Purification of selenium-containing leachate in wastewater tanks at a tunnel construction site

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Abstract. The leachate containing heavy metals which generated from excavated soil and rock in the civil engineering works appropriate measures are required. We conducted indoor and outdoor experiments to purify heavy metal-containing leachate using a water tank, and proposed a method for treating heavy metals using the purification function of plants at civil engineering works. The plant used was Eleocharis acicularis, which belongs to the Cyperaceae family. The results of the indoor tank experiment on selenium indicated a decrease in the selenium concentration in the leachate from 0.093 to 0.008 mg/L in 14 days. The selenium content per kg of Eleocharis acicularis based on dry weight increased from 0.010 to 0.205 mg, indicating that the plant absorbed selenium. The outdoor tank experiment revealed that the selenium concentration in the leachate decreased from 0.090 to 0.007 mg/L in 21 weeks, and the daily absorption of selenium was 0.0005 mg/L. The lead concentration decreased from 0.004 to 0.001 mg/L in one week, and the arsenic concentration decreased from 0.003 to less than 0.001 mg/L in three weeks. Calculation of the leachate purification cost using Eleocharis acicularis under the current outdoor experiment conditions resulted in a 56% treatment cost reduction compared with the regular treatment cost.

1. Introduction

In a tunnel, cutting of earth and other civil engineering works may generate excavated soil and rock containing arsenic (As), lead (Pb), selenium (Se) and other heavy metals [1]. Temporary storage of such excavated soil and rock may generate leachate containing heavy metals and other substances at levels exceeding the environmental quality or standard effluent values due to rainfall or other reasons. In view of such potential above-standard contents of heavy metals and other substances in leachate from excavated soil, appropriate measures are required in terms of protection of the surrounding environment and project costs. In recent years, the heavy metal-absorbing effect of phytoremediation, an environmental remediation technology using Eleocharis acicularis and other plants, has been attracting attention. This Eleocharis acicularis absorbs and accumulates heavy metals has been shown to be effective in mine effluent treatment [2-4]. Eleocharis acicularis is a perennial that grows in clumps at ponds, marshes, reservoirs, and paddy fields, and it is distributed throughout all in Japan. Eleocharis acicularis propagates with runners that branch off from the root area. The grown height is about 15 to 20 cm. The authors have so far confirmed a 75% to 89% reducing effect on the total amount of arsenic.
contained in the effluent as well as a 40% to 60% reduction in the effluent itself by purification experiments using an artificial channel [5-7].

In this study, an indoor experiment to confirm the selenium absorption effect of *Eleocharis acicularis* was conducted in a small water tank using leachate from temporarily stored soil at a tunnel construction site to elucidate the heavy metal absorption/accumulation effect of *Eleocharis acicularis* and to establish a treatment technique for efficient absorption/accumulation. Another experiment at the tunnel site involved adding *Eleocharis acicularis* to a tank storing leachate containing selenium, lead and arsenic, and analysis of the concentration of heavy metals in the leachate and the amount absorbed by *Eleocharis acicularis* provided the daily absorption capacity of the plant, which is necessary for purification design. This paper also presents the cost reduction effect of leachate purification using *Eleocharis acicularis*, which was calculated by comparing the purification costs using the plant with regular treatment costs.

2. Materials and Method

2.1. Purification experiment using an indoor water tank

*Eleocharis acicularis* of 0.4 kg in wet weight was placed on a plastic sheet floating in a small water tank (W20 x D40 x H30 cm) as shown in Figure 1. Then 10 litres of leachate from tunnel construction site of Hokkaido Prefecture Japan. (selenium concentration: 0.093 mg/L) from tunnel excavation soil was poured into the tank to submerge the plant. Water was collected from the tank and the pH, EC and water depth were measured at the beginning of the experiment and on the 1st, 3rd, 5th, 10th and 14th days (end of the experiment). Approximately 10 g of *Eleocharis acicularis* was also collected at the beginning and end of the experiment to analyse the selenium concentration. At the same time, water from a blank case (on the left in Figure 1) of leachate without *Eleocharis acicularis* was collected and analysed.

