Demonstration of Plasma Torch melting for the Treatment of Cement-Solidified Radioactive Waste Forms Using Surrogates

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1. Introduction

As the decommissioning of nuclear power plants begins, securing sufficient storage capacity is essential for smooth progress. However, certain radioactive wastes remain in long-term storage without being transferred for final disposal due to unverified disposal compliance. Among these are radioactive wastes generated by solidifying concentrated liquid waste and spent resin in cement. Plasma technology is recognized for its broad applicability across a wide range of radioactive waste types [1]. Furthermore, it offers a superior volume reduction ratio(VRR), which is a critical advantage for efficient waste management. To investigate the feasibility of treating and reducing the volume of such cementitious wastes, a demonstration test was conducted in this study using surrogate materials and applying plasma torch melting technology.

2.Experimental Methods

2.1 Preparation of Surrogate Sample

The Surrogate waste was designed to closely emulate the actual cement-solidified waste forms stored in nuclear power plants. Specially, the sample were prepared by mixing cement-solidified concentrated liquid waste with shredded steel drum components in a mass ratio of 24:1. The inclusion of steel components was intended to simulate the metallic structural materials typically associated with waste packaging and to evaluated their effect on the melting process. The detailed elemental composition of the cement-solidified portion is summarized in Table 1, while the elemental composition of the steel drum components is presented in Table 2. This prepared surrogate mixture served as the feed material for the demonstration tests.

Table 1. Composition of cementitious surrogate

Elem.	B	Na	Mg	Al	Si	S	K	Ca	Fe
wt%	5.4	37.2	5.2	3.4	21.5	0.9	0.8	23.7	1.9

Table 2. Composition of the steel drum components

Elem.	Fe	C	Mn	Si
wt%	99.2	0.1	0.6	0.1

2.2 Plasma Torch Melting System

This plasma torch melting system used in this study has a maximum power capacity of 100 kW. The system is equipped with a versatile plasma torch capable of operating in both non-transferred and transferred modes, with nitrogen employed as the working gas. The furnace is designed to maintain an internal operating temperature of approximately 1,100°C and kept under negative pressure to prevent the leakage of hazardous substances during the melting process. To ensure structural durability at high temperatures, the furnace is cooled using a water-jacket system. For the discharge of molten slag, a dam-type overflow system is utilized, allowing for stable and controlled removal of the melt.

2.3 Feeding Plan

For the demonstration test, a total of 26kg of the prepared surrogate mixture was dried on a workbench to remove any residual moisture. The samples were fed into the furnace at one-hour intervals. Once the melting of the initial feed was gradually increased in subsequent stages. This stepwise approach was employed to monitor the system's thermal response and to determine the maximum sustainable processing capacity. The specific mass for each feeding stage is detailed in Table 3.

Table 3. Feeding mass of samples per cycle

Cycle	Time (h)	Feeding Mass (kg)	Cumulative Mass (kg)
1st	0	1	1
2nd	1	1	2
3rd	2	2	4
4th	3	2	6
5th	4	2	8
6th	5	3	11
7th	6	3	14
8th	7	3	17
9th	8	4	21
10th	9	5	26

3. Results and Discussion

3.1 Electrical Operational Performance

The Operational stability of the plasma torch is a primary factor in ensuring the consistent melting of cement-solidified waste. During the demonstration, the system was operated within the designed ranges for transferred mode, as summarized in Table 4. The current and voltage were precisely controlled to maintain a steady thermal plasma arc despite the periodic introduction of surrogate materials.

Table 4. Operational parameter ranges

Parameter	Range
Torch distance (mm)	55 ~ 110
Current (A)	150 ~ 160
Voltage (V)	560 ~ 608
Power Output (kW)	85 ~ 98

The system exhibited highly stable electrical Characteristics throughout the 26 kg feeding process. The average operating voltage and current were recorded at 584 V and 155 A. Consequently, the average power output was maintained at 92 kW.

3.2 Pressure Control and Response

Maintaining a consistent negative pressure is a critical safety requirement to prevent the leakage of internal gases and contaminants to the environment. The dynamic response of the melting chamber pressure during the feeding stages is illustrated in Figure 1 and Figure 2. As shown in Figure 1, a sharp increase in pressure was observed at each feeding interval. This transient peak was observed at each feeding interval. This transient peak was primarily caused by the opening of the feeding hopper, which led to a temporary inability to maintain the required negative pressure across the system. In response to this disturbance, the automatic control system immediately increased the exhaust fan speed. As demonstrated in Figure 2. The system pressure was successfully restored to its stable negative state within 2 to 4 seconds after the peak.

Fig. 1. Pressure change during the feeding process

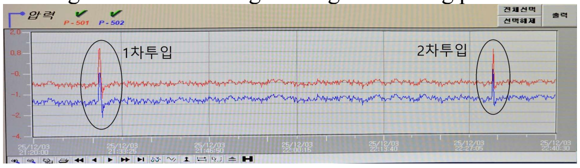
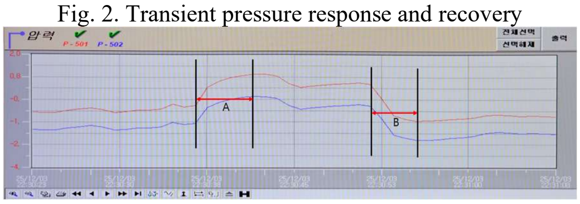


Fig. 2. Transient pressure response and recovery



3.3 Formation and Discharge of Molten Slag

Throughout the test, the fed surrogate material formed a stable melt pool, with excellent surface flatness observed. Based on visual inspection, the molten slag exhibited highly favorable fluidity due to its low viscosity. Notably, the process achieved optimal flow characteristics without the need for additional additives to control viscosity, confirming that the surrogate composition was well-suited for thermal treatment. This high mobility allowed the discharge of the melt to proceed smoothly without any interruptions or abnormal phenomena.

Table 5. Timeline for feeding and discharge

Cycle	Elapsed Time (h)	Discharge Duration(min)	Remarks
1	0	-	
2	1	-	
3	2	-	
4	3	-	
5	4	-	
6	5	8	1st Disch.
7	6	-	
8	7	9	2nd Disch.
9	8	8	3rd Disch.
10	9	5	4th Disch.

3.4 Volume Reduction and Material Balance

One of the primary objective of this study was to evaluate the volume reduction efficiency of the plasma melting process for cement-solidified waste. To ensure a precise material balance, the final molten product was categorized into discharged slag and residual holdup within the melting chamber. The results are summarized in Table 6.

Table 6. Material balance and volume reduction

Parameter	Input	Disch.	Holdup	Total (Final State)
Mass (kg)	26.0	19.9	6.1	26.0
Volume (L)	28.5	5.3	2.8	8.0
Density (kg/L)	0.91	3.78	3.78	3.78
VRR (%)	-	-	-	71.8
VRF	-	-	-	3.55

4. Conclusions

This study confirmed the technical feasibility and high volume reduction efficiency of a 100 kW-class plasma melting system for treating cement-solidified surrogate waste. The system demonstrated robust performance with an average power of 92 kW and maintained a safe environment by restoring pressure within 2 to 4 seconds after feeding disturbances. The treatment achieved VRR of 71.8%(VRF of 3.55). Overall, the plasma melting system proved to be an effective solution for the stabilization and significant volume reduction of cementitious waste.

REFERENCES

[1] Application of Thermal Technologies for Processing of Radioactive Waste(IAEA-TECDOC-1027), IAEA, p. 10, 2006