Rocznik Świętokrzyski. Ser. B – Nauki Przyr. 36: 105–112, 2015

Polska Akademia Nauk – Oddział w Krakowie,
Kieleckie Towarzystwo Naukowe

Use of macrophytes for demineralization of salinized water reservoirs

Zastosowanie marofitów do demineralizacji zasolonych zbiorników wodnych

A. ZHUTOV[1], T. GUBINA[1], S. ROGACHEVA[1],
N. SHILOVA[1], B. WIŁKOMIRSKI[2]

Streszczenie. Badano możliwości zastosowania wyższych roślin wodnych *Eichhornia crassipes*, *Ceratophillum demersum* i *Elodea canadensis* do mineralizacji wody ze zbiorników chłodzących. W eksperymentach laboratoryjnych ustalono, że uprawa *E. crassipes* w ciągu 30 dni prowadzi do redukcji zawartości soli o 25,8% w wodzie pochodzącej ze zbiorników chłodzących. Procesy deminaralizacji przy użyciu *C. demersum* i *E. canadensis* nie była efektywna. Ustalono, że *E. crassipes* absorbuje aniony chlorkowe i siarczanowe (odpowiednio 49,3 i 25,8%), jak również kationy sodu wapnia (odpowiednio 13,0 i 33,5%). *C. demersum* nie akumuluje tych jonów, *E. canadensis* absorbuje kationy w niewielkich ilościach.

Słowa kluczowe: woda, zasolenie, demineralizacjha, fitoekstrakcja, makrofity

Key words: *water, salinity, demineralization, phytoextraction, macrophytes*

[1] **A. Zhutov, T. Gubina, S. Rogacheva, N. Shilova,** *Yuri Gagarin State Technical University of Saratov, Saratov, Russia, 77 Politechnicheskaya street, Saratov, Russia, 410054*

[2] **B. Wiłkomirski,** *Department of Environmental Protection and Modeling, The Jan Kochanowski University in Kielce, Świętokrzyska 15, 25-406 Kielce, Poland, bowi@ujk.edu.pl*

INTRODUCTION

In the past few decades nuclear energy has acquired increasing economic importance, especially for the production of electricity. Currently nuclear power reactors are operating in 31 countries around the world (Sharma et. al. 2014). A power plant generates electricity by boiling water to steam, which turns a turbine that then turns a generator. Cooling systems are required to cool the steam back to water so the cycle can continue.

Nowadays there is the unsettled problem of water mineralization in the basin-coolers of nuclear power stations. Active evaporation from the water surface of the reservoir due to its high temperature and dissolution of the underlying rocks leads to increasing salinity. As water resources are rapidly being exhausted, more and more interest is paid to the desalination not only of seawater but also other types of saline water. Using saline water is possible only under conditions its substantial dilution, which is awkward in the arid regions.

The number of desalination methods exist but most of them require large amounts of energy which is costly both in environmental pollution and in money terms (Almulla et al. 2003). Among different methods of desalination the most useful are: the construction of cooling towers, the using of adsorbents and ion-exchanger. But these methods are unacceptable to large volumes of water.

One of the promising method of basin-coolers demineralization is the application of higher aquatic plants (HAP). This is a group of plants that have adapted to living in aquatic environments, both in saltwater or freshwater. They are also referred to as hydrophytes or macrophytes.

The ability of HAP to accumulate, utilize and transform different chemical substances (Pilon-Smits 2005; Singh et al. 2012). HAP can accumulate in their biomass significant amounts of heavy metals, pesticides, radionuclides. Aquatic plants absorb different contaminants through root, and/or stems and leaves, and of course, various species show different behaviour regarding their ability to accumulate elements in individual organs (Nirmal Kumar et al. 2008).

Toxic substances absorbed by plants are inactivated by passing various chemical transformations or stored in plant tissues. Macrophyte removal from the reservoirs is usually not difficult.

The aim of the present study is to establish the possibility of using some of the higher aquatic plants to reduce water salinity in basin-coolers of energy complex.

OBJECTS AND METHODS OF RESEARCH

Experiments were carried out using following species of HAP: *Eichhornia crassipes*, *Ceratophillum demersum*, and *Elodea canadensis*.

Eichhornia crassipes commonly known as water hyacinth is a free-floating plant, growing plentifully in the warm water bodies. This plant is native to Amazon basin (Photo 1). This plant was used for many years for phytoremediation of water and sediments contaminated with heavy metals (Liao, Chang 2004).

Ceratophyllum demersum, commonly known as hornwort, rigid hornwort, coontail, or coon's tail, is a species of genus *Ceratophyllum*. It is a submerged, free-floating aquatic plant, with a cosmopolitan distribution, native to all continents except Antarctica It is also a popular aquarium plant. Plants are able to accumulate heavy metals without the production of any toxicity or reduction in growth (Abdallah 2012, Chorom et al. 2012).

Elodea canadensis (American or Canadian Waterweed or Pondweed) is a perennial aquatic plant, or submerged macrophyte, native to most of North America. It has been introduced widely to regions outside its native range. There were also some effort to use this plants in the process of phytoremediation (Javed, Greger 2011).

