Advances in Microbiology, 2025, 15(6), 313-319
https://www.scirp.org/journal/aim
ISSN Online: 2165-3410
ISSN Print: 2165-3402

Removal of Strontium, Cobalt, and Cesium from the Mixed Aqueous Solution Using *Arthrobacter nicotiane* Cells

Takehiko Tsuruta*, **Akira Shiga**

Graduate School of Mechanical and Biochemical Engineering, Hachinohe Institute of Technology, Hachinohe, Japan
Email: *tsuruta@hi-tech.ac.jp

How to cite this paper: Tsuruta, T. and Shiga, A. (2025) Removal of Strontium, Cobalt, and Cesium from the Mixed Aqueous Solution Using *Arthrobacter nicotiane* Cells. *Advances in Microbiology*, **15**, 313-319.
https://doi.org/10.4236/aim.2025.156022

Received: May 20, 2025
Accepted: June 22, 2025
Published: June 25, 2025

Abstract

The removal of strontium, cobalt, and cesium ions from the aqueous solution using biomass was investigated. *Arthrobacter nicotianae* known for its high capacity to remove cationic metal ions was used for the removal of these metal ions. Several factors affected the removal of these metal ions using *A. nicotianae* including solution pH, concentration of metal ions, and cell amount. The amount of each metal ion removed increased with the rising pH (1 - 5) of the solution. Meanwhile, the ion uptake per gram of dry biomass (mmol metal ion/g dry wt. cells) increased with increasing metal ion concentration. However, removal efficiency (%) decreased. The metal ion uptake (mmol metal ion/g dry wt. cells) was found to fit the Langmuir isotherm. Conversely, increasing the biomass content enhanced total percentage of metal ions removed (%); however, the amount of each metal ion removed (μmol metal ion/g dry wt. cells) decreased. The removal of strontium using *A. nicotianae* occurred rapidly, approaching equilibrium within approximately 5 min. The amounts of cobalt and strontium removed were higher than that of cesium removed. The maximum amount of cobalt, strontium and cesium is estimated to be 179, 175, and 56.1 μmol/g dry wt. of cells, respectively.

Keywords

Strontium Removal, Cobalt Removal, Cesium Removal, *Arthrobacter nicotiananae*

1. Introduction

Radioactive elements such as cesium, iodine, strontium, plutonium, barium, cobalt, lanthanum, yttrium, and tellurium were detected around the Fukushima Daiichi nuclear power plant, Japan, which was damaged by a magnitude 9.0 earthquake and the subsequent tsunami.

The removal of radioactive elements from contaminated sources is a significant area of research in environmental control. Special attention has been given to studying microorganisms that remove containing bacteria [1]-[4], actinomycetes [5]-[7], fungi [5] [8]-[11], and yeasts [4] [12].

We investigated the removal and recovery of uranium from aqueous systems using microorganisms isolated from uranium mines [13]. Several bacterial strains with extremely high uranium removal capacities were identified suggesting that the microbial biomass could serve as an effective adsorbing agent for the removal and recovery of uranium and heavy metals present in aqueous systems surrounding the Fukushima Daiichi nuclear power plant.

We screened various species and strains of bacteria, actinomycetes, fungi, and yeasts to monitor the efficiency of uranium adsorption [14]. The basic features affecting uranium adsorption such as coexisting cations and anions, cell amounts, and the adsorption kinetics, were evaluated, with *Arthrobacter nicotianae* cells exhibiting the highest uranium uptake. Similarly, Additionally, the study examined the removal of another actinoid element, thorium ions, which may be present along with uranium in refining effluents [15]. Similarly, cadmium [16] and all of rare earths [17] [18] were also removed the highest amount of each metal ion using *A. nicotianae* cells in the all of microorganisms examined.

This paper discusses the use of biomass for the removal of strontium (Sr), cobalt (Co), and cesium (Cs) from the mixed solutions in water.

