CHEMICAL ENGINEERING TRANSACTIONS
VOL. 78, 2020

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-76-1; **ISSN** 2283-9216

DOI: 10.3303/CET2078093

Biosorption Capacity of Selected Aquatic Plants

Kim Z. Visperas, Frankie G. Marzo, Jacklyn C. Andrada*

Don Mariano Marcos Memorial State University, Bacnotan, La Union, Philippines
jca4square@gmail.com

The massive growth of aquatic plants can contribute to the problem of biological pollution; however, these plants can be utilized to solve other environmental issues. There are plants noted to have a contribution to the adsorption of heavy metals. This study investigated the biosorption capacity of selected aquatic plants. The biosorption of Pb^{2+} was tested using pulverized water lettuce (*Pistia stratiotes* (L.)), water hyacinth (*Eichhornia crassipes)*, and water spinach (*Ipomoea aquatica*). The increase in biosorbent doses under laboratory conditions at 24 h of contact time has a moderate influence on the pH of the aqueous solution. Metal ion adsorptions were strongly dependent on pH, with an optimum pH of 4-5. The maximum adsorption capacity (q_e) of Pb^{2+} was 3.62, 2.31, and 3.52 mg g^{-1} using water lettuce, water hyacinth, and water spinach. The biosorption efficiency of the aquatic plants is moderately influenced by the biosorbent doses, with a maximum efficiency of 99.99 %.

1. Introduction

Considered as the most hazardous pollutants amongst all toxic metals (Ayucitra et al., 2017), lead (Pb) and its waste are dangerous for the environment (Lima et al., 2014). Its ingestion may have a detrimental effect on human health; hence, there is a need to eliminate it from the environment.

Several advanced techniques are present for the reduction of the environmental impact of industrial wastewater containing heavy metal ions (Shafiq et al., 2018). Conventional treatment processes can help in heavy metal removal. Various treatment options are used to remove heavy metals from industrial wastewaters (Gunatilake, 2015). One of these options is biosorption.

Biosorption aimed to remove or recover organic and inorganic substances from solution by biological material, which can include living or dead microorganisms and their components, seaweeds, plant materials, industrial and agricultural wastes, and natural residues (Fomina and Gadd, 2014). Compared with conventional heavy metal removal methods, the biosorption process is potentially advantageous. The high selectivity in the recovery and removal of specific heavy metals is beneficial in treating large volumes of mixed wastes and wastewater with various heavy metals. Further, the use of natural renewable biomaterials that are considered cheap and abundant provides relatively low investment and operational costs. With the enhanced recovery of bound heavy metals ions, hazardous waste produces significantly reduced in volume (Sheba and Nandini, 2016). In biosorption, the sorbent materials generally are of low cost and can be waste or industrial by-products of natural origin (Silva et al., 2019). Studies showed the potential of aquatic plants to have biosorption capacity. Among the potential biosorbents include water hyacinth, water lettuce, and water spinach.

Water hyacinth *(Eichhornia crassipes)* has attracted significant attention as the world's worst invasive aquatic plant due to its exceptionally rapid proliferation and congest growth (Mahamadi, 2011). But its quest for nutrient absorption has provided a way for its usage in phytoremediation (Rezania et al., 2016). The review study of Mahamadi (2011) showed the excellent removal capabilities of the biomass of water hyacinth for several metals of environmental concern. Water lettuce (*Pistia stratiotes* L.), on the other hand, was investigated by Lim et al. (2016), for its potential as an active, low-cost biosorbent in the removal of methyl violet 2B (MV). The study of Rodrigues et al. (2017) demonstrated the potential use of water lettuce dry biomass for the biosorption of zinc and cadmium, with results more significant than 70 % reductions in the concentrations of the metals in the contaminated solutions. Water spinach, on the other hand, was used in

Paper Received: 08/07/2019; Revised: 15/07/2019; Accepted: 24/11/2019
Please cite this article as: Visperas K.Z., Marzo F.G., Andrada J.C., 2020, Biosorption Capacity of Selected Aquatic Plants, Chemical Engineering Transactions, 78, 553-558 DOI:10.3303/CET2078093

the study of Halim (2010) as biosorbent and was found capable of removing a high percentage of Ferrum from industrial wastewater.

