REMOVAL OF HEAVY METALS IONS FROM DRAINAGE WATER USING DUCKWEED-BASED TREATMENT PONDS

Ayman K. Allam[1], Ahmed Tawfik[1], and Abdelazim Negm[1]*

[1]Environmental Engineering Department, School of Energy and Environmental Engineering, Egypt-Japan University of Science and Technology, E-JUST, Alexandria, Egypt.
E-mail: ayman.elkhelaly@ejust.edu.eg
** (Seconded from Zagazig University), negm@ejust.edu.eg*

ABSTRACT

The potentials of using of duckweed (*Lemna gibba*) for removing heavy metals from drainage water (DW) was investigated. Removal of chromium (Cr), lead (pb) and Zinc (Zn) was examined by using continuous flow duckweed based treatment system (DBS) with different hydraulic retention times (HRTs), and different concentrations of heavy metals. The Cr showed the highest removal rates, followed by Zn and Pb. The DBS performance was very good, with removal efficiencies varying between 75-91.3%, 43.81-85.7% and 33.42-59.09% for Cr, Zn and Pb, respectively. Overall, the duckweed (*Lemna gibba*) is efficient in the purifying DW from the heavy metals, representing an effective, eco-friendly, and low-cost treatment technology.

Keywords: Duckweed, Heavy metals, Drainage water, Uptake, Egypt

1 INTRODUCTION

There is a rising concern with the occurrence and persistence of heavy metals (HM) in the aquatic environment, due to their harmful potential impacts on the aqueous ecosystems and human health. Significant amounts of heavy metals are discharged into aquatic ecosystems due to the anthropogenic activities. (El-Shafai et al., 2006; Sekomo et al., 2012). Reverse-osmosis, adsorption, chemical precipitation, flotation, coagulation-flotation, ion exchange, oxidation with ozone/hydrogen peroxide, photocatalytic degradation and membrane filtration technology can effectively remove HM at higher concentrations (Kurniawan et al., 2006). These methods have their limitations in application, high costs and sludge disposal problems. Therefore, development of a cost-effective, less complex and environmentally friendly method to eliminate HM from the aquatic environment is imperative (Reinhold et al., 2010).

Phytoremediation of pollutants is based on the ability of certain plants to absorb and to bioaccumulate contaminants in their tissues. Duckweed is a small floating aquatic macrophytes which grow on the nutrient rich surface and in fresh waters. Phytoremediation of contaminated water using duckweed species is promising due to its ability to grow at wide ranges of temperature, pH, and nutrient level in areas where land is available for its application (Soda et al., 2013). The duckweed species are naturally found in the agriculture drainage system in Egypt. Improving the design of duckweed-based water treatment systems to remediate surface waters requires a better understanding of heavy metals uptake by aquatic plants. In this study, the performance of duckweed in removing HM from real drainage water was assessed using continuous flow DBS. The duckweed uptake for Cr, Zn and Pb from drainage water were evaluated. More specifically, the effect of initial concentrations of HM with respect to the hydraulic retention time (HRT) were identified.

2 MATERIAL AND METHODS

2.1 Laboratory set-up

Three DBS consisted of a series of three DWPs. Each DWP had the following dimensions (L= 0.50 m; W=0.30 m and D= 0.235 m) with a capacity of 35.25 L/pond, Fig.1. The DBSs were designed and fabricated from glass. All sides of the units were covered by light impervious sheets in order to reduce the unwanted algal growth throughout the system. The reactors were continuously fed with natural DW using a peristaltic pump (Masterflex® L/S). The hydraulic retention time (HRT) was adjusted to be 7 d/DBS.

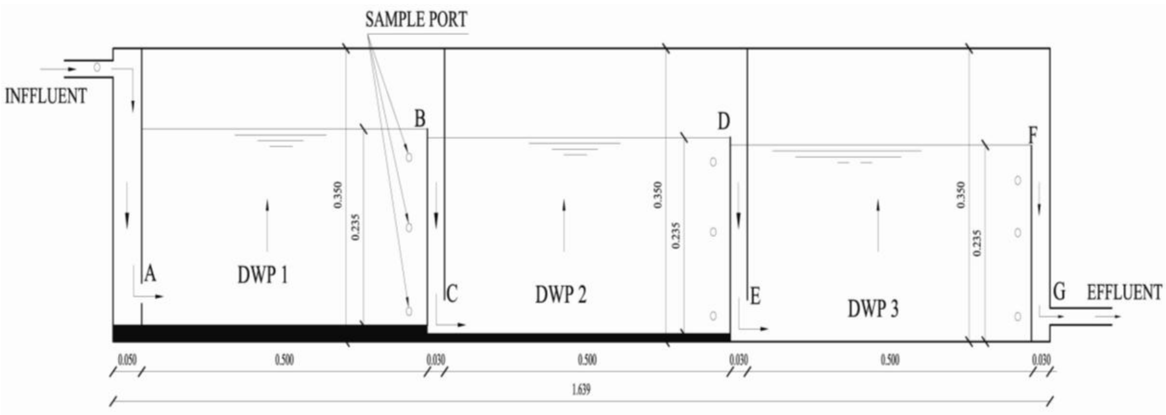

Figure 1. Front view for one of the identical duckweed-based treatment systems (width of all systems = 0.30 m, all dimensions in meters).

