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A RAPID AND CONTINUOUS SYSTEM FOR IMMOBILIZATION OF NUCLEAR MATERIAL WASTE BY VITRIFICATION

*M.U. SHAREEF, S.H. HUSSAIN[1], F. RASHID[2] and M. TUFAIL

Department of Nuclear Engineering, PIEAS, P.O. Nilore, Islamabad, Pakistan

[1]PIEAS, P.O. Nilore, Islamabad, Pakistan

[2]Health Physics Division, PINSTECH, P.O. Nilore, Islamabad, Pakistan

The nuclear technology has prime importance and backbone for rapid development of medical sciences, industries and in power generation as an alternate source of energy. Despite all these facts there is a major problem which is always associated with nuclear technology, that is, the generation of undesirable radioactive wastes. The radioactive wastes are quite problematic and need major attention for its treatment, conditioning and properly disposal to keep the environmental activities and human ecosystem healthy and safe. There are different large scale methods and processes to treat and dispose off the radioactive wastes. These processes are evaluated and designed by the various world competent and pronounced scientists in the light of rules and safety limits set by IAEA and other regulatory authorities to protect the environment and eventually protect our ecosystem. The research and development work on radioactive waste has been proceeding for the last fifty years but still it is a core issue and a big challenge for the nuclear scientists and radiation workers. In this study a rapid and continuous system for immobilization of nuclear waste into glass matrix by vitrification has been designed. In general treatment methods, Borosilicate glass is preferred because it is efficient, cost effective and rapid to that of other radioactive waste form. In this process the simulated waste is mixed with glass forming material and process for melting to form a glassy substrate in continuous manner. The waste is being converted into vitreous form and encapsulate into a glass matrix.

Keywords: Radioactive waste; Arc furnace, Vitrification, Silicate glass

1. Introduction

The nuclear technology has prime importance and backbone for rapid development of biosciences and industries. With the development of nuclear industry throughout the world, the amount of radioactive waste is increasing. Removal of radionuclides from these liquid wastes has become more and more important [1] because of the present scenario. The liquid wastes arise from the reprocessing of nuclear fuels for the recovery of plutonium and unburned uranium containing more than 99% of the dissolved fission products constituting high level waste (HLW) [2]. It is essential and wise decision to keep such HLW away from the biosphere for environmental protection. For this reason the nuclear waste should be transmuted into a waste form which can be disposed off safely. To prevent the radioisotopes leaching into the groundwater and eventually to the biosphere, variety of immobilization techniques are available which merit from certain important waste characteristics such as structural and chemical stability and high resistance for leachability. Borosilicate glasses are widely used vitrification method for the immobilization of HLW. The commercial level vitrification plants for the immobilization of reprocessing wastes are in operation in UK, France, Germany-Hungary, Germany-Belgium, Russia, USA and North Korea. The encapsulation in borosilicate glass is the principal immobilization process used in France, Belgium, England and India for HLW from fuel reprocessing. Phosphate glasses have been used in Russia for stabilizing hazardous waste and offer a solution to certain specific waste streams in USA. The physical form of HLW is an important aspect of the waste management program. Vitrification involves the mixing of calcined waste with a borosilicate glass frit and glass forming materials. The mixture is melted in a high temperature furnace and the liquid glass cast into a mold by pouring directly into stainless steel canisters [3].

* Corresponding author : ubaid_sharef@yahoo.com

Vitrification technique is used due to its excellent chemical stability and resistance to leachability. The chemical stability of glass allows it to remain stable in a corrosive environment for a very long period. Glass has ability to encapsulate a variety of radionuclides into its structural network. Immobilization by vitrification is now a relatively mature technology and indeed, has become the preferred method of treatment of HLW[4, 5].

2. Raw Materials Preparation

The raw materials used for borosilicate glass were silica sand, sodium borate, sodium carbonate (soda ash) and alumina. The composition of glass forming raw materials is given in Table 1.

Table 1. Composition and raw materials for borosilicate glass

Raw Materials	Composition
Silica Sand	60-70 %
Sodium Borate	10-20 %
Sodium Carbonate	15-25 %
Alumina	4-6 %

2.1. Simulated waste preparation

A simulated nuclear waste means, it has similar chemical composition with stable nuclides thus has the same chemical properties without radiation hazards. The pictorial view of simulated waste form is shown in the Fig.1. The simulated waste was prepared with twenty three available stable nuclides (excluding Technetium) according to the literature [6]. Osmium has been added instead of Technetium due to similarities in chemical behavior. In general, more than two hundred fission products are found in HLW. The stable isotopes used for the preparation of simulated waste is listed in Table 2.

