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# Solidification and leaching behavior of Radioactive Liquid Organic Waste: A Review

Sehyun Cho[a] and Jaehyuk Kang[a,b,*]

[a] *Major of Energy Chemical Engineering, Faculty of Applied Energy System, Jeju National University, Jeju, Republic of Korea*
[b] *Department of Nuclear Engineering, Jeju National University, Jeju, Republic of Korea*
[*] *Corresponding author : jaehyukkang@jejunu.ac.kr*

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## 1. Introduction

Radioactive liquid organic waste (RLOW) is generated from various operations in nuclear facilities, including radiochemical analysis, equipment maintenance, etc. These liquid scintillation counting (LSC) cocktail waste is one of the most common forms of RLOW produced in research institutes, nuclear power plants, and medical facilities. Such wastes typically contain organic solvents, and their high mobility and chemical instability require appropriate treatment or solidification prior to disposal [1]. If not properly managed, these wastes may pose potential risks to the environment due to the possible release and migration of radionuclides.

Solidification is widely used as a pre-disposal treatment method, as in converts liquid to dispersible waste into stable solid forms and reduces the risk of radionuclide leaching. Cement-based solidification has been the most commonly applied technology due to its simplicity and low cost. However, incorporation of liquid organic waste into cement matrices may lead to phase separation and mechanical stability reduction [1].

To overcome these limitations, various alternative solidification materials, including alkali-activated cement and geopolymer-based materials, have been proposed. Among them, acid-based geopolymer has attracted attention due to their dense amorphous network structure, chemical stability, and reaction mechanism such as geopolymerization and polycondensation different with cement-based materials. These characteristics suggest potential advantages for the immobilization of liquid organic wastes.

In addition to the challenges in solidifying liquid organic waste, some organic constituents may act as chelating agent which influences radionuclide mobility and leaching behavior. However, the specific components responsible for such effects in RLOW have not been clearly identified. Furthermore, RLOW consists of various organic compounds, such as aromatic solvents and surfactants, which may differently affect the radionuclides leaching behavior.

To address these issues, this study systematically summarizes organic components that may act as chelating agents influencing radionuclide mobility within waste forms. Therefore, the objective of this review is to provide fundamental information for understanding how these organic components interact with radionuclides and solidification matrices and influence solidification and leaching behavior.

## 2. Types of RLOW

RLOW was generated from various operations in nuclear facilities (Tabel. 1). Typical examples include LSC cocktail wastes from radiochemical analysis, contaminated oil from mechanical system, and decontamination solutions. These liquid organic waste often exhibited chemical instability and may enhance radionuclide mobility, making their treatment and solidification particularly challenging. Additionally, organic materials such as Ethylenediamine tetraacetic acid (EDTA) delayed cement hydration reaction by forming stable complexes with $Ca^{2+}$ ions, reducing their availability for hydration reaction (Fig. 1). This complexation interfered with the formation of hydration products such as calcium silicate hydrate, thereby slowing the overall hydration process and delaying strength development [2].

Table 1. Typical types and characteristics of RLOW [2, 3].

| RLOW | Generation source | Key characteristics |
|---|---|---|
| LSC cocktail | Radiochemical analysis, laboratories, medical facilities | Complex composition, high volatility, |
| Waste oil | Mechanical systems, pumps, turbines | Hydrophobic and incompatible with water for solidification using cement |
| EDTA-containing solution | Decontamination and cleaning process | Strong chelation, high mobility of radionuclides |

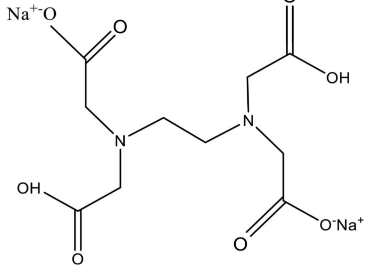


Fig. 1. Molecular structure of EDTA-2Na [2].

