Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2026

Sorption Behavior of Uranium at the Copper Canister–Bentonite Interface under Deep Geological Repository Conditions

Ajeong Kim [a#], Seokju Hong [a], Wooyong Um [a, b*]
[a]*Division of Advanced Nuclear Engineering (DANE), Pohang University of Science and Technology (POSTECH), Pohang 37673, Republic of Korea*
[b]*Division of Environmental Sciences and Engineering (DESE), Pohang University of Science and Technology (POSTECH), Pohang 37673, Republic of Korea*
[#]*Presenting author: jeong20876@postech.ac.kr*
[*]*Corresponding author: wooyongum@postech.ac.kr*

***Keywords : Deep geological disposal, uranium, sorption, copper canister, montmorillonite, interface**

1. Introduction

In the KBS-3V disposal concept, spent nuclear fuel is sealed in copper canisters with cast iron inserts and emplaced within compacted bentonite buffer in crystalline bedrock at approximately 500 m depth [1, 2]. Over the long-term evolution of the repository, groundwater saturation may occur, potentially leading to chemical interactions between barriers composed of different materials. A recent study observed that copper specimens in direct contact with saturated bentonite corroded more rapidly than those exposed to water alone, with Cu_2O forming on the canister surface as an early-stage corrosion product and Cu ions simultaneously leaching toward the bentonite [3].

Previous studies on uranium(U) behavior in deep geological disposal environments have predominantly focused on the sorption properties of bentonite or montmorillonite as isolated systems. However, in the event of canister failure, released U would sequentially encounter the Cu_2O layer formed on the canister surface and the surrounding bentonite, yet the U sorption behavior at this interface has not been thoroughly investigated. Recent studies have demonstrated that Cu_2O can effectively capture and immobilize U [4], however its sorption mechanism under deep groundwater conditions remains unclear. On the bentonite side, competitive sorption among coexisting cations at clay mineral surfaces has been reported [5], but the competitive sorption of Cu^{2+} and UO_2^{2+} onto montmorillonite under repository-relevant conditions has received little attention to date.

Therefore, this study investigated U sorption behavior at both sides of the copper canister–bentonite interface environment; U sorption kinetics and mechanisms on Cu metal and Cu_2O solids as well as the effect of coexisting Cu^{2+} ion on U sorption onto Na-montmorillonite under KURT synthetic groundwater conditions. By considering interfacial reactions rather than evaluating individual barrier independently, this study aims to contribute to more accurate prediction of U sorption and migration behavior during the long-term evolution of a geological repository.

2. Methods and Materials

Uranium sorption kinetic batch experiments were conducted using Cu metal powder, Cu_2O powder, and Na-montmorillonite (Na-MMT) as sorbents. A synthetic groundwater simulating the KAERI Underground Research Tunnel (KURT) groundwater composition was used as the background solution with 4.2 μM U. The solid-to-liquid ratio was 0.1 g/10 mL, and reactions were carried out at 10 time points from 30 minutes to 28 days in duplicate. U Sorption experiments were performed under both oxidizing and reducing conditions to represent the early and mid-to-late stages of repository evolution, respectively. Reducing experiments were conducted in a glove box filled with Ar + 4 % H_2 and initiated after the Eh was confirmed to be below zero. After reaction, the supernatant was centrifuged and filtered through a 0.22 μm syringe filter for analysis.

To evaluate the effect of Cu^{2+} on U sorption onto Na-MMT, competitive sorption experiments were performed under U-only (5 μM) and U in the presence of Cu^{2+} (5 μM U + 10 μM Cu^{2+}) conditions at the same conditions as above.

3. Results and discussion

3.1. Solid characterization

X-ray diffraction analysis of Cu metal samples under oxidizing conditions revealed the emergence of a Cu_2O(111) patterns from day 3 onward, with increasing intensity over time. Under reducing conditions, no Cu_2O peak was detected even after 28 days. For Cu_2O samples, no significant changes were observed. Across all conditions, no new crystalline U phases were identified.

3.2 pH and Cu leaching behavior

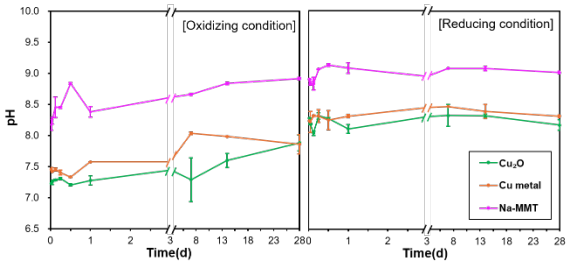


Fig. 1. Evolution of pH as a function of reaction time for Cu_2O, Cu metal, and Na-MMT under (a) oxidizing and (b) reducing condition, respectively.

Under oxidizing condition, the pH of Cu_2O and Cu metal samples converged to 7.8–8.0 by day 28, while the pH of Na-MMT stabilized at 8.5–8.8 (Fig.1a). Under reducing condition, the pH values were generally higher due to limited CO_2 in the glove box, with Na-MMT at approximately 9.0 and Cu_2O/Cu metal at 8.1–8.3 (Fig.1b). Leaching of Cu ion was observed from both Cu_2O and Cu metal under oxidizing conditions, with higher release during the initial 24 hours followed by a decreasing trend. Under reducing conditions, Cu leaching from Cu metal was barely detectable, whereas Cu_2O continued to release Cu, reaching 2.87 ppm by week 4. This suggests that Cu_2O maintains a degree of Cu solubility even under reducing atmospheres, and that the supply of Cu ion toward the bentonite may persist regardless of redox conditions.