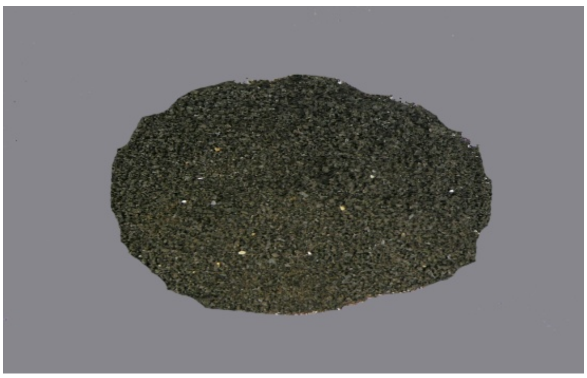

Figure 1. Simulated waste (SW).

Table 2. High level simulated waste containing some of important radio nuclides [6].

Sb	Ba	Cs	Cd	Ce	Cr
Dy	Eu	Gd	Fe	Mo	Ni
Pd	Pr	Rb	Os	Se	Ag
Sr	Ti	Y	Nb	Rh	

2.2. Preparation of borosilicate glass with S.W

The Borosilicate glass constituents and the simulated waste (2% by weight) were mixed homogeneously. This mixture was transferred in a graphite crucible (GC) (Fig. 2) and shifted into the prototype electric arc furnace.

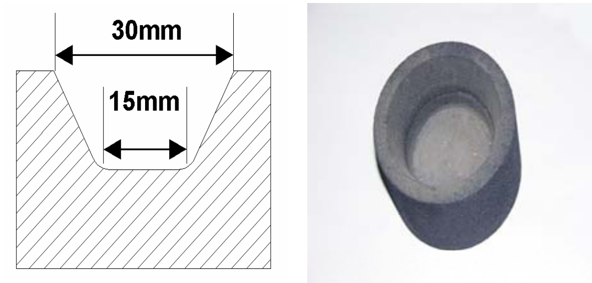

Figure 2. Graphite crucible

3. Materials and Methods

3.1. Fabrication of a proto-type arc- furnace

A 20 V, 6A transformer is used for the construction of Arc-furnace. With the help of an Arc, a high thermal efficiency can be achieved which is necessary for rapid melting, in this away uniform mixing of the composite materials can be achieved. Following design parameters were considered for the construction of Arc-furnace.

Total Load (F):

Mass of plunger + electrode (m) = 87.532gm

Acceleration due to gravity (g) = 9.8 m/s^2

$$F = mg \tag{1}$$

F = 0.8578 N

Magneto-motive Force (F_m):

When a current flows through a conductor it produces magnetic field around the conductor. The force that produces magnetic field is called magneto-motive force (F_m).

$$F_m = I \times N \quad (2)$$

Where,

I = Current in Ampere = 6 A

N = Number of turns = 210 turns

F_m = 1260 A-turns

Reluctance (R):

Reluctance in the magnetic field is the opposition to the establishment of the magnetic field in a material.

$$\mathcal{R} = l / \mu A \quad (3)$$

Where,

l = length of the inductor

μ = magnetic permeability

A = cross sectional area of wire

$$\mu = \mu_r \times \mu_o \quad (4)$$

Where,

μ_r = Relative magnetic permeability of material (Copper wire)

μ_o = magnetic permeability of vacuum

$\mu_o = 4\,\pi \times 10^{-7}$ Wb/A-turns

$\mu_r = 0.99999$

$\mu = 1.2566\times10^{-6}$ Wb/A-turns

$$A = \pi r^2 \quad (5)$$

$\mathcal{R} = 8.0655\times10^{10}$ A-turns/Wb

Magnetic Flux (φ):

The group of force lines going from the north pole to the south pole of a magnet is called the magnetic flux.

$$\varphi = F_m / \mathcal{R} \quad (6)$$

$\varphi = 1.5622\times10^{-5}$ Wb

Magnetic Flux Density ($\mathcal{B}$):

Magnetic flux density is the amount of flux per unit area in the magnetic field.

$$\mathcal{B} = \varphi / A \quad (7)$$

Where,

A = cross section area of the bobbin

$\mathcal{B} = 4.9726\times10^{-5}$ T

3.2. Operation of arc-furnace

The design and construction of electrical arc furnace (EAF) was carried out in such away that a continuous melting process can be achieved to minimize manual work as low as possible to avoid radiation exposure hazards. The arc current is automatically controlled according to the configuration of the schematic diagram as shown in (Fig. 3). The current is flowing from the one terminal of the secondary coil of the transformer into one of the solenoid terminal. The second terminal of the solenoid is fixed with the plunger. When the solenoid gets energies, it pulls the plunger due to magnetic force. The lower end of the plunger is provided with a graphite electrode (10 mm × 90 mm). Tip of the electrode touching the graphite crucible (GC) in OFF condition. The second terminal of the transformer secondary is fixed to the GC. In this way a close circuit is complete. When the circuit supply is on the solenoid pulls the plunger upward, this act disconnecting the closed loop. The solenoid coil again become OFF and the electrode tip again touches the GC and makes the circuit on again, this cycle remain continued and hence an Arc is generated between the electrode and GC. A spring is used to push back the plunger downward. Due to the Arc the gap between the electrode and the GC becomes the hottest zone. Variation in the spring tension helps to change the rate of current flow through the solenoid and eventually in the arc. The Arc generation is shown in (Fig. 4).