Photo 1. *Eichhornia crassipes* (http://bergenwatergardens.com/true-floating-plants/)
Fot. 1. Eichhornia crassipes (http://bergenwatergardens.com/true-floating-plants/)

Plants of all the investigated species were placed in water samples collected from the cooling reservoir and cultured for 10, 20 and 30 days under artificial lighting of 7500 lux and temperature 24°C. Total salt content of water samples was determined by gravimetric method. Precipitation was weighed on the analytical balance AND HR-2002, Japan.

The quantitative content of components in the test water samples was controlled using a mass spectrometer ICP-MS VG PQ ExCell, USA. Anion and cation contents were determined using Dionex ICS-900 Ion Chromatography System, USA.

Experiments were performed in triplicate. The data were processed statistically. Comparison of the indicators was performed using Student's T-test, significance of differences is true for the significance level of 0.05.

RESULTS AND DISCUSSION

Analysis of water taken from the cooling reservoir showed that salt concentration was 1.2 – 1.3 $g^{*}dm^{-3}$, that exceeds background levels of salinity for 4 times. The increased mineralization was caused by the presence of sulfates and chlorides of sodium, potassium, calcium and magnesium.

Plants of all the investigated species were planted into the samples of the collected water. *C. demersum* and *E. canadensis* are known to be submerged macrophytes which are widespread throughout Russia. They are species potentially useful for extraction of heavy metals, radionuclides and organic compounds. *E. crassipes* belongs to tropical floating aquatic plant, however it is able to actively grow in the northern regions under favorable summer conditions in the temperature range 16–32°C. *E. crassipes* can accumulate significant amounts of various pollutants during vegetation, assimilating them into metabolic processes and adsorbing them on the surface of underwater part of plants.

Plants were grown in three periods (10, 20, 30 days respectively). After finishing of each experimental period mineralization in water samples was determined. The results are shown in Fig. 1.

The results presented in Fig. 1. proved that all the investigated plants decreased the total salt concentration in the water in which they were cultivated. However, the level of this reduction was different. The highest decreasing of salinity was observed in the case of *E. crassipes*. After 10 days of cultivation total salt content decrease by 11.5% from the initial value was observed, followed by 20.6% after 20 days and 25.8% after 30 days, respectively.

The effect of demineralization obtained during the experiments with next two investigated species was much smaller. *E. canadensis* cultivation lead to the slight decrease of water mineralization reaching the 11.4% of the original value. *C. demersum* was practically not active in investigated process because during the growth of this plant for 30 days, water salinity was reduced only by 3.5%. On the second stage of the experiment (20 days) even a slight increase of the salt concentration was observed, which possibly indicated reverse emission of absorbed ions from the plants.

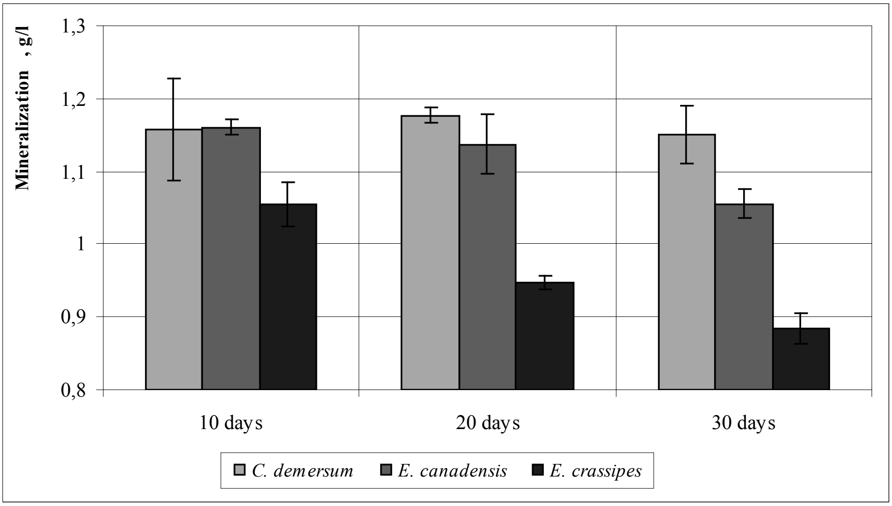

Fig. 1. Total salt concentration in the water samples during cultivation of macrophytes. Bold line – the initial level of mineralization

Rys. 1. Całkowite stężenie soli w wodzie w czasie eksperymentów z uprawą makrofitów

We hypothesise that the pool of adsorbed salts can be used by the plant for its biomass production. The variation in the extent of the absorption rate could be explained by the differences in the specificity of metabolic pathways and their effectiveness and regulation (Gupta, Huang 2014).

During the process of plants cultivation the concentrations of ions Na^{+}, Ca^{2+} and Cl^{-} were measured. The results are shown in Fig. 2. It is seen that the concentration of the defined ions decreases monotonically and significantly in samples with *E. crassipes*. The content of sodium ions is reduced by 1.5 times, whereas for other ions even more, i. e. calcium – 1.7 times and chlorine – 2.8 times, respectively.