2. Materials and Methods

2.1. Culture of Microorganisms

The microorganisms were grown in a medium containing 3 g/L meat extracts, 5 g/L peptone, and 5 g/L NaCl in deionized water. The cultures of microorganisms, maintained on agar slants, were grown in 300 mL of the medium in a 500-ml flask with continuous shaking (120 rpm) at 30˚C. To get a sufficient number of resting microorganisms after separation from the growth medium, the cultures were grown for 72 h. The cells were collected by centrifugation, washed thoroughly with deionized water, and used for subsequent removal experiments.

2.2. Effect of pH on Metal Removal Using *A. nicotianae* Cells

Metals were supplied as nitrates. Effect of pH on metals removal using *A. nicotianae* cells was examined as followed. pH of the solution was adjusted to a desired value (1.0 - 5.0) using 0.1 M HNO_3. Resting cells (15 mg dry wt. basis) were suspended in 100 mL solutions containing 35 μM of each metal and incubated for 20 h at 30˚C. Microorganisms were then collected by filtration through a nitrocellulose membrane filter (pore size 0.2 μm). Control studies confirmed that free metals ions were not adsorbed onto the filter.

The amount of each metal removed using the cells was determined by measuring the difference between the initial and final metal content in the filtrate using an atomic absorption analysis quantometer (AA-6300, Shimadzu Corporation, Kyoto).

2.3. Dependence of Cesium, Cobalt, and Strontium Removal on External Metal Concentrations Using *A. nicotianae* Cells

Dependence of external metal concentrations on metals removal using *A. nicotianae* cells was examined as followed. Resting cells (15 mg dry wt. basis) were suspended in 100 mL solution (pH 5) containing metals (20 - 200 μM) for 20 h at 30 ˚C. The amount of each metal remaining in the cell-free filtrate was measured, as described above.

2.4. Dependence of Cesium, Cobalt, and Strontium Removal on Cell Amounts Using *A. nicotianae* Cell

Dependence of the cell amounts on metals removal using *A. nicotianae* cells was examined as followed. Resting cells (5 - 80 mg dry wt. basis) were suspended in 100 mL solution (pH 5) containing 130 μM of metal for 20 h at 30˚C. In this section the solution containing relatively high metal concentration (130 μM) because of using wide range of cell amounts, however, the solution containing 35 μM of metal because of a relatively low resting cells amount (constantly 15 mg) in the pH dependence experiment. Metals remaining in the cell-free filtrate were measured as described above.

3. Results and Discussion

3.1. Effect of pH on the Removal of Cobalt, Strontium and Cesium

The effect of pH on the removal of Sr, Co, and Cs containing the same concentration of each metal using *A. nicotianae* was examined. Metal removal was examined in solutions with varying pH (pH 1 - 5). Strontium hydroxide was precipitated at pH 6. As shown in Figure 1, the removal efficiency of all metals increased with increasing pH of the solution. Removal efficiencies of Co and Sr pH 5.0 were 96% and 98% respectively, however, that of Cs was 27%. Accordingly, the removal of Co and Sr is easier than that of Cs. Additionally, approximately 40% of Sr was removed at pH 2, whereas Co and Cs were not removed under similar conditions. Approximately 34% of Co was removed at pH 3; however, Cs removal remained minimal under these conditions. Therefore, these metals can be effectively separated using *A. nicotianae* by adjusting the pH.

3.2. Effect of External Metal Concentration on the Removal of Cobalt, Strontium and Cesium

The effect of the external metal concentration on the removal of Co, Sr, and Cs was then examined. As illustrated in Figure 2(a), the amount of each metal removed (μmol/g dry wt. cells) increased with increasing external metal concentration, whereas the total percentage of metal removed (%) decreased. Under these experimental conditions, Co (100%) and Sr (94.0%) were mostly removed from a solution containing 20 μM of each metal. However, the amount of removed total cesium (%) was 29.4% from the solution containing 20 μM of both metals. The maximum amounts of Co, Sr, and Cs removed were 215, 194, and 81 μmol/g dry wt. cells, respectively. Accordingly, the relative degree of each metal removed was observed to be Co > Sr >> Cs, indicating that *A. nicotianae* cells can remove Co and Sr more readily than Cs.

