in Table 1. In the first test, bottom ashes and fluorescent lamps glass powders have been injected in the plasma discharge at the same time and with the same percentage (50%), whereas the second test has been carried out using fly instead of bottom ashes. The main operating parameters for both experiments are very similar, using argon as a fluidization gas in the fly ash treatment to improve the powder flow rates at the exit of the powder feeder.

	BOTTOM ASH	***FLY ASH***
Plasma gas/ flow rate	Argon– 15 slpm	Argon – 15 slpm
Sheath gas/ flow rate	Argon – 50 slpm, Hydrogen 10 slpm	Argon – 50 slpm, Hydrogen 10 slpm
Carrier gas/ flow rate	Argon – 5 slpm	Argon – 3 slpm
Fluidization gas/flow rate	-	Argon – 2 slpm
Ash quantity/ratio ash-glass	50g (1:1)	100g (1:1)
Powder feeding rate	5,6 g/min	7,2 g/min
Plate power	23,4 kW	22,75 kW
Time	20 minutes	20 minutes

Table 1. Experimental conditions for plasma treatment of in-flight bottom and fly ashes with waste-glass powders

3.3 Characterization of the obtained glassy material

In both experiments, the glassy material obtained after the treatment, has been crushed to powder in order to make possible the characterization of their chemical composition with the scanning electron microscopy (SEM) combined with energy dispersive X-ray spectrometry (EDS). SEM micrographs suggest that in both cases the main matrix is formed by the typical glass phase, with a certain quantity of small metallic spheroidized particles (Fig. 2). EDS analysis have been carried out (Fig. 3) to confirm results obtained with the SEM analysis. Similar peaks of main glass formers, such as Si, Ca and Al can clearly be seen in both graphs of Figure 3. The Na peak, can be related to the different original composition of bottom and fly ashes.

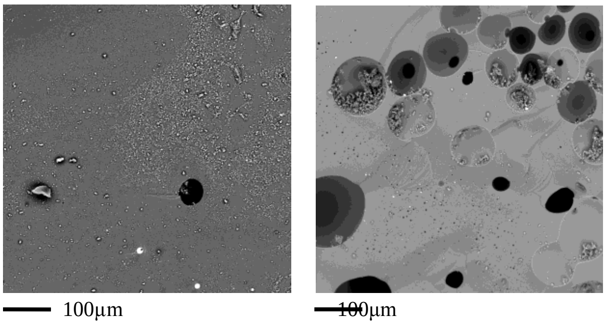

Figure 2. SEM morphologies of bottom ash glassy slag (left) and fly ash glassy slag (right)

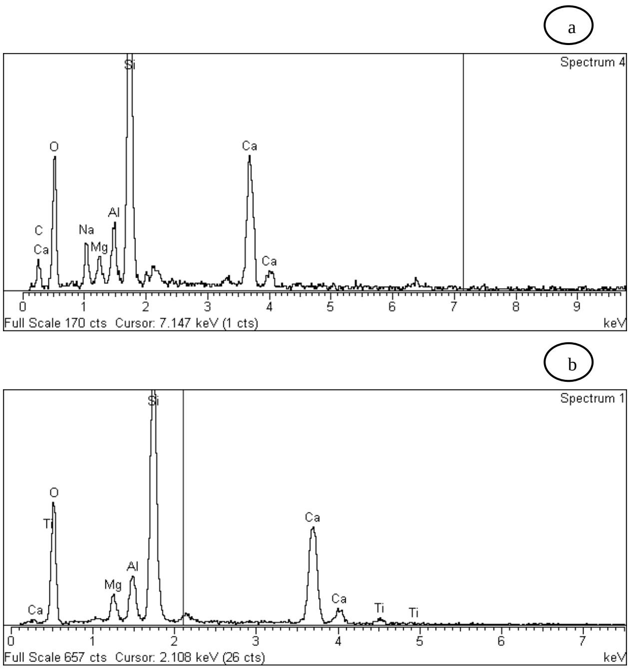

Figure 3. EDS spectra of (a) bottom ash glassy slag and (b) fly ash glassy slag

XRD data given in Figures 4 and 5 confirm the typical broad band of amorphous nature glasses, where crystalline phases have not been formed.