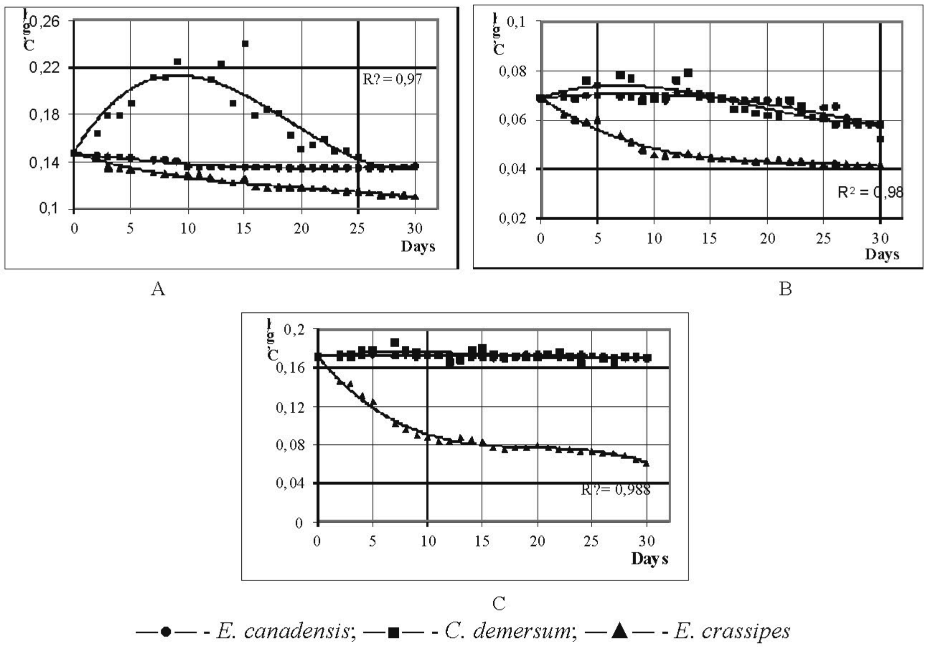

Fig. 2. Changes in the ions concentration: A – Na^+, B – Ca^{2+} and C – Cl^- in water samples during macrophytes cultivation

Rys. 2. Zmiany w stężeniu jonów: A – Na^+, B – Ca^{2+} i C – Cl^- w próbkach wody podczas uprawy makrofitów

For two other investigated species, i. e. *E. canadensis* and *C. demersum*, wavelike dependences were observed what indicated probably the effect of plasmolysis/deplasmolysis. A significant reduction in ions concentration during cultivation of these plants were not find.

On the 10th day of experiments the chemical analysis of water samples was carried out. In Table 1 the results of the analysis of the ions defining the salinity of the cooling reservoir are presented. It is clear that the highest value of the ions absorption (Na^+ – 13%, Ca^{2+} – 33%) is observed for *E. crassipes*. However, the concentration of K^+ decreases by 27%. This process can be explained by the ions redistribution between the plant cells and an aqueous environment, emerging as the result of "action" of sodium-potassium channels of cells. In the probes with *E. canadensis* the reduction of Na^+, K^+, Ca^{2+} cations concentration is also observed, but less than for *E. crassipes*.

Table 1. Changes of ion concentration in water samples after 10-day plant cultivation
Tabela 1. Zmiany w stężeniu jonów w prókach wody po 10 dniach uprawy

Ions *Jony*	Changes of ion concentration, % *Zmiany w stężeniu jonów*		
	E. canadensis	*E. crassipes*	*C. demersum*
Na^+	- 8,0	- 13,0	–
K^+	- 8,0	+27,0	–
Ca^{2+}	- 1,0	- 33,5	–
Cl^-	+ 3,2	- 49,3	+ 1,0
SO_4^{2-}	- 2,5	- 25,8	+ 0,4

«+» – increasing of ion concentration
«-» – decreasing of ion concentration

The results of chemical analysis of water anionic composition showed that among the investigated species *E. crassipes* has the best ability to absorb anions. Thus, the percentage of Cl^- and SO_4^{2-} absorption by *E. crassipes* was 49.28% and 25.82%, respectively. Other investigated macrophytes did not absorb chloride ions during the growth. Increasing of Cl-concentration in the probes with *E. canadensis* and *C. demersum* was within the average statistical inaccuracy. Accordingly, these macrophytes cannot effectively reduce the concentration of ions defining water mineralization.

According to literature data aquatic plant-based water treatment systems have proved effective and economical in improving the quality of wastewaters containing excess nutrients, organic pollutants, and heavy metals (VahdatiRaad, Khara 2012; Jaikumar 2012). Our experiments also showed and proved that the hydrobotanic method of cleaning of mineralized water is perspective. *E. crassipes* can provide steady decline of water salinity. One can say that is very promising plant for mass scale desalination processes. From the other hand it is worth to remember that *Eichhornia crassipes* is invasive weed forming multiple hazards ranging from ecological and economical to social. It tends to endanger biodiversity, cause eutrophication, as well as affect agriculture and aquaculture. Hence, the sufficient methods must be used to control its aggressive propagation (Patel 2012).

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