2.2. Purification experiment using an outdoor water tank

In an open water tank (W1.8 x L7.0 m) placed in a roofed space, 33.6 kg wet weight of *Eleocharis acicularis* (wet weight of *Eleocharis acicularis* per 1 m² of area is 4 kg) was put in plastic containers (with holes in the bottom) floated with Styrofoam. In the tank, 17.5 m³ of leachate containing 0.090 mg/L of selenium was stored (Figure 2) in tunnel construction site of Yamanashi Prefecture Japan. Water was weekly collected from the tank from the beginning of the experiment, and concentration of heavy metals (lead, arsenic, selenium), pH, electric conductivity and turbidity were measured.

At the time of each water sampling, a pump (lift capacity 3.5 L/min) was installed at the bottom of the water tank, and the water was stirred for 15 minutes before sampling. The target reduction value of

![Figure 1. Indoor tank experiment. Left: blank tank. Right: tank with *Eleocharis acicularis*.](image-url)
the selenium concentration at this site was 0.01 mg/L, which is the environmental quality standard value in Japan. The difference between the initial concentration of selenium and the target value was divided by the number of days required from the beginning of the experiment to the time when the concentration fell below the target value, to calculate the daily amount of selenium absorbed by *Eleocharis acicularis*. The cost reduction rate was also analysed by comparing the leachate purification cost using the plant with the regular treatment cost.

2.3. Analysis method

The concentrations of selenium, lead and arsenic in the leachate were analysed using the Inductively coupled plasma atomic emission spectroscopy (ICP-AES, Hitachi High technology Co., Ltd. Japan. P-4010), after adding and storing with nitric acid (Hokkaido Wako Junyaku Co., Ltd. Japan. Concentration 60.0-63.0 %) to make the selenium concentration 1% after filtering. As pre-treatment, *Eleocharis acicularis* was washed thoroughly with ultrapure water, dried for two days at 40ºC in a dryer and reduced to a fine powder. The powder specimen, to which 30% hydrogen peroxide (Hokkaido Wako Junyaku Co., Ltd. Japan. Concentration 30.0-35.5 %), 61% nitric acid and 38% hydrofluoric acid (Hokkaido Wako Junyaku Co., Ltd. Japan. Concentration 46.0-48.0 %) were added, was then evaporated to dryness at 98ºC. After adding 61% nitric acid and evaporating again at 98ºC, the specimen was dissolved with 30% nitric acid. The concentrations of selenium, lead and arsenic in the solution were analysed by the ICP-AES method. Here, the heavy metal content of *Eleocharis acicularis* is a value corresponding to the dry weight at the time of analysis.

3. Results and Discussion

3.1. Indoor experiment results

Figure 3 shows the results of the indoor experiment. The selenium concentration of the leachate in the tank with *Eleocharis acicularis* decreased to less than one tenth, from 0.093 to 0.008 mg/L, in 14 days, whereas the concentration in the tank without the plant increased by 20% to 0.112 mg/L. This increase in concentration was thought to be due to the decrease in the initial water volume of 10 litres to 7.5 litres through evaporation in both tanks. The pH level that was measured concurrently changed from 6.3 to 7.4 in the tank with *Eleocharis acicularis* and from 7.2 to 7.9 in the tank without the plant. The EC level changed from 124 to 162 mS/m in the tank with *Eleocharis acicularis* and from 124 to 151 mS/m in the tank without the plant. The cause of the increase in pH and EC was also considered to be due to evaporation. The selenium content of *Eleocharis acicularis* increased from the initial value of 1.0 mg/kg to 22.1 mg/kg in 14 days. The converted weight of selenium per kg of dry weight of *Eleocharis acicularis* changed from 0.010 mg to 0.205 mg. After these results confirmed that the plant absorbs...
selenium, an outdoor experiment was conducted. During the indoor tank experiment, no leaf withering or new leaf growth was confirmed.