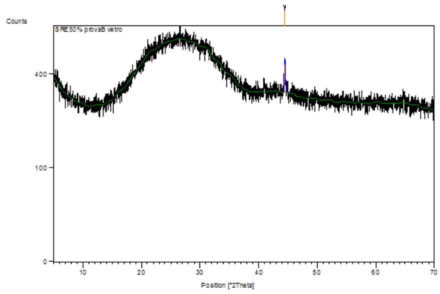

Figure 4. XRD graph of the plasma treated bottom ash glassy slags

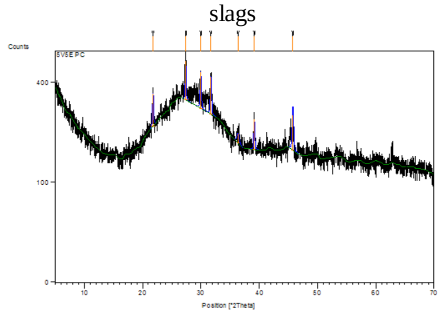

Figure 5. XRD graph of the plasma treated fly ash glassy slags

Before the final leaching tests, and in order to confirm the chemical composition of each glasses after the plasma treatment, chemical analysis have been accomplished (Table 2). These results confirm the presence of glass formers and all the heavy metals, contained in the ash, which are encapsulated in the glassy network, excepted Pb which probably was volatized during the thermal process.

Oxide	Bottom ash experimentation %	Fly ash experimentation %
SiO_2	55,14	52,34
CaO	17,69	28,91
Al_2O_3	8,25	9,02
Na_2O	6,46	2,47
Fe_2O_3	5,88	0,642
MgO	2,53	3,04
K_2O	1,08	0,375
P_2O_5	0,933	0,397
TiO_2	0,714	1,80
As_2O_3	0,312	0,204
SO_3	0,275	0,142
BaO	0,246	0,394
CuO	0,164	/
ZnO *	1130	223
MnO*	577	431
Cr_2O_3 *	520	545
SrO *	444	741
NiO*	304	285
Zr *	129	216
P_2O_5 *	88	185
Total	**100**	**100**

* Measured in ppm

Table 2. Chemical composition of glassy slags coming from bottom/fly ashes treatment

Compliance leaching test results for hazardous residues derived glass are given in Table 3. In order to determine the risk category of the discharge, the UNI ISO 10802 rule includes the procedure to carry out a leaching test. Every single metallic element must be below the law limit indicated by the Waste Acceptance Criteria (WAC). Table 3 demonstrates that the concentrations of heavy metals in leachates were below the law limits (Tab 5 DM, decree passed by the Italian Goverment 03/08/2005), and these results evidence that plasma treated hazardous incinerator residues are suitable for disposal to inert waste landfill. Furthermore, the relatively low leachable level of the elements that constitute the crystal lattice (Al, Na and Si) guarantee a high-resistant glass material.

	Cu	***Mn***	***Ba***	***Zn***	***Cr***
WAC	*5 ppm*	*Nd*	*10 ppm*	*5 ppm*	*1 ppm*
Bottom	4,54	0,185	0,304	0,150	0,026
Fly	0,366	0,29	2,170	0,075	0,051

	As	***Ni***	***Al***	***Na***	***Si***
WAC	*0.2 ppm*	*1 ppm*			
Bottom	0,019	0,88	5,27	12,1	0,72
Fly	0,061	0,032	21.1	31,2	4,14

Table 3. Compliance leaching test for bottom/fly ash glassy slags

4. Conclusions

The accomplished studies demonstrate the effectiveness of the use of inductively coupled plasma torches (ICPTs) as high-temperature sources for the treatment and the value increasing of hazardous wastes for different applications. Despite this, the upscaling of these processes for their industrial application is still far.

Presented results show that the use of crucible instead of substrates allow to increase the percentage quantity of collected powders and to effectively create a molten pool. Moreover, the use of SiO_2 demonstrated to be necessary to obtain a uniform glassy scarp. Finally, the effectiveness of vitrification of hazardous incinerator residues (bottom and fly ashes) with a laboratory scale radiofrequency (RF) thermal plasma source have been demonstrated. The process also allows the waste fluorescent lamps dismantling . EDS and XRD analysis show the glassy nature of the obtained samples, and from the leaching tests appears evident that concentrations of heavy metals are surely below the law limits.

Future developments will imply the optimization of the operating conditions and of the experimental set-up, in order to increase the process efficiency in terms of duration and cost of the treatment process. The proper optimization of the lab-scale process will then be a necessary precondition for implementing the next phase of scaling-up of the process for industrial applications.

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