The relationships between the residual Co, Sr, and Cs concentrations in the solution and the amount of each metal removed are illustrated in **Figure 2(b)**. The figure clearly indicates that the removal of these metals using *A. nicotianae* cells obeyed the *Langmuir isotherm*, and $Q = Q_{max}K_LC_e/(1 + K_LC_e)$, where Q represents the amount of metal removed (μmol metal/g dry wt. cells), C_e is the residual metal in solution (μmol metal/L), and K_L is a *Langmuir* constant. The maximum amount of Co, Sr, and Cs removed (Q_{max}) and *Langmuir* constant (K_L) shown in **Table 1**. *Langmuir isotherm* is indicated that the relative degree of maximum removal follows the order for Co = Sr > Cs.

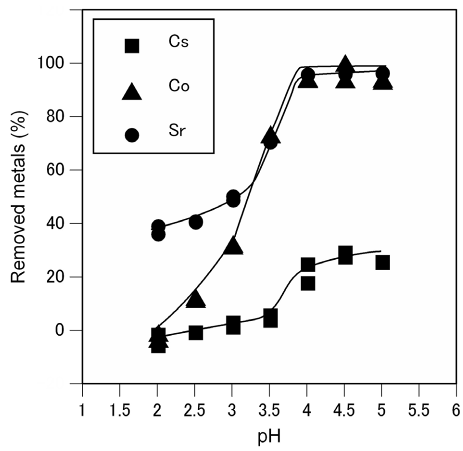
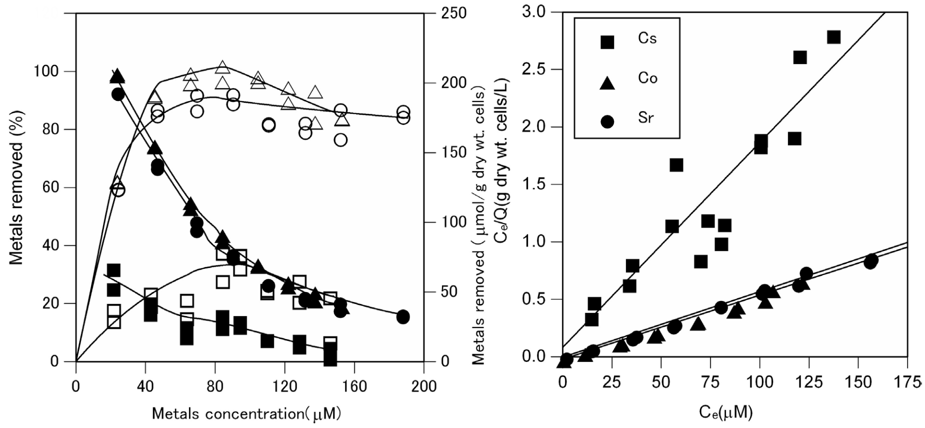


Figure 1. Effect of pH on the removal of Sr, Co, and Cs using *A. nicotianae* cells.



(a) (b)

Figure 2. (a) Effect of metal concentration on the removal of Co, Sr, or Cs using *A. nicotianae* cells. (b) *Langmuir* isotherm of each metal removal using *A. nicotianae* cells.

Table 1. Maximum amounts of removed metal ions and *Langmuir* constant.

	Metal Ion		
	Co	Sr	Cs
Q_{max} [μmol/g dry wt. cells]	179	175	56.1
K_L [L/μmol]	−3.85	−0.632	4.58

3.3. Effect of Cell Amount on the Removal of Cobalt, Strontium and Cesium

The effect of *A. nicotianae* cell amount on the removal of Co, Sr, and Cs was examined the results are illustrated in Figure 3. The total amount of each metal removed increased with rising cell amount, whereas the relative amount of each metal removed by the cells (μmol metal/g dry wt. cells) reduced. Under these experimental conditions, approximately 90% of Co and Sr were removed using over 78 mg of the dry wt. basis of the cells. However, the amount of total removed cesium was only 10% using 78 mg of the *A. nicotianae* cells used. The maximum amounts of Co, Sr, and Cs removed were 277, 227, and 176 μmol/g dry weight, respectively. cells using 5.2 mg dry wt. cells, respectively.

