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# Removal of Some Heavy Metals from Polluted Water by Water Hyacinth (*Eichhornia crassipes*)

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Water hyacinth(Eichhornia crassipes.(Mart.) Solms) grows abunduntly throughout the tropical and subtropical regions of the world (PENFOUND & EARLE 1948), and is also widely distributed in the southwest regions in Japan(UEKI *et al.*1976). Recently, this plant has received attention because of its potential for removal of pollutants when utilized as a biological filtration system(WOLVERTON *et al.* 1978).

There are many reports which refer to the removal of mineral nutrients(ORNES *et al.*1975, ROGERS & DAVIS 1972, SHEFFIELD 1967) by aquatic plants, especially water hyacinth from polluted wastes, but few refer to the removal of heavy metals, such as copper(SUTTON *et al.*1971), silver, cobalt, strontium(WOLVERTON *et al.*1975a), mercury, lead(WOLVERTON *et al.*1975b), cadmium, and nickel(WOLVERTON *et al.* 1975c) by water hyacinth from heavy metal-contaminated waste effluents.

The purpose of this study was to examine the ability of water hyacinth to remove toxic heavy metals from the metal-containing solution without nutrients in winter. Cadmium, lead, and mercury were chosen for this investigation since they are common toxic metals found in industrial wastewater.

Cadmium has not been shown to be essential to the growth of plants; however, it can be readily adsorbed(TATSUYAMA *et al.*1979). Lead is not essential but is found in all plants, and is also a hazard to humans(KOPITO *et al.*1967) and animals. Typical water pollution by cadmium in industrial effluent was identified by the occurrence of "Itai-itai" disease caused by cadmium poisoning(ISHIZAKI *et al.* 1968). "Minamata" disease is caused by methylmercury poisoning(TAKEUCHI 1962).

## MATERIALS AND METHODS

### Experimental conditions

Adult plants of water hyacinth were obtained from the University of Okayama on February 1, 1982. Roots were cut to uniform lenghts of about 15 cm, and were kept in plastic tanks for 7 days prior to the starting of experiments. Individual plants were planted in 2.0-L plastic pots in a phytotoron house, where they were maintained at 25 ± 2 °C.

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The plants were exposed to individual metals where cadmium ($CdCl_2 \cdot 2\frac{1}{2}H_2O$) and lead($PbNO_3$) were added at nominal concentrations of 1.0, 4.0, and 8.0 ppm, and mercury($HgCl_2$) was added at nominal concentrations of 0.5, 1.0, and 2.0 ppm. Plants were also exposed to mixture of metals as follows: Cd 1.0ppm + Pb 1.0ppm + Hg 0.5ppm; Cd 4.0ppm + Pb 4.0ppm + Hg 1.0ppm; and Cd 8.0ppm + Pb 8.0ppm + Hg 2.0ppm. One control group was prepared. There were two replicates for analysis of metals on the 1st, 2nd, 4th, 12th, and 16th days after the beginning of the experiments. Water characteristics were(mg/L): Ca 12.1; Mg 1.8; Na 4.2; K 0.90; $SO_4$ 5.2; Cl 4.0; $SiO_2$ 12.4; Alkalinity 38.2 as $CaCO_3$; Dissolved solid 65.0; Cd 0.001; Cu 0.02; Zn 0.07; Pb 0.08. pH was 7.1-7.3.

Analysis

The plants were divided into two parts:tops(including rhizome) and roots. Each sample was dried at 80 °C for 48h in a hot-air drier and ground with a mill. The ground sample was dissolved in $HNO_3$-$HClO_4$(2:1) and made up to a fixed volume by the addition of the DDTC-MIBK extraction method. Mercury was determined with a flameless atomic absorption spectrophotometer after combution of a fresh sample under an oxygen gas flow and then converted into mercuric ion with an oxidising agent.