Several studies explore the live biomass of aquatic plants to remove heavy metals. However, the use of live plants may influence the plant itself, as with the study of Malar, et al. (2014) using water hyacinth, which resulted in the gradual decrease of its chlorophyll content. Studies show higher removal efficiency of dried biomass; however, the investigations conducted on these are only a few. In the study of Gunasundari and Senthil Kumar (2017), the adsorption capacity of dried biomass of *Spirulina platensis* (SP) for Cu (II) ions was found higher than with raw SP. Similarly, in the study of Sibi (2014), dried biomass of 5 microalgae showed higher biosorption rate and faster kinetic than the living ones.

In this study, the biosorption capacity of the dried biomass of aquatic plants, particularly on Pb^{2+}, was investigated. These can provide a more efficient means of treating contaminated waters.

2. Materials and methods

3.2.1 Preparation of the biosorbents

Locally gathered stems and leaves of water hyacinth, water lettuce, and water spinach were washed with water, chopped into small parts, oven-dried for about 3.5 h at 60 °C, and pulverized using mortar and pestle. Tissue analysis of the aquatic plants was done using Atomic Absorption Spectrophotometry (AAS) to determine possible lead content.

3.2.2 Preparation of the aqueous solution

The aqueous solution was prepared to attain homogeneity in the Pb^{2+}. The 1,000 ppm lead (II) nitrate ($Pb(NO_3)_2$) solution was diluted in distilled water. Through Pb (flame) method, the aqueous solution was determined to have 70.10 mgL^{-1} Pb^{2+} and a pH value of 0.

3.2.3 Pb^{2+} biosorption experiments

Different mass: 1 g, 2 g, and 3 g of each biosorbent were measured and used as treatments. These were added to the aqueous solutions and were carefully mixed by swirling for about 30 min for each treatment. These were allowed to stand for about 24 h before filtering through filter paper. The filtrate of each treatment was subjected to laboratory analysis through Pb (flame) method. pH values were also measured.

3.2.4 Calculation of biosorption parameters

The computation of the biosorption capacity (q_e) using Eq(1), in mg g^{-1}, and percent biosorption (R %) known as biosorption efficiency of the aquatic plants followed the formula (Kanamarlapudi, 2018) as given in Eq(2):

$$q_e = \frac{(C_i - c_e)V}{m} \quad (1)$$

$$R\ \% = \frac{C_i - c_e}{C_i}\ x\ 100 \quad (2)$$

where q_e is the amount of adsorbed metal ions of the adsorbent (mg/g); C_i is the initial concentration of metal ion in the solution (mgL^{-1}); C_e is the equilibrium concentration of metal ion in the solution (mgL^{-1}); V is the volume of the medium (L); and m is the amount of the biomass used in the adsorption process (g).

3.2.5 Correlation analysis

Using Pearson R, the correlation of biosorbent dose to pH, biosorbent dose to biosorption efficiency, and pH to biosorption efficiency were determined.

3. Results and discussion

3.1 Lead content of the aquatic plants before treatment

The result of tissue analysis revealed no detection of Pb^{2+} in the 3 aquatic plants acquired locally and used in the study. It establishes that the aquatic plants used are not contaminated. It indicates that possible detection or increase of Pb^{2+} in the aqueous solution is not associated with the aquatic plants.

3.2 pH values before and after treatment

The application of the treatment, using water hyacinth as biosorbent has increased the pH value. The highest amount of application, at 3 g, produced the most considerable change in pH value from 0 to 5. Figure 1 shows a directly proportional relationship between the increasing amount of application and the rising pH values.

From the study of Moyo et al. (2013), however, results have shown little potential for the remediation of pH by water hyacinth.