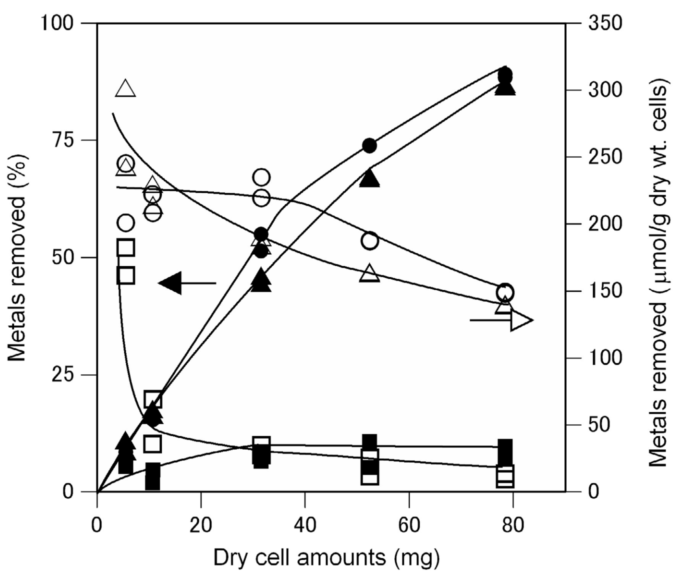


Figure 3. Effect of cell amounts on the removal of Co, Sr, and Cs using *A. nicotianae* cells.

4. Conclusions

The removal of Co, Sr, and Cs, metals detected around the Fukushima Daiichi nuclear power plant from a solution containing mixed metal ions using *A. nicotianae* was demonstrated and investigated.

The removal efficiency of the metal increases as the pH of the solution rises. The relative degree of metal removal by *A. nicotianae* cells was observed to be Co, Sr >> Cs.

The metal removal efficiency (μmol/g dry wt. cells) increased with increasing metal concentration in the solution. The relative degree of metal removal by *A. nicotianae* cells was Co = Sr > Cs.

The total percentage of metals removed increased with increasing cell number. and the relative degree of metal removal by *A. nicotianae* cells was Sr > Co > Cs.

In this paper, the main purpose is removal of radioactive ions such as Co. Sr, Cs from contaminated sources. Therefore, desorption of adsorbed metals and the reusability of the biomass was not examined. However, these metal ions are also rare metals, desorption and separation of adsorbed metals are now investigating. The most of adsorbed metals can be desorbed using immobilized microorganisms by column system. Desorption and separation of the metals adsorbed will be reported in the next paper. Additionally, the removal of Co, Sr, and Cs were almost adsorption, because of most of removed metals were easily desorbed using immobilized microorganisms by column system.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Andres, Y., MacCordick, H.J. and Hubert, J. (1993) Adsorption of Several Actinide (Th, U) and Lanthanide (La, Eu, Yb) Ions by Mycobacterium Smegmatis. *Applied Microbiology and Biotechnology*, **39**, 413-417. https://doi.org/10.1007/bf00192103

[2] Hu, M.Z., Norman, J.M., Faison, B.D. and Reeves, M.E. (1996) Biosorption of Uranium by *Pseudomonas aeruginosa* Strain CSU: Characterization and Comparison Studies. *Biotechnology and Bioengineering*, **51**, 237-247. https://doi.org/10.1002/(sici)1097-0290(19960720)51:2<237::aid-bit14>3.0.co;2-j

[3] Marqués, A.M., Roca, X., Simon-Pujol, M.D., Fuste, M.C. and Congregado, F. (1991) Uranium Accumulation by Pseudomonas Sp. Eps-5028. *Applied Microbiology and Biotechnology*, **35**, 406-410. https://doi.org/10.1007/bf00172734

[4] Strandberg, G.W., Shumate, S.E. and Parrott, J.R. (1981) Microbial Cells as Biosorbents for Heavy Metals: Accumulation of Uranium by *Saccharomyces cerevisiae* and *Pseudomonas aeruginosa*. *Applied and Environmental Microbiology*, **41**, 237-245. https://doi.org/10.1128/aem.41.1.237-245.1981