## RESULTS AND DISCUSSION

Plant growth

Periodical changes in the growth of plants throughout the experiments are shown in Table 1. In the Cd and Hg groups, the fresh weight of plants was slightly decreased with increasing metal concentration compared with those at the beginning of experiments, expect for the 1.0ppm Cd group. The Pb group was increased 1.5-1.9 times that at the beginning of the experiment at every concentration on the 16th day, but in the metal mixed group(Cd+Pb+Hg), it was decreased by 12-27 percent of that of the initial values.

In contrast, the plants without added metals were increased about 1.6 times that of the initial values. It was considered that a decrease in the growth was induced by metal toxicity.

Relationship of metal concentrations in plants and in solution

Cadmium: The concentrations of cadmium(µg/g in dry matter) in the tops and roots of plants exposed to cadmium-containing water are presented in Table 2. The Cd concentrations in both tops and roots tended to increase with increasing concentrations of cadmium, and with the passage of time, except for the 8.0ppm Cd group. In roots, it increased exponentially from the initial to the 12th day of the experiments. However, the concentrations of Cd in the mixed metal(Cd+Pb+Hg) group tended to be lower than those in the cadmium alone group. The concentration in the control group was 8.8 ± 2 µg/g and 1.1 ± 0.2 µg/g in roots and tops, respectively.

Table 1. Relative changes in the growth of plants on a fresh weight basis compared with the initial fresh weight(=1.00)

| Treatment | Days after treatment 1 | 2 | 4 | 8 | 12 | 16 |
|---|---|---|---|---|---|---|
| Cd 1.0 ppm | 1.07 | 0.96 | 1.08 | 1.13 | 1.10 | 1.24 |
| 4.0 | 0.94 | 0.92 | 1.00 | 0.95 | 0.91 | 0.96 |
| 8.0 | 1.00 | 0.99 | 1.02 | 0.86 | 0.86 | 0.88 |
| Pb 1.0 ppm | 1.02 | 1.07 | 1.16 | 1.32 | 1.49 | 1.93 |
| 4.0 | 1.08 | 0.97 | 1.03 | 1.37 | 1.34 | 1.71 |
| 8.0 | 1.02 | 1.10 | 1.08 | 1.44 | 1.36 | 1.65 |
| Hg 0.5 ppm | 1.00 | 0.96 | 0.92 | 0.90 | 0.92 | 0.88 |
| 1.0 | 0.88 | 1.03 | 0.96 | 0.91 | 0.96 | 0.98 |
| 2.0 | 0.94 | 1.43 | 0.88 | 0.86 | 0.99 | 0.86 |
| Cd 1.0+Pb 1.0+Hg 0.5ppm | 1.04 | 0.96 | 0.92 | 0.90 | 0.92 | 0.88 |
| Cd 4.0+Pb 4.0+Hg 1.0 | 0.89 | 0.82 | 0.78 | 0.67 | 0.76 | 0.73 |
| Cd 8.0+Pb 8.0+Hg 2.0 | 0.94 | 1.06 | 0.90 | 0.93 | 0.70 | 0.85 |
| Control | - | 1.05 | - | 1.19 | - | 1.67 |

Table 2. Concentration of cadmium(μg/g in dry matter) in water hyacinth treated with cadmium alone or with Pb and Hg

