Melting of Aluminum in the Electric Arc Furnace

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1. Introduction

A large amount of metallic radioactive waste will be generated from dismantling nuclear facilities. The most part of the dismantled material is of slightly contaminated. Therefore, the metallic radioactive wastes can be recycled in the nuclear industry by the appropriate technical procedure. Melting technology has been known as the one of the most effective technology in the volume reduction and recycling of the metallic radioactive wastes[1].

This study is concerned with the melting technology of contaminated aluminum and the nuclides distribution into the slag, ingot and dust phase. To find the optimum operation condition, the effects of melting temperature, melting time and kinds of flux agents on the distribution of surrogate nuclide elements were investigated in the D.C. graphite arc furnace.

2. Experimental

2.1 Test Apparatus

The electric arc melting (EAM) was selected for melting of the metallic radioactive wastes. Lab scale D.C. graphite arc melting system was fabricated to investigate the characteristics of metal melting itself and the behavior of contaminants as shown in Fig. 1. The melting system consists of one graphite electrode and copper crucible with no refractory which serves as counter electrode. A lack of refractory means no refractory interactions to compete with metal/slag interactions. The cooling water flows in the surroundings of graphite arc electrode and copper crucible. The melting operation involves two modes of which one is the plasma arc melting in the initial stage and the other is the Joule heating after building up the pool. The input power can be supplied by controlling the D.C voltage from the D.C power supplier.

Figure 1. Electric arc melting apparatus.

2.2 Selection of Surrogate Elements

The surrogate elements was chosen by their chemical properties, the reaction among the elements and the ease of handling and chemical detection[2]. In order to evaluate the suitability of the elements to be used as a surrogate, an index expressed by the ratio of the Gibb's free energy can be used. The compounds of surrogate elements selected in the tests are given Table 1.

Table 1. The form of the surrogate elements

Surrogate elements	Chemical form	Amount Used (ppm)
Co	$CoCl_2 \cdot 6H_2O$	1,000
Cs	CsCl	1,000
Sr	$SrCl_2 \cdot 6H_2O$	1,000
Ce	$Ce(NO_3)_3 \cdot 6H_2O$	1,000

2.3 Selection of Fluxes

The fluxes have been widely studied for melting of radioactive aluminum scrap metal, because of high thermal conductivity, high thermal capacity, low density, moderate viscosity, high electrical conductivity, mutual miscibility. Alkali metal halides are the major components used as the flux for aluminum melting. Four fluxes were used in this study as given in Table 2. The flux of 5wt% was added to the crucible filled with aluminum prior to the beginning of the melting.

Table 2. Flux composition

Flux type	Composition
Flux A	NaCl(45%),KCl(40%), Na_3AlF_6(15%)
Flux B	NaCl(45%),KCl(40%), KF(15%)
Flux C	CaF_2(100%)
Flux D	LiF(14%),KCl(76%), $BaCl_2$(10%)

2.4 Experimental method

The scrap of aluminum waste (10×10×1mm sheet type) was prepared as the feed material for melting tests. The test raw material of the aluminum analyzed and results of the chemical analyses are given in Table 3.

Table 3. Chemical composition

Species	Si	Fe	Ti	Etc.	Al
Average (%)	0.125	0.24	0.013	0.02	99.601

Cu:0.002%, Mn:0.003%

In a typical melting experiment, the surrogate elements of 1,000 ppm were mixed with the flux and added to the metal in the crucible. The mixture was melted under argon atmosphere. After the completion of melting, molten metal was solidified in the crucible.

The ingot samples were taken as the chips by drilling of the ingot to the depth of about 10mm in two different locations.

3. Results

3.1 Melting parameters

The melting tests were performed using the contaminated aluminum with surrogate elements. The optimum conditions for decontamination were established by varying the operating parameters over a series of test. The results optimized standard melting parameters were shown in Table 4. The most important parameters were the melting temperature and the composition of the flux. It can be thought that the flux had two potential functions. One is to protect the surface of the melt against oxidation. The other is to dissolve easily metal oxides from the surface of the metallic waste. The surrogate elements incorporated with metal oxides dissolve in the layer of flux together with the aluminum oxides.

Table 4. Standard melting condition

Composition	NaCl(45%),KCl(40%), KF(15%)
Temperature	700~800
Purging gas	Ar
Dwell-Time	30 min
Mass	5wt% of scrap metal

3.2 Metal/Slag analyses

To study the solubility of contaminants or their retention in the metal by melting, the solidified ingots were sampled and analyzed for their surrogate elements.

In melting of the aluminum with flux agent, it could be found that cobalt easily move into slag phase. Photographs of the ingot are presented in Figure 2, 3.

Figure 2. Ingot using Flux A.

Figure 3. Ingot using flux C.

3.3 Volume Reduction

One of the most important attributes of a metallic waste treatment system is the volume reduction, which results the reduction of disposal cost. The volume reduction ratio, VR, can be defined as follows:

VR = Input waste volume / Output waste volume.

Where, the input waste volume is the sum of the waste and flux. The VR for the test is shown in Table 5.

Table 5. Volume reduction

Input waste V.	Output waste V.	VR
349.19(cm^3)	96.16(cm^3)	3.6

REFERENCES

[1] K.L. Hopkinson, A. Bishop, M.T. Cross, J. Harrison and F. Selgas, "Recycling and reuse of radioactive material in the controlled nuclear sector", EUR18041 EN, European Commission (1998).

[2] S.A. Worcester, L.G. Twidwell, D.J. Paolini, T.A. Weldon, R.E. Mizia, "Decontamination of metals by melt refining/slagging; first year processes report", Westinghouse Idaho Nuclear Company, Inc. WINCO-1198(1994).