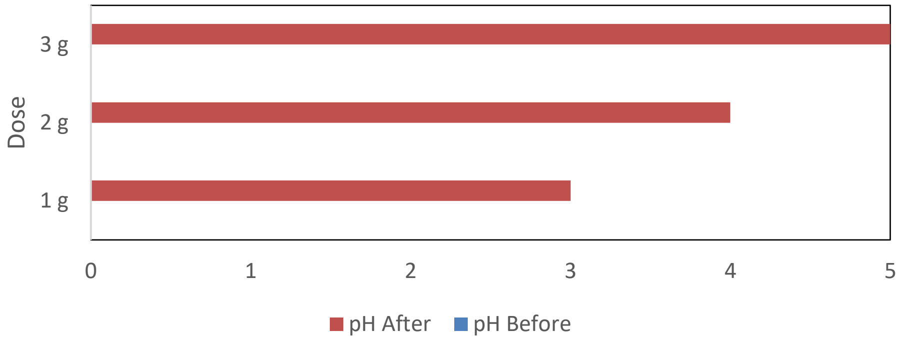

Figure 1: pH values of the aqueous solution before and after treatment using water hyacinth

Among the aquatic plants, the application of water lettuce has the highest increase in pH, notably in all the treatments, with a pH value of 5 (Figure 2). It indicates the ability of water lettuce in improving water quality. As affirmed by the study of Lu et al. (2015), the use of water lettuce improved the eutrophic waters of ponds.

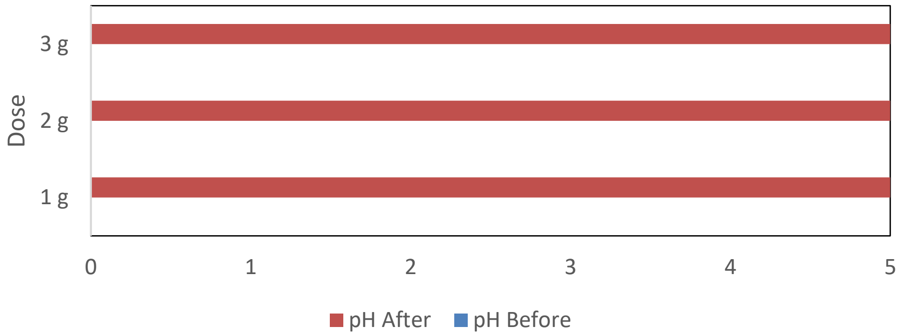

Figure 2: pH values of the aqueous solution before and after treatment using water lettuce

The use of water spinach raised the pH value of the aqueous solution to a pH value of 4 in all treatments (Figure 3). It indicates that water spinach can lower H^+ ions, which can be influenced by its metal binding capacity. In the study of Nguyen, et al. (2018), the pH of the wastewater out of the hydroponic systems increased slightly using water spinach. Another study by Azira et al. (2013) wherein water spinach was cultivated in medium growth bed to examine its ability to remove nutrients from aquaculture wastewater, and results highlighted the effectiveness of water spinach in improving the pollutant removals in the aquaponic system.

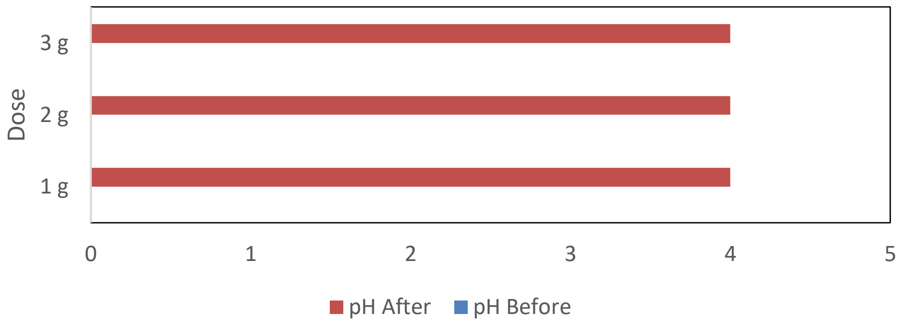

Figure 3: pH values of the aqueous solution before and after treatment using water spinach

3.2 Pb^{2+} content before and after treatment

As shown in Figure 4, the after application of water hyacinth resulted into a high reduction in the Pb^{2+} content of the aqueous solution. At 1 g of application, the biosorption capacity of water hyacinth was computed to be 2.31 mg g^{-1} with a biosorption efficiency of 62.71 % (Table 1). Water hyacinth is notably efficient in minimizing various contaminants due to its extracellular accumulation, cell surface sorption and intracellular accumulation (Priya and Selvan, 2017).