## 3. Solidification Studies for Liquid Organic Waste

### 3.1. Cement materials

Cement materials have been widely used for the solidification of RLOW because of their simplicity and low cost. Ordinary Portland cement (OPC) is the most commonly used binder, while alternative materials such as sulfoaluminate cement (SAC) have been investigated to improve stability. In a previous study using simulated TPB organic solvent, both OPC and SAC waste forms satisfied the mechanical stability and leaching requirements. However, differences were observed in the leaching behavior of radionuclides. The SAC waste form exhibited better resistance to $Cs^+$ leaching than OPC waste form (Fig. 2) [4].

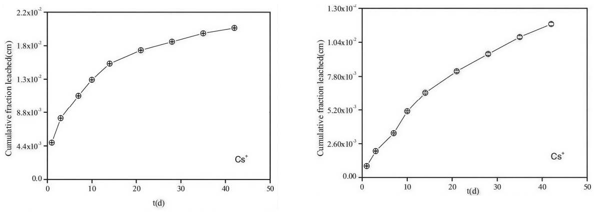


Fig. 2. Cumulative leaching fraction of $Cs^+$ from OPC(left) and SAC(right) waste form [4].

This improved leaching resistance of SAC is mainly attributed to differences in hydration products. XRD analysis indicated that ettringite was the dominant hydration product in SAC waste form, whereas OPC waste form contained significant amounts of $Ca(OH)_2$ (Fig. 3). The ettringite structure provided effective sites to immobilize the radionuclides [4].

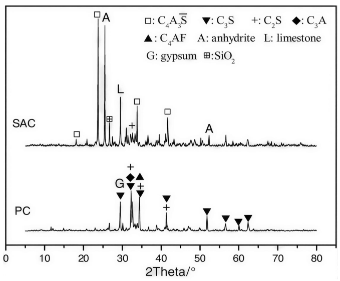


Fig. 3. XRD results of SAC and PC (OPC) waste forms [4].

### 3.2. Geopolymer material

Geopolymer had recently attracted significant attention as alternative solidification materials for RLOW due to their dense microstructure and low permeability. These inorganic binders form a three-dimensional network structure through geopolymerization reaction between aluminosilicate precursors and alkali or acid activators.

Previous study demonstrated that geopolymer could incorporate liquid organic waste without significantly affecting the geopolymerization process and structural stability [5].

Leaching test confirmed the high immobilization performance of geopolymer waste form, with total organic carbon (TOC) release below 0.08% of the incorporated CTAB over 28 days, indicating effective immobilization within the geopolymer waste form (Fig. 4) [5].

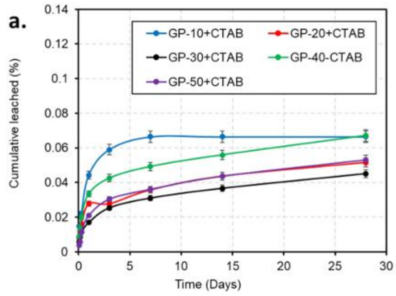


Fig. 4. Cumulative leached TOC for 28 days [5].

This improved immobilization was attributed to the dense geopolymer network and low permeability [5]. These results suggested that geopolymer were promising materials for the immobilization of RLOW.

## 7. Conclusion

Cement materials have been widely used for the solidification of RLOW. However, their immobilization performance may be limited due to the interaction between organic components and $Ca^{2+}$ ions. In contrast, geopolymer material exhibited superior immobilization performance due to their dense network structure and low permeability, resulting in significantly reduced leaching behavior. Therefore, geopolymer material was demonstrated as alternative solidification material for RLOW. However, study on the types of organic components which can act as chelating agents and their mechanisms was insufficient. Since these organic components can form complexes with radionuclides and influence leaching behavior, understanding them is crucial. Therefore, future research will aim to identify the types of organic components that act as chelating agents in various liquid organic waste and characterize their chelation mechanism.

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