4. Results and Discussion

For the assessment of the constructed experimental setup 23 g of material was used in two experiments. In one experiment the glass forming mixture without SW was used.

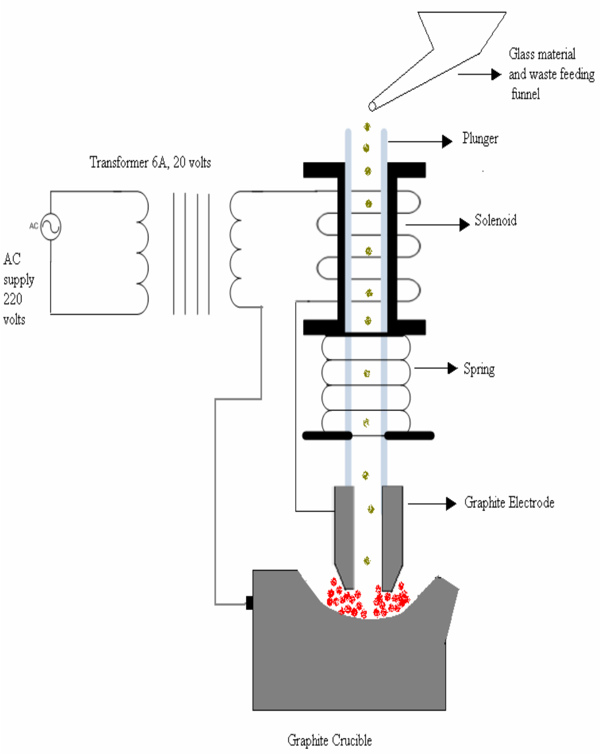

Figure 3. Schematic diagram of electric arc furnace.

Figure 4. Electric Arc generation

Figure 5 shows a tare (without SW) borosilicate glass button while figure 6 shows yellowish colored glass button with simulated waste. Although the materials were melted rapidly but the Arc was remained switched on for further extra nine minutes to observe the Arc behavior, if change due to the molten glass in the GC. Then GC was removed from the setup and placed in the open atmosphere for cooling. This rapid cooling of vitrified product helps to eliminate any chance of devitrification. The vitrification process also destroys the organic compounds if present in the waste and then produces high stable products. In Borosilicate glass Silicon dioxide (SiO_2) is main network former while boric oxide also acts as network former as well as fluxing material. Aluminum oxide (Al_2O_3) improves the chemical durability and reduces the tendency to crystallize. Sodium oxide (Na_2O) acts to lower the viscosity of glass and produces desirable chemical and optical properties. Borax and alumina mixing with silica produces a glass highly resistant to attack by hot alkaline solutions. The test was carried out to assess the efficiency and performance of a prototype electric arc furnace. The vitrification of simulated nuclear waste in a borosilicate glass in the form of buttons is shown in (Figs. 5 and 6), without any physical defect.

Figure 5: Tare Borosilicate glass

Figure 6: Borosilicate glass with SW

5. Conclusion

After successful preliminary fabrication experiment of prototype (6A, 20 V) Arc-furnace, the project work is being continued for a higher current (30A) Arc-furnace. The new, under designing setup will provide with tubular graphite electrode and a feeding funnel as shown in Fig. 3. The tubular electrode is meant for a continuous feed of glass forming material with SW through the funnel. In this way a nonstop continuous vitrification process can be achieved. vitrification by Arc-furnace is a rapid and continuous process which requires less manual work. It can be well protected and shielded from radiation and automation can be incorporated.

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References

[1] International Atomic Energy Agency, Design and Operation of Evaporator for Radioactive Wastes, Technical Report Series No.87 (IAEA, Vienna, 1968).

[2] International Atomic Energy Agency, Handling and Storage of High Level Radioactive Liquid Wastes requiring Cooling, Technical Report Series No.191 (IAEA, Vienna, 1979).

[3] Ronnie D.Lipschutz,“Radioactive Waste, Politics, Technology, and Risk”, Ballinger Publishing Company (Cambridge, Massachusetts, 1980).

[4] N.E. Brenzenva et al, “Vitrification of high sodium- aluminum wastes: Composition ranges and properties, Scientific Basis International Symposium Boston, 1978, McCarthy, G.J., Ed., (Plenum Nuclear Waste Management, New York, (1979) 43-50.

[5] Chang Ho Oh, “Hazardous and Radioactive Waste Treatment Technologies Handbook”, CRC (Press, Boca Raton, Florida, USA, 2001).

[6] Masumitsu Kubota, “Recovery of Technetium from high Level Liquid Waste Generated in Nuclear Fuel Reprocessing” Department of Chemistry and Fuel Research, Radiochimica Acta 6.3,91-96 (Japan Atomic Energy Research institute, April 27,1993).