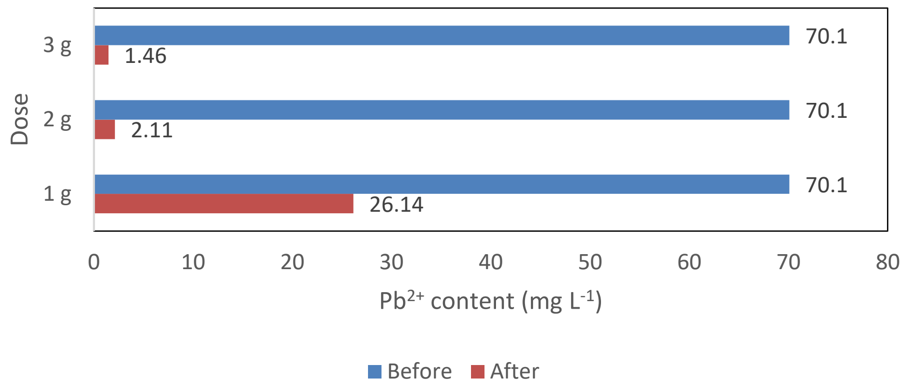

Figure 4: Pb^{2+} content (mg L^{-1}) of the aqueous solution before and after treatment using water hyacinth

Table 1: Biosorption capacity and biosorption efficiency of water hyacinth

Treatment	Biosorption capacity (q_e), mg g^{-1}	Biosorption efficiency (R %)
1 g	2.31	62.71
2 g	1.78	96.99
3 g	1.20	97.92

The application of water lettuce at 1 g, as can be gleaned in Figure 5, has caused the most significant reduction in lead content resulting in 1.19 mg L^{-1}, compared with the other biosorbents. It implies that water lettuce has the highest biosorption capacity in terms of lead, at 1 g of application. At 2 and 3 g of application, the Pb^{2+} was already below the detection limit, < 0.01 mg L^{-1}.
In the short term (up to 8 d), Vesely et al. (2011) found that there is an extremely high lead accumulation in the biomass of water lettuce. This accumulation capacity is potential for a relatively fast and effective decrease of high concentration of this risk element in contaminated water or sewage. Similarly, the study of Rodrigues et al. (2017) demonstrated greater than 70 % reductions in the concentrations of the metals in the contaminated solutions using water lettuce. The surface morphology of contaminated biomass was found to have changes demonstrating the biosorption mechanisms and confirming the potential of the dry biomass for use in the remediation of solutions contaminated with heavy metals such Zn and Cd.

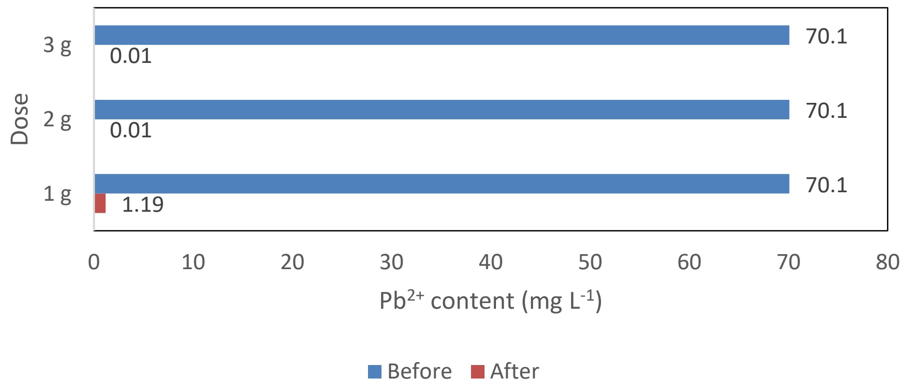

Figure 5: Pb^{2+} content (mg L^{-1}) of the aqueous solution before and after treatment using water lettuce

As shown in Table 2, the biosorption capacity of water lettuce at 1 g is already 3.62 mg g^{-1} indicating high biosorption efficiency (98.30 %).