| Treatment | Part | Days after treatment 1 | 2 | 4 | 8 | 12 | 16 |
|---|---|---|---|---|---|---|---|
| Cd 1.0 ppm | top | 36.6 | 54.3 | 130 | 225 | 379 | 461 |
| | root | 805 | 711 | 815 | 1570 | 2010 | 2650 |
| Cd 4.0 | top | 173 | 298 | 446 | 690 | 1402 | 1696 |
| | root | 1448 | 1641 | 1800 | 2810 | 4518 | 7615 |
| Cd 8.0 | top | 295 | 615 | 1008 | 1806 | 2187 | 2326 |
| | root | 4444 | 4784 | 5789 | 7530 | 8207 | 10600 |
| Cd 1.0 + Pb 1.0 + Hg 0.5 ppm | top | 28.0 | 25.3 | 53.9 | 157 | 207 | 385 |
| | root | 581 | 589 | 681 | 1190 | 1570 | 2015 |
| Cd 4.0 + Pb 4.0 + Hg 1.0 ppm | top | 148 | 178 | 304 | 632 | 977 | 1299 |
| | root | 940 | 1340 | 1421 | 2380 | 3700 | 420 |
| Cd 8.0 + Pb 8.0 + Hg 2.0 ppm | top | 136 | 187 | 532 | 742 | 1015 | 5455 |
| | root | 3296 | 3282 | 3690 | 4695 | 6610 | 9030 |
| Control | top | - | - | - | - | - | $1.1 \pm 0.2$ |
| | root | - | - | - | - | - | $8.0 \pm 2.0$ |

Lead: The concentrations of lead in plants exposed to lead are presented in Table 3. The concentration of lead(μg/g in dry matter) in both tops and roots tended to increase exponentially with the passage of time in the lead alone group throughout the experimental period. In the 8.0 ppm Pb group, it had reached 25,790 μg/g in roots and 1,810 μg/g in tops of plant with exposure to Pb for 16 days.

Table 3. Concentrations of lead(μg/g in dry matter) in water hyacinth treated with lead alone or with Cd and Hg

| Treatment | Part | Days after treatment | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 4 | 8 | 12 | 16 |
| Pb 1.0 ppm | top | 28.9 | 29.2 | 53.4 | 279 | 351 | 492 |
| | root | 2280 | 3150 | 4300 | 4405 | 6050 | 6200 |
| Pb 4.0 ppm | top | 223 | 220 | 243 | 595 | 761 | 820 |
| | root | 7530 | 7200 | 8705 | 11900 | 17200 | 22620 |
| Pb 8.0 ppm | top | 945 | 1060 | 1238 | 1639 | 1776 | 1810 |
| | root | 10400 | 11250 | 13740 | 18400 | 21900 | 25790 |
| Cd 1.0 + Pb 1.0 + Hg 0.5 ppm | top | 27.3 | 27.6 | 58.3 | 110 | 213 | 265 |
| | root | 2111 | 2250 | 2950 | 4510 | 5677 | 6905 |
| Cd 4.0 + Pb 4.0 + Hg 1.0 ppm | top | 133 | 191 | 223 | 354 | 458 | 527 |
| | root | 5056 | 5096 | 5600 | 7490 | 8649 | 10550 |
| Cd 8.0 + Pb 8.0 + Hg 2.0 ppm | top | 433 | 521 | 613 | 839 | 1020 | 1205 |
| | root | 10100 | 10580 | 12750 | 16500 | 17250 | 20100 |
| Control | top | - | - | - | - | - | $1.6 \pm 0.3$ |
| | root | - | - | - | - | - | $7.9 \pm 2.0$ |

Mercury: The concentrations of mercury(μg/g in fresh matter) in plants exposed to mercury are presented in Table 4. Those in the tops of plants were markedly lower at every concentration of mercury, also those in roots increased exponentially with the passage of time from the initial to the 8th day of the experiments. The phenomenon of withering of roots and change to a black color of the surface of roots induced by mercury toxicity appeared on the 5th and 8th days after exposure to water containing 1.0, 2.0, and 0.5 ppm of Hg. By contrast, each metal concentration in the mixed metal group tended to be lower than that in the Pb alone group, but higher than that in the Cd and Hg alone group.

The test solution was changed every other day for each concentration of metal, and the old solutions were analyzed for metal concentrations. Cd concentrations in the residual solution before replacing plants ranged from 0.50-0.86, 1.21-2.95, and 2.25-5.30 ppm in solutions initially containing 1.0, 4.0, and 8.0 ppm of Cd, respectively. Those in the Pb group ranged from 0.28-0.49, 0.90-1.46, and 2.29-4.79 ppm in solutions initially containing 1.0, 4.0, and 8.0 ppm of Pb, respectively, and those in the Hg group ranged from 0.003-0.076, 0.013-0.041, and 0.035-1.04 ppm in solutions initially containing 0.5, 1.0, and 2.0 ppm of Hg, respectively.