2.2 Heavy metals contamination and calculation

Three heavy metals (Cr, Zn, and Pb) were investigated in this study to represent a broad range of the detected heavy metals in the agricultural drainage water, Nile delta, Egypt. These contaminants were added as, potassium dichromate (VI) ($K_2Cr_2O_7$), Zinc chloride ($ZnCl_2$) and Lead (II) chloride ($PbCl_2$). Heavy metals stock solutions were prepared at five nominal concentrations of 0.25, 0.5, 1.0, 2.0, and 4.0 mg/l. After the adaptation period, the contaminants were added to the three DBSs in the concentrations shown in Table 1.

Table 1. Details of the operational conditions

	DBS.1	DBS.2	DBS.3
Run No.	**Cr (mg/l)**	**Zn (mg/l)**	**Pb (mg/l)**
Run.1	0.25	0.25	0.25
Run.2	0.50	0.50	0.50
Run.3	1.00	1.00	1.00
Run.4	2.00	2.00	2.00
Run.5	4.00	4.00	4.00

Amount of removal for the heavy metals through the continuous flow DBS system were appointed by the following equation, (Sekomo et al. 2012):

$$\frac{(C-C^*)}{(C_i-C^*)}=\left(1+\frac{kt}{Nh}\right)^{-N} \quad (1)$$

where C_i the initial concentration, C is the final concentration, C^* is the background concentration, k is the first-order rate constant, N is the number of tanks in series, h is the depth and t is the hydraulic retention time..

2.3 Duckweed

Duckweed was collected from Gharbia drain in the middle of the delta, Egypt. They was washed by tap water, and acclimatized for one week with drainage water under laboratory conditions. The duckweed stocking density (SD) at the start of the study was 50 mg/cm^2 (wet weight) to prevent the duckweed overcrowding.

2.4 Samples collection and analytical methods

Composite samples were collected in replicates from influent and treated effluents every 2.33 d for analysis. Dissolved oxygen (DO), temperature, pH and total dissolved solids (TDS) were measured using Thermo Scientific Orion Star$^{(TM)}$ A111 meters. All prepared samples were analysed for heavy metals using atomic absorption spectrophotometer (AA-7000, SHIMADZU atomic absorption spectrophotometer) was used. All experiments were done for 21 d. (3 times the HRT) to allow the system to reach the steady state conditions. All experiments were carried out under outdoors conditions with a temperature of 23-25 °C & 16 h photoperiod.

3 RESULTS AND DISCUSSIONS

3.1 Environmental conditions in the DWPs of the DBSs

The environmental conditions through the DBSs were shown in Table 2. For all runs, water temperature decreases along the longitudinal profile for the DBSs. The water temprature decreases by approximately 0.5^{0}C which could be attributed for the shading caused by duckweed mat. The results aligned well with other duckweed studies (Zimmo et al., 2005) where similar decrease in the temperature was reported from laboratory studies with *Lemna gibba* treating wastewater through DBSs. Environmental conditions measured showed that DBSs had neutral pH in all DWPs. For all runs, an increase was registered in DO levels in all DBSs. The DBSs provided an improvement for the DO levels of 36.36±1.1%, 28.57±1.2%, 20.83±1.2%, 15.70±1.3% and 13.21±0.6%, at HRT of 18d for Run.1, Run.2, Run.3, Run.4,and Run.5, respectively. The results revealed that the DO improvement level is HM concentration dependent.

This could be attributed for the duckweed growth and higher production of oxygen through photosynthesis and subsequently greater dissolution of oxygen in water due to decrease in dissolved solids with increasing the HRT. The improvement for the DO levels in the DWPs of the DBSs is in conformity with that found by Zimmo et al., 2005 who reported that the DO levels increases through the duckweed ponds. The DBSs recorded removal efficiencies for TDS of 49.23±2.3%, 35.65±1.37%, 31.44±1.23%, 32.20±1.23% and 26.71±0.68% after HRT of 7 d. for Run.1, Run.2, Run.3, Run.4,and Run.5, respectively. The results revealed that the removal ratio decreases with the increase of HM concentration. This could be attributed for duckweed capacity for absorption of dissolved solids from drainage water.