[5] Byerley, J.J., Scharer, J.M. and Charles, A.M. (1987) Uranium (VI) Biosorption from Process Solutions. *The Chemical Engineering Journal*, **36**, B49-B59. https://doi.org/10.1016/0300-9467(87)80031-x

[6] Friis, N. and Myers-Keith, P. (1986) Biosorption of Uranium and Lead by *Streptomyces longwoodensis*. *Biotechnology and Bioengineering*, **28**, 21-28. https://doi.org/10.1002/bit.260280105

[7] Golab, Z., Orlowska, B. and Smith, R.W. (1991) Biosorption of Lead and Uranium by Streptomyces Sp. *Water*, *Air*, *and Soil Pollution*, **60**, 99-106. https://doi.org/10.1007/bf00293968

[8] Galun, M., Keller, P., Malki, D., Feldstein, H., Galun, E., Siegel, S., *et al.* (1983) Recovery of Uranium (VI) from Solution Using Precultured Penicillium BIOMASS. *Water*, *Air*, *and Soil Pollution*, **20**, 221-232. https://doi.org/10.1007/bf00279632

[9] Galun, M., Keller, P., Malki, D., Feldstein, H., Galun, E., Siegel, S.M., *et al.* (1983)

Removal of Uranium (VI) from Solution by Fungal Biomass and Fungal Wall-Related Biopolymers. *Science*, **219**, 285-286. https://doi.org/10.1126/science.219.4582.285

[10] Tsezos, M. and Volesky, B. (1981) Biosorption of Uranium and Thorium. *Biotechnology and Bioengineering*, **23**, 583-604. https://doi.org/10.1002/bit.260230309

[11] White, C. and Gadd, G.M. (1990) Biosorption of Radionuclides by Fungal Biomass. *Journal of Chemical Technology & Biotechnology*, **49**, 331-343. https://doi.org/10.1002/jctb.280490406

[12] Shumate, S.E., Strandberg, G.W. and Parrott Jr, J.R. (1978) Biological Removal of Metal Ions from Aqueous Process Streams. *Biotechnology and Bioengineering Symposium*, **8**, 13-20.

[13] Sakaguchi, T., Tsuruta, T. and Nakajima, A. (1996) Removal of Uranium by Using Microorganisms Isolated from Uranium Mines. *Proceedings of the Technical Solutions for Pollution Prevention in the Mining and Mineral Processing Industries*, *Engineering Foundation Conference*, Palm Coast, 21-25 January 1995, 183-191.

[14] Tsuruta, T. (2002) Removal and Recovery of Uranyl Ion Using Various Microorganisms. *Journal of Bioscience and Bioengineering*, **94**, 23-28. https://doi.org/10.1263/jbb.94.23

[15] Tsuruta, T. (2003) Accumulation of Thorium Ion Using Various Microoganisms. *The Journal of General and Applied Microbiology*, **49**, 215-218. https://doi.org/10.2323/jgam.49.215

[16] Tsuruta, T., Umenai, D., Hatano, T., Hirajima, T. and Sasaki, K. (2014) Screening Micro-Organisms for Cadmium Absorption from Aqueous Solution and Cadmium Absorption Properties of *Arthrobacter nicotianae*. *Bioscience*, *Biotechnology*, *and Biochemistry*, **78**, 1791-1796. https://doi.org/10.1080/09168451.2014.930321

[17] Tsuruta, T. (2006) Selective Accumulation of Light or Heavy Rare Earth Elements Using Gram-Positive Bacteria. *Colloids and Surfaces B*: *Biointerfaces*, **52**, 117-122. https://doi.org/10.1016/j.colsurfb.2006.04.014

[18] Tsuruta, T. (2007) Accumulation of Rare Earth Elements in Various Microorganisms. *Journal of Rare Earths*, **25**, 526-532. https://doi.org/10.1016/s1002-0721(07)60556-0