Table 2: Biosorption capacity and biosorption efficiency of water lettuce

Treatment	Biosorption capacity (q_e), mg g^{-1}	Biosorption efficiency (R %)
1 g	3.62	98.30
2 g	1.84	99.99
3 g	1.23	99.99

Figure 6 shows the high reduction of Pb^{2+} in an aqueous solution after application of water spinach. The application of 3 g of water spinach resulted in the reduction in the lead, with a value of 0.56 mg L^{-1} after 24 h. The computed biosorption capacity was 1.22 mg g^{-1}, with a biosorption efficiency of 99.20 % (Table 3). It implies that at a higher amount of application of biosorbent, the higher the biosorption capacity and efficiency.

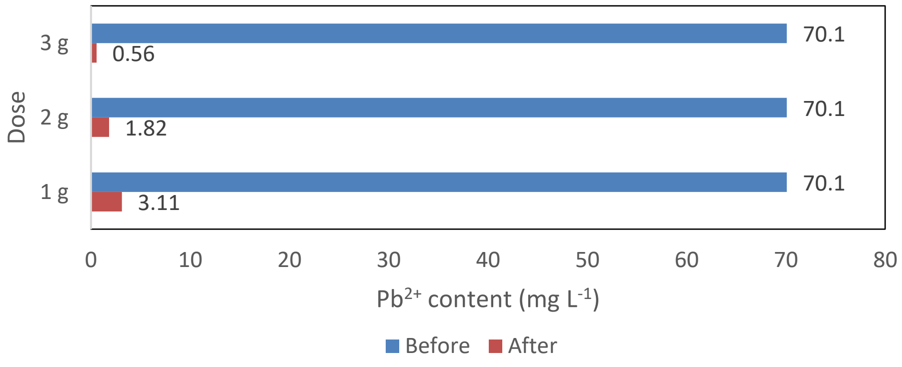

Figure 6: Pb^{2+} content (mg L^{-1}) of the aqueous solution before and after treatment using water spinach

Table 3: Biosorption capacity and biosorption efficiency of water spinach

Treatment	Biosorption capacity (q_e), mg g^{-1}	Biosorption efficiency (R %)
1 g	3.52	95.56
2 g	1.79	97.40
3 g	1.22	99.20

3.3 Correlation analysis

Correlation analysis showed the biosorbent dose to have a moderate relation with pH and biosorption efficiency with a correlation coefficient value of 0.4082 and 0.4914. pH, on the other hand, has a strong influence on biosorption efficiency (0.7543). It indicates that at optimum pH value, biosorbents attain its significant removal efficiency.

Table 4: Correlation analysis

Correlation	Parameters		
	Dose-pH	Dose-Biosorption efficiency	pH- Biosorption efficiency
Pearson-r value	0.4082	0.4914	0.7543

4. Conclusions

This work shows that water lettuce, water hyacinth, and water spinach are good biosorbent for Pb^{2+}. It further indicates that the biosorption efficiency is achieved better at optimum pH. Among the three aquatic plants investigated, water lettuce provided the highest Pb^{2+} removal with 99.99 % efficiency. The in-situ application of these biosorbents is recommended as future studies to compare its efficiency.

References

Ayucitra A., Gunarto C., Kurniawan V., Hartono S.B., 2017, Preparation and characterization of biosorbent from local robusta spent coffee grounds for heavy metal adsorption, Chemical Engineering Transactions, 56, 1441-1446.

Azira S.N., Mahmood B., Mood C., 2013, Treatment of fish wastewater by using water spinach *(Ipomoea aquatica)* in an aquaponic system, Universiti Malaysia Pahang (UMP) Institutional Repository <http://iportal.ump.edu.my/lib/item?id=chamo:84968&theme=UMP2> accessed 24.05.2019.

Fomina M., Gadd G.M., 2014, Biosorption: Current perspectives on concept, definition and application, Bioresource Technology, 160, 3-14.

Gunasundari E., Senthil Kumar P., 2017, Adsorption isotherms, kinetics and thermodynamics analysis of Cu (II) ions onto the dried algal biomass *(Spirulina platensis)*, Journal of Industrial and Engineering Chemistry, 56, 129-144.