Table 4. Concentrations of mercury($\mu$g/g in fresh matter) in roots of water hyacinth treated with mercury alone or with Cd and Pb

| Treatment | Days after treament | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 4 | 8 | 12 | 16 |
| Hg 0.5 ppm | 14.71 | 22.4 | 33.1 | 80.0 | 197 | 244 |
| Hg 1.0 ppm | 8.75 | 151 | 233 | 536 | 538 | 580 |
| Hg 2.0 ppm | 186 | 203 | 395 | 660 | 677 | 680 |
| Cd 1.0+ Pb 1.0 + Hg 0.5 ppm | 10.9 | 19.4 | 25.0 | 66.7 | 73.0 | 94.0 |
| Cd 4.0+ Pb 4.0 Hg 1.0 ppm | 36.7 | 123 | 169 | 278 | 280 | 288 |
| Cd 8.0+ Pb 8.0 + Hg 2.0 ppm | 153 | 175 | 1241 | 269 | 349 | 357 |
| Control | - | - | - | - | - | $<$0.001 |

Metal concentration factors

The concentration factors of water hyacinth exposure for 16 days to metal-containing factors water are shown in Table 5. The values for Cd, Pb, and Hg are presented as fresh matter of plants. The values of concentration factors in roots of plants tended to be higher than that in tops. Similar results were observed in the mixed groups. The concentration factors for Cd, Pb, and Hg in the tops and roots of water hyacinth ranged as follows: For Cd, 3.50 x 10 - 4.66 x 10 in the tops, 2.90 x 10 - 1.01 x $10^2$ in roots in the Cd alone group, and 1.91 x 10 - 3.60 x 10 in the tops, 3.14 x 10 - 6.16 x 10 in roots in the mixed metals group. For Pb, 1.86 x 10 - 4.18 x 10 in the tops, 1.27 x $10^2$ - 2.96 x $10^2$ in roots in the Pb alone group, 1.02 x 10 - 2.23 x 10 in the tops, 2.49 x 10 -1.26 x $10^2$ in roots in the mixed metals group. Also for Hg, 0.032 x 1-0.044 x 1 in the tops, 3.40 x $10^2$ - 4.88 x $10^2$ in roots in the Hg alone group, 1.79 x $10^2$ - 2.88 x $10^2$ in roots in the mixed metals group.

Table 5. Concentration factors for Cd, Pb, and Hg by water hyacinth with exposure to metal-containing water

| Part / Metals | metal alone | | mixed metals | |
|---|---|---|---|---|
| | top | root | top | root |
| Cd 1.0 ppm | 4.370 x 10 | 1.009 x $10^2$ | 3.604 x 10 | 6.155 x 10 |
| 4.0 | 4.664 x 10 | 4.722 x 10 | 3.090 x 10 | 3.262 x 10 |
| 8.0 | 3.495 x 10 | 2.897 x 10 | 1.913 x 10 | 3.141 x 10 |
| Pb 1.0 ppm | 4.184 x 10 | 2.958 x $10^2$ | 2.227 x 10 | 2.486 x 10 |
| 4.0 | 1.864 x 10 | 2.202 x $10^2$ | 1.017 x 10 | 9.497 x 10 |
| 8.0 | 2.026 x 10 | 1.270 x $10^2$ | 1.177 x 10 | 1.260 x $10^2$ |
| Hg 0.5 ppm | 0.044 x 1 | 4.380 x $10^2$ | 0.005 x 1 | 1.880 x $10^2$ |
| 1.0 | 0.032 x 1 | 4.880 x $10^2$ | 0.048 x 1 | 2.880 x $10^2$ |
| 2.0 | 0.048 x 1 | 3.400 x $10^2$ | 0.041 x 1 | 1.785 x $10^2$ |

Consequently, it is considered that lead was markedly absorbed by the root tissue of water hyacinth from the solution containing the higher level, 20 ppm of Pb. The concentration factors for Hg in tops of water hyacinth were markedly lower than for Cd and Pb due to a hazard of metal-translocation with withering of roots induced by mercury toxicity, but that factors in roots were higher similar to those for Pb owing to adsorption of Hg on the surface of root tissues.