**Figure 3.** Indoor tank experiment results. (a) Selenium, dry weight of *Eleocharis acicularis*, selenium concentration in leachate, selenium concentration in the blank tank. (b) pH and EC levels of leachate.
3.2. Outdoor experiment results
Table 1 shows the results of the outdoor experiment. The initial selenium concentration of 0.090 mg/L decreased to 0.007 mg/L after 21 weeks, and fell below the target value of 0.01 mg/L set at this site. The initial concentration of lead (0.004 mg/L), which was below the target (environmental quality standard) value of 0.01 mg/L, decreased to less than 0.001 mg/L in one week. The initial concentration of arsenic (0.003 mg/L), which was also below the target (environmental quality standard) value of 0.01 mg/L, decreased to less than 0.001 mg/L in three weeks. The pH and EC levels changed from 7.2 to 7.4 and 601 to 665 mS/m, respectively. Turbidity decreased from the initial value of 170 to 23 in one week. This reason thought to be that the particles in the water settled naturally. Meanwhile, the selenium content of *Eleocharis acicularis* increased from the initial value of 0.1 mg/kg to 8.9 mg/kg. The converted weight of selenium per kg of dry weight of *Eleocharis acicularis* changed from 0.005 mg to 0.414 mg. As demonstrated by the experiment, the selenium concentration in leachate was successfully reduced by using *Eleocharis acicularis*. Next, the difference between the initial concentration and the reduction target value of 0.01 mg/L was divided by the number of days required from the beginning of the experiment to the time when the concentration fell below the target value, to calculate the amount of selenium absorbed by *Eleocharis acicularis*. The reduction target value of 0.01 mg/L was first subtracted from the initial concentration of 0.090 mg/L, and the concentration difference of 0.080 mg/L was found. This concentration difference was divided by the number of days required until the concentration fell below 0.01 mg/L.

### Table 1. Outdoor tank experiment results.

| Measuring data week passed | Pb (mg/L) | As (mg/L) | Se (mg/L) | pH | EC (ms/m) | Turbidity |
|----------------------------|-----------|-----------|-----------|----|-----------|-----------|
| initial value              | 0.004     | 0.003     | 0.090     | 7.2| 601       | 170       |
| 1 week                     | less than 0.001 | 0.002 | 0.084 | 6.8 | 604 | 23        |
| 2 week                     | less than 0.001 | 0.002 | 0.081 | 6.6 | 608 | 11        |
| 3 week                     | less than 0.001 | less than 0.001 | 0.074 | 6.8 | 612 | 7         |
| 4 week                     | less than 0.001 | less than 0.001 | 0.074 | 6.9 | 617 | 5         |
| 5 week                     | less than 0.001 | less than 0.001 | 0.070 | 6.9 | 622 | 7         |
| 7 week                     | less than 0.001 | less than 0.001 | 0.062 | 6.9 | 630 | 9         |
| 9 week                     | less than 0.001 | less than 0.001 | 0.051 | 7.0 | 636 | 4         |
| 10 week                    | less than 0.001 | less than 0.001 | 0.046 | 7.1 | 640 | 10        |
| 11 week                    | less than 0.001 | less than 0.001 | 0.042 | 7.2 | 642 | 11        |
| 12 week                    | less than 0.001 | less than 0.001 | 0.036 | 7.1 | 644 | 6         |
| 13 week                    | less than 0.001 | less than 0.001 | 0.032 | 7.2 | 647 | 11        |
| 15 week                    | less than 0.001 | less than 0.001 | 0.024 | 7.0 | 654 | 12        |
| 17 week                    | less than 0.001 | less than 0.001 | 0.016 | 7.1 | 658 | 7         |
| 19 week                    | less than 0.001 | less than 0.001 | 0.011 | 7.2 | 663 | 8         |
| 21 week                    | less than 0.001 | less than 0.001 | 0.007 | 7.4 | 665 | 6         |
| 24 week                    | less than 0.001 | less than 0.001 | 0.004 | 7.5 | 681 | 10        |

### Table 2. Heavy metals concentration of water and *Eleocharis acicularis*.

| Heavy metals | Measuring data passed | Concentration of water (mg/L) | Concentration of *Eleocharis acicularis* (mg/kg-DW) | Daily content by *Eleocharis acicularis* (mg/kg-DW) |
|--------------|------------------------|-------------------------------|-----------------------------------------------------|---------------------------------------------------|
| Fe           | 0.049                  | 2.440                         | 16.60                                               |                                                   |
| Cu           | -                      | -                             | -                                                   |                                                   |
| Zn           | 0.006                  | 61.7                          | 0.420                                               |                                                   |
| As           | 0.002                  | 0.2                           | 0.001                                               |                                                   |
| Pb           | -                      | -                             | -                                                   |                                                   |
| Se           | 0.090                  | 16.8                          | 0.114                                               |                                                   |