3.3 Uranium removal efficiency

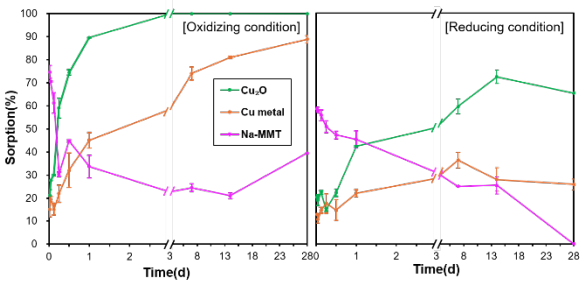


Fig. 2. U removal efficiency (%) of Cu_2O, Cu metal, and Na-MMT as a function of reaction time under (a) oxidizing and (b) reducing conditions.

Under oxidizing condition, Cu_2O exhibited the highest U removal efficiency among the sorbents (Fig.2a), showing 99.9 % of U removal efficiency by day 3 and was maintained through day 28. In contrast, Cu metal showed low U initial removal efficiency, but a sharp increase was observed after day 3, reaching approximately 90 % by day 28. These results suggest that Cu_2O acts as the dominantly active solid phase responsible for U sorption. The Na-MMT displayed the highest U removal efficiency among the three sorbents at early reaction times (approximately 74 %), but this decreased continuously over time, declining to approximately 39 % by day 28.

Under reducing condition, the overall removal efficiency was lower than oxidizing condition (Fig.2b), which is attributed in part to the suppressed formation of the Cu_2O active phase on Cu metal and potentially to differences in U speciation at the higher pH observed under reducing condition. Among the sorbents, Cu_2O showed a gradual increase in removal efficiency, reaching approximately 65 % by day 28, but did not match the performance observed under oxidizing condition. The U removal efficiency by Cu metal reached approximately 26 % by day 28, while Na-MMT exhibited a continuous decline, approaching approximately 0 % by day 28. Further analysis is needed to elucidate the cause of the time-dependent decrease of U removal.

3.4 Cu^{2+}–UO_2^{2+} competitive sorption preliminary experiments on Na-MMT

The U removal efficiency on Na-MMT was 40.5 % under the U-only condition (5 μM) and 41.6 % in the presence of Cu ion (10 μM), showing no significant difference. This suggests that Cu does not act as a severe competitive ion for U sorption on Na-MMT at this low Cu concentration. The d(001) spacing of Na-MMT increased from 12.6 Å (unreacted) to 14.8 Å after the U-only condition and 13.9 Å in the presence of Cu, suggesting that both Cu and U react with the MMT interlayer. Additional experiments with different U:Cu molar ratios of 1:100 and 1:1000, incorporating variations in addition sequence (simultaneous addition, Cu pre-addition followed by U, and U pre-addition followed by Cu), are currently in progress.

4. Conclusions

A uranium removal efficiency of approximately 99.9% was achieved by Cu_2O within 3 days under oxidizing condition, while Cu metal reached approximately 90 % by day 28 as a surface Cu_2O layer developed. Under reducing condition, U removal efficiency was lower for all sorbents, with Cu_2O reaching approximately 65 % and Cu metal 26 % by day 28, respectively. On the bentonite side, Cu ion at low concentration did not exhibit a competitive effect on U sorption onto Na-MMT. Future work will include XPS analysis and DFT calculation to figure out the sorption mechanism and competitive sorption experiments at higher U:Cu molar ratios to further elucidate U sorption behavior under interface-relevant conditions.

Acknowledgements

This work was supported by the Institute for Korea Spent Nuclear Fuel (iKSNF); the Korea Foundation of Nuclear safety (KOFONS). Funded by the Korea Government (Nuclear Safety and Security Commission, NSSC) (No. RS-2021-KN066120). This work was also supported by the Human Resources Development Project for High-Level Radioactive Waste (HLW) Management, hosted by the Korea Radioactive Waste Agency (KORAD) and the High-Level Radioactive Waste Management Commission (HRWC).

REFERENCES

[1] Ewing, R. C. (2015). Long-term storage of spent nuclear fuel. Nature Materials, 14, 252–257.
[2] Posiva SKB (2017). Safety functions, performance targets and technical design requirements for a KBS-3V repository. Posiva SKB Report 01.
[3] Harper, C. O., Brown, J. L., & Amos, R. T. (2026). The impact of bentonite on copper corrosion early in deep

geological repository lifecycles. Journal of Nuclear Materials, 156651.
[4] Liu, H., Guo, H., Huang, D., Zhou, L., Lei, J., Liu, Y., & Zhu, W. (2025). Ultrafast photoassisted capture of uranium over Cu_2O/CuO heterojunction enabled by rapid interfacial electron transfer. ACS Materials Letters, 7(1), 295–303.
[5] Orucoglu, E., Grangeon, S., Gloter, A., Robinet, J. C., Madé, B., & Tournassat, C. (2022). Competitive adsorption processes at clay mineral surfaces: A coupled experimental and modeling approach. ACS Earth and Space Chemistry, 6(1), 144–159.