Table 2. Environmental conditions in the DWPs through DBSs

Pond system	Pond number	T (^{o}C)	Ph	DO (mg/L)	TDS (mg/L)
Run.1	Inf.	23.8±0.12	7.17±0.12	2.53±0.13	451±20.1
	Eff.	23.4±0.33	7.14±0.17	3.45±0.31	229±14.4
Run.2	Inf.	23.6±0.21	6.86±0.18	2.59±0.14	432±23.7
	Eff.	23.3±0.21	7.11±0.16	3.33±0.25	278±14.6
Run.3	Inf.	23.6±0.18	6.75±0.25	2.64±0.27	487±24.5
	Eff.	23.3±0.14	7.02±0.16	3.19±0.18	334±16.7
Run.4	Inf.	23.7±0.12	6.62±0.21	2.55±0.16	437±22.6
	Eff.	23.4±0.33	6.91±0.18	2.95±0.18	293±15.5
Run.5	Inf.	23.6±0.13	7.02±0.11	2.42±0.14	453±20.2
	Eff.	23.4±0.30	6.91±0.08	2.74±0.16	333±16.0

Note: Values = Mean ± SD

3.2 Effect of heavy metals concentrations

The influent and effluent concentrations of HM for each DWPs were given in Table 3. The results revealed that the duckweed has the potential to reduce the concentration of HM from DW. The duckweed uptake rate of low initial concentrations of HM was faster than that of high initial concentrations, suggesting that the uptake rate of HM is initial concentration dependant.

Table 3. Influent and effluent concentrations of the DWPs

RUN No.	DBS No.	HM ions (mg/l)	Influent	DWP1	DWP2	DWP3
Run.1	**DBS.1**	**Cr**	0.23±0.01	0.08±0.00	0.04±0.00	0.02±0.00
	DBS.2	**Zn**	0.21±0.01	0.15±0.01	0.12±0.01	0.03±0.00
	DBS.3	**Pb**	0.22±0.01	0.17±0.01	0.14±0.01	0.06±0.00
Run.2	**DBS.1**	**Cr**	0.54±0.03	0.20±0.01	0.11±0.01	0.06±0.00
	DBS.2	**Zn**	0.48±0.02	0.36±0.02	0.30±0.02	0.18±0.01
	DBS.3	**Pb**	0.51±0.03	0.41±0.02	0.38±0.02	0.27±0.02
Run.3	**DBS.1**	**Cr**	1.07±0.05	0.43±0.02	0.28±0.01	0.16±0.00
	DBS.2	**Zn**	1.02±0.05	0.79±0.04	0.56±0.03	0.42±0.01
	DBS.3	**Pb**	1.04±0.05	0.87±0.04	0.82±0.04	0.60±0.03
Run.4	**DBS.1**	**Cr**	2.13±0.10	0.93±0.03	0.69±0.01	0.46±0.01
	DBS.2	**Zn**	2.01±0.10	1.86±0.08	1.39±0.06	0.89±0.03
	DBS.3	**Pb**	2.11±0.09	1.82±0.09	1.71±0.08	1.34±0.07
Run.5	**DBS.1**	**Cr**	3.94±0.21	1.83±0.06	1.38±0.03	0.98±0.01
	DBS.2	**Zn**	4.04±0.20	3.47±0.18	3.02±0.17	2.27±0.14
	DBS.3	**Pb**	4.07±0.18	3.73±0.17	2.91±0.15	2.71±0.13

Note: Values = Mean ± SD

Overall, Cr showed the highest removal rates, followed by Zn and Pb. After 7 d. of HRT, the DBSs achieved Cr removal efficiencies of 91.30%, 88.89%, 85.05%, 78.40% and 75.13% for Run.1, Run.2, Run.3, Run.4 and Run.5, respectively. For Zn, the removal efficiencies were 85.71%, 62.50%, 58.82%, 55.72%, and 43.81%, respectively. While for Pb, the removal efficiencies were 59.09%, 47.06%, 42.31%, 36.49%, and 33.42%, respectively. However, the DBSs removal efficiencies for Cr, Zn and Pb are substantially higher than that obtained by Sekomo et al., 2007, who reported 90%, 70%, and 36% of removal efficiencies for Cr, Zn and Pb, respectively.

3.3 Effect of HRT

In general, looking at the longitudinal profile, all the three heavy metals were characterized by an increasing pattern in their removal efficiencies with increasing the HRT. For Run.1, the DBS achieved removal efficiency for Cr of 65.22%, 82.61%, and 91. 30% after 2.33, 4.67, and 7 d., respectively. While for Run.5, the DBS achieved removal efficiency for Cr of 53.55%, 64.97%, and 75.13% after 2.33, 4.67, and 7 d., respectively. Similar trends were found for Zn and Pb. The longer HRTs ensure a greater degree of homogenization in the DBSs and therefore a greater potential for pollutant removal. Moreover, the pollution load applied on the DBSs decreases (under conditions of constant influent composition).

4 CONCLUSIONS

The results indicated that the duckweed uptake rate of HM is initial concentration dependant. A significantly improved removal in HMs with increasing the HRT through the DBSs. The Cr showed the highest removal rates, followed by Zn and Pb. The DBS performance was very good, with removal efficiencies varying between 75–91.3%, 43.8–85.7% and 33.42–59.09% for Cr, Zn and Pb, respectively. Overall, the results showed that duckweed could be used in HM removal from drainage water, representing an effective, eco-friendly, low cost treatment technology.

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