<u>The capacity for removal of heavy metals by water hyacinth</u>

The maximum value for the metal content of an individual plant is defined as the equation of a logistic-curve.

$$\frac{dt}{dn} = \lambda n \left( 1 - \frac{n}{N} \right) \quad \ldots (1)$$

Index n refers to the metal content in one plant; N is the maximum value of n; t is the time(days); $\lambda$ is the coefficient of the growth rate. By integration(1), the next equation was obtained.

$$n = \frac{N}{1 + \kappa e^{-\lambda t}} \quad \ldots (2)$$

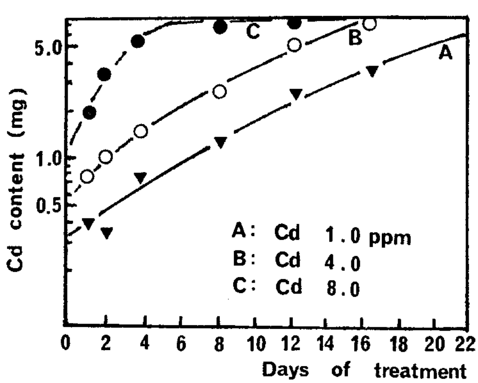



Fig. 1a

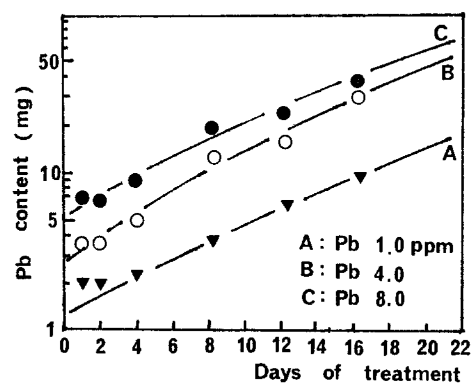
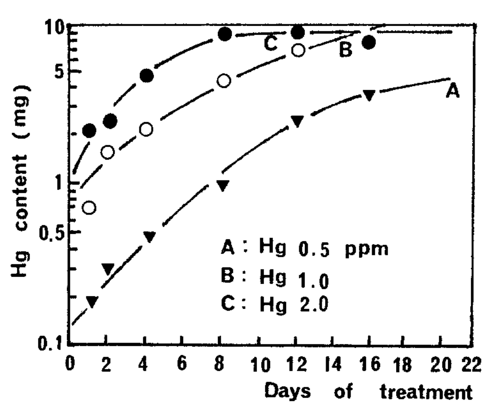



Fig. 1b




Figs. 1a-1c. Changes in metal content(mg) per individual water hyacinth with the passage of time in water containing individual metal alone

Index $\kappa$ refers to constant factor of the initial conditions. The maximum contents in individual plants (including the amounts of metal adsorption on the surface layer of roots) as obtained from equation(2) are presented graphically in Figs. 1a - 1c.

These maximum values for the metal content(μg) of individual plant(in fresh matter) were as follows: 9.52 μg/ 65.3g, 19.2 μg/49.0 g, and 8.0 μg/ 64.8g in Cd 1.0, 4.0, and 8.0 ppm containing solution, respectively; 1.4 μg/ 62.0g, 660μg/ 88.5g, and 1,170 μg/84.0g in Pb 1.0, 4.0, and 8.0 ppm containing solution, and 4.8 μg/ 62.0g, 116 μg/ 49.5g, and 84.9 μg/ 52.5g in Hg 0.5, 1.0, and 2.0 ppm containing solution, respectively.