Gunatilake S.K., 2015, Methods of removing heavy metals from industrial wastewater, Journal of Multidisciplinary Engineering Science Studies, 1(1), 12-18.

Halim M.H., 2010, Biosorption of ferrum (II) from industrial wastewater by using water spinach *(Ipomoea aquatic)*, Universiti Malaysia Pahang (UMP) Institutional Repository, <http://iportal.ump.edu.my/lib/item?id=chamo:58116&theme=UMP2> accessed 24.05.2019.

Kanamarlapudi S.L.R.K., Chintalpudi V.K., Muddada S., 2018, Application of biosorption for removal of heavy metals from wastewater, IntechOpen, DOI: 10.5772/intechopen.77315.

Lim L.B.L., Priyantha N., Chan C.M., Matassan D., Chieng H.I., Kooh M.R.R., 2016, Investigation of the sorption characteristics of water lettuce (WL) as a potential low-cost biosorbent for the removal of methyl violet 2B, Desalination and Water Treatment, 57(18), 8319-8329.

Lima L., Silva J., Da Silva M., Vieira M., 2014, Lead biosorption by *Salvinia natans* biomass: Equilibrium study, Chemical Engineering Transactions, 38, 97-102.

Lu Q., He Z.L., Graetz D.A., Stofella P.J., Yang X., 2010, Phytoremediation to remove nutrients and improve eutrophic stormwaters using water lettuce (*Pistia stratiotes* L.), Environmental Science and Pollution Research, 17(1), 84-96.

Mahamadi C., 2011, Water hyacinth as a biosorbent: A review, African Journal of Environmental Science and Technology, 5, 1137-1145.

Malar, S., Shivendra Vikram, S., Favas, P.J., Perumal, V., 2016, Lead heavy metal toxicity induced changes on growth and antioxidative enzymes level in water hyacinths [*Eichhornia crassipes* (Mart.)], Botanical Studies, 55, DOI:10.1186/s40529-014-0054-6.

Moyo P., Chapungu L., Mudzengi B., 2013, Effectiveness of water hyacinth *(Eichhornia crassipes)* in remediating polluted water: The case of shagashe river in masvingo, zimbabwe, Advances in Applied Science Research, 4(4), 55-62.

Nguyen, T.V.D., Thu Huynh, H.N.T., Nguyen, M.N.H., Ngo, T.V., 2018, The use of water spinach *(Ipomoea aquatic)* in domestic wastewater treatment, Journal of Agriculture and Development, 17(3), 49-54.

Priya, E.S., Selvan, P.S., 2017, Water hyacinth (*Eichhornia crassipes*) – An efficient and economic adsorbent for textile effluent treatment – A review, Arabian Journal of Chemistry, 10(2), S3548-S3558.

Rezania S., Ponraj M., Talaiekhozani A., Mohamad S.A., Md Din M.F., Mat Taib S., Sabbagh F., Md Sairan D., 2016, Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganic pollutants in wastewater, Journal of Environmental Management, 163, 125-133.

Rodrigues A.C.D., do Amaral Sobrinho N.M.B., dos Santos A.M., Pereira A.C.C., Lima E.S.A., 2017, Biosorption of toxic metals by water lettuce (*Pistia stratiotes*) biomass, Water, Air, & Soil Pollution, https://doi.org/ 10.1007/s11270-017-3340-6.

Shafiq M., Alazba A.A., Amin M.T., 2018, Removal of heavy metals from wastewater using date palm as a biosorbent: A comparative review, Sains Malaysiana, 47, 35-49.

Sibi, G., 2014, Biosorption of arsenic by living and dried biomass of fresh water microalgae - potentials and equilibrium studies, Journal of Bioremediation & Biodegradation, 5(249), DOI: 10.4172/2155-6199.1000249.

Sheba C., Nandini M., 2016, Heavy metal lead removal by biosorption: A review, International Journal of Engineering Research & Technology, 5(11), 519-524.

Vesely T., Neuberg M., Trakal L., Száková J., Tlustoš P., 2011, Water lettuce *Pistia stratiotes* L. response to lead toxicity, Water, Air, and Soil Pollution, DOI: 10.1007/s11270-011-0989-0.