25 weeks passed data [8] | 21 weeks passed data

| Heavy metals | Measuring data passed | Concentration of water (mg/L) | Concentration of *Eleocharis acicularis* (mg/kg-DW) | Daily content by *Eleocharis acicularis* (mg/kg-DW) |
|--------------|------------------------|-------------------------------|-----------------------------------------------------|---------------------------------------------------|
| Fe           | 0.144                  | 7.960                         | 45.00                                               |                                                   |
| Cu           | 0.004                  | 215.0                         | 1.60                                                 |                                                   |
| Zn           | 0.106                  | 2.380                         | 17.40                                                |                                                   |
| As           | 0.059                  | 399.0                         | 2.90                                                 |                                                   |
| Pb           | -                      | -                             | -                                                   |                                                   |
| Se           | 0.080                  | 1,401                         | 10.20                                                |                                                   |
below the target value, 147 (21 weeks x 7 days), and the daily amount of selenium absorbed by *Eleocharis acicularis* was found to be 0.080 mg/L/147 days = 0.0005 mg/L. This outdoor experiment in a tank revealed the daily amount of selenium absorbed by *Eleocharis acicularis*. However, the value was calculated under the condition whereby 8.4 m² (33.6 kg wet weight) of the plant was placed in 17.5 m³ of leachate. Table 2 shows the results of the heavy metals concentration of water and *Eleocharis acicularis*. Nurfitri et al [8] shown the content of heavy metals in the roots and leaves of *Eleocharis acicularis* in a 25-week mine wastewater purification experiment using *Eleocharis acicularis*. Our experimental period was 21 weeks. In addition, our experiment used the water tank, and the experiment of Nurfitri et al [8] was the result of under the condition that water flows. Comparing both, although the water concentration was different, *Eleocharis acicularis* contained copper and lead in addition to iron, zinc and arsenic. Our experiment also contains selenium in the aquarium. The daily selenium content of *Eleocharis acicularis* was calculated by dividing the selenium content of *Eleocharis acicularis* by the experimental period, and the result was 0.114 mg/kg.

3.3. Treatment cost reduction rate with the use of *Eleocharis acicularis*

Based on the results of the outdoor tank experiment in the previous section, the leachate purification cost by using *Eleocharis acicularis* was calculated and compared with the regular treatment cost to find the reduction rate, assuming the following site conditions.

3.3.1 Site conditions
i) The volume of the leachate was 17.5 m³
ii) The concentrations of the heavy metals (lead, arsenic, selenium) in the leachate were maintained at the environmental quality standard value of 0.01 mg/L.
iii) Multiple tanks were prepared assuming large amounts of generated leachate due to heavy rainfall.
iv) Regular unit price of leachate treatment: USD367/m³ (JPY40,000/m³)

3.3.2 Costs and comparison
i) Regular treatment cost =USD367/m³ (JPY40,000/m³) × 17.5 m³ = USD6,422 (JPY700,000)
ii) Purification cost using *Eleocharis acicularis*
   - Cost of *Eleocharis acicularis* = USD110 m³ (JPY12,000/m³) × 8.4 m³ = USD925 (JPY100,800)
   - Analysis cost = USD110/set (JPY12,000/set) × 17 number of analysis = USD1,872 (JPY204,000)
   Total: USD 2,796 (JPY304,800)

3.3.3 Cost difference and reduction rate
i) Difference = regular treatment cost - purification cost using *Eleocharis acicularis*
   = USD6,422 (JPY700,000) - USD2,796 (JPY304,800) = USD3,626 (JPY395,200)
ii) Reduction rate = purification cost using *Eleocharis acicularis* / regular treatment cost
   = USD2,796 (JPY304,800) / USD6,422 (JPY700,000) = 0.435

An on-site purification experiment using *Eleocharis acicularis* was conducted based on the above results, and leachate was successfully treated at approximately 44% of the regular treatment cost.

4. Conclusions
This experiment revealed the following findings.
- The results of an indoor purification experiment using a water tank confirmed the absorption of selenium by *Eleocharis acicularis*.
- The results of an outdoor tank experiment showed that the daily amount of selenium absorbed by *Eleocharis acicularis* was 0.0005 mg/L.
- Calculation of the treatment cost of leachate containing heavy metals under the conditions of the current outdoor experiment revealed that leachate can be purified at 44% of the regular treatment cost.
Since a sufficient effect may not be obtained with leachate containing mud due to the adhesion of mud to the stems and leaves of the plants, the authors intend to conduct studies on purification methods using plant fibber in the future.

Acknowledgment: The authors wish to express their gratitude to the staff of the Hokkaido Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, Japan for their cooperation with this study.

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