The maximum and optimum values for the amount of metal removed by water hyacinth in natural field were estimated using the values reported by OKI *et al.*(1981). The optimum and maximum values for standing crops on a fresh weight basis in natural field were 10 $kg/m^2$ and 45 $kg/m^2$, respectively.

The amount of metal removed by water hyacinth is summarized in Table 6. From these results, the maximum values of removal of metals were as follows: 177 kg/ha in 4.0 ppm Cd containing water, 6,270 kg/ha in 8.0 ppm Pb containing water, and 1,050 kg/ha in 1.0 ppm Hg containing water. The optimum amounts of metals removed were: 39.3 kg/ha in 8.0 ppm Cd containing water, 1,390 kg/ha in 8.0 ppm Pb containing water, and 234 kg/ha in 1.0 ppm Hg containing water.

Water hyacinth would be ideally suited for heavy metal removal systems. But this plant is not capable of growing from January to March in Japan. Further investigation is necessary to extend the growing season of plant throughout the year by utilizing the thermal effluents from the industry, such as the iron foundry.

Table 6. Calculated maximum values for removal of heavy metals by water hyacinth in natural fields

| Treatment | Maximum content per individual plants (g/kg) | Mean values ($g/m^2$) | Maximum values ($g/m^2$) |
|---|---|---|---|
| Cd 1.0 ppm | 0.146 | 1.46 | 6.56 |
| 4.0 | 0.393 | 3.93 | 17.7 |
| 8.0 | 0.124 | 1.24 | 5.60 |
| Pb 1.0 ppm | 1.05 | 10.5 | 47.5 |
| 4.0 | 7.46 | 74.6 | 336 |
| 8.0 | 13.9 | 139 | 627 |
| Hg 0.5 ppm | 0.007 | 0.77 | 3.47 |
| 1.0 | 2.34 | 23.4 | 105 |
| 2.0 | 0.17 | 1.70 | 7.52 |

The amounts of absorption by water hyacinth estimated as reported by OKI *et al.*(1981).

(A): Mean values of standing crop 10 kg fresh weight/$m^2$

(B): Maximum values of standing crop 45 kg fresh weight/$m^2$

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## REFERENCES

ISHIZAKI,A.& M.FUKUSHIMA: Jap.J.Hyg. 23, 271 (1968) (in Japanese).

KAPITO,L.,R.K.BYERS,H.SCHWASHMANI: N.Engl.J.Med. 276, 949 (1967).

OKI,Y.,K.NAKAGAWA & M.NOGI: Proc. 8th Asian-Pacific Weed Sci. Soc. Conf. p113 (1981).

ORNES,W.H. & D.L.SUTTON: Hyacinth Control Journal 13, 56 (1975).

PENFOUND,W.T. & Y.Y.EARLE: Ecol. Monogr. 18, 448 (1948).

RORNES,M.H. & D.E. DAVIS: Weed Sci. 19, 643 (1971).

SHEFFIELD,C.E.: Hyacinth Control Journal 4, 5 (1967).

SUTTON,D.L.,R.D.BLACKBURN,W.C.BALEWE: Weed Sci. 19, 643 (1971).

TAKEUCHI,T., N. MORIKAWA, H.MATSUMOTO, Y.SHIRAISHI: Acta Neuropath 2, 40 (1962).

TATSUYAMA,K., H.EGAWA, H.YAMAMOTO: Weed Res. Japan 24, 260 (1979) (in Japan).

UEKI,K., M.ITO, Y.OKI: Proc. 5th Asian-Pacific Weed Sci. Soc. Conf. p424 (1978).

WOLVERTON,B.C. & R.C. McDONALD: NASA Technical Memorandum TMXX - 72727 (1975a).

WOLVERTON,B.C. & R.C. McDONALD: NASA Technical Memorandum TMXX - 72723 (1975b).

WOLVERTON,B.C. & R.C. McDONALD: Econo. Botany 32